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# THE EFFECTS OF WEATHER ON RAPID RUNWAY REPAIR (VOLUME I OF II)

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MAY 1983

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30 JUN 1982 - 5 NOV 1982





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This technical report is divided into two volumes. Volume I contains the technical analysis and weather effects on RRR process, while Appendix A, Weather Data, is published as Volume II because of its size.

This report presents the results of a study to identify the effects of weather on Rapid Runway Repair (RRR). There are two major components of the study. The first characterizes the aspects of weather that affect RRR, by area for Korea, Europe, and England. Graphs present data on

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temperature, precipitation, visibility, wind, and humidity. The second component studies the effects of weather on the RRR process. The process is divided into activities, with associated efficiencies under various weather conditions. Values for the efficiencies are developed from military and industrial data. The two components are combined with a critical path analysis of several RRR procedures. The report identifies potential solutions to some weather-related problems, and makes recommendations for further study.

## PREFACE

This report was prepared by the BDM Corporation, 7915 Jones Branch Drive, McLean, Virginia 22102, under Contract F08635-80-C-0206 with the Air Force Engineering and Services Center, Engineering and Service Laboratory (AFESC/RD), Tyndall Air Force Base, Florida.

The work was accomplished during the period beginning 30 June 1982 and ending 5 November 1982. The work was performed at the BDM Corporation.

AFESC/RDCR project officer was 2nd Lt James A. Kirkland.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

1. RESEARCH OBJECTIVE

The goal of this study is to determine the degrading effects of weather conditions on the ability of the U.S. Air Force to provide operational airbase runway capabilities in Europe and Korea after an attack. Two primary objectives necessary to achieve this goal are: (1) characterization of weather in Europe and Korea and (2) assessment of the effect of weather on the rapid runway repair (RRR) process. The primary research focus is on the USAF bomb damage repair (BDR) capability. The secondary focus is on the alternate launch and recovery surface (ALRS) capability and explosive ordnance disposal (EOD) and damage assessment. The goal in both cases is to provide quantitative descriptions of the environmental causes and degrading effects of weather conditions on the resources of the BDR process and the ALRS systems.

2. SCOPE

Specific project aims necessary to accomplish research objectives are:

a. Weather Characterization

(1) Characterize weather in England, Germany, and Korea from data provided by the Environmental Technical Applications Center (ETAC).

(2) Identify a probable range of weather at selected bases with emphasis on key extremes.

(3) Identify data shortfalls.

b. Assessment of Weather Effects

(1) Identify activities in the RRR process (damage assessment, bomb damage repair, and explosive ordnance disposal) affected by weather and estimate delays.

(2) Model three repair procedures (AM-2 Mat, FOD Cover and Concrete Cap) to determine key activities causing delay.

(3) Quantify the effect of weather on activity and procedure durations.

(4) Identify data shortfalls.

The report assesses the environmental conditions for the following airbases:

a. Bitburg Airbase, Germany
b. Hahn Airbase, Germany
c. Ramstein Airbase, Germany
d. Rhein-Main Airbase, Germany
e. Sembach Airbase, Germany
f. Spangdahlem Airbase, Germany
g. Zweibrucken Airbase, Germany
h. Upper Heyford Airbase, England
i. Kunsan Airbase, Korea
j. Osan Airbase, Korea

These 10 bases are divided into several geographic regions. The weather conditions assessed account for almost all possible environmental situations. Principal weather features considered are:

a. Temperature,
b. Precipitation,
c. Visibility,
d. Wind and
e. Relative Humidity.

The influence of these weather conditions on the airbases of concern decreases the efficiency of RRR resources, and thus degrades the repair process. The resources are divided into personnel, materials, and equipment. Quantitative effects are described in detail in the chapters and appendices of this report.

3. OVERVIEW

The environment plays an especially significant role in modern warfare because high-technology weapon and support systems depend upon proper operating conditions. High-performance aircraft, engineering equipment, personnel wearing chemical protective equipment, and high-quality repair materials are essential components of airbase and RRR operations, but can be effective only within a range of conditions.

Data on weather and other environmental conditions have been compiled for hundreds of years. Average conditions can be defined with a high degree of accuracy from this data base. Combining the known parameters of weapon and support systems with knowledge of ambient environmental conditions would decrease uncertainty and enhance airbase repair capabilities.

Having established expected ambient conditions from existing climatological and meteorological data, the study examines effects of the environment on the personnel, equipment, and procedures used in RRR. These effects are measured in two ways. First, the effects of weather on activities comprising the RRR processes are determined. Next, key activities are determined using the Critical Path Method (CPM) so that recommendations for necessary improvements may be ranked according to priority. Information on military personnel and equipment performance measures was obtained through interaction with the responsible Defense Department agencies such as the Air Force Weapons Laboratory, Human Engineering Laboratory, U.S. Army Engineer Topographic Laboratories, Cold Regions Test Center, Army Research Institute of Environmental Medicine, and Aerospace Medical Research Laboratory. Information on RRR equipment and procedures was provided from military technical manuals and standards, as well as through interviews with construction contractors so that determinations of performance degradation caused by the environment could be made. This research provided information on how, when, and where performance degradation exists, the extent of the degradation, and how such degradation can be eliminated or mitigated.

## 4. REPORT ORGANIZATION

The organization of this study is dictated by the need to conduct research and evaluation in both meteorology and civil engineering for a specific application (airbase operational engineering), and to integrate these disciplines into a coherent whole that permits assessment of weather effects on specific processes. The sequence of Report Sections is:

Section I: Introduction - Problem overview and scope.

Section II: Program Overview - Details of modeling approach.

Section III: The RRR Process - Description of the procedures, equipment, materials and personnel for RRR.

Section IV: Weather Characterization for the RRR Process - Characterization of English, German, and Korean theaters.

Section V: Weather Effects on Men - Discussion of general effects and effects specific to the RRR process.

Section VI: Weather Effects on Equipment - Discussion of general and RRR process specific effects.

Section VII: Weather Effects on Materials - Discussion of weather effects on RRR materials.

Section VIII: Activities - Discussion of effects on activities comprising the RRR process.

Section IX: Using the Study and Final Model - Examples of study use and recommendations for further research.

Section X: Conclusions and Recommendations - Summary of effects and recommendations.

In addition, five appendices are included:

Appendix A: Weather Data - Graphical summaries of relevant data.

Appendix B: Biometeorology - In-depth discussion of weather effects on men.

Appendix C: Equipment - In-depth discussion of weather effects on equipment.

Appendix D: Materials - In-depth discussion of weather effects on materials.

Appendix E: Activities - Mathematical modeling of individual activities.

## SECTION II

## PROGRAM OVERVIEW

### 1. INTRODUCTION

The U.S. Air Force Engineering and Services Center is responsible for the research and development of methods and procedures for rapid runway repair (RRR). The Air Force program to develop this capability follows a two-path approach: first, developing methods to rapidly repair a minimum operating strip (MOS) measuring 50 by 5,000 feet for limited continuous launch and recovery of tactical fighter and cargo aircraft; and secondly, developing alternate launch and recovery systems providing an immediate capability until the bomb-damaged MOS is repaired. Each approach must be readily implemented across the full spectrum of weather at U.S. airbases worldwide.

An overview of the project methodology for assessing the effects of weather on methods and procedures for rapid runway repair is given here. Detailed discussion of project conclusions, recommendations, and results is included elsewhere in this report.

### 2. PROBLEM OVERVIEW

One goal of the RRR program is standardization of equipment, materials, and procedures. The diversity of climatic conditions severely restricts performance standards. Materials must be suitable for worst case weather extremes in the widely varying climates of Korea and Europe. Men and equipment must meet RRR repair time requirements during low visibility (fog, haze, night operations), precipitation (rain, snow, sleet, freezing rain), extremes of temperature and humidity, and wind.

Such conditions lengthen recovery time in two ways. First, degraded work efficiencies lengthen the repair process. These delays include: effects of slippery/icy conditions on the ability of equipment to push debris or pull matting; reduced output from men performing strenuous work such as AM-2 mat assembly and scab repair in temperature extremes; and degradation of damage assessment, explosive ordnance disposal (EOD), and survey in poor visibility.

Additionally, weather can stop work or require additional work to be performed. Some moisture-sensitive polymer concretes cannot be used even in a light rain. Some conditions change repair procedures. Wet scabs must be dried in preparation for repair material. Delays are measured in this study.

Equally important are estimates of the probabilities (both single and joint) of occurrence of degrading conditions. Generally, conditions causing the most severe delays are least likely to occur. The likelihood of such events must be weighed. This study addresses both the delaying effects of weather events on RRR and the probability of occurrence of such events through the two component methodologies discussed next.

## 3. SOLUTION METHODOLOGY

The methodology depicted in Figure 1 was developed to achieve the two major research objectives. Research components and data flows have been broadly grouped into two categories. The weather analysis and RRR process modeling components in the figure have been completed. A third component, located to the right of the vertical dashed line, is a methodology for combining probabilities of occurrence of weather events with derived weather effects to obtain expected repair duration, probability of meeting RRR mission requirements, and other statistics. Only the weather and RRR process components of the analysis are required for this current effort. Examples of the third component are included. These give direction for additional research and development in this area.

The remainder of this section is an overview of the problem solution methodology.

### a. Weather Analysis Component

The goals of the weather analysis component are:

- Determine which weather statistics are relevant;
- Determine the present availability of these statistics;
- Characterize weather to the maximum extent possible, using presently available data; and
- Identify data shortfalls, and provide sources and recommendations for further data gathering.

(1) Determine Necessary Statistics. The first step in the analysis was to identify the required weather statistics. This also involved determining which weather conditions to include in the study. Both the statistics and the conditions were selected in support of the primary goals: the weather characterization and the assessment of weather effects on the repair process.

The conditions were chosen by examining weather events that degrade men, materials, and equipment used in RRR. These conditions were broadly categorized as follows:

- Temperature,
- Precipitation,
- Visibility,

- Wind, and
- Relative Humidity.

Thus, one set of statistics included were the mean and extreme values within each category.

These data were useful in developing the weather characterization, but were not compatible with the requirements for RRR. The highly specific nature and short duration of the repair process produces specific and granular data requirements. For example, repair teams must restore launch and recovery capabilities to an MOS within 4 hours after an attack. Thus, the probability of occurrence of events during that time is of primary interest. Because these weather events are highly dependent, the joint probabilities of occurrence are an additional requirement.

The duration of hindering weather events is also important, especially for those events prohibiting critical aspects of the repair process.

Thus, two key data components exist: the joint probability of occurrence of events, and conditional probabilities of their durations. Event probabilities change monthly for each airbase. Estimating the joint probabilities of all feasible combinations of the five weather conditions in an arbitrary 4-hour period by month necessitates estimating several hundred probabilities for each base. Summarizing results for individual airbases into a coherent picture of worldwide capability further increases the effort.

One way to reduce the number of estimates required is to establish a fictitious "worst case" airbase, either by theater or worldwide.

(2) Gather Statistics. The most accurate data source is raw data gathered over many years. Relative frequencies of occurrence of events may be computed from the raw data, using standard software. This technique is highly accurate, but its required long lead times were inappropriate because of the short duration of this study. The U.S. Air Force Environmental Technical Applications Center (ETAC), Scott Air Force Base, Illinois, has such a data base of pertinent raw data and routinely issues data summaries called RUSSWOs (Revised Uniform Summary of Surface Weather Observations). RUSSWO summaries include data for thunderstorms, rain and drizzle, freezing rain or drizzle, snow, sleet, hail, fog, smoke, haze, blowing snow, dust, and sand, as well as wind, temperature, relative humidity, visibility, and ceiling. Data are compiled from hourly statistics into summaries by hour, day, and month. These summaries are available for each of the airbases of interest. RUSSWO data, while compiled from hourly observations, fails to provide the precise statistics of interest. In addition, the marked statistical dependence among data makes derivation of the desired statistics difficult.

A search of the technical libraries at the National Oceanic and Atmospheric Administration headquarters, Silver Spring, Maryland, and the Defense Technical Information Center was conducted. Additional research was conducted through the National Technical Information Service and at local university libraries. The focus of the search was for existing mathematical models and weather data bases. Search produced several dozen relevant studies. For example, if data are available concerning transition probabilities of weather events, mathematical models of event duration may be developed using the theory of Markov and Semi-Markov Processes. These techniques are popular and give good results for many phenomena. However, they require time-consuming model development, and the existing data do not support the specific and extensive data input requirements.

(3) Characterize Weather and Derive Needed Statistics. Finally, a characterization of weather by theater, identification of data shortfalls, and recommendations for further weather-related research were completed.

(a) Characterization of Weather by Theater. A characterization of weather for the English, German and Korean theaters was developed with emphasis on both mean and worst case temperature, precipitation, obscured visibility, wind, and relative humidity. This characterization, based on RUSSWOs and other ETAC-provided data, has two purposes. First, it provides data to compare with design specifications of current equipment and materials. Secondly, it provides a baseline for assessing the suitability of new materials and equipment worldwide. Weather characterization results are discussed in Section IV.

(b) Identification of Data Shortfalls and Formulation of Recommendations. Statistics developed to furnish needed model parameters were assessed. The possibility of using statistical procedures to derive needed statistics from existing data was investigated and results were reported in Section IV. Detailed recommendations for further data gathering to enhance model accuracy are also given in Section IX.

b. Effects of Weather on the RRR Process

The goals of the RRR process model component are:

- Determine the extent of degradation of activity durations for each RRR process activity for the spectrum of environmental conditions;
- Determine the aspect of the activity causing the delay;
- Estimate the effect of activity delay;

- Furnish recommendations for modifications of existing procedures, materials, and equipment; and

- Identify data shortfalls and areas for further analysis.

These analyses goals, met using the methodology illustrated in Figure 1, are discussed below.

(1) Effects of Weather on RRR Basic Resources. The basic resources of the RRR process were divided into three categories: men, equipment, and materials. Sections V, VI, and VII discuss the effects of various weather conditions on these basic resources and identify conditions that prevent the utilization of a resource. Where a weather condition decreases the effectiveness of a resource, efficiency curves are developed. Data sources included equipment manufacturers' manuals, research reports, and discussions with contractors, as well as questionnaires, which were distributed to contractors, equipment manufacturers nationwide, and U.S. Air Force personnel in charge of PRIME BEEF training. Questionnaires and result summaries are included in Appendix C.

(2) Activity Models. The next step in assessing the effects of weather on the RRR process is to fragment the RRR procedures into activities which use the resources identified above. Repair procedures were divided into component activities such as load and deliver select fill, load and deliver AM-2 mat, assemble AM-2 mat, compact, grade, and clear debris. The following major repair/reconstitution procedures were modeled:

(a) Crushed Limestone Repair with AM-2 Mat FOD Cover;

(b) Crushed Limestone Repair with T-17 Neoprene FOD Cover;

(c) Structural Concrete Cap over Crushed Limestone Fill;

(d) Scab Repair;

and, secondarily:

(e) Explosive Ordnance Disposal; and

(f) Damage Assessment.

A baseline of men, equipment, and materials necessary for activity completion was determined. Mathematical models of activities comprising the RRR process were then created. Durations were estimated by functions incorporating parameters such as:

(a) Resource Parameters - Blade widths, bucket volumes, capacities, speeds,

(b) Damage Parameters - Size, type, and extent of damage; and

(c) Work Efficiencies - Functions reflecting the degradation of production rates for men and equipment.

Duration expressions were developed and graphs of the activity duration as a function of temperature, visibility, and other factors were plotted. In some cases, conditions stop the repair process. Other conditions require additional activities to be performed, such as drying scabs after rain (to permit adequate bonding of polymer concrete).

c. Using the Models

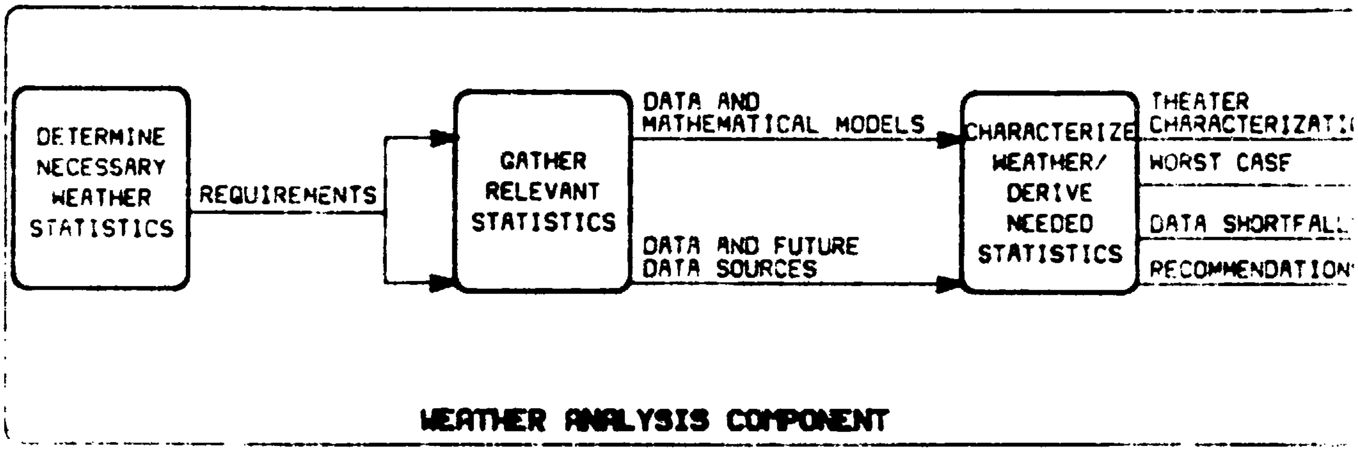
In Figure 1, the weather analysis and RRR process modeling components lie to the left of the dotted vertical line, delineating project scope. Methodology components to the right of the vertical line illustrate study extensions and improvements. Results from the weather and RRR process modeling components are combined. Expected project duration, the cumulative distribution of project duration, and the probability of meeting RRR mission requirements may be estimated. Examples of these techniques were included in Sections VIII and IX to illustrate the use of project results.

(1) Activity Durations and Worst Case Analysis. Combining the weather results and the RRR process models provides an analysis tool with many uses. The user may focus on a particular theater in a particular month. Consulting the weather data, he obtains the expected climatic conditions. He can then use the activity duration models to predict activity durations under these conditions.

Another approach is to calculate worst-case, 99th-percentile durations. For each weather condition, the base and month recording the most severe condition is located. Then the level which is exceeded in only 1 percent of the observations is found. Calculating the corresponding activity duration provides an estimate for a 99-percent confidence interval for the activity under this weather condition on the worst base, in the worst month.

(2) Develop CPM Model. The Critical Path Method (CPM) is an analytic technique for determining the start and finish times of activities in a project. An estimated duration is assigned to each activity. Some activities have slack time, the time between the earliest start time and the latest finish time exceeding the estimated duration. Critical activities have no slack time. The concatenated activities, with no slack time, form a critical path whose duration is the length of the repair.

Each repair procedure was modeled using the CPM. In some activities degradation was absorbed in the activities' slack times and did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DATA AND FUTURE DATA SOURCES
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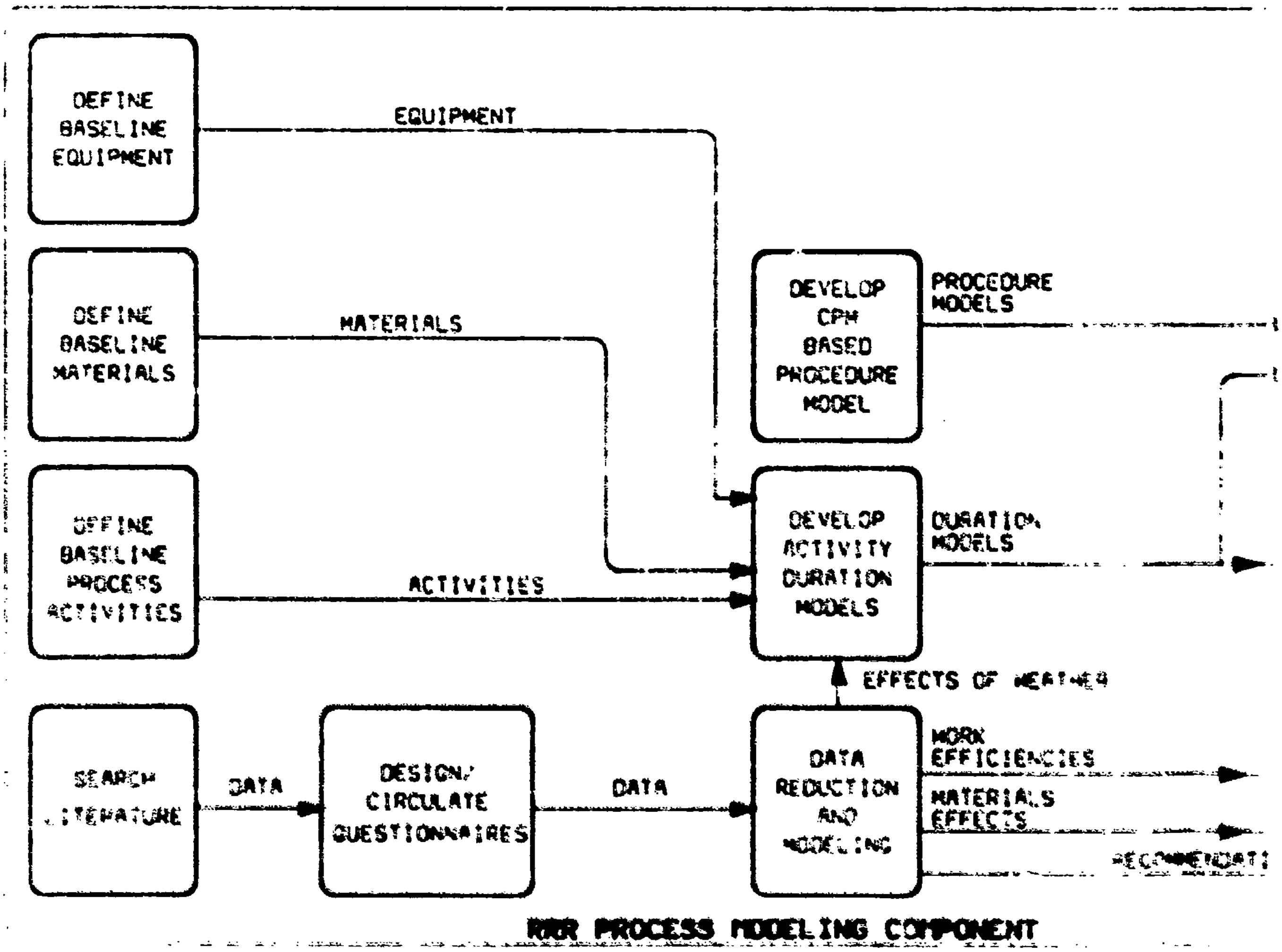
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DEFINE BASELINE PROCESS ACTIVITIES
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DEVELOP ACTIVITY DURATION MODELS
DURATION MODELS
EFFECTS OF WEATHER
SEARCH LITERATURE
DATA
DESIGN/ CIRCULATE QUESTIONNAIRES
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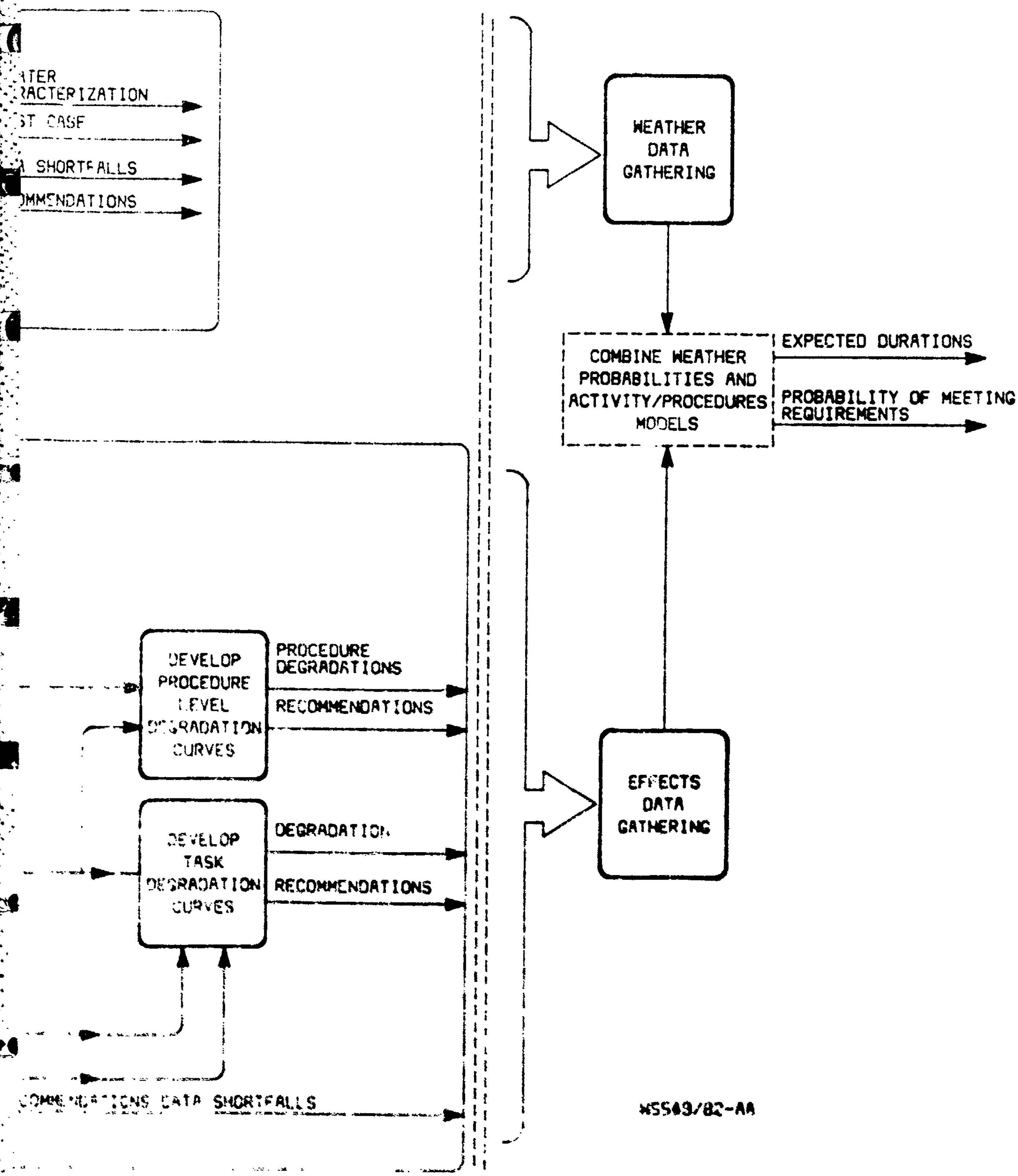


Figure 1. Solution Methodology



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not increase repair duration. Degradation in activities forming the critical path delays the project. CPM allows assessment of the relative importance of task delays. For example, AM-2 mat assembly, which has slack in good conditions, has proportionally less slack in hot conditions, but does not become a critical activity.

A CPM analysis was conducted to estimate repair durations at the 99th percentile extremes. These estimates indicate likely durations of repair for broad ranges of single conditions. Results of CPM analysis are included in Section IX of this report.

## SECTION III

## THE RRR PROCESS - REPAIR PROCEDURES

### 1. GENERAL

Bomb damage repair (BDR) is the response in RRR to any damage on the airfield surface. Damage to an airfield surface consists of scabs and craters. Scabs are generally caused by rocket and cannon fire and are defined to be any pavement damage less than 5 feet in diameter and not penetrating into the subgrade. Craters are pavement damage at least 5 feet in diameter or damage which penetrates the runway surface into the subgrade. Craters are caused by bombs. An attack could include unexploded bombs and antipersonnel bomblets. Unexploded bombs are general purpose bombs which are duds or designed to detonate after landing. Bomblets are canister-released chemical or antipersonnel weapons.

### 2. THE PROCEDURE FLOW

The first step in the RRR process is to evaluate the conditions on the runway and to select a portion of the runway as a minimum operating strip (MOS). The MOS is selected as a temporary runway surface for immediate launch and recovery operations based on the small amount of damage on it. The first recovery procedure, called damage assessment, involves locating damage on the runway and selecting the MOS. Selection is based on number of scabs, craters, and UXO present. After damage assessment, explosive ordnance disposal (EOD) begins. UXO and bomblets on and around the MOS are rendered harmless.

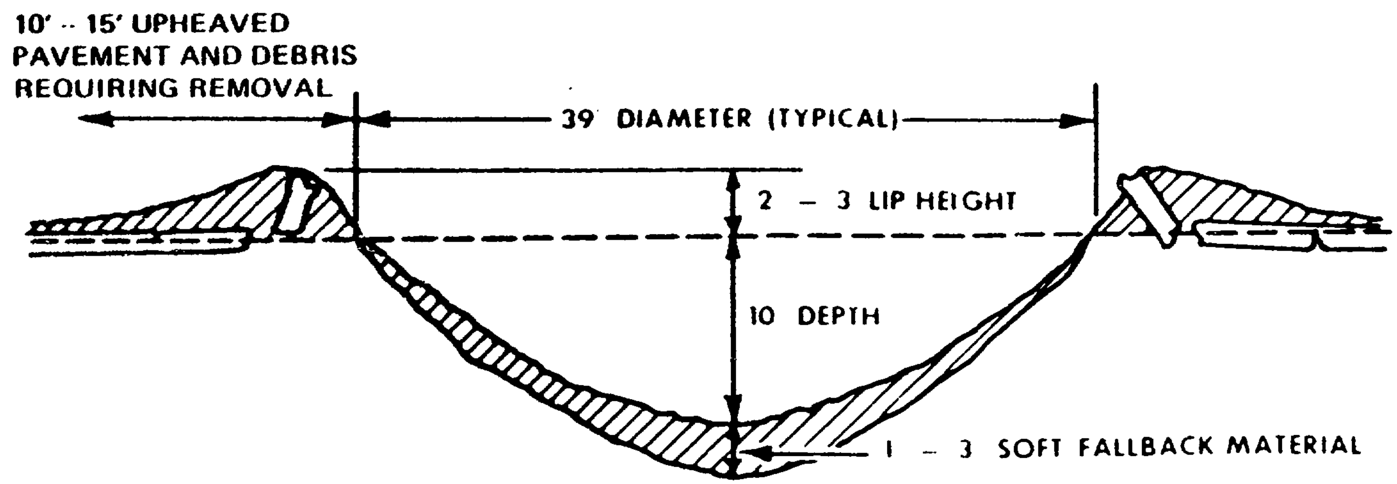
Bomb damage repair commences as soon as EOD on the MOS is complete. Repair of the MOS is started. A typical 750-pound bomb will form a crater 39 feet in diameter and 10 feet deep (AF Regulation 93-2) (see Figure 2). Scabs on the MOS are repaired as crater repair progresses. Work on the scabs should be completed at approximately the same time as crater repair. Finally, the MOS is marked.

### 3. PROCEDURE DESCRIPTION

A more detailed description of the procedures involved in the RRR process follows.

#### a. Damage Assessment

The assessment has two major steps (Reference 1). The first task is determination of the position, type, and magnitude of munitions damage to the pavement system and the severity of the UXO threat. The second task is analysis of collected information and selection of minimum operating strip (MOS) and taxi surfaces which can be repaired quickly.




Note: Acutal depths may range 8.5 feet to 13 feet and actual diameter may range 30 to 43 feet.

Figure 2. Typical 750-Pound Bomb Crater.

Damage assessment is currently done by teams of men walking on the pavement surfaces. These teams mark and record damage they find. They are in frequent radio contact with the Damage Control Center and describe the runway environment to the Center. Locations of scabs, craters, UXO, and area-denial devices are reported. Locations are given relative to the position of local airfield landmarks.

Information reported by the damage assessment teams is plotted in the Survival Recovery Center. The Center's staff chooses an MOS which requires a minimal amount of explosive ordnance disposal (EOD), bomb damage repair (BDR), and scab repair. The current methodology for MOS selection employs a template representing the potential MOS. The template is placed on a map of damage assessment information and moved about until an acceptable MOS is found.

After MOS selection, the Damage Control Center assigns crews to repair damage. EOD crews begin disposing of unexploded bombs and bomblets. BDR crews are assigned to repair craters and scabs on the MOS and access taxiways to the MOS.

b. Scab Repair

The fast-setting concrete Silikal® R-7/Bw is used to repair the scabs. The concrete is mixed by hand, poured into the scab, troweled, and allowed to cure. At 72°F, the concrete cures in 17 minutes (Reference 2).

When conditions are not ideal, the scab repair procedure is different. Cold weather increases cure time. An accelerator is added to the concrete mix in cold weather. The cure time at 25°F (with an accelerator) is only 3 minutes more than at 72°F.

The scab must be dry to ensure an adequate bond between the runway pavement and the polymer concrete. Hot air blowers, infrared heaters, and compressed air jets are used to dry scabs in preparation for concrete mix placement.

During heavy rainfall, the scab will be impossible to dry. In this case, an alternate repair is needed. AF Regulation 93-2 suggests that a 3/4-inch steel plate can be bolted to the pavement over the scab as a temporary repair.

c. Bomb Damage Repair

The most extensive runway damage is caused by general purpose bombs. Three repair procedures for bomb craters are briefly described below. A detailed description of specific activities involved in bomb damage repair is given in Appendix E. A detailed description of the resources for crater repair is given in Appendices B, C, and D.

(1) AM-2 Mat Repair Procedure. Equipment arrives at the repair site and debris is pushed from the runway back into the crater. Debris consists primarily of pieces of concrete scattered by the explosion. Two areas on the runway surface are cleared as soon as possible to allow for AM-2 mat assembly and select fill stockpiling. These activities are discussed later.

Backfilled debris requires compaction. This is accomplished by a loader or dozer moving over the loose debris. Often upheaved pavement around the crater must be removed. A loader or a dozer wedges its bucket (or blade) under the cracked pavement and breaks the pavement loose.

During crater preparation, crushed stone is delivered to the repair site in dump trucks. The crushed stone is stockpiled at the crater until the upheaved pavement has been removed and the backfilled debris compacted. Fill is placed until it comes 2 inches above the crater lip.

Concurrent with crater preparation, AM-2 matting is loaded onto a lowboy and delivered to the mat assembly area. The mat is delivered in bundles of panels. The AM-2 mat, consisting of interlocking aluminum panels, is assembled at the repair site and used as a foreign object damage (FOD) cover for the crater. The FOD cover keeps loose crushed stone from being drawn into the aircraft engines. These panels are placed in an aluminum mat frame.

After the fill is placed, a vibratory roller compacts it. After four compactor passes, a grader levels the select fill. Compaction then continues for an additional 28 passes. The crater is ready for AM-2 mat FOD cover. Two pieces of equipment pull the mat from its assembly site to the crater.

The mat must then be anchored to the runway surface. Holes are drilled in the runway and filled with a molten lead-sulfur compound (this compound has been heated earlier). As soon as the lead-sulfur is poured, a bolt is placed through the mat and into the hole. When the lead-sulfur cools, the bolts keep the mat firmly in place.

The activity network for this procedure is given in Figure 3.

(2) FOD Cover Repair Procedure. An AM-2 mat FOD cover is not always necessary for effective crater repair. Smaller craters can be repaired with crushed stone and a flexible foreign object damage (FOD) cover. Typical FOD covers are neoprene coated 2-ply nylon membranes with reinforcement strips. These covers are currently in the approval process for inclusion in RRR.

The FOD cover repair procedure is very similar to the AM-2 mat procedure. The crater is backfilled with debris, upheaved pavement is loosened, and debris is compacted. Crushed stone is placed in the crater

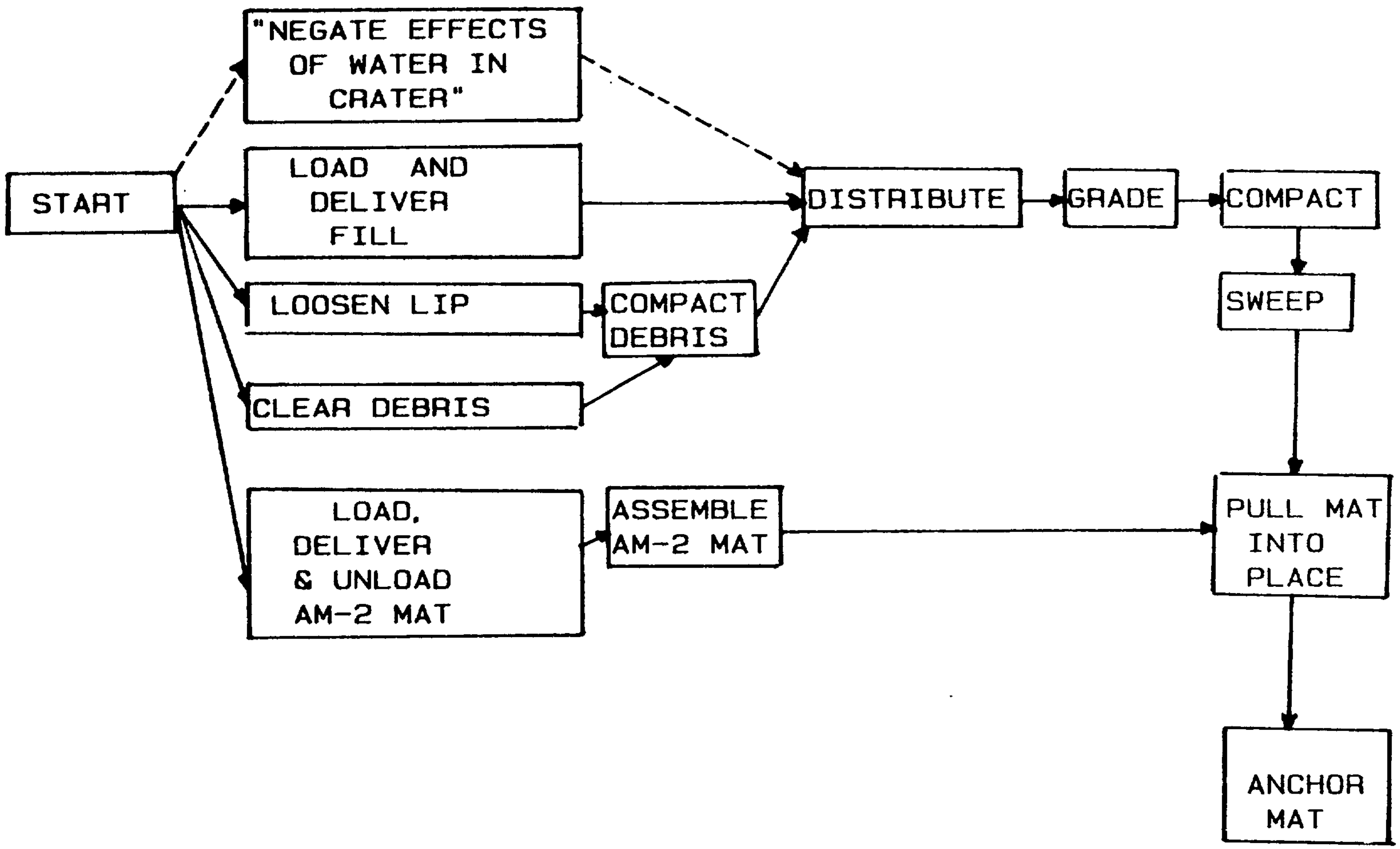



Figure 3. AM-2 Mat Repair Procedure.

and then compacted and graded. The FOD cover is delivered to the crater rolled up. Unlike the AM-2 mat procedure, no assembly at the crater is necessary. Two end plates are bolted to the runway surface at two ends of the crater. They are fastened in the same fashion as the AM-2 mat (with a molten lead-sulfur compound poured into holes drilled into the runway). The FOD cover is attached to one of the end plates and rolled across the crater. It is pulled tight and attached to the second end plate. The repair is complete when anchoring plates are placed on the remaining two sides of the crater and the FOD cover is anchored.

Figure 4 gives the activity network for this repair procedure.

(3) Structural Cap (Down Percolation) Repair Procedure. This repair method is similar to the AM-2 mat and FOD repair procedures. Debris is backfilled, the upheaved pavement loosened, and the debris compacted.

A neoprene sheet is placed over compacted debris and the crater is filled with select limestone fill to within 10 to 14 inches of the runway surface. Loose aggregate is placed and graded even with the runway surface. The components of the polymer concrete are pumped into a continuous concrete mixer, then discharged into the loose aggregate. This repair procedure is still in the development stage.

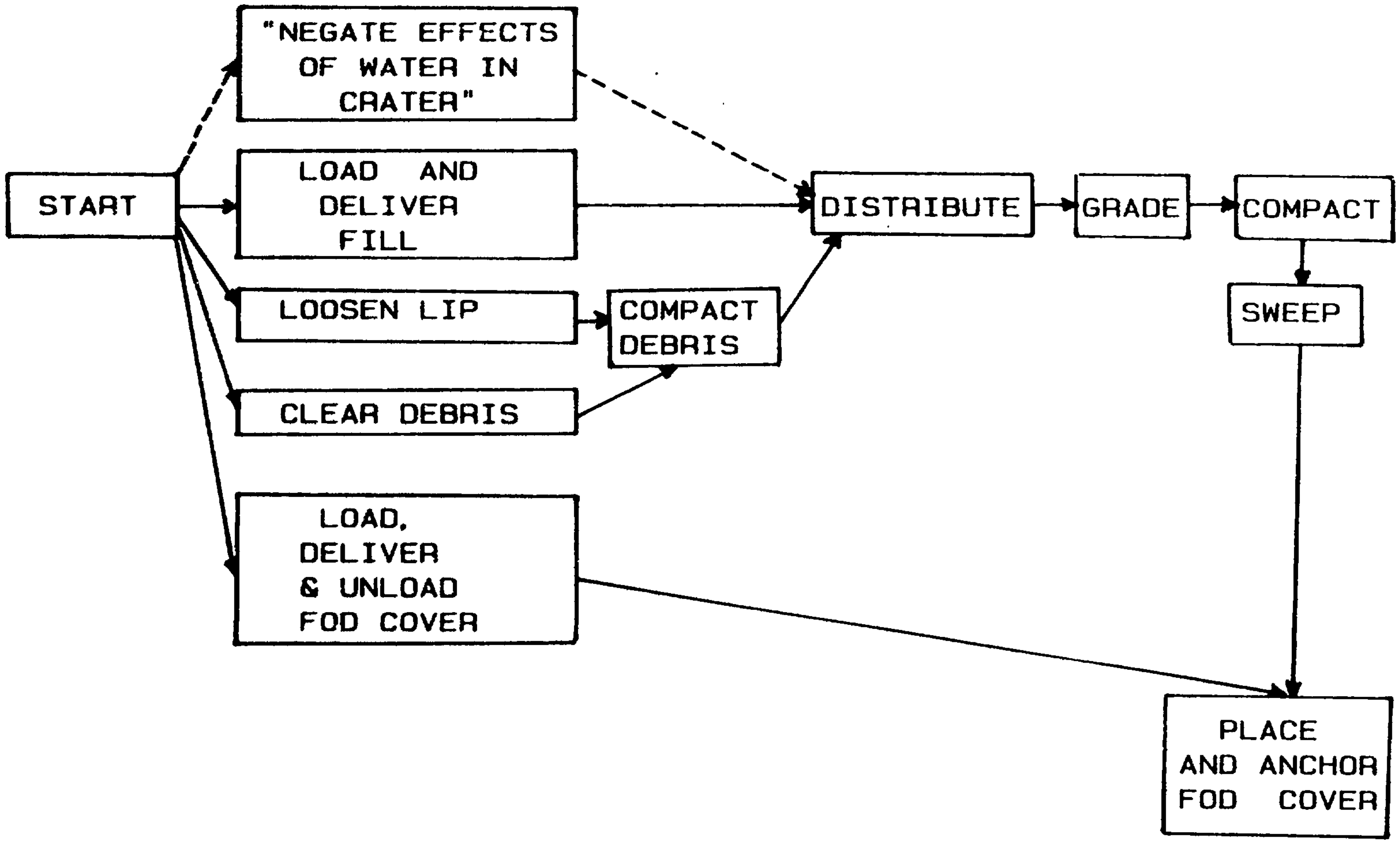



Figure 4. FOD Cover Repair Procedure.

## SECTION IV

## WEATHER CHARACTERIZATION FOR THE RRR PROCESS

### 1. INTRODUCTION

One analysis component was the development of a weather model from a quantitative analysis of weather data summaries. This model has two purposes. Primarily, it is intended to provide probabilities of events affecting the RRR process. A secondary purpose is to furnish a baseline of expected weather to aid in evaluation of new equipment and materials, as well as to provide a general characterization of climate.

Data supporting these purposes differ significantly. For example, thorough weather characterization must include summaries of relative humidity, temperature, and wind chill. In contrast, it is sufficient to consider only effective temperature in estimating activity duration.

These dual purposes resulted in the inclusion of a diverse and comprehensive collection of weather statistics.

### 2. IDENTIFICATION OF THE NECESSARY STATISTICS

#### a. The Weather Conditions

In determining which weather conditions to study, RRR resources were subdivided into three categories: men, materials, and equipment. Various weather conditions were then examined for potential degradation in work efficiency of the resources. For example, low visibility has no effect on the actual materials or equipment, but can affect equipment operations.

Many conditions affect visibility, including ceiling and sky cover, fog, haze, and smoke. These conditions are broadly categorized as "Low Visibility" since their effect on the RRR process is similar. Such broad groupings focus the study and simplify the analysis process.

Similar considerations resulted in the following weather categories for use in subsequent analysis.

(1) Temperature,
(2) Precipitation - rain, freezing rain, snow,
(3) Visibility,
(4) Wind and wind chill, and
(5) Relative humidity.

Data extracted from these summaries for use in estimating durations of activities comprising the RRR process are:

(1) Effective Temperature,
(2) Precipitation,

(3) Slippery Conditions,
(4) Visibility, and
(5) Wind.

b. The Weather Data

For each of the five major weather categories, appropriate data summaries were identified.

The short duration of the RRR process is a driving factor in determining the appropriate statistics. Data that are summarized monthly or annually are useful for characterizing climate. The short-term nature of the repair procedure also requires more detailed statistics. For example, one question of interest is the probability of the occurrence of rain in any given 4-hour period. This kind of question then naturally leads to another: If it is raining, what is the expected duration of the rain? Similar statistics are also desirable for the other weather conditions considered.

Another set of statistics necessary to more fully develop the weather model are the joint probabilities of the occurrence of two or more of the weather conditions. For example, since temperature and relative humidity together produce a significant effect on a man's work efficiency, it is necessary to know about the probability of their simultaneous occurrence. However, this type of statistic cannot be derived from so-called "single" probabilities because the two conditions are not independent. In this case, then, a very specific data gathering effort is required.

Other joint probabilities that would be of interest in this study are temperature and wind, precipitation and wind, and temperature and precipitation. These requirements will be further detailed in Section IX.

c. Theater Characterization

Finally, the dual objective of the weather model is a key factor in determining the necessary statistics. The model must characterize the weather throughout the three theaters by considering the average weather conditions, as well as the adverse conditions occurring periodically. Mean values are used to describe the expected weather conditions; extreme maximum/minimum values (depending on the condition) determine the worst case situation. This information can be combined by deriving expected ranges of values; in particular, ranges which include 98 percent of the recorded values are useful. By presenting the information in this format, the 1-percent cutoffs used for design specifications can be easily determined.

3. DATA SEARCH

The next step in developing the weather model is to search available data summaries for the important statistics. Two types of summaries were provided by the U.S. Air Force Environmental Technical Applications Center

(ETAC); they were (1) a variety of data collections called Revised Uniform Summaries of Surface Weather Observations, or RUSSWOs, and (2) data depicting unconditional durations of various weather conditions.

The RUSSWOs consist of hourly, monthly, and yearly weather summaries which have been derived from raw data collected hourly over many years. They describe a variety of conditions, including dry and wet bulb temperatures; rain, freezing rain, and snow; ceiling, visibility, fog, and sky cover; wind speed and direction; and relative humidity. In most cases both mean and extreme maximum/minimum values are included.

The other sets of statistics produced by ETAC were also derived from hourly observations. These data measured the durations of such weather conditions as extreme high and low temperatures, precipitation, and limited visibility.

Together, these groups of statistics are sufficient to develop a complete weather characterization of the English, German, and Korean theaters. However, they are not in a format which supports a model of the conditions affecting the RRR process. First, as previously discussed, these statistics must be summarized over a period of a few hours. But, this information cannot be derived from the current statistics since nothing is known about the distribution of the actual observations. Secondly, the joint probabilities relevant to this study are not included in the available data summaries. Again, such statistics cannot be determined from the data because of the many interdependencies among the conditions.

Thus, it was necessary to search further for either an existing compendium of data summaries or a methodology for estimating the desired statistics from the data currently available.

At Scott Air Force Base, Illinois, ETAC has raw data which have been collected over several decades stored as an extensive data base. However, these data cannot be combined into formats useful to this part of the analysis with existing software. That is, the needed probabilities can be derived from the raw data, but require a long and expensive effort.

The data gathering search continued with a thorough review of the technical libraries at the National Oceanic and Atmospheric Administration (NOAA), Silver Spring, Maryland, and the Defense Technical Information Center (DTIC). Additional research was conducted through the National Technical Information Service (NTIS) and at local university libraries. This search uncovered many relevant studies. Among the mathematical models identified, the most relevant results were contained in An Approach to Modeling Weather Data by Means of Markov and Semi-Markov Chains (Reference 3). This document, written in 1973, was produced in partial fulfillment of the author's requirements for the degree of Doctor of Philosophy in Meteorology at Arizona State University. This survey was divided into two broad categories: one dealing with the persistence of weather spells and the attempt to determine the approximate form of the duration of the spells; the other dealing more specifically with fitting Markov Chains to these sequences of weather data. However, all of these models have specific and extensive data input requirements which were unsupported by existing data.

The weather model based on the data provided by ETAC is a simplified version of the actual desired model. Because of a lack of available resources, however, it is nevertheless appropriate for estimating probabilities of occurrence and durations of various weather conditions affecting the RRR process.

## 4. CHARACTERIZATION OF THEATERS

To more effectively summarize the large quantities of weather data, the ten airbases considered in this study were categorized into three theaters: the English theater, the German theater, and the Korean theater. Of course, in the German and Korean theaters, some variance exists in the data from different airbases depending on altitude, surroundings, and latitude, among other things. However, since an extensive characterization for each of the airbases would be inappropriate for this study, this natural division by country was assumed.

There are two main purposes for compiling such a weather characterization. First, by considering mean values, the average, or expected, weather conditions can be determined. Secondly, frequency of occurrence of adverse conditions is considered for determining design specifications for materials and equipment. Thus, this effort is supportive of both of these goals where the required data is available. Appendix A offers an extensive graphic representation of the characterization summaries.

### a. English Theater

The English theater, which consists only of Upper Heyford AFB for this study, possesses a very mild climate. In fact, it is unusual for the temperature to either rise above 85°F in the summer or fall below 20°F in the winter. This phenomenon can be attributed to several things. One reason for the moderate temperatures is that the ocean waters along England's eastern coast are warmed by the Gulf Stream. Another reason is that the prevailing winds approach from the west, producing a cooling effect in summer and a warming effect in winter.

As a result, it seldom snows at Upper Heyford AFB; however, it rains very frequently throughout the entire year. In fact, a measurable amount of precipitation can be expected approximately 155 days per year. Because this is in the form of a low intensity/high duration rainfall, the total amount of yearly precipitation averages only 25 inches.

Although foggy conditions occur often, the ground (horizontal) visibility at Upper Heyford is not severely diminished. In spring and summer (April-August), the visibility range averages greater than 1/4 mile more than 99 percent of the time. Even in the "worst" month, February, the visibility falls below 1/4 mile less than 4 percent of the time.

Upper Heyford receives moderately strong surface winds since it is close to the English Channel. Annually, the mean wind speed is approximately 8 knots with the greatest averages occurring in the winter months. The average maximum gusts are approximately 37 knots, although gusts of over 50 knots have been recorded.

In terms of relative humidity, the influence of the ocean is again apparent. Three-fourths of the observations recorded a relative humidity of greater than 70 percent, with an annual mean of 78 percent. Although the mean per month varies little from this value, the winter months do tend to be slightly higher.

b. German Theater

Like the English theater, the German climate is considered to be fairly mild. The similarities are partially a result of the latitudinal proximity of the airbases. There are, however, obvious discrepancies which can be attributed to the geographical differences between the two theaters; namely, the German bases are inland, surrounded by the Alps and the rolling mountains of the Midlands.

The winds that blow across Germany from the Atlantic result in warm summers and cool winters, with temperatures typically ranging from 10°F to 85°F. In the winter, though, the temperature is typically very near the freezing level for long periods of time. This results in a major difference between the English and German theaters: the frequency of occurrence of snowfall.

The German airbases are very damp, and precipitation in the form of a steady drizzle occurs quite frequently throughout the year. The long durations of freezing temperatures often cause this drizzle to be transformed into a light snowfall. For example, an average January in the German theater can be expected to have approximately 16 days of precipitation, 6 of which are in the form of snow.

The rainfall has a very low intensity, especially in the winter. During the summer, rain will typically occur half the days, but amounts greater than about 0.4 inches occur only 2-4 days each month.

The German theater tends to be foggy in the winter when the warm air currents combine with the cold land surface. In considering the mean of the seven airbases, the range of visibility is less than 1/4 mile in approximately 6.5 percent of the observations. However, at Hahn AFB, the visibility presents more of a problem. In December, for example, the visibility is under 1/4 mile nearly 13 percent of the time.

The surface winds in Germany can be described as being moderate. The mean annual wind speed is 6 knots, and winds of greater than 28 knots generally occur less than once a month.

Like Upper Heyford, the German atmosphere is a very humid one, with the winter months recording the highest relative humidities. That is, the annual mean relative humidity is approximately 77 percent, whereas the mean measured over the winter months alone reaches 80-85 percent.

c. Korean Theater

The geographic features associated with the Korean theater define the nature of its climate. First, Korea is a peninsula and is influenced by both the Yellow Sea surrounding it and by the continent of Asia. A second driving factor, then, is Korea's latitudinal location. In general, the Korean theater possesses a humid, monsoonal climate, typical of East Asia.

Unlike the European airbases, Korea experiences a wide range of temperatures. The summer months are very hot with mean temperatures around 78°F. At the other extreme, the winter months are very cold, generally having a mean temperature below freezing. Extreme minimum temperatures in January and February have reached as low as -20°F.

Since Korea is located in the East-Asian Monsoon belt, it annually experiences both a summer and a winter monsoon. The summer monsoon produces extremely high intensity/low duration rainfalls. In fact, about 60 percent of the annual rainfall occurs during the rainy season of June through September. In July, the mean amount of monthly rainfall is nearly 12 inches with an extreme 24-hour rainfall of more than 10 inches.

In general, the winter monsoon is dry and cold. Thus, except for a few snowfalls occurring mostly in December and January, little precipitation is produced.

The Korean theater very seldom experiences fog or severely limited visibility. November is the "worst" month, but even then there is less than a 2-percent chance of the visibility range being less than 1/4 mile. In every other month, this frequency of occurrence is less than 1 percent.

Korean winds are generally mild to moderate with slightly greater wind speeds recorded during the winter months. The annual mean wind speed is less than 6 knots, but the highest monthly average, which occurs in March, is under 7 knots. Maximum gusts, however. average 33 knots annually.

The relative humidity varies greatly from the winter to the summer. The winter months are quite dry and average a relative humidity of less than 70 percent. During the rainy summer months, though, the relative humidity rises to approximately 77 percent.

## SECTION V

## WEATHER EFFECTS ON MEN

### 1. INTRODUCTION

This section describes the effects of weather on human efficiencies. Weather conditions included are hot and cold temperatures; precipitation, including rain, snow, sleet, and ice; high humidity; high wind; and low visibility. Data sources for these effects are reviewed. Results are discussed and summarized in efficiency graphs. Appendix B contains a more complete discussion of these effects.

The data come primarily from studies completed in the commercial sector. The conditions and motivation for completing work in adverse conditions are substantially different here than in the RRR environment. These data provide a conservative assessment of worker performance. They serve in this analysis as a point of reference from which more realistic estimates of RRR personnel performance are derived. Additional information from PRIME BEEF trainers and construction contractors was obtained through telephone conversations and questionnaires and factored into final estimates of worker efficiency. The efficiency curves reflect this bias. Data for RRR efficiency in bad weather are not available. Subsections provide estimates of worker efficiency in varying temperatures, precipitation, humidity, wind, and low visibility. Discussion of each condition begins with an overview of related, yet relevant data.

Weather effects have been broken into effects on men, equipment, and materials. For example, precipitation affects a vibratory roller operator's comfort, his equipment's traction, and the crushed stone which he compacts. These effects are treated separately in this analysis with only the first addressed in this section.

### 2. TEMPERATURE AND WORKER EFFICIENCY

Worker efficiency is best described as the degree of effectiveness of an individual in performing his task. Worker efficiency is highly sensitive to temperature. Most sources acknowledge that a temperature range of approximately 50°-75°F is best. Others pinpoint specific ideal work temperatures such as 60°F. Variations arise depending on the type of work. Reference 4 states that 60°F is best for heavy manual labor while 67°F is optimal for moderate to light labor. Clearly, many variables exist such as clothing, work speed, individual acclimatization, and other environmental factors such as wind and humidity. The following subsections explore the effects on human workers at extreme low and high temperature levels.

a. General Findings on Worker Efficiency in Cold Weather

Worker efficiency generally begins to decline below 50°F if special precautions or protection are not provided. This decline may be exacerbated by material and equipment problems. This section describes reduction in worker efficiency for construction tasks similar to RRR.

Most manual labor is not appreciably harmed when performed below 32°F unless it involves the use of sensitive materials such as asphalt, paint, masonry, mortar, or thin sections of concrete. Structural steel work or working with steel sections becomes difficult due to icing and metal surfaces become too cold to handle without skin protection. More pronounced reduction of efficiency occurs between 10°-32°F, again varying with the type of work and other climatic conditions (especially presence of high wind or snow). Below 10°F, significant problems affect humans performing a variety of construction jobs. The paragraphs that follow provide a brief description of the particular job, how the job relates to RRR, and how low temperatures in the two ranges (10°-32°F and below 10°F) affect the humans performing it.

Damage assessment, EOD clearance, and a variety of other RRR tasks require surveying operations. Such activities require considerable "inactive" outdoor work in which the body does not warm itself through exercise. Also, they require exposure of the hands and face for observations and instrument leveling. Work efficiency drops considerably below 32°F, and frequent breaks for warming are required. Surveying has been conducted at temperatures as low as -35°F, with very marked decreases in efficiency.

Excavation is an essential ingredient of the damage repair process. Reference 5 divides the effects of low temperature on excavation into three segments. The first, discussed in Section VI, pertains to limits to the operation of excavation machinery. The second and third describe the work performance by humans.

Operator performance in low temperature suffers because of the clothing, equipment, and accessories required for shielding against the cold. More room may be required for the equipment operator seat. Because of the greater clothing bulk, handling levers, pedals, switches, and other instruments is more difficult. This results in reduced excavating operation efficiency unless the operator is accustomed to working in cold weather. Protective cabs, heaters, defrosters, and other climate controls can also affect performance since they may limit operator's hearing or sight as needed. Details of equipment operation are presented in Appendix C.

Excavation workers are generally able to perform their tasks satisfactorily at temperatures down to 0°F, provided they are acclimated and properly clothed. Below this temperature, worker productivity declines very rapidly, especially if other inclement weather conditions such as snow or wind are present. Table 1 presents an estimate of the working efficiency of man at various temperatures based on the construction site experience.

TABLE 1. WORKING EFFICIENCY OF MEN AT VARIOUS TEMPERATURES (Reference 6).

| Temperature (°F) | Percent Efficiency |
|---|---|
| 70 | 100 |
| 20 | 75 |
| 0 | 50 |
| -23 | 25 |
| -40 | 14 |
| -50 | 10 (Point where man in outdoor environment must spend practically all his energy to survive) |
| -80 | 0 |

Concrete form construction is not used with current Air Force techniques of RRR. However, the U.S. Army Corps of Engineers and the German Air Force use concrete repairs. A potential U.S. Air Force technique (concrete cap) could require the construction of some concrete forms. More important, concrete form work is significant under low temperature conditions because it involves a great deal of outdoor work by general laborers, and is therefore similar to the labor-intensive RRR activities such as scab repair and AM-2 mat assembly. Outdoor concrete work efficiency is markedly reduced by cumbersome clothing. Heavy gloves hinder such work. General labor has been accomplished at -20°F, although such operations are not economical. Construction at lower temperatures requires heat and shelter for both people and concrete. The low temperature limit to economical operations lies between 0 and 10°F. Higher temperatures are preferred, at least exceeding 32°F, and if possible 40°-50°F, according to most manufacturers interviewed in Reference 5.

Low temperatures impose severe restrictions upon many construction operations. Table 2 summarizes lower limits for economic accomplishment of tasks that relate to RRR. These data are based on the experiences of firms located in northern states such as Montana, Minnesota, Iowa, and Alaska operating under economic constraints. Such results, while not directly applicable to RRR, provide a baseline from which to extrapolate relevant RRR limits. These limits, together with their formulation, are provided later in this section.

TABLE 2. LOW TEMPERATURE LIMITS TO ECONOMIC CONSTRUCTION ACTIVITIES (Reference 5).

| | Activity | Temperature (°F) |
|---|---|---|
| 1. | Surveying | -10 to 0 |
| 2. | Material Stockpiling | None (With Exceptions) |
| 3. | Excavation | 20 |
| 4. | Concrete Forms | 0 to 10 |
| 5. | Concrete Pouring | 10 |
| 6. | Painting | 32 |

Above 32°F, only minor operational efficiency limitations occur. Most operations are satisfactory at 10°F, with minor changes in equipment and procedures given negligible wind and no precipitation. Below 10°F, interruptions and cost increase greatly.

b. Worker Efficiency in Hot Weather

Outdoor construction efficiency declines above the optimum work range of 50°-75°F. Efficiency declines gradually as temperature increases to its maximum in most northern latitudes of about 100°F. Reduced efficiency is traceable to reduced worker output rather than to equipment or material effects. Above 100°F, very little work can be accomplished because of the increased susceptibility to error and accidents caused by worker discomfort and lack of motivation.

Nearly all phases of construction experience reduced worker efficiency and increased worker discomfort during high temperatures. Heat, in conjunction with humidity, sunlight, and wind, causes discomfort. These complicating circumstances make firm conclusions difficult regarding the effect of heat on worker efficiency. Otherwise, difficult work can be accomplished at the same temperature when sheltered from direct sunlight, exposed to moderate wind or breezes, and in low relative humidity. Unless it is very dry and other conditions are also favorable, little work can be efficiently accomplished when the temperature is above 100°F.

c. Derivation of Worker Efficiencies

Figure 5 summarizes the temperature effects discussed above. Three levels of effort are represented, since the worker's level of activity influences his reactions to his thermal environment. The ideal temperature range cited above (50°-75°F) was broadened by 5°F for the strenuous worker to reflect the greater motivation and preparedness to be expected from the RRR worker as opposed to the commercial construction worker. The data points in Table 1 determine the strenuous work curve under cold conditions, and the medium and light curves were adjusted downward based on the discussion above. Fewer data were available for hot temperatures. It was assumed that strenuous labor efficiencies would decline linearly from 100 percent at 80°F to 0 percent at 120°F. Medium and light efficiencies were scaled upwards accordingly.

Questionnaires were widely distributed among members of the RRR community requesting worker efficiencies for various tasks and environments. Averaged results from these questionnaires were considered in determination of the efficiency curves.

Reference 7 provides a different perspective on the labor efficiency issue. Labor efficiency was estimated in relation to ambient temperatures by independent consultants in a variety of industries. The results of this survey of field experts are presented in Figure 6. The most important data to the study at hand pertain to industrial construction and petroleum exploration and recovery. The heavy labor, outdoor environment activities appear to be skewed toward the lower temperature range when compared to the other activities shown on the figure. Notice the close similarity of these results to the derived RRR process efficiencies.

3. PRECIPITATION AND WORKER EFFICIENCY

a. Introduction

In this subsection, the effect of precipitation on worker efficiency is investigated. The effect of the precipitation itself is isolated from the effects of likely attendant conditions. Efficiency in snowfall, for example, estimates worker degradation caused by snow, but ignores low temperature or heavy wind effects. Derived efficiencies are for men only. Precipitation has drastic effects on certain RRR materials, but these effects have been examined separately in Section VII, Weather Effects on Materials. Similarly, the effects of slippery surfaces on equipment traction are included in Section VI, Weather Effects on Equipment. Given these assumptions, the primary effect of precipitation on workers is from discomfort and poor traction.

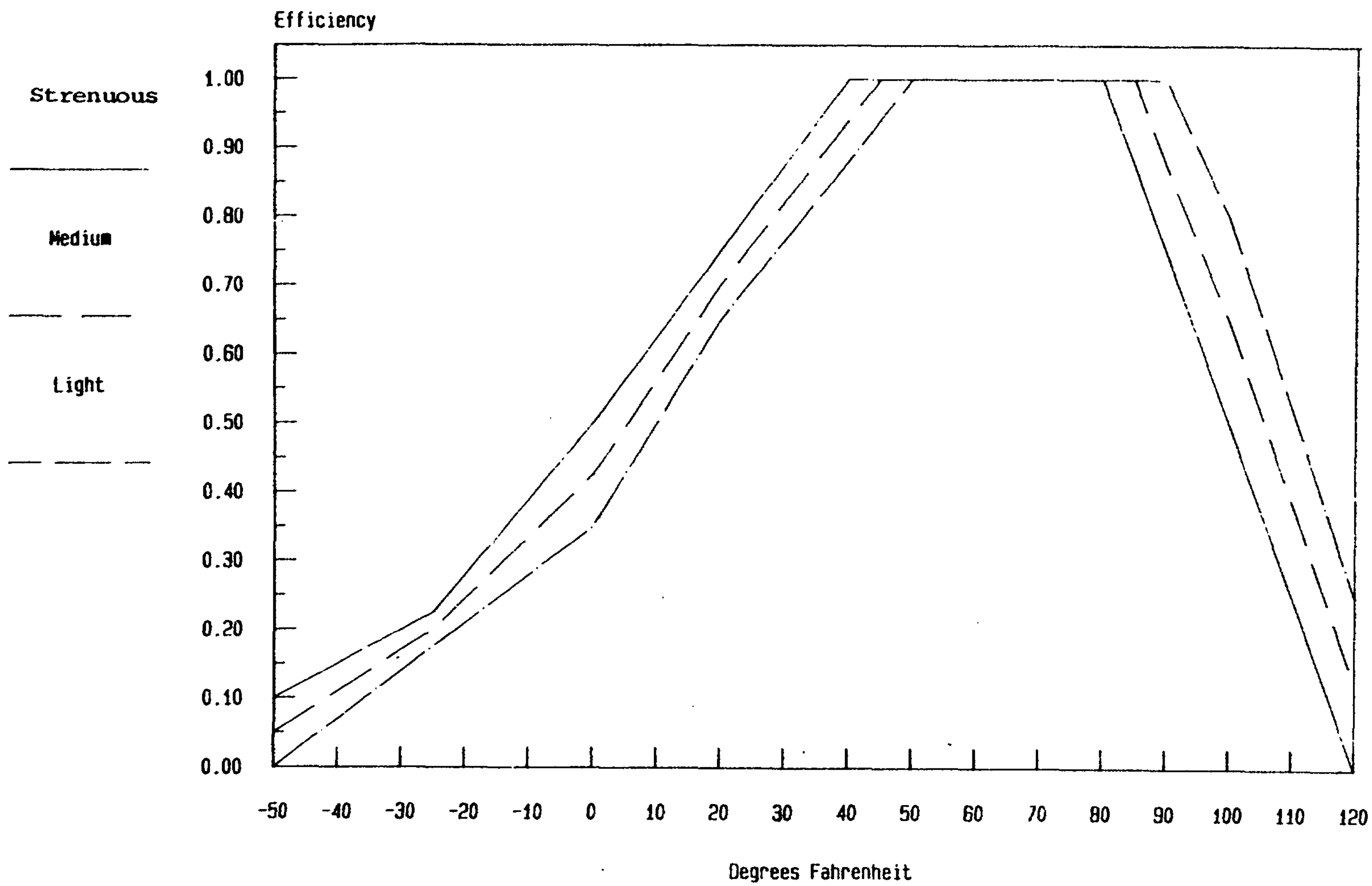



Figure 5. Human Efficiency (Effects of Temperature).

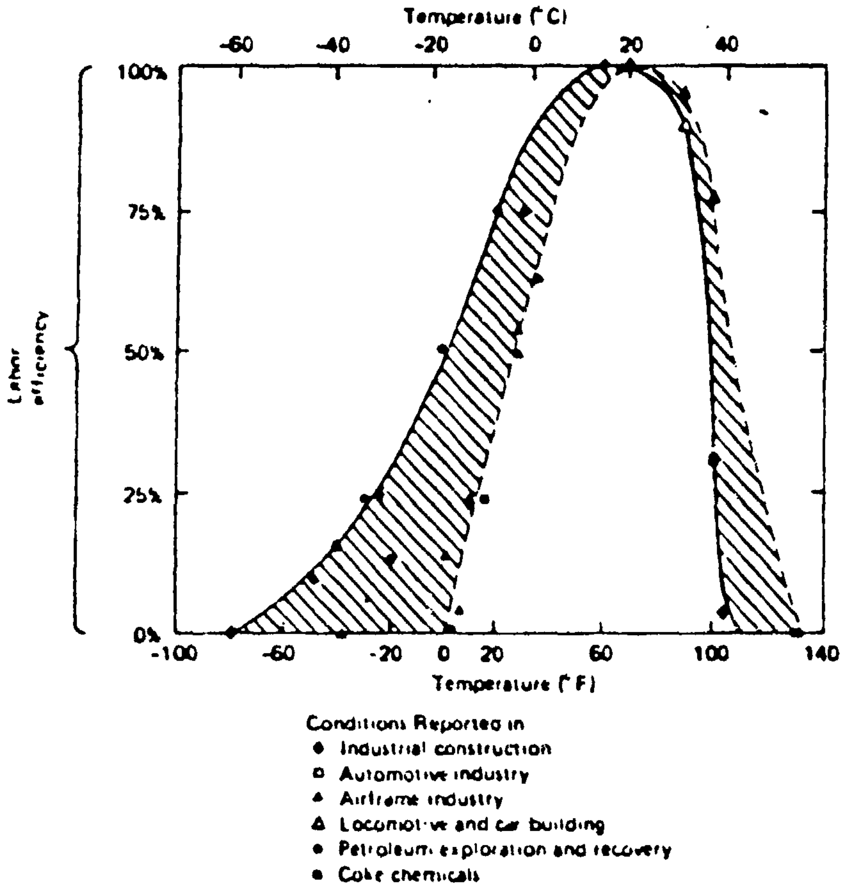



Figure 6. Labor Efficiency at Various Temperatures. Labor Efficiency Estimates Made Independently by Consultants in Industries Named. Compiled by L.E. Doye, University of Illinois.

b. Worker Efficiency During Rainfall

The effect of rainfall on workers varies with temperature and wind conditions. Lack of adequate clothing, low temperature, strong winds, or a heavy volume of rainfall can preclude outdoor work, either singly or in combination. Workers are more likely to continue work if they are used to the prevailing conditions, provided that the equipment and materials are not degraded by the moisture. With favorable conditions (temperature above 50°F, little to no wind) and assuming no adverse impact to other construction resources, it is estimated that worker efficiency declines by only 10 percent.

c. Worker Efficiency During Snowfall

Snowfall has many of the adverse effects of both rainfall and cold temperature, plus additional disadvantages for certain activities.

Snowfall has a severe impact on surveying. Both falling and fallen snow degrade survey work. Falling snow is especially degrading to such RRR activities as damage assessment, EOD detection and removal, repair quality assessment, and vehicle operations.

In general, snow does not greatly hinder equipment operator efficiency during excavation except for the previously discussed effects of cold. However, excavation times lengthen through the need to clear snow-covered areas.

Workers are handicapped as snow and ice developing from the snow make footing poor. Vision and visibility are adversely affected by the falling snow with impact on many RRR activities.

Figure 7 summarizes the effects of precipitation on worker efficiency. Considerations of temperature and slipperiness are treated separately. Recognizing that drizzle can sometimes be helpful, in general, precipitation will increase working times slightly. Protective gear must be worn, and once donned, the wet gear degrades operations. The 10-percent figure was used to characterize worker efficiency in medium rainfall. The light rainfall figure was interpolated. Heavy rainfall would probably be somewhat more debilitating, as protective gear becomes less effective.

d. Worker Efficiency During Sleet and Ice

Icy conditions caused by sleet or other precipitation which subsequently freezes can severely reduce worker efficiency. Outdoor worker efficiency is more seriously impaired by sleet and ice than by rain or snow. Civilian workers seldom continue operations during sleet storms.

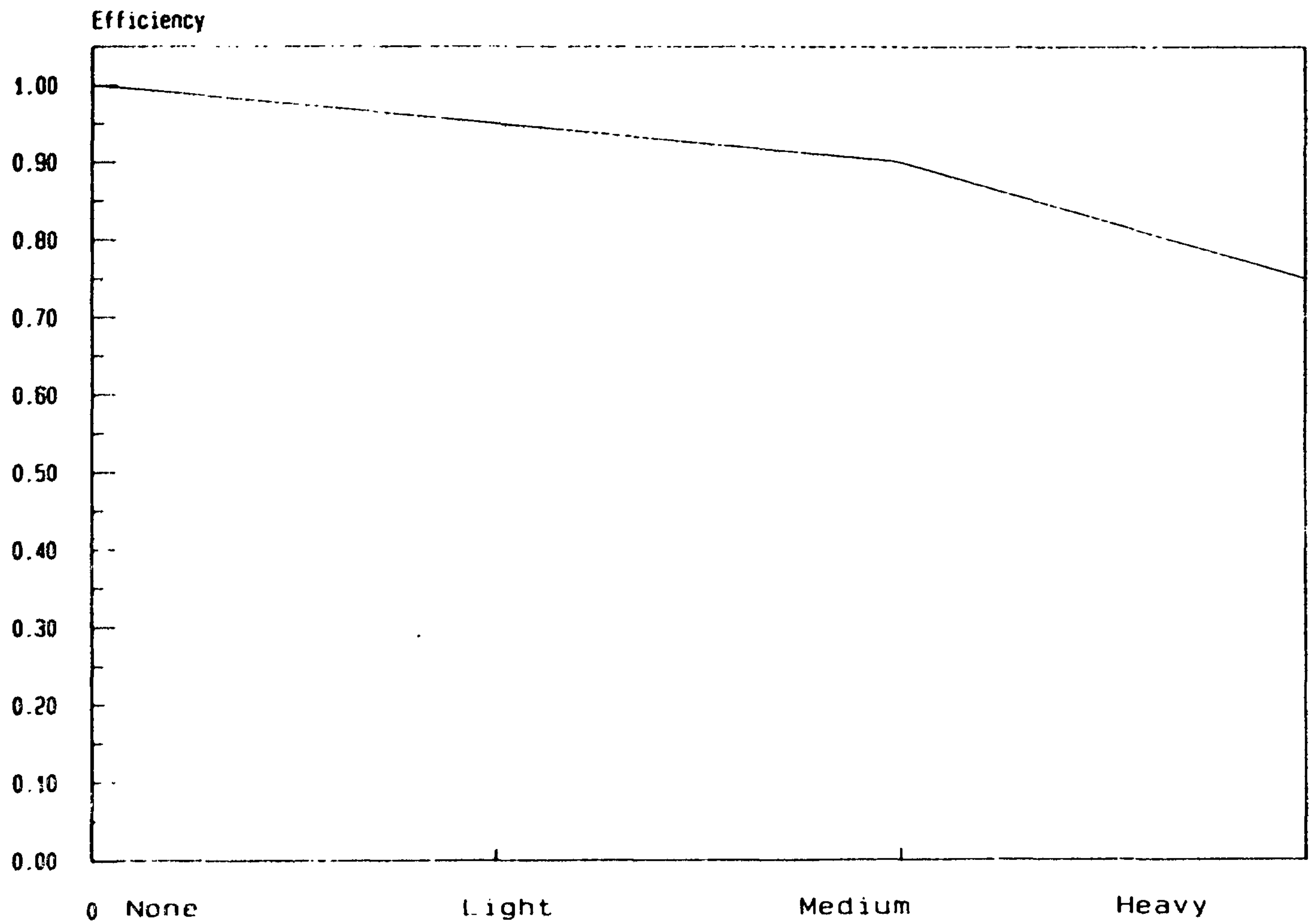



Figure 7. Human Efficiency (Effects of Precipitation).

e. Summary of Precipitation Effects on Men

Figure 8 indicates the trend of worker efficiency in various slippery conditions. Of itself, rain will not cause particular traction problems for men; however, when mixed with the dirt and debris caused by the cratering, the resulting muddy surface could impose some delay. Efficiency was set at 95 percent to characterize this situation. Snow may be turned to slush by varying temperatures, as well as by being trampled by men and machines in the course of the repair. The resulting surface, while not posing the hazards of an icy pavement, will still cause some delays. Onsite tasks can be expected to take half again as long, which translates to a worker efficiency of about 65 percent. For icy conditions, efficiency is 25 percent. This number is derived from analysis and interpolation of the data found in Reference 8 under the topic "Hand Excavation Under Average, Adverse, and Favorable Conditions."

## 4. WORKER EFFICIENCY DURING PERIODS OF HIGH HUMIDITY

Moderate to low relative humidity is considered optimum for construction operations. High humidity can severely affect equipment, materials, and the comfort of workers. Both low and high temperatures are more acceptable if humidity is low. Work at temperatures that exceed 100°F is possible only when the air is very dry, and the efficiency declines considerably, even when temperatures exceed 85°F with high humidity levels.

The effects of humidity, apart from temperature or wind, have not been modeled in this analysis. Instead, these effects have been analyzed collectively using effective temperatures. A discussion of the relation between humidity, temperature, and effective temperature is provided in Appendix A.

## 5. WORKER EFFICIENCY DURING HIGH WIND

a. Introduction

Winds of less than 15 mph do not impose severe restrictions upon construction operations. However, a continuing wind velocity of around 15 mph has a debilitating effect on workers, resulting in a loss of efficiency. This effect is described in more quantitative detail elsewhere in this chapter. An average wind velocity of 30 mph is considered to be a maximum limit for most exposed outdoor work. This level of wind does not completely eliminate the possibility of construction activities, especially those of RRR, although wind can affect RRR in terms of dust, flying debris, and hindrance to the use of repair materials on the postattack runway. However, it becomes a very critical factor when associated with other conditions such as low temperature, rainfall, and snowfall. For example, at 0°F with 20 mph winds, a worker is less efficient than at -50°F temperature with no wind.

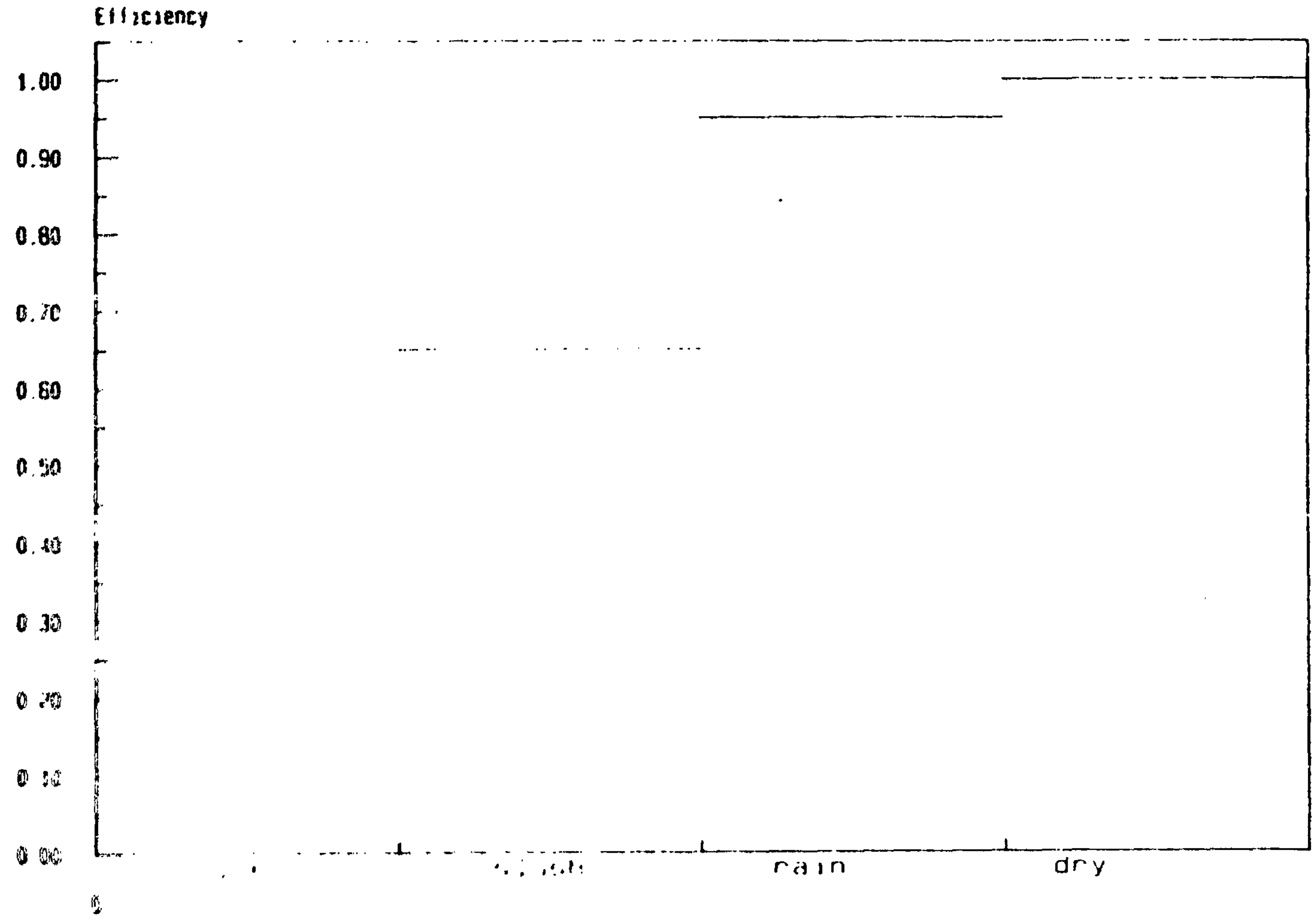



Figure 8. Human Efficiency (Effects of Slipperiness).

The operations that are especially susceptible to wind interference include structural steel work, and any type of work that involves the use of aerial tramways or cranes. This could include the use of excavators or other equipment items with large booms whose exposure to wind could endanger workers. Clearly, AM-2 mats and FOD covers can adversely affect the safety of the construction workers at winds greater than 30 mph (such wind normally includes gusts of 40-60 mph).

b. Worker Efficiency in Wind

For the purpose of depicting the effects of wind on worker efficiency, Figure 9 divides workers into two classes: workers lightly affected and onsite workers. Workers lightly affected by wind are those in protected environments, such as equipment operators. Their efficiency remains constant until winds of 30 mph are experienced. Onsite workers, including mat assembly and surveying personnel, are moderately affected. Winds of 15 mph may require that surveying equipment be weighted. Also, the debilitating effect noted above begins. Winds of 30 mph were judged to reduce efficiency to 25 percent, reflecting the previous comments.

## 6. WORKER EFFICIENCY DURING LOW VISIBILITY

In addition to fog, a variety of the climatic conditions already discussed may cause reduced visibility. Figure 10 summarizes the effects of reduced visibility on four classes of workers. Survey was judged to be the activity most sensitive to low visibility. Surveyors usually make sitings every 1000 feet. If visibility drops to half this distance, twice as many sitings are required and worker efficiency is halved. Hence, the linear decline shown in Figure 10. The next most sensitive activities are EOD and damage assessment. The damage assessment teams work from markers located every 500 feet along both sides of the runway. In order that every part of the runway be visible from at least one marker, visibility must be 261 feet. If the visibility were only half of this, say 130 feet, then less than 260 ÷ 500, or 52 percent of the runway is visible from a marker. Reference 9 has shown that damage assessment in the dark can be expected to take twice as long as daytime assessment. Applying this gives a time of 2 x 48 percent + 1 x 52 percent = 148 percent for damage assessment under the condition, or an efficiency of 1/1.48 = .68. This model breaks down when visibility goes to 0, since at night artificial lighting can be used, whereas dense fog is opaque. Hence, the efficiency of zero for zero visibility.

The EOD task was judged to be similar to damage assessment since there is an initial need to find the UXO or to relocate it based on prior discovery. Also, when moving the UXO to the side of the runway, workers must find their last position to continue the search.

Travel activities are also affected by low visibilities. However, as most RRR travel is at speeds of 25 mph or less, the effect is not as pronounced as it would be at highway speeds. At 25 mph, a visibility of

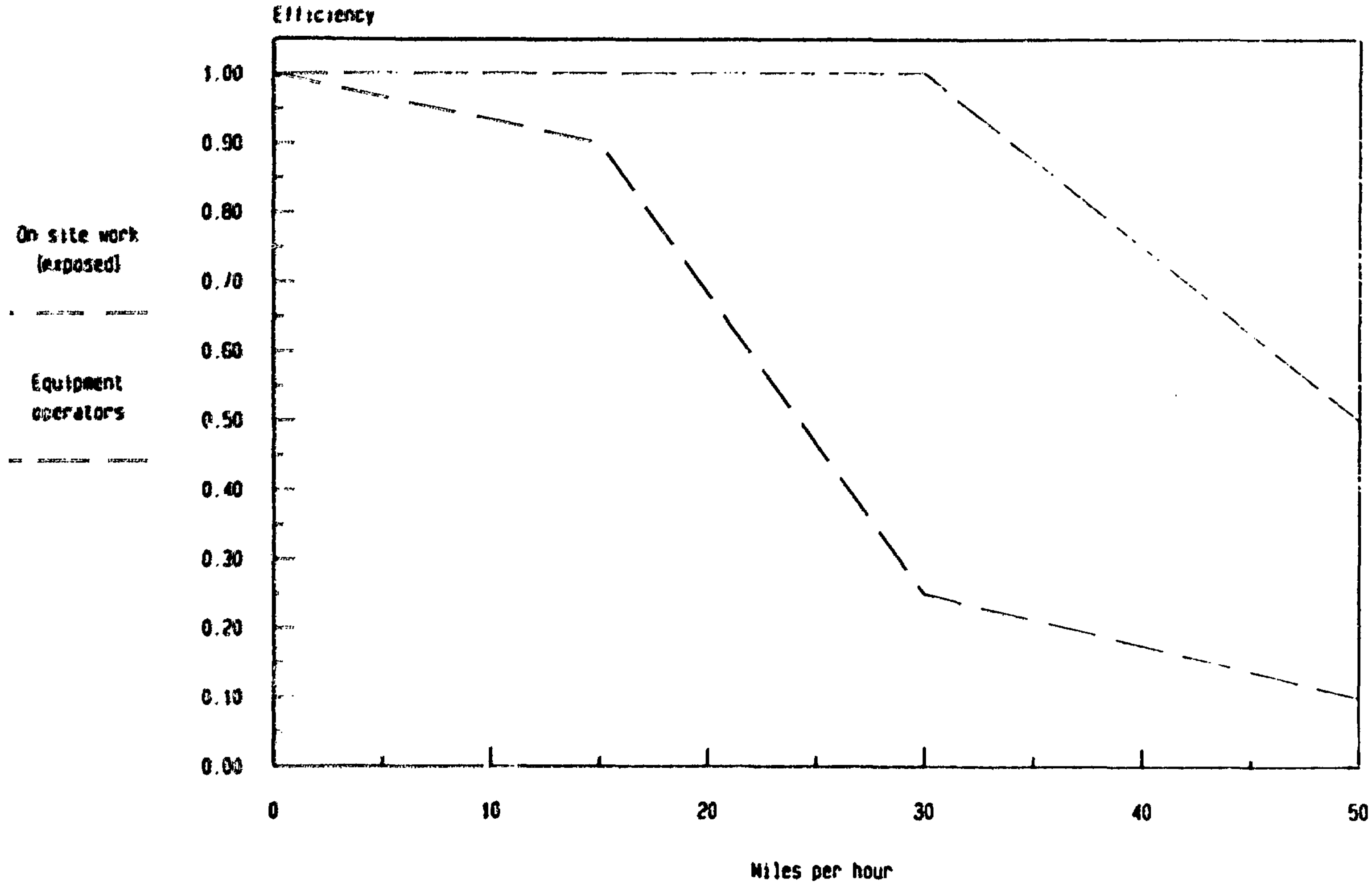



Figure 9. Human Efficiency (Effects of Wind).

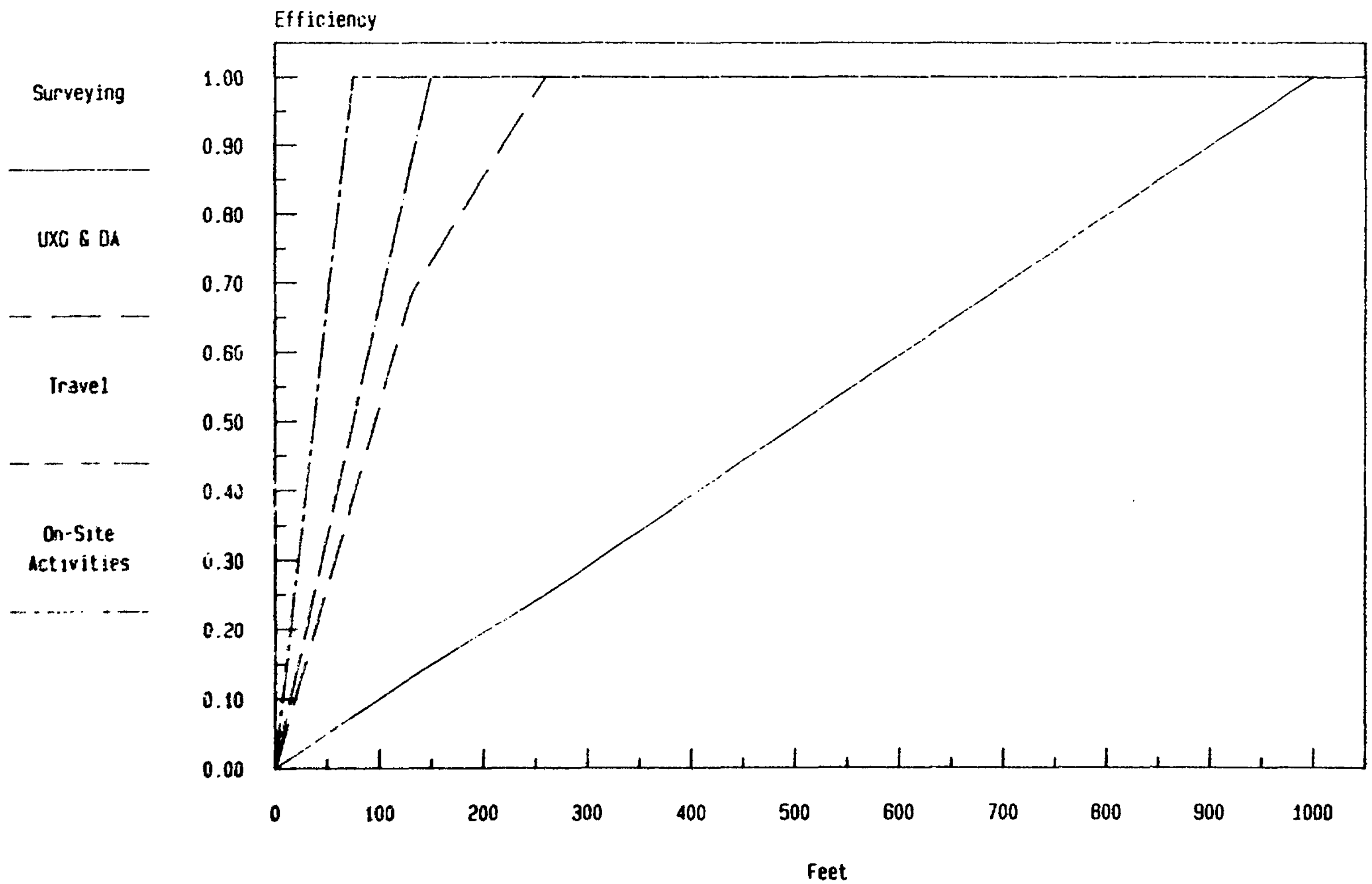



Figure 10. Human Efficiency (Effects of Visibility).

150 feet permits the operator to see about 4 seconds ahead. It was judged that less visibility than this would require him to reduce his speed.

The remainder of the onsite activities were assumed to proceed at a normal pace as long as visibility permitted workers to see across most craters. When this ability is lost, command and control problems multiply and efficiency declines. Most craters were taken to be less than 75 feet in diameter.

## 7. SUMMARY

This section has discussed the effects of low visibility, extreme temperatures, precipitation, slippery conditions, and wind on human efficiency. Reference to the data in Appendix A gives expected and 99-percent levels for these weather conditions. Combining these with the efficiency graphs developed in this section gives average and 99-percent level effects on human efficiency.

The average effects are all small. The 99-percent level effects of low visibility and precipitation are also small. The 99-percent level high temperatures have a moderate effect on human efficiency. The 99-percent level low temperatures have a serious effect, but this can be reduced with proper clothing. For wind and slipperiness, the 99-percent level effects are also serious and not so easily addressed.

SECTION VI

WEATHER EFFECTS ON EQUIPMENT

## 1. INTRODUCTION

This section summarizes the effects of weather on the various equipment items used in the RRR process. Appendix C contains a detailed discussion of each piece of equipment, and conclusions and recommendations for its operation under adverse weather conditions.

Equipment information for this section and its appendix is based on the types and models specified in AF Regulation 93-2, where available. Information includes the capacities and capabilities of the equipment and its components, the expected effects of weather on equipment and equipment components, and the expected interaction between equipment, environment, and the RRR process. Information sources include manufacturers, technical data, and military technical and operational manuals. Other sources included construction industry studies, performance and cost factors handbooks, and questionnaires, reports, and interviews with contractors.

Where conclusions, estimates, or other information are drawn from outside sources, they are referenced in the text according to their order in the reference listing. Where engineering judgment is used to describe the effects of weather, a short summary of the reasoning is included.

## 2. GENERAL

A brief discussion of assumptions and caveats is necessary before discussing specific equipment items. In general, all construction equipment manufacturers try to produce their equipment for use in a rugged environment with wide variations in climatic conditions. Additionally, equipment must conform to certain minimum standards such as those of the National Institute of Safety and Health (NIOSH) and the Mine Safety and Health Administration (MSHA). These regulatory agencies often require protective devices of various types to help insure the safety of the operator and the public. Many machines have optional protective devices such as guards or shields for radiators, crankcases, engines, track rollers, wheels, or brakes. A large number of other options exist for safety, convenience, and efficiency. Frequently, however, the equipment item and its standard and optional accessories are designed for operations under economical or cost-effective conditions, not for adverse or dangerous conditions. For this reason, the discussion of each equipment item takes individual components and options into account.

In spite of this apparent abundance of protection, the RRR process requires that repair of the runway be potentially undertaken at any time of the year, at any hour of the day or night, under conditions of manmade impediment (chemical warfare, UXO, or bomblet threat), for long periods of time without stops or breaks, by untrained operators with limited resources available. These reasons dictate that an especially hard look be taken at the equipment. This permits selection or modification of equipment so that the greatest number of environmentally adverse conditions can be overcome.

## 3. CONCLUSIONS

### a. Introduction

With proper maintenance and precautions the RRR equipment can be operated successfully in most adverse weather conditions. The following considerations are treated in more detail in Appendix C.

### b. Specific Pieces of Equipment

The scooploader is a rubber-tired vehicle which is strongly affected by slippery or wet surface conditions. It normally includes an all-weather cab, which reduces the effects of weather on the operator.

The motor grader is also strongly affected by slippery or wet surface conditions. It may or may not include an all-weather cab. The earth moving of the motor grader will be impacted by frozen surface conditions. Frozen material that has accumulated on moving parts must be thawed and removed prior to operation. If the machine is to be left unprotected in cold weather, it should be parked on a bed of planks or brush to keep it from freezing to the ground. The radiator fins and filters must be cleaned more frequently in hot or dusty weather.

The full-tracked dozer is only moderately affected by surface conditions. It can operate in muck or water up to the height of its tracks. It often has no cab, which leaves its operator exposed to the weather. In cold weather, special starting procedures must be followed, including the use of primer capsules. More so than the other equipment items, it must be parked on a bed of planks or logs during freezing weather to prevent the large surface area of its tracks from freezing to the ground.

A winterization kit is available for the 5-ton dump truck. The fuel burning power plant heater should be used in low position when the truck is left in the cold. The gear level should also be left in neutral to prevent freezing in gear; proper fuels should be employed; and tire pressures should be increased. If the truck is not operated for prolonged periods during hot weather, batteries should be stored in a cool area.

A winterization kit is also available for the equipment transporter tractor. A transmission strip heater is standard equipment. In temperatures below $0^{o}F$, maintenance must bypass the power steering cooling system. Correct tire pressure is critical in cold and hot weather and the possibility of frozen brake shoes must be checked before normal operations.

The same equipment and precautions hold for the concrete mobile mixer chassis and prime mover as for the equipment transporter. In addition, the mixer, water tank, liquid admix, sand and stone bins must be heated in cold weather. A heating torch is used to warm the water lines as needed. The bins should be covered with tarps to retain heat. The equipment should be cleaned immediately after operations to avoid freeze damage. Hot weather precautions for the concrete mobile mixer include placement of tarps over the aggregate bins to retain moisture, immediate cleanup and frequent fluffing of the cement using the fluffer valve.

c. All Equipment

It is especially critical that vehicles and equipment be kept in the best possible condition during periods of extremely cold weather. Low temperatures can change the strength, elasticity, hardness, and other properties of many materials, and reduce the operating efficiency of systems composed of moving parts.

Extreme cold has deleterious effects on petroleum products such as rubber, plastics, leather, ceramics, and other materials. Rubber becomes stiff in extreme cold and bending may cause it to break. For example, rubber tires may develop flattened areas when parked for several days in an area without protection in subzero temperatures. These areas have little resiliency until they are warmed up, and permanent damage can result if used before warming. This may apply to rubber heater hoses and hydraulic lines. Leather, as well as rubber, becomes less pliable. Plastics and other synthetics are less ductile. Canvas and similar fiber products become stiff and difficult to work. Glass, being a poor conductor of heat, may crack if subjected to sudden temperature changes.

Proper operation and maintenance procedures are more important under cold conditions than at any other time. Maintenance discipline before, during, and after operations can insure that coolants, lubricants, batteries, and other components sensitive to the cold are ready for use.

Drivers must be familiar with driving and operating the vehicle under the low temperature conditions. The impact of ice and snow on turning, braking, and other operations is especially critical. Good visibility must be maintained in spite of ice, snow, and condensation. The ability to conduct necessary prestart, start, warmup, operation, stop, shutdown, and cool-down procedures, is important. Operators must be aware of the danger of carbon monoxide poisoning in the cabs and passenger-carrying compartments. Windows should be cracked when engine is operating or heater is in use. Garages or closed areas used for vehicle maintenance must be monitored for dangerous levels of carbon monoxide. Dry cold weather produces great amounts of static electricity in the layers of clothing worn by personnel and in liquids being transported. Extreme caution must be exercised when refueling vehicles because the spontaneous discharge of static electricity may ignite these flammable fuels. Static electricity should be "drained off" by grounding vehicles or fuel containers prior to starting refueling operations. Personnel should ground themselves by touching a vehicle or container (away from vapor openings) with the hand.

Certain special considerations must be given to maintenance requirements. Additional time must be allocated for thawing out certain vehicle components before repairs can be started. These "thaw times" must be added to repair times for normal conditions. A mechanic's efficiency is reduced when working in cold climates, especially if operations and maintenance are conducted outdoors because of the bulky, cumbersome clothing that must be worn in extreme-cold areas. As it is impossible to handle extremely cold metal with a bare hand, some form of mitten or glove must be worn at all times. The resultant loss of the sense of touch further reduces efficiency. Even the most routine operations, such as handling latches or opening engine enclosures, become exasperating and time-consuming when they must be performed with mittened hands. Experiments have proven, for example, that the time required to screw a nut on the largest bolt available is twice as long when mittens are worn than that for a similar operation conducted with bare hands. The space required to insure access to controls and assemblies which are commonly replaced or which require periodic adjustment, inspection, and cleaning is also increased when bulky cold weather clothing is worn. Comparison measurements of personnel wearing warm-weather clothing versus those wearing cold-weather clothing are shown below.

Comparison Clothing Measurements (Reference 10)

| | Warm Weather | Cold Weather |
|---|---|---|
| Hand (width) | 10 cm (4") | 15 cm (5") |
| Wrist (circumference) | 19 cm (7 1/8") | 53 cm (21") |
| Head (circumference) | 58 cm (28") | 96 cm (38") |
| Breadth across shoulders | 46 cm (18") | 81 cm (32") |
| Foot (width and length) | (3 1/2 x 11") | (5" x 14") |

4. EQUIPMENT EFFICIENCY

If the maintenance procedures and precautions discussed above are followed, RRR equipment can generally be operated in adverse weather conditions without loss of machine efficiency. This is in distinct contrast to loss of efficiency of equipment operators, discussed in Section V. This also assumes that airfield surfaces have been kept clear of builtup snow. Alternate launch and recovery surfaces should also be kept cleared during times of hostility.

The exception to this situation is slippery conditions. The resulting lack of traction will increase the times of many RRR equipment tasks. To characterize this decrease in efficiency, RRR equipment was divided into two categories: equipment strongly affected by slippery conditions and equipment moderately affected by slippery conditions. All light-wheeled vehicles performing any operation and medium to heavy vehicles performing heavy effort were classified as strongly affected. Tracked equipment travel and other equipment not highly impacted by poor ground conditions were classified as moderately affected. See Appendix E for a complete classification.

Figure 11 graphs the efficiencies under conditions characterized as icy, slushy (snow which has been trampled by men and machines), and rainy (water mixed with crater debris produces a muddy surface which will be slicker than that usually associated with rain alone). The source for the strongly affected curve in Figure 11 is based on engineering judgment, surveys, and a variety of sources, most importantly, the "adverse/average/favorable man-day estimates" found in Reference 8. The moderately affected curve was estimated on the basis of the strongly affected one.

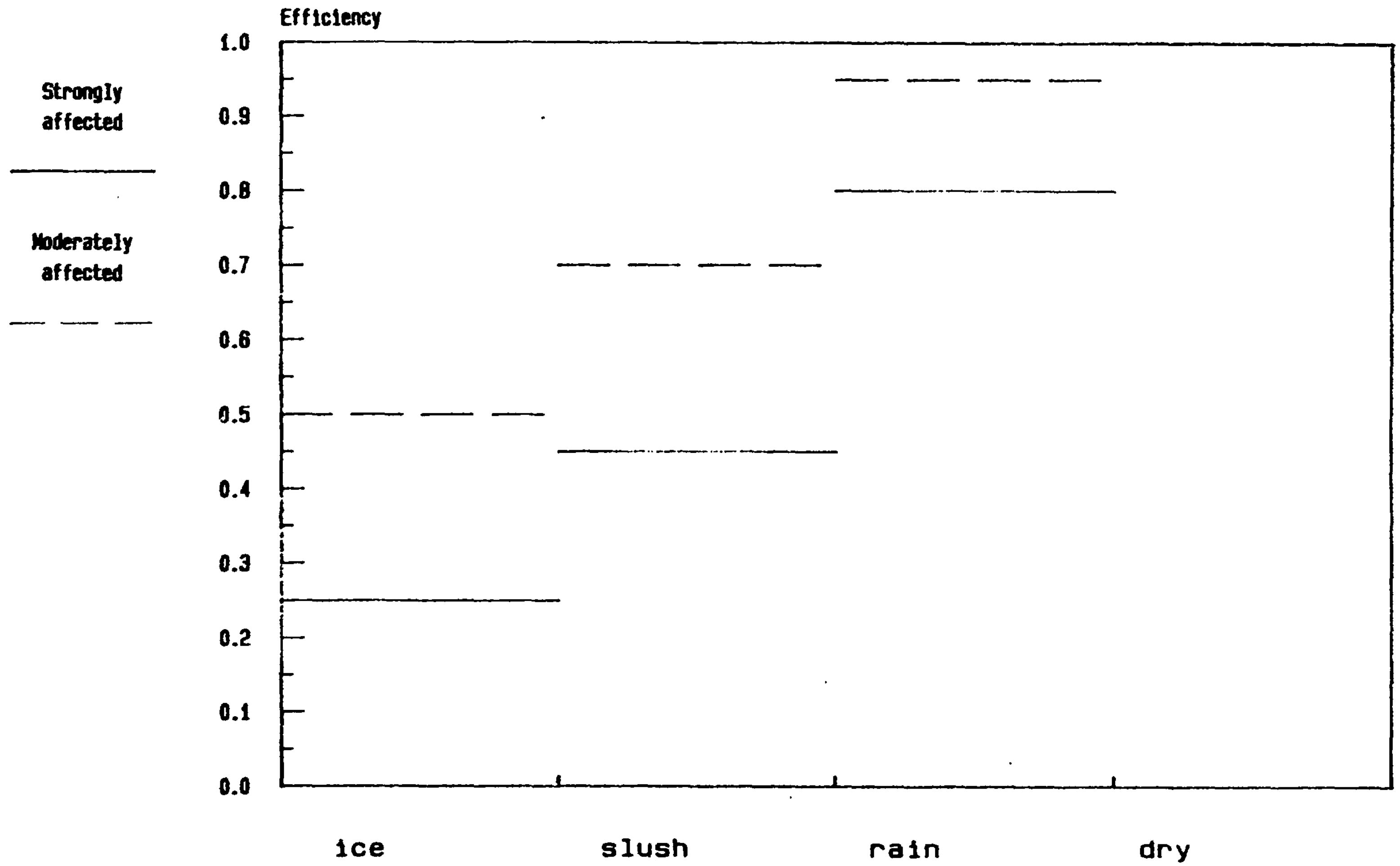



Figure 11. Equipment Efficiency (Effects of Slipperiness).

## SECTION VII

## WEATHER EFFECTS ON MATERIALS

### 1. GENERAL

One aspect of RRR especially sensitive to weather is the variety of materials used to regenerate the airfield. Severe weather degrades human and equipment performance but progress is not normally suspended. Weather effects on materials, however, can stop the repair work completely, under certain weather conditions. The precise limits of a material's tolerance to environmental extremes are difficult to determine. Many of the RRR materials have not been tested over a wide range of weather conditions but the following represents the best, most recent attempt to quantify the degradation of material by ambient environmental conditions.

Many information sources were used to develop an idea about how weather affects materials. The observations of people who work with these materials were helpful. Past tests to determine the effects of weather on repair materials were also helpful for this study. Other information was provided by reports documenting the efficiency of equipment and operations under varied conditions, though not primarily concerned with weather or materials. These conclusions and data elements, though generally not especially important to the report they were taken from, are useful to our analysis of weather by providing the basis for engineering judgments and estimations. A sense of specific material sensitivities to weather emerged from these varied sources.

The information about the degradation of RRR materials in severe weather is incorporated in the descriptions of RRR activities and procedure networks. During a freezing rain storm, the joints in the AM-2 mat are filled with ice. Sections of the mat may also freeze to the ground. This results in greatly decreased efficiency for the men in the AM-2 mat assembly activity. The activity, therefore, takes longer under freezing rain conditions. If the assembling activity appears to be slowing down the entire procedure considerably, then freezing rain is a potentially important problem that needs further study.

Another way that the material affects information used in this report is to direct the weather probabilities study. Since freezing rain has been identified as having an effect on the AM-2 mat, the chances of freezing rain are analyzed. This probability analysis will help to ascertain how serious the threat of freezing rain is to the RRR team.

Many different materials included in the RRR set are used to repair the airfield. Crater covers, nuts and bolts, polymer concrete, and sander disks are examples of these materials. Many of the materials are relatively unaffected by weather or not critical to the repair. These materials are omitted in this section. Knowledge of the effectiveness of sander disks, as an example, is not especially important to understanding the runway repair process. The sander disks are, therefore, not considered in this materials analysis section. Alternatively, characteristics of crushed stone are important to the repair effort because much effort is expended in its placement and compaction. Moisture content is crucial to the compaction of crushed stone so precipitation could have significant impact. Crushed stone is, therefore, analyzed in this section.

Materials whose weather degradation is significant in the RRR process are listed below:

a. Crushed Stone

b. Polymer Concrete Cap Repairs for Small Craters

c. Repair of Scabs with Silikal® Polymer Concrete

d. AM-2 Mat

e. FOD Cover

f. Paint

g. Lead - Sulfur Compound

2. CONCLUSIONS AND RECOMMENDATIONS

Each of the six materials listed above is described in detail in Appendix D. The weather conditions that affect the performance of the material are identified and a qualitative description of the effects is made. The primary problems and some potential solutions are summarized below.

a. Crushed Stone

The crushed stone required to fill craters using the crushed stone and FOD cover technique is well-graded limestone or silica. For concrete cap repairs a less well-graded aggregate is acceptable. The primary weather problems with crushed stone result from moisture, both in the stockpile and in the crater. Additionally, while in the stockpile, precipitation and numerous freeze-thaw cycles over a period of time can cause the aggregate to segregate, and low temperatures can cause it to freeze. Stockpiles should be protected from such weather elements with tarps.

In the crater, the water content of the crushed stone can affect successful compaction. Acceptable water content ranges from 2.5 percent to 4.5 percent for well-graded crushed stone. The aggregate requirements are less stringent. The problem of low moisture content is fairly easily solved by sprinkling during compaction. High moisture content is a more serious problem. A proposed solution is to add a layer of coarser aggregate below the well-graded stone to allow excess water to drain. Research and testing of this potential solution are needed.

b. Polymer Concrete

Polymer concrete for concrete cap repairs of small craters is fairly insensitive to poor weather conditions. It can be placed and cured successfully when environmental temperatures range from -25°F to 125°F. Moisture affects the flexural strength of the completed repair. However, adequate flexural strengths have been obtained over a range of temperatures for both wet and dry aggregate. Research and testing continue on polymer concrete repair materials.

c. Silikal•

A specific brand of polymer concrete, Silikal• is currently used for scab repair. With the use of a low temperature accelerator, Silikal• can be used in temperatures ranging from -25° to 104°F.

Moisture is a more serious problem. Even a 2-percent water content in the Silikal• reduces the strength by 50 percent. Also, moisture in the scab degrades the bonding between the Silikal• and the runway pavement. Work must be suspended until precipitation has stopped, after which the scabs must be dried. One potential solution to scab repair in wet weather is to use a steel plate. This procedure is discussed in more detail in Appendix D.

d. AM-2 Mat

The major weather conditions affecting the AM-2 mat are freezing rain and slush. The freezing rain can fill joints in the AM-2 mat. This condition significantly interferes with mat assembly. This activity, however, is not on the critical path for the AM-2 mat repair procedure. Delay in the mat assembly may not necessarily increase the repair time.

e. FOD Cover

Extremes in temperature do not significantly degrade FOD cover effectiveness significantly. Tests have demonstrated that the FOD cover strength and resistance to elongation change less than 5 percent in the temperature range -25°F to 125°F (Source: Conversation with Battelle Columbus Laboratories).

Precipitation is not a severe problem with FOD covers because the FOD cover is impermeable.

Very heavy winds might interfere with FOD cover placement. The FOD cover must be pulled tight across the repair before being anchored. A strong, continuous wind could make this difficult, requiring extra time and men. This activity is also not on the critical path, so that this delay may not be a serious one.

f. Paint

Precipitation has a severe effect on painting. Even a light rain makes centerline painting impossible (Reference 5). Limited experience in this area indicates that snow and sleet probably do not halt centerline painting for expedient repairs. The centerline will need repainting, but it will be visible.

High temperature has little effect on paint, while humidity greatly affects the time required for paint to dry. Nevertheless, this is not a critical factor in centerline construction and, therefore, need not be considered.

Cold temperatures pose a serious problem to the painting activity. In temperatures under 50°F the paint becomes so viscous that it clogs the nozzles on the paint striper and impedes proper flow. Local paint companies have suggested that an oil-based paint may be used at temperatures below 32°F for expedient repairs. Although the quality of the job would be poor, it would serve its purpose as a runway marker. The temperature where runway marking is impossible is difficult to estimate, but at 10°F the paint would probably become too viscous to place. Water-based paints are useless at temperatures less than 32°F.

## SECTION VIII

## ACTIVITIES

### 1. GOAL

The goal of this analysis has been to develop a model which has two characteristics. First, it should produce valuable results with the raw data available. And second, it should be extendable and improvable as better data is developed. Having a carefully designed model already in place allows well-planned data gathering.

### 2. APPROACH

To analyze the effects of weather on bomb damage repair, one must know how weather affects the basic units of RRR; how the basic units are built into RRR activities; the duration of those activities under good conditions must be derived; and finally, the weather conditions likely to occur at the airbases in question must be studied.

#### a. The Effects of Weather on the Basic Units of RRR

This analysis was reported in Sections V-VII and will be summarized here. The efficiency graphs developed in these chapters are collected and repeated at the end of Appendix E for ease of reference (Figures E-1 through E-7).

For this part of the analysis, weather was divided into five categories: visibility, temperature, precipitation, slipperiness, and wind. In each case, only environments of reasonable probability were considered. No one would argue that it would not be difficult to repair a runway in hurricane conditions. But such conditions are sufficiently rare that it is better to consider more probable weather conditions and plan for the degradation that they will produce.

The basic units of rapid runway repair are divided into three categories: men, equipment, and materials. It is then necessary to characterize the effect of each of the five weather conditions listed above on men, on equipment, and on materials. Various effects are possible. The efficiency of the unit may be degraded by the weather condition, for example, men working in cold temperatures take longer to complete their tasks. Or the unit may not be usable in a particular condition: i.e., paint cannot be applied in heavy rain. The unit may be unaffected by the condition, for example, paint in hot weather. And finally, the weather condition may require a change in the activity network before the activity can proceed. An example here would be that in wet conditions the scab must be dried before Silikal* can be used for scab repair.

Assigning a particular effect as only affecting men or equipment is not always straightforward. Consider, for example, a truck traveling in low visibility. Its speed and thus its efficiency is reduced. However, the actual effect is on the driver, whose vision is limited and who must operate the truck at a lower speed and not on some mechanical facet of the truck itself. In general, effects were assigned to equipment or materials, only when some physical result occurred.

Figures E-1 through E-7 show that the basic units of men, equipment, and materials had to be further subdivided to usefully characterize the effect of a particular condition. For example, low visibility affects men in different ways, depending on the type of task they are accomplishing.

b. RRR Activities and Their Duration Formulas

The next stop in characterizing the effects of weather on bomb damage repair is to understand how the basic RRR units of men, equipment, and materials are combined to accomplish the RRR activities. Appendix E gives this analysis for each of 21 activities. The type of equipment and sequence of required actions is discussed. From these, a duration formula is developed which depends on the efficiency of the units involved, as well as on the values of various other parameters, such as crater size, distance to the stockpile, etc. Using reasonable assumptions for the required parameters, the duration as a function of efficiency is derived and graphed. The duration formulas are summarized in Table 3.

c. The Duration/Weather Condition Graphs

Once duration has been graphed as a function of efficiency, and efficiency as a function of weather condition, these graphs may be composed to yield the duration/weather condition graphs (Figures E-8 through E-17). These graphs are presented as the level curves on K, where K is the duration of the activity under ideal conditions.

As an example in using the duration/weather condition graphs, consider the activity of preparing scabs under conditions of limited visibility. The activity description in Appendix E gives the duration formula as 15/Em minutes. That is, in ideal conditions, when Em=1, scab preparation will take 15 minutes, given that two two-man crews are available for a 15-scab field. Under visibility in the weather section of the activity description, scab preparation is defined to be an onsite activity. So, to read the duration under low visibilities, enter Figure E-10, "Effects of Visibility on Duration of Onsite Activities," with K=15.

d. Worst Case Analysis

The last step in characterizing the effects of weather on RRR activities is to use the weather data gathered in Appendix A to determine the range of durations that is likely to occur.

TABLE 3. SUMMARY OF ACTIVITY DURATION FORMULAS.

| Activity | | Duration (Minutes) |
|---|---|---|
| Prepare scabs | | 15/EM |
| Dry scabs | | 7.5/EM |
| Mix and place concrete in scabs | | 48/EM |
| Paint MOS | | 75/ES |
| Pull mat into place | | 10/EM |
| Damage assessment | | 93/EM |
| Load, deliver, unload FOD cover | | 5/EL + 2/EF |
| Assemble AM-2 mat | | 45/EM |
| Distribute fill | 57' Crater | 51/E |
| | 31' Crater | 15/E |
| | 57' Concrete Cap | 21/E |
| | 31' Concrete Cap | 6/E |
| Sweep | | 28/EW |
| Clear debris | | 16/E |
| Place and anchor FOD cover | 57' Crater | 27/EM |
| | 31' Crater | 21/EM |
| Loosen lip | 57' Crater | 30/E |
| | 31' Crater | 10/E |
| Anchor AM-2 mat | | 21/EM |
| Grade | 57' Crater | 15/EG |
| | 31' Crater | 5.6 EG |
| Load, deliver and unload AM-2 mat | | 5/EL + 18/EF |
| Place polymer concrete | 57' Crater | 63/EM |
| | 31' Crater | 26/EM |
| Cure concrete | | 20 |
| Compact | 57' Crater | 51/EV |
| | 31' Crater | 20/EV |
| Load and deliver fill | 57' Crater | 28.8/ET + 15.6/EL |
| | 31' Crater | 9.6/ET + 5.2/EL |
| | 57' Crater | 14/ET + 7.8/EL |
| | 31' Concrete Cap | 4.8/ET + 2.6/EL |
| Compact debris | 57' Crater | 21/E |
| | 31' Crater | 8/E |
| Remove bomblets | | 16/ED |
| Disarm bomb | | 20/EM |
| Survey | | 20/EM |

EM = Efficiency of men
ES = Efficiency of striper
EL = Efficiency of lowboy
EF = Efficiency of forklift
E = Efficiency of loader or dozer
EW = Efficiency of sweeper
EG = Efficiency of grader
EV = Efficiency of vibratory roller
ET = Efficiency of dump truck
ED = Efficiency of dozer

The weather data presented in Appendix A provide the cutoff points for conditions that occur less than 1 percent of the time. For example, a survey of the temperature graphs shows that the worst case maximum occurs in Germany in July. Less than 1 percent of the observations were greater than 99°F. The duration/temperature graph then gives the duration of various tasks at this temperature.

A survey of the weather effects, portions of Appendix A, shows that in general the degradations that arise from low visibility and wind are not substantial. Temperature, precipitation, and slipperiness are more serious problems. The next question to be addressed is how the duration of these conditions affects the worst case analysis. Returning to the example of high temperature given above, the implicit assumption is that the maximum temperature of 99°F was maintained for the entire repair period. This is conservative, but not severely so. Any 4-hour period in which the temperature reaches 99°F is likely to be a hot one, with work efficiencies not greatly exceeding the 99°F efficiency figure. The duration estimate given by the duration/temperature graph, while somewhat high, is still a useful prediction.

The problem of weather condition duration in the case of precipitation and slipperiness is somewhat different. Many of the effects of precipitation do not degrade efficiency, but instead, they alter the activity network or prevent work from proceeding. In these cases, it is more important to consider both the probability of the weather condition and the distribution of its duration. The data here are incomplete, but the available precipitation duration data have been graphed. These graphs appear in Appendix A.

## 3. EXAMPLE

As an example in using the activity duration models, consider the activity of assembling the AM-2 mat. From Appendix E, the duration formula is seen to be

$$45/Em.$$

To illustrate the way that the weather data may be combined with the activity models to predict durations, this example will calculate the duration of assembling the mat under a variety of average weather conditions. Under ideal conditions $Em = 1$ and the duration is 45 minutes.

Begin by considering summer temperatures. Reference to Figures A-2 and A-3 gives a mean monthly maximum July temperature of 85°F for Germany and 92°F for Korea. In the description of this activity in Appendix E, the level of work is given to be strenuous. The efficiencies can be read from Figure E-2 on the strenuous curve, or durations can be read directly from Figure E-12 with $K = 45$. They are 51 and 65 minutes for Germany and Korea, respectively.

Figures A-204 through A-210 show that most of the time visibilities in both Korea and Europe are above 990 feet. Figure E-1 uses the onsite curve, as described in Appendix E, to reveal that the efficiency equals one for visibility above 75 feet. Hence, in conditions of average visibility, assembling the mat is not likely to be delayed.

As an example involving precipitation, consider the data for Upper Heyford. Figures A-165 through A-196 and A-92 through A-103 show that Upper Heyford experiences prolonged periods of light rain. The efficiency of mat assembly in light rain is given in Figure E-3 as .95. Duration is then 45/.95 = 47 minutes. Duration can also be read directly from Figure E-15 with K = 45.

Besides directly impeding the work, precipitation may also cause slippery conditions which, in turn, cause delay. Because of the lack of joint probabilities and joint efficiencies, these effects must be considered separately at this point. Figure A-140 shows that the Korean bases in January receive some snow 41 percent of the days. Once a repair process has begun, snow creates slush-covered surfaces that hinder repair progress. Figure E-4 gives a human efficiency of .65 on a slushy surface, which yields a mat assembly time of 45/.65 = 69 minutes.

Finally, consider windy conditions. The direct effect of a 15-mile per hour wind (approximately 13 knots) on mat assembly is to reduce efficiency to .90, or to increase duration to 45/.90 = 50 minutes (see Figure E-5). Figure A-222 shows that 24 percent of the wind observations in Upper Heyford in February revealed speeds of 11-16 knots.

## SECTION IX

## USING THE STUDY AND FINAL MODEL

Analysis goals for weather and activities modeling were met with results summarized in Sections V-VIII. While these results are important individually, simple techniques allow results to be combined to produce valuable estimates of RRR capabilities. One potential study use is determining 99-percent effects of various weather conditions on RRR. These effects were estimated using weather data and the activity models described previously. These components were combined using the Critical Path Method (CPM) described next.

### 1. CRITICAL PATH METHOD MODELING

The Critical Path Method (CPM) is a method for determining the start and finish times of activities in a project. Based on the activity network and estimated durations for each activity, the CPM method determines project duration. It identifies activities which must be started as early as possible to keep from delaying the repair. These activities form the critical path whose duration is the duration of the repair. Any delay in an activity on the critical path will delay the repair, whereas delays in noncritical activities may be absorbed.

Using the CPM, each repair procedure was modeled under ideal conditions and under each of six worst-case conditions: heat, cold, visibility, precipitation, wind, and slipperiness. For the three crater repair procedures included in Figure 12, the critical path is similar. It consists of:

a. Loosen lip,

b. Compact debris,

c. Distribute fill,

d. Grade,

e. Compact,

f. Sweep, and

g. Place mat/Place FOD cover/Pour concrete cap.

Hauling activities, clearing debris, and assembling mat are all activities with slack times. These results, however, are sensitive to distance, to repair, and condition of surface. They may also change when multiple-crater repairs or crater repairs with scabs are modeled.

| | DURATION (HOURS: MINUTES) | | | | | | |
|---|---|---|---|---|---|---|---|
| PROCEDURE | IDEAL | 99% HOT | 99% COLD | 99% PRECIP | 96.5% VISIBILITY | 99% WIND | 99% SLIPPERY |
| AM-2 (57') | 3: 49 | 5: 20 | 4: 43 | 5: 05 | 3: 49 | 5: 08 | 11: 40 |
| FOD (31') | 1: 43 | 2: 27 | 2: 06 | 2: 17 | 1: 43 | 2: 39 | 5: 25 |
| CONCRETE CAP (57') | 1: 29 | 2: 33 | 1: 29 | 1: 59 | 1: 29 | 1: 29 | 4: 13 |
| SCAB (15) | 1: 23 | 1: 39 | 1: 44 | 1: 50 | 1: 23 | 4: 40 | 4: 32 |
| DAMAGE ASSESSMENT | 1: 33 | 1: 53 | 1: 46 | 2: 04 | 1: 33 | 6: 28 | 6: 12 |
| EOD | : 20 | : 24 | : 66 | : 26 | : 20 | : 20 | : 20 |
| BOMBLET ZONE (200'X300') | : 16 | : 24 | : 16 | : 21 | : 16 | : 16 | 1: 04 |
| SURVEY | : 20 | : 24 | : 25 | : 26 | 1: 03 | 1: 23 | 1: 20 |

Figure 12. RRR Process.

For each weather category, the weather data were scanned to determine the level that occurred less than 1 percent of the time. The maximum/minimum of those levels was assumed to be the worst case. Work efficiencies for men and equipment were determined, using the results in Sections V and VI. Activity durations in these conditions were then estimated, using the activity models summarized in the previous section. The CPM was used to estimate repair duration based on these estimates. Results are summarized in Figure 12.

Referring to this figure, the estimated repair duration of the AM-2 mat procedure under ideal conditions is 3 hours, 49 minutes. The 5-hour, 20-minute duration in the 99-percent hot column indicates that heat stress alone will drive the time of one AM-2 mat repair beyond 5 hours, 20 minutes less than 1 percent of the time. This assumes that other factors such as poor visibility, wind, precipitation, and slippery conditions are not present. Similarly, in 99-percent cold, but otherwise ideal conditions, repair duration is 4 hours, 43 minutes. Taken together, these figures indicate that 98 percent of AM-2 mat (single crater) repair times will lie between 3 hours, 49 minutes and 5 hours, 20 minutes, given ideal conditions, except, possibly, for temperature.

Similarly, estimated repair durations were determined for 99-percent extremes of low visibility, wind, and precipitation. For example, it was determined from weather data that a visibility of less than 200 feet could be expected less than 1 percent of the time at the worst base in the worst month. Estimated AM-2 mat repair duration in this low visibility situation (assuming other weather parameters are in ideal range), is 3 hours, 49 minutes, the same as the estimated repair duration in ideal conditions. Thus, although low visibility potentially can seriously lengthen the repair process, such severe conditions occur in less than 1 percent of observations and are, therefore, marginally important.

Care is needed in interpreting these results. Because of the assumption of ideal conditions, except for temperature, results do not indicate that 98 percent of repair durations will lie within the given bounds. Further, conclusions concerning the average length of repair or distribution of repair times may not be drawn from the table. The 99-percent precipitation figures include only effects of slippery conditions and do not include project stoppage. Data on possible durations of rainfall are included with weather data.

These simple examples illustrate how study results may be used to achieve useful data with techniques requiring elementary statistics and a hand calculator. Average repair time in a given month over all temperatures (assuming otherwise ideal conditions), could be estimated using weather results concerning relative frequencies of temperature by hour and the developed activity and CPM models.

## 2. FINAL MODEL

One analysis goal is determination of data shortfalls. These shortfalls are identified next, along with a description of potential data use.

The current study allows statistics to be derived from available results, using simple techniques. However, because of shortfalls in data, certain statistics cannot be derived. These are discussed next, followed by suggestions for providing a more accurate and complete model for projection of these results.

### a. Joint Probabilities

RUSSWO and other weather data deal primarily with single probabilities of occurrence of events. Thus, it is possible to estimate the effect of cold temperatures or slippery conditions, but not simultaneous production of cold weather and slippery conditions. Techniques do exist for approximating the joint effects on efficiencies of men and equipment, but the lack of statistics concerning joint occurrence of these events makes such estimates of limited value. It is important to know both what delay is expected from the conditions and how likely the conditions are. This data shortfall can be eliminated by ETAC, who has the required data bases and software to develop these data. While many statistics are desirable, study results indicate that the joint probabilities of occurrence of the conditions in Table 4 are the most important.

Taken together, these joint conditions form a mutually exclusive, collectively exhaustive set. There are 70 possible combinations. Joint probabilities should be provided for a typical European airbase (e.g., Hahn). Results can be summarized by season or year depending on funding, although the number of ETAC runs grows with increased specificity of data.

### b. Durations of Conditions

Durations of conditions which can stop repair are also of interest. Again, ETAC has the required data bases and software which (with small modification) can supply the needed data. Expected duration of each category of precipitation, given temperature and wind in their possible categories, is needed. For example, the expected duration of drizzle, with temperature between 35°F and 80°F and wind less than 30 mph, is desired. There are 50 such combinations, although some are impossible.

### c. Repair Model

The CPM model can provide useful duration estimates for single crater repairs. In multiple-crater repairs, resources tend to be spread among competing activities. This resource scarcity makes CPM unreliable since it implicitly assumes unlimited resources.

The computer model for Bomb Damage Repair (BDR) incorporates the many variables necessary to estimate multiple-crater repair durations. Further, it is designed to incorporate work efficiencies so that previously developed efficiency curves may be directly incorporated into model input.

d. Final Model

ETAC joint probabilities may be combined with BDR model duration estimates to provide extremely useful results. The technique for combining them is quite similar to that described previously in this section. The more complete ETAC data, combined with the more accurate BDR model duration estimates, will result in the capability to estimate:

(1) Expected duration of recovery time across all weather conditions,

(2) Expected recovery time durations by month for a given theater of operation,

(3) Distribution of recovery times (allowing estimates of the frequency of recovery times within defined limits),

(4) The probability of meeting TAFSON requirements, and

(5) Ninety-nine percent durations of recovery times (in all weather).

These are examples of final model use. Just as the current study results may be combined in varied and interesting ways, so can the final model data be used to provide many important results. This analysis tool would have a continuing value, since the BDR model may be easily extended to incorporate new repair procedures or threats.

## SECTION X

## CONCLUSIONS AND RECOMMENDATIONS

The final section of this report summarizes analysis results and points out direction for further study. Each program objective has been met, within limits of data availability.

### 1. MEN

#### a. Temperature

Expected temperature extremes are capable of significantly lengthening repair times. The effect of cold temperatures may be lessened with appropriate clothing, although clothing bulk may slightly degrade performance. Although chemical environment was not investigated in this effort, the combination of heat and chemical ensemble produces a dramatic degradation in work efficiency. Cold suits, designed to overcome these difficulties, will serve equally well in temperatures over 95°F.

#### b. Precipitation

Worker efficiency is moderately affected by rainfall. This degradation stems primarily from worker discomfort and can be lessened by proper rain attire. Precipitation occurs often enough to be a significant problem.

#### c. Wind

Periods of sustained high winds have a moderate effect on workers. Winds above 15 mph may require weighting of surveying equipment. Periods of moderate to high winds occur frequently enough to be considered a moderate problem, especially for AM-2 mat assembly and FOD cover placement.

#### d. Low Visibility

Extreme low visibility has a serious impact on worker efficiency. However, such periods are rare enough that low visibility need not be of major concern for RRR.

#### e. Slippery Conditions

Icy conditions severely degrade worker performance. While scattered mud and debris may help with traction, freezing rain and ice are expected frequently enough to cause concern. Deicing of work surfaces in such conditions is of value.

## 2. EQUIPMENT

In general, all construction equipment manufacturers design their equipment for use in a rugged environment with wide variations in weather. While many weather conditions are potential problems, most weather effects can be lessened or limited through proper maintenance and precautions. All-weather cabs are a potential improvement as well as addition of winterization kits. Since icy conditions are potential repair time drivers, surface deicing procedures are recommended.

## 3. MATERIALS

Repair can be stopped because of weather effects on repair materials. Crushed stone stockpiles are sensitive to freeze-thaw cycles which cause aggregate to segregate. Low temperatures may cause the stockpile to freeze. Covering stockpiles with tarps can help. Rain or drizzle can make compaction of crushed stone impossible. Placing uniform size aggregate or ballast rock in water-filled craters can help. Many polymer concretes lose strength rapidly with water content and even a light rain can force alternate procedures. Painting in the rain is considered impossible by manufacturers, even with oil-based paints. Rain also reduces bonding capability of such concretes. While moisture-resistant concretes are being developed, precipitation remains a problem. Frequency of occurrence is sufficiently high to warrant concern. Freezing rain affects AM-2 mats by filling in joints and making assembly difficult. High winds may make FOD cover placement difficult. Both freezing rain and high wind occur frequently enough for moderate concern. Finally, low visibility and temperature have no appreciable effect on materials except for paint which thickens at temperatures below 32°F, prohibiting painting. Lime marking may provide a temporary alternative to paint.

## 4. EFFECTS SUMMARY

While certain extremes do affect repair durations, the RRR process can be carried out in a wide range of conditions with only slight degradation in duration. The most serious effects are on materials, but many of these can be ameliorated with changes in repair techniques and materials advances.

## 5. FURTHER STUDY

Government-provided data do not include needed joint probabilities. Data shortfalls may be corrected with data obtained from ETAC. ETAC has the required data bases and most necessary software. These data may be combined with bomb damage repair model duration estimates to determine many important statistics such as probability of meeting TAFSON requirements and expected repair duration (across all conditions).

TABLE 4. DESIRED JOINT PROBABILITIES FOR ARBITRARY 4-HOUR PERIODS.

| | |
|---|---|
| TEMPERATURE | |
| | Less than 10° |
| | Between 10°F and 35°F |
| | Between 35°F and 80°F |
| | Between 80°F and 95°F |
| | Greater than 95°F |
| PRECIPITATION | |
| | No precipitation |
| | Drizzle (but not freezing rain) |
| | Rain between 0 and 1 inch per hour (but not freezing rain) |
| | Rain greater than 1 inch per hour (but not freezing rain) |
| | Freezing rain |
| | Snow between 0 and 2 inches per hour |
| | Snow greater than 2 inches per hour |
| WIND | |
| | Less than 30 miles per hour |
| | Greater than 30 miles per hour |

Since the BDR process is short, the joint probability of occurrence of these conditions in an arbitrary 4-hour period is desired. For analytic tractibility a mutually exclusive, collectively exhaustive set of conditions is needed. Since weather can change quickly, decisions for categorization of a given 4-hour period must be predetermined. For temperature and wind, characterize the entire period by the first hour. For periods containing different types of precipitation, choose the condition causing the greatest degrading effects.

NOTE TO READER: Because of its extensive length and the illustrative nature of the material contained therein, Appendix A, Weather Data, is published as Volume II of this report, while Appendices B, C, D, and E remain as part of Volume I.

## APPENDIX B

## BIOMETEOROLOGY

This appendix provides an overview of biometeorology, including its definition, divisions, scope, and some background information on its concepts and applications. The goal is to provide quantitative information on the productivity or efficiency of people engaged in runway construction and related repair activities when exposed to the ambient environmental conditions of Europe and Korea. The approach taken is to quantify the change in efficiency from a baseline "ideal conditions" case to the range of expected adverse conditions.

No universally accepted definition for biometeorology exists because of its relatively recent emergence as an interdisciplinary science. However, Reference 11 describes it as a branch of ecology which studies the factors of the atmospheric environment and living organisms, plants, animals and man. The broadly conceived environment includes the micro, macro, and cosmic spheres as they influence the earth's natural atmosphere, as well as the manmade atmosphere found in equipment items, shelters, buildings, and urban systems. Investigations of the discipline are conducted under laboratory or natural conditions, and are rigidly controlled to describe the measurable and reproducible factors which show high statistical correlation with physiological and pathological processes so as to suggest valid cause and effect relationships. Some of the more important factors or forces studied include weather and climate, food and water, and disease.

The general branches of biometeorology include phytology (plants), zoology (animals other than man), and human biometeorology. Human biometeorology is most clearly distinguishable from the other branches of biometeorology due to the existence and importance of the cultural environment.

Reference 11 ascribes to man a high degree of biological fitness. This means that man is endowed with organs, systems, and capabilities that allow him to survive in and prevail over his environment. The systems that enable him to survive and prevail are both internal and cultural. These systems provide man with a high degree of adaptability arising from such characteristics as genetic individuality, phenotypic plasticity, and culture. The first two characteristics are often grouped under the term biological variability. Detailed coverage of these concepts cannot be provided within the scope of this report. However, an overview of each can provide a better understanding of human efficiency and adaptability to changing conditions and adverse environmental environments.

Genetic individuality refers to the unique combination of genetic traits with which each individual is endowed. This inborn diversity permits the natural selection and evolution of man to proceed. Phenotypic plasticity refers to changes within the individual that result from changes in its environment. Repeated exposure to unaccustomed levels of heat or cold results in acclimatization. This contributes to intraindividual variability as chemistry, organs, and other system elements respond to their environment. Thus, both interindividual and intraindividual variability is at work, both helping man to adapt to changing circumstances. An understanding of these concepts helps one to understand the efficiency at which humans operate.

The final factor that needs to be understood involves culture. Culture can either help or hinder man's ability to deal with his environment. Man is responsible for numerous devices and developments to support his health and comfort such as clothing, heating, cooling, mobility, equipment, housing, and others. On the other hand, man has developed items that can hinder his health and comfort, such as pollution, or, more significant for RRR, weapons or devices such as bomblets, chemical munitions, or others that are used against enemy forces. This report takes the cultural improvements into account, such as construction equipment, climate control cabs, and clothing or similar items. The manmade items that threaten the repair work, such as threat munitions, are not described in this report but are covered in other RRR documents.

Biological variability has many components. Theories have been put forth as to the role of geography or race in variability. Functional differences are sometimes used to describe the differences apparent over different races or geographical areas. For example, while inhabitants of cold climates can maintain a higher skin temperature of hands immersed in cold water than inhabitants of warm regions, there is no agreement that the difference is based on race and geography versus phenotypic changes such as acclimatization or habituation.

Individuality between different humans in terms of their physiological and biochemical makeup is another issue which complicates an evaluation of human efficiency under different environmental conditions. The fact that no two individuals are exactly alike makes it difficult to predict what their reaction to different environmental conditions will be, except within patterns of mean values. Mean values derived from large samples have been found to be accurate predictors of mean population characteristics.

Another factor that impacts efficiency involves temporal variability. Humans can adjust to both the internal environment and the external environment as changes occur over time. System sensors and responders are constantly obtaining information from the environment and adjusting themselves to it. Often, adjustments must be made as a result of time or the astronomical, terrestrial, or biological effects associated with time. The seasonal cycle, the circadian rhythm (24-hour cycle), and the female menstrual cycle are examples of temporally induced changes in humans, and certain other animals and organisms. Another component of temporal variability is simple daily variation. Biologically measurable events in terms of chemistry or behavior have often been ascribed to the effects of weather on organisms. Considerable statistical evidence exists showing that there is a relationship between biological activity and weather. Meteorological processes that correlate with biological events are called meteorotropisms. Certain elements of a population exhibit greater susceptibility to meteorological processes. Known examples include individuals with amputations, scars, arthritic joints, or failing hearts. Most of the personnel working on the damaged runway can be expected to be healthy and not exhibit these physical problems, yet knowledge of the more drastic effects on these individuals can help achieve a better understanding of the effects of meteorotropisms on the general population. A final long-range concern involves the cultural changes that man makes to his environment. As man alters the physical world with technological advances, he eliminates to a greater degree the need for biological change or adaptation which makes him less fit for the challenges of such activities as runway repairs under emergency conditions.

Physiological regulation is an essential characteristic of humans by which the body receives information about its environment and reacts to the information. The environment provides both internal and external stimuli to the body. Some bodily functions react directly with the stimuli while others react indirectly as a result of messages received, transmitted, and sent from the nervous system. The need to capture, understand, and react to the stimuli is an important function, and the precision by which the body can regulate itself is termed homeostasis, or the ability to adjust to change and attempt to maintain a healthy equilibrium. This need for maintaining a steady state is true for both the internal and the external environments. Both environments provide stimuli which the human organism detects and to which it reacts. This detection of extreme positions (such as low temperature or strong hunger) results in searching for and orientation on ameliorating conditions (shelter, food), baseline conditions, or the steady state.

The degree and the repetition of stressful conditions determine the type of adjustments that the human organism must make. Repeated exposure to similar stresses results in a decreased level of organismic reactions. When the stress is a result of meteorological conditions, then the phenotypic plasticity which changes the reaction to the stress is known as acclimatization. A large range of phenotypic plasticity, as exhibited by humans, indicates a high measure of adaptive capacity. When the stress is so great that the steady state of the internal environment cannot be maintained then cellular organismic functions are disturbed, resulting in death if the condition continues.

The stressful conditions of concern to this study pertain to the ambient environment or meteorological challenges. Homeostatic mechanisms exist in humans to adapt to the meteorological challenges of the environment. Those of principal concern to the study are:

(1) Thermoregulation,
(2) Mechanisms of heat conservation, and
(3) Mechanism of accelerating heat loss.

Other factors affect the efficiency of RRR workers in different environmental conditions. Consideration must be given to visibility and other sensory perceptions, the ability to ambulate on different surface conditions, material associated with RRR, and others. In addition, long-term rest periods and optimal points for relaxation and other respites must be provided. However, the three effects of temperature on the body are crucial to an understanding of human efficiency in different environmental conditions. Then the other conditions are discussed as well.

## 1. THERMOREGULATION

The temperature of the human internal environment is normally maintained at close to 98°F (37°C). The range of ambient temperatures within which man's homeostatic mechanisms feel little stress and within which the rate of resting heat production is minimal is called the range of thermoneutrality. Man's nude zone is 28°C to 30°C, and his clothed zone of thermoneutrality is 29°C to 31°C. Ambient temperatures beyond the zone of thermoneutrality cause the rate of resting heat production to rise, either to discharge the excess heat or to retain it through the exercise of heat-conserving mechanisms. Homeostatic mechanisms of the temperature-regulation center (sensitive cells in the hypothalamus of the brain stem) act in conjunction with temperature sensitive receptors located in the deep layers of the skin to determine the external temperature and make the necessary adjustments.

## 2. HEAT CONSERVATION

The physiological response of the body to cold is known as vasoconstriction. In response to messages transmitted by neurons from the medullary portion of the brain stem, the muscle walls of the small arteries and veins under the skin contract, thereby reducing the blood flow in the peripheral regions of the body. This reduces the radiant and conductive heat loss from the surface of the body. At the same time, the blood vessels deep inside the body dilate to accommodate the blood shifted out of the peripheral regions, resulting in increased heating for the deep body.

There are times when the vasoconstrictive activity described above is insufficient to conserve the necessary heat and the internal temperature begins to decline. In this case, the thermoregulatory center of the brain sends impulses to skeletal muscles, causing them to contract and to initiate reflex shivering. The additional muscular activity results in the production of extra metabolic heat. Other activities are spurred by the cold. One is a voluntary increase in body movement by the individual. The others are relatively minor, such as modest stimulation of thyroid gland activity which results in extra heat production in the cells and tissues, and a slight decrease in blood volume, as water moves from the blood to interstitial spaces.

## 3. HEAT DISSIPATION

The immediate reaction to high heat levels is a vasomotor dilation of the arteries and veins near the body surface. More blood and thus more body heat is carried to the body surface to be eliminated by radiation and conduction. This is offset by constriction of vessels deep inside the body and a decline in blood pressure due to the fact that the internal constriction does not completely accommodate the peripheral vasodilation. Reflex sweating is initiated as different impulses from the skin's thermoreceptors stimulate the temperature-regulating portion of the brain. The sweat extracts heat of vaporization from body heat stores thus releasing body heat. An increase in the temperature of the internal environment stimulates metabolic processes and increases the rate of resting heat production. This is partially offset by reflex relaxation of skeletal muscles and by a decline in voluntary activity to the point of acting drowsy, needing greater than normal amounts of sleep and moving more slowly.

The low partial pressure of oxygen also severely affects human efficiency, but the differences in altitude which most critically affect the oxygen level in the atmosphere do not influence the RRR process.

## 4. STUDIES

Many of the military studies and much of the field of biometeorology pertain to the performance degradation resulting from the wear of clothing or equipment, especially chemical warfare (CW) or Chemical, Biological and Radiological (CBR) warfare protective clothing. Very valuable insights into the interaction between body heat buildup and protective clothing are provided in Reference 12. In this study heat buildup and performance degradation to M-1 tank crewmen were measured under highly controlled field conditions. The M-1 tank was located near the data collection station and was wired to provide on-line data collection and processing of deep body temperature, mean weighted skin temperature, interior and exterior air temperatures, wet bulb temperature, and wet bulb globe temperature.

Other studies have been performed to evaluate the performance of entire units in different environmental conditions and using different scenarios. Most of these studies describe Army units performing such actions as a forced march, assault, or defense. Most are not applicable to the Air Force RRR mission without considerable estimation and extrapolation of data. However, they make clear the problems associated with heavy physical exertion while sweating in chemical, biological, or radiological (CBR) protective ensembles. Figure B-1 presents a good general method of

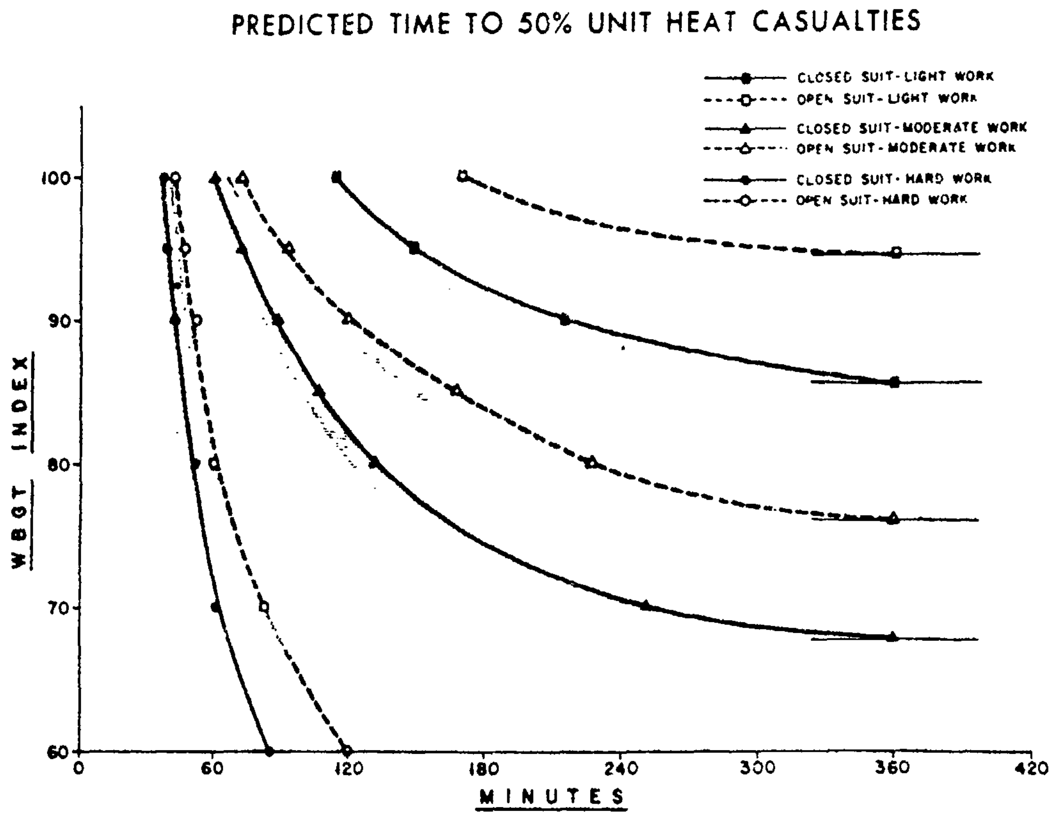



Figure B-1. Prediction Graph for 50-Percent Unit Survival Time for CB Protective Uniforms. (Reference 51).

estimating unit heat casualties using variable work rates, protective ensembles, WBGT index points, and times.

The WBGT is an empirical index of atmospheric warmth:

$$WBGT = 9.7\ tw + 0.1\ td + 0.2\ tg$$

where $tw$ = wet bulb temperature
$td$ = dry bulb temperature
and $tg$ = globe temperature.

Because it is generalized, this diagram can probably provide the best estimate of performance degradation of units performing the RRR mission.

Many factors affect the degree to which an individual may become susceptible to heat failure or to reduced efficiency during heat stress. Water input or expenditure is vital, and this is dependent upon salt content within the body. Normally, the body stores considerable reserves of salt as the average diet often contains excess levels of salt. Other aspects of diet, to include the variation between protein and carbohydrate levels are also vital to an understanding of thermal stress. General health and the amount and conditions of sleep can have significant impacts as well.

Physiological failure as a result of heat stress can take on gradations short of death. These failures can be either acute or chronic. For RRR application, we are most concerned with the acute failures. They include heat cramps, dehydration, heat exhaustion, and heatstroke or sunstroke. These failures must be understood and guarded against, due to the health effects on the individual, as well as their effect on recovery operations. The occurrence of any of these failures reduces the efficiency of the individual to zero, and may require the assistance of from one to several other RRR workers, or other assets, and could disrupt the RRR process.

Heat cramps are spasms in voluntary muscles, due to reduced sodium chloride concentrations in the blood. Spasms will usually disappear with the intake of additional salt. Dehydration is caused by loss of body fluid and causes, in order of severity, irritability, loss of muscular efficiency uremia, and possibly death. It results in a reduction of blood volume and can lead to heat exhaustion. Dehydration problems can be overcome with ingestion of water. Heat exhaustion is a state of collapse that results from inadequate heart output or blood volume reaching the cerebral cortex. Reduced volume of blood can be a result of increasing vasodilation of the circulatory system, dehydration or lowered cardiac efficiency (due to disease or lack of physical fitness or training for the particular level of effort). Symptoms include fatigue, headache, nausea, and below-normal temperatures. Recovery procedures involve resting in a cool place with the feet raised above head level. Heatstroke results from a failure of the body's heat regulating mechanisms. Normally, the critical upper temperature for man is 106°F. Heatstroke can be caused by increased heat gain as a result of high temperature, solar radiation, intense exercise or inhibition or sweating or circulation (as while wearing CBR outfits) in RRR environment. Recovery from heat stroke involves rapid cooling of the body by moistening or dipping in cool to cold water, by increased air circulation, or by packing in ice or similar means.

Considerable study has been devoted to the water requirements of man in hot climates, to include studies by Adolph and the U.S. Army Quartermaster Corps (Reference 7). They show, for example, that men performing strenuous work in the sun require twice as much water per day at 36°C as they would at 25°C.

Chronic physiological problems that come about as a result of heat stress include chronic heat exhaustion, forms of tropical dermatosis, and renal stones. Interestingly, no chronic physiological failures resulting from cold stress have been identified (Reference 7).

Another topic described in the literature involves the effects on humans of high or low pressure fronts, and the changes in humidity and atmospheric electrical charging they cause. Reference 11 describes the influence of weather on individual health and fitness, using such criteria as reaction speed, working efficiency, and number of accidents. The decisive factor is individual proneness to disturbance or illness, but weather has been found to be a significant accelerating or retarding factor. This is clearly important to the RRR process, in which many personnel must perform many actions that involve coordination, speed, endurance, and other aspects relating to general fitness.

## 5. THE ROLE OF CLOTHING IN PROTECTING MAN

Lowry (Reference 14) describes the role of clothing in protecting man from extreme environments using a series of equations that relate the temperature difference between the environment and the body core. The critical parameter is the resistance to conduction, which is made up of two components: body and clothes. Clothing can greatly increase resistance beyond that possible from the vasomotor controls of the body. The vasomotor controls provide only a fine tuning on the overall resistance.

Reference 15 also provides valuable insights into the degree of protection against environmental extremes which can be provided by clothing. It describes in greater detail the role of barriers such as clothing in reducing the ability of the body to eliminate excess heat. (The topic of this report is the reduction of heat stress problems for tank crewmen in chemical protective ensembles in high temperature environments). Heat production for the average human at rest is about 1 Met (equivalent to the 50 kcal/m$^2$/hr as described by Lowry), or 90 kcal/hr or 105 watts for the average adult male (with 1.8 m$^2$ of body surface area). Normal work is expected to double this heat production level and hard work triples it. A production rate of 6 to 7 Met proves exhausting for the average man if sustained for more than a few hours. Still air and clothing insulation can block the elimination of body heat. Before evaluating the effects of insulation, it is necessary to understand how body heat is normally eliminated. Usually about 12 percent of resting heat production is eliminated from the lungs by respiration, another 12 percent by evaporation of body water diffusing through the skin, and the remaining 76 percent eliminated by convection and radiation. Radiation accounts for 60 percent of the last component when wearing minimal clothing and in still air. This is based on a comfortable environment (moderate temperature, low relative humidity, and minimal clothing). In cases of working humans, some heat elimination is facilitated by the extra convective air motion generated by the pumping of body parts or other movement, but most is lost by the production and evaporation of sweat. Even in cold environments, as much as 42 percent of working heat production can be eliminated by sweat.

Clo units provide a measure of the insulation provided by the still air layer or clothing next to the skin. One clo unit of clothing insulation is defined as allowing 5.55 kcal/m$^2$/hr of heat exchange by radiation and convection for each $^oC$ of temperature difference between the skin ($T_s$) and the ambient adjusted dry bulb temperature ($T_{adb}$). $T_{adb}$ is calculated as 1/2 of combined air temperature plus mean radiant temperature. Mean radiant temperature is the weighted average heat emitted by an object or person into its surroundings. The heat exchange by radiation and convection ($H_{R+C}$) for the average man (1.8 m$^2$ of surface area) can be estimated as:

$$H_{R+C} = (10/\#\ \text{clo units})\ (T_S - T_{adb}) \tag{1}$$

Not counting the insulation provided by clothing, the still air layer ($I_A$) next to the skin provides approximately .8 clo units of insulation. For a nude man, the .8 clo still air layer limits heat exchange by radiation and convection to about 12.5 kcal/hour for 1/4$^oC$ of difference between skin and air temperature. Thus, a resting man producing 90 kcal/hour will lose 11 kcal/hour by respiration, 11 kcal/hour by evaporation of body water diffusing through his skin, and will have a requirement to begin sweating ($E_{req}$) to eliminate the remaining 68 kcal/hour. The requirement for sweating ($E_{req}$) can be estimated as:

$$E_{req} = M \quad (H_{R+C})$$

where M is the heat produced during rest or work and $H_{R+C}$ is estimated by Equation 1. Reference 15 points out that the external air layer can be reduced with increasing air motion to a minimum of about .2 clo at air speed above 4.5 meters/second (10 mph).

In designing insulated clothing it is important to realize that the relative contribution of trapped air layers is greater than the contribution of the fabric thickness in terms of the total thickness of the clothing ensemble on the human. Also still air layers thicker than .5 cm are treated as contributing only .5 cm of insulation because internal air convection currents seriously degrade insulating characteristics associated with still air. A typical value for clothing insulation is 1.57 clo per centimeter of thickness. Table B-1 provides values for the intrinsic insulation in clo units for standard items of civilian clothing. The total insulation of a clothing ensemble is approximately .69 of the sum of the values of the individual clothing items. This accounts for the compression of one layer on the next. Most two-layer clothing ensembles exhibit similar insulation characteristics as other two layer ensembles, as do three-layer systems, etc., regardless of differences in fabric type, layer thickness, and other factors.

## 6. CONCLUSIONS

The material in this appendix synopsizes past research so that findings in the different areas of biometeorology can be applied to the RRR problem. Numerous factors and complex interactions are involved in achieving a quantitative understanding of man's ability to adapt to his environment. Such understanding is important to an understanding of human efficiencies and capabilities under different conditions. This knowledge can then be used to modify or eliminate the critical problems so that RRR can be performed within given constraints of time or other resources.

A number of organizations and studies have determined ranges for human performance. For example, the American Society of Heating and Ventilating Engineers has devised standard comfort zones for normal categories of human activities. A number of U.S. Army studies describe the expected performance of soldiers under conditions of strenuous physical and psychological strain. These studies are based on the environmental conditions in conjunction with the particular human activity, and where possible are carried out using experimental data. Some of the studies take into account the fitness and the level of motivation of the test subjects. Thermal strain indexes and other measurement devices provide a form of quantification for the cost of the environment on humans.

The cost of thermal and other stresses are modified by man's use of clothing, shelter, and other devices. These can provide solutions in situations wherein ambient conditions would otherwise preclude accomplishment of the activity or mission. Potential solutions include the use of special protective outfits and other equipment items, or the use of special procedures and processes which minimize environmental influence. Recommendations for accomplishing the RRR mission in spite of prevailing conditions are given in Section X.

TABLE B-1. CLO INSULATION UNITS FOR INDIVIDUAL ITEMS OF CLOTHING AND FORMULA FOR OBTAINING TOTAL INTRINSIC INSULATION (Reference 15).

| Clothing | |
|---|---|
| Underwear | |
| Sleeveless | 0.06 |
| T shirt | 0.09 |
| Underpants | 0.05 |
| Torso | |
| Shirt | |
| Light, short sleeve | 0.14 |
| long sleeve | 0.22 |
| Heavy, short sleeve | 0.25 |
| long sleeve | 0.29 |
| | (Plus 5% for tie or turtleneck) |
| Vest | |
| Light | 0.15 |
| Heavy | 0.29 |
| Trousers | |
| Light | 0.26 |
| Heavy | 0.32 |
| Sweater | |
| Light | 0.20* |
| Heavy | 0.37* |
| Jacket | |
| Light | 0.22 |
| Heavy | 0.49 |
| Footwear | |
| Socks | |
| Ankle Length | 0.04 |
| Knee High | 0.10 |
| Shoes | |
| Sandals | 0.02 |
| Oxfords | 0.04 |
| Boots | 0.08 |

TOTAL: I = .69 x (the sum of the individual items)

* Less 10% if short sleeve or sleeveless

APPENDIX C

# RRR EQUIPMENT: MAINTENANCE AND PERFORMANCE IN SEVERE WEATHER

## 1. INTRODUCTION

This appendix lists the various items of equipment that are used in the RRR process. For each piece of equipment, severe weather performance is discussed. Also, special severe weather precautions, operating procedures, and maintenance are reviewed.

## 2. GENERIC EQUIPMENT ITEMS

### a. Loader Scoop- Type

AF Regulation 93-2 requires seven rubber-tired, scoop-type loaders. Manufacturers of such equipment (model designation in parentheses) include Case (W24C), John Deere (644C), Caterpillar (950), International (520B), and Fiat-Allis (FR-15). Federal regulations require certain safety features on this generic type of equipment, which include: rollover protective structure (ROPS), sound suppression, seat belt, backup alarm, warning horn, and brake systems.

The following optional features are also available to protect against adverse conditions from most manufacturers: Lighting systems, spark arrestors, rain cap, heater, defroster, air conditioner, windshield wiper and washer (front and back), supplemental steering, power train guard, engine enclosure, and vandalism protection. In terms of a general description, the Case W24C sample loader is approximately 7.62 meters (25 feet) long, and weighs approximately 11,058 kg (24,400 pounds). It is powered by a six-cylinder in-line diesel turbocharged engine (Case Model 504 BD-T) that develops 117 kw (157 hp) at 2,200 rpm and has a bucket 2.6 meters (8.5 feet) wide capable of holding 1.91 $m^3$ (2.5 cubic yards) of load. It has articulated steering, rubber tires, four-wheel drive, and a multipurpose bucket. The engine is located above the rear axle, behind the operator's compartment. The powershift transmission (Allison Model TI-2420-1) has four forward and two reverse speeds. It has a single-lever control and shifts from first low to second low and first high to second high automatically. The twin turbine integral with transmission torque converter has a 5.1 to 1 stall ratio. Front and rear drive axles provide four-wheel drive. The loader is articulated with steering control provided by a tandem type hydraulic pump and mechanical followup linkage. The tandem hydraulic pump provides the power to operate the lift, tilt, and clam cylinders of the multipurpose bucket. The bucket can be used as a clam bucket or for scraping or bulldozing. Some refill capacities for the loader are:

| | |
|---|---|
| Fuel Tank (Cell) | 280.8 liters (74.20 gallons) |
| Hydraulic Tank (Reservoir) | 78.7 liters (20.80 gallons) |
| Radiator | 45.4 liters (12.00 gallons) |
| Lubricating System | 16.1 liters ( 4.25 gallons) |

The generic loader, scoop- type is divided into the following components or major assemblies for purposes of this report:

(1) Engine and fuel system;

(2) Transmission and torque converter;

(3) Differentials and final drives;

(4) Electrical system;

(5) Axles, wheels, and tires;

(6) Brakes;

(7) Steering;

(8) Loader hydraulic system;

(9) Cooling system; and

(10) Cab.

Each of the above components is briefly described below and juxtaposed with the environmental conditions by which it can be affected. The Case W24C Loader is used as a representative sample of generic loaders.

(1) Engine and Fuel System. The Case W24C is powered by a Case A504BD diesel engine with six cylinders and a displacement of 504 $in.^3$ or 8.26 liters. This engine generates maximum rate horsepower (SAE net) of 132 at 2200 rpm. This is at sea level (29.92 in. Hg.) and at 60°F dry air. Engine accessories include the oil and water pumps, air cleaner, fan, and muffler. The fuel system is considered part of the engine for this discussion.

Temperature extremes have limited effects on a diesel engine in proper operating condition. Diesel fuel does not have the vaporization problem of gasoline at low temperatures. It is also less flammable than gasoline, so there is a decreased probability of spontaneous combustion during refueling operations from static electricity buildup in the clothing

In addition to the engine performance, consideration must be given to maintenance requirements. Cold weather places a premium on proper maintenance and operations. Additional time must be allowed for conducting prestarting, starting, and warmup of most engines, to include diesels. Maintenance operations are complicated by the need for protection from the cold, precautions against carbon monoxide concentration within enclosed areas, and the reduction in the efficiencies of operators and mechanics due to the bulky clothing required when handling extremely cold metal in and around the engine.

Extreme heat (up to 100°F) does not cause unusual engine problems. The effect of precipitation (rain, snow, other) on the engine is negligible if the engine is properly maintained and covered. Other climatic extremes also have little to no effect.

(2) Transmission [illegible] a power shift type with four forward gears and two reverse gears. It has a single-lever control with modulated clutching. In general, adverse weather conditions are not expected to impact these components, with the possible exception of transmission fluid.

(3) Differentials and Final Drives. The Case W24C has torque proportioning differentials front and rear for maximum traction. Adverse environments are not expected to impact the system with the possible exception of their effects on the lubricants, of which there are 17 quarts in both the front and rear systems.

(4) Electrical System. The W24C has two 12-volt batteries for a total voltage of 24 volts and a 40 amp alternator. A 65 amp alternator can be purchased as optional equipment. The batteries should be protected by removing them and storing them in a sheltered area if the equipment is left outdoors for extended periods in cold weather.

(5) Axles, Wheels and Tires. Front- and rear-drive axles provide the equipment with four-wheel drive capability. The front axle is fixed while the rear axle oscillates up or down 11.5°. One wheel can drop up to 16 inches with all other wheels remaining on the ground for maximum traction in uneven areas. The axle shafts can be removed without disturbing the wheels or the planetaries. The tire designation is L2. Wheel rim diameter is 25 inches and overall diameter with tires is either 58.5 or 63.7 inches. Overall width with tire is 21.4 or 24.4 inches. Inflation pressures should be increased somewhat if the equipment is to be left in the cold for extended periods. The excess pressure should be released before resuming normal operations. Check tire pressure when tires are cool or cold, never after being heated as a result of operations. After operating in a muddy or snowy environment, the tires should be

scraped clean. When left outdoors in such conditions, if subfreezing conditions are anticipated, park the vehicle on a bed of brush, planks, or logs to keep tires from freezing to the ground. A tire inflation kit is available as an option.

(6) Brakes. The W24C has air over hydraulic, caliper disc brakes for all four wheels. An air-actuated mechanical parking brake is available on the vehicle. This brake is automatically set if the air pressure drops below the effective operating level. If the parking brake is set for long periods in temperatures below freezing, the parking brake mechanism may freeze shut.

(7) Steering. The W24C has a center-pivot articulated design with hydrostatic power steering system. The steering angle in each direction from center is 40°. The turning radius measured from the outside of the tires is 36 feet, 6 inches. It is important to thaw frozen mud or snow and ice from the moving portions of the mechanical components of the system. Also, the steering fluid should be given time to fully warm up before placing severe loads on the system. An auxiliary steering system is available as an option.

(8) Loader Hydraulic System. The hydraulic system consists of the pump, two lift cylinders and two bucket cylinders, a control valve, hydraulic lines, and the reservoir. The pump is dual-stage, gear-type, and is driven off the vehicle engine. Insure adequate pump lubrication in temperatures below freezing.

(9) Cooling System. The cooling system has a capacity of 6.75 gallons. Antifreeze solution is set at -40°F. An adequate level and mixture of coolant is required for the prevalent operating conditions.

(10) Cab. A Rollover Protective Structure (ROPS) canopy is standard equipment on the vehicle. Optional equipment that can be purchased includes a ROPS cab with air pressurization and sound supression, heater, defroster, air conditioning (24,400 BTU/hour), and two rear wipers. The operator should be able to operate effectively in most environmental conditions with an appropriate mix of the standard and optional items.

b. Tractor, Full-Tracked, Low-Speed

A large variety of types, sizes, and makes of tracked tractors or bulldozers are available at different airbases. The more common manufacturers of this equipment type are Caterpillar, International, and Allis-Chalmers. In general, and when properly maintained, these equipment items are not susceptible to adverse weather. They are designed to operate in a wide variety of environments. This is facilitated by their low average ground-bearing pressure of from 6 to 9 pounds per square inch. They can operate in muck or water as deep as their track height. The model described in this section is the Allis-Chalmers Model HD16M, which comes equipped with either a reversible rear winch or with a hydraulic ripper.

This equipment item is characterized as being a full-tracked, low speed, medium drawbar pull, with oscillating track. It is powered by a six-cylinder turbocharged diesel engine and has two forward and two reverse gears. Working tools include a hydraulically controlled bulldozer blade with backrip scarifier and either a rear-mounted winch or hydraulic ripper. The principal equipment components are:

(1) Engine;

(2) Fuel system;

(3) Electrical system;

(4) Engine cooling and lubricating system;

(5) Engine exhaust system;

(6) Steering clutches, torque converter, and transmission;

(7) Tracks and truck frames;

(8) Accessory equipment: winch, ripper;

(9) Bulldozer and scarifier; and

(10) Hydraulic system.

Each component is briefly described and the unusual climatic elements which can affect it are discussed in the sections which follow.

(1) Engine. The diesel engine is an 844-cubic inch version with a rated horsepower of 200 at 1750 rpm. The Allis-Chalmers Model 16000 is used.

In extremely cold weather, it is important to park the dozer in a sheltered location and to cover it with tarps to protect the engine, accessories, and controls from the effects of ice and snow. It is also important to allow a long warmup period so that no large loads are placed on the system until all components have had a chance to warmup.

The procedure for starting the engine is initiated by following the same procedures as are used during normal weather conditions. After the preoperational checks have been performed, place a primer capsule in each primer. Crank the engine using the starter for about 15 seconds with the engine shutoff knob pulled all the way back to the STOP position. This assures proper lubrication of engine components before engine is started. Then pull engine governor hand control lever slightly past 1/4-throttle position and push engine shutoff knob forward to the RUN position. Puncture a primer capsule and press the starter switch button. If necessary, puncture the second and third capsules until the engine runs smoothly. Operate the engine at 1/2-throttle for 10-15 minutes to allow oil in engine, clutch, torque converter, and transmission hydraulic system to circulate before applying load to the system. During the warmup period, the transmission range selector should be in the NEUTRAL-START position and both steering levers in their neutral position.

(2) Fuel System. The engine fuel flow system consists of two fuel pressure systems, one low pressure, and the other high pressure. The low-pressure system draws fuel from the fuel tank through the first and second stage filters to the fuel injection pump. The high-pressure system forces fuel to the fuel injection nozzles which then spray the fuel into the combustion chamber.

In cold temperatures, it is important to eliminate all water from the fuel system. Any water accumulation in the fuel tank must be drained daily. The tank must be refilled immediately after each operating period and not allowed to remain partially empty over long periods of time. Clean all ice, snow, and moisture from the filler opening before refueling.

When operating in hot, humid, or dusty environments, it is also important to drain condensation from the fuel filters and fuel tanks. Dirt and water in the filter and sediment bowl need more frequent cleaning.

(3) Electrical System. The HD16M tractor has two 12-volt batteries. In extremely cold weather, the batteries should be protected by removing them and placing them in a warm, sheltered area when the equipment is not being used. In humid or dusty weather, it is necessary to clean moisture and sand from electrical connections more frequently.

(4) Engine Cooling and Lubricating System. The cooling system includes the radiator, water pumps, water and oil manifold, engine oil cooler, water inlet and outlet manifolds, two 180° thermostats, a pusher-type cooling fan, engine temperature gauge, and water passages in the engine block and cylinder heads. The radiator has a capacity of 18 gallons.

It is especially important to inspect the system in cold weather for leaks and the general condition of hoses and clamps. Antifreeze should be added to the system in the amounts and types shown in Reference 16. Always operate the engine for 15 minutes immediately after adding anti-freeze to insure that the solution is fully mixed. When draining the cooling system in below freezing weather, be sure that the system drains completely. It is also important to use the correct grade of lubricant during cold weather. In general, when ambient temperatures drop below OF, OE10 grade oils should be replaced with OES. For more information on lubricants, consult the appropriate Lubrication Order.

When operating in hot weather, keep close watch over the engine coolant temperature gauge. Frequently check the radiator fins and air passages, and remove foreign matter. Use only clean water low in alkali content or approved coolant mixture for refilling the radiator. Check to assure that crankcase breather and other breathers are open and free of dirt, and check and refill lubrication points more frequently, especially in dusty conditions. Air filters should be changed or cleaned more frequently. Keep all lubricating points well lubricated and wipe clean after lubrication.

(5) Engine Exhaust. The exhaust flow is from the cylinders through the exhaust manifold, turbocharger, aspirator, and exhaust pipe to the atmosphere. Extreme environmental effects have little to no impact on this system.

(6) Steering Clutches, Torque Converter and Transmission. This system includes the steering clutch and brake system, the transmission, the final drives, and the torque converter. In general, extreme environmental conditions have little effect, provided that proper grades of lubricants are used. Lubricating grease, which is a semisolid to begin with, becomes hard and loses a great amount of its lubricating properties in cold weather. GAA is a type of grease that is generally acceptable for all temperatures. It is a mixture of mineral oil and metallic soaps. The general guidance is to use only high-grade short-fiber grease. This normally provides for lubricating antifriction bearings at speeds up to 3000 rpm at maximum temperatures of up to 300°F. The grease needs sufficient adhesive qualities to cling to the bearings in all extremes of high- and low-operating temperature.

(7) Tracks and Truck Frames. Major components of this system are the tracks, truck frames, truck wheels, track support rollers, track release, and track support idler. When the tractor is to be parked for long periods, it is necessary to run it onto planks or logs to keep the tracks from freezing to the ground. Remove mud and snow from the tracks during operations or immediately after, when the material is still warm. If mud or ice freezes onto the tracks or the tracks freeze to the ground, heat the frozen material to loosen it, do not attempt to break the tractor loose using engine power.

(8) Accessory Equipment (Winch, Ripper). In general, the winch and ripper assemblies are not impacted by adverse weather conditions.

(9) Bulldozer and Scarifier. The tractor comes with the bulldozer and scarifier mounted. This system is made up of the moldboard, scarifier assembly, brace assemblies, and push beam assemblies. In general, none of these components are sensitive to extreme environmental conditions.

(10) Hydraulic System. The hydraulic system consists basically of a gear-type hydraulic pump, hydraulic tank assembly, control valve assembly, two double-acting hydraulic lift and tilt cylinders, an accumulator, and the necessary control linkage and lines to complete the system. These components are not generally susceptible to extreme environmental conditions.

In temperatures below freezing, extra precaution should be taken to insure adequate pump lubrication. Before starting the engine, remove the filler cap on the hydraulic tank to relieve any vacuum which might be in the tank. Replace the filler cap. Do not allow t e engine to run over half speed until after 5 minutes when the oil in the hydraulic system is warm. In temperatures below 10°F, it is often necessary to dilute the oil in the hydraulic system to insure free circulation.

c. Motor Grader

AF Regulation 93-2 requires three motor graders to implement the crushed stone method of small crater repair. Manufacturers of such equipment include Caterpillar (models include 112F, 120, 120B, 120G), John Deere (Model JD670A), and some models of Champion, Fiat-Allis, Galion, Raygo, and Wabco. In general, Federal regulations require certain safety features such as rollover protective structure (ROPS), sound suppression, seat belt, backup alarm, warning horn, and brake system. Optional features to protect against adverse weather conditions that are available from most manufacturers include: lighting systems, spark arrestors, rain cap, engine enclosure, heater, defroster, air conditioner, windshield wiper and washer, rotating warning light, directional signals, and vandalism protection.

The generic motor grader can be divided into the following major components or assemblies:

(1) Engine, fuel, and cooling system;

(2) Transmission, drive lines, and axles;

(3) Steering system;

(4) Earthmoving equipment (scarifier assembly and sideshift blade);

(5) Electrical system;

(6) Wheels and tires; and

(7) Cab (with or without overhead cover and enclosure).

Each of the systems listed above is briefly described in terms of the weather conditions by which it can be affected. The John Deere Model JD670A is used as a representative sample of a generic loader.

(1) Engine, Fuel and Cooling System. The JD670A is powered by the six-cylinder diesel JD6-414T turbocharged engine generating SAE net 125 horsepower at 2300 rpm. Engine displacement is 414 cubic inches. Engine accessories include the oil and water pumps, air cleaner, fan, muffler, and all other components of the fuel and cooling system.

Precautions must be taken for operation in extreme hot and cold climates for most equipment of this type. In cold weather, it is necessary to start the engine and allow it to reach normal operating temperature before applying load. Also frozen material on any moving part must be thawed out before operating the grader. The cooling system must be checked for correct coolant quantity. Condensation must be drained from the fuel tank and fuel filter before and after operation. In extreme heat, the grader may overheat if operated continuously in low gear. Cooling-off periods are required if the water temperature or transmission oil pressure gauges start to approach the red or danger zone. The coolant level in the cooling system must be kept within 1 inch of the top of the radiator. Grill and radiator fins should be checked for accumulation of dust, sand, and insects which could block air passage. The coolant should be changed more regularly (at least once a year) to prevent the formation of scale and rust. Alkaline or "hard" water should not be used when filling or flushing the coolant system if it can be avoided. Battery electrolyte level should be checked more frequently, and a weaker than normal solution should be used. The grader should not be parked for long periods under the sun without overhead cover. Proper lubrication for the system for high temperature operations should also be provided. The fuel system (fuel supplies and filter) should be checked frequently due to the condensation of water that can be caused by variations in temperatures. Operation under rainy or humid conditions require the same precautions as operation in hot conditions.

During operations in dusty environments, special care must be taken to keep the air intake, cooling, and fuel systems clean. Compressed air can be used to blow sand accumulation out of the cooling system fins, and the air restriction indicator needs to be checked daily, as well as the dust cup. Lubrication is more critical, and all grease fittings should be cleaned prior to lubrication and lubricated more frequently. When parked, the grader (especially engine, transmission, and hydraulic pump components) should be covered.

(2) Transmission, Drive Lines and Axles. The transmission is a full-range power shift with six forward and four reverse speeds. Environmental conditions are not expected to adversely impact these components.

(3) Steering System. The steering system uses hydraulic power steering with left- and right-wheel lean on the front wheels, and hydraulic power frame articulation of 22° left and right for the rear. Adverse environments are not expected to impact this system provided that the hydraulic fluids are of the correct specifications and that frozen mud or snow is thawed prior to attempting to operate the moving parts of the steering system.

(4) Earthmoving Equipment. Under extremely cold conditions, it is necessary to ensure that all operating fluids (oil, hydraulic, etc.) reach appropriate temperature before placing load on the system. Frozen mud and snow on moving parts must be thawed or removed prior to using earthmoving

equipment. The blade sideshift and steering system must be operated with care until fluids and parts reach their operating temperature. The material being operated places certain restrictions on the use of the earthmoving equipment. Frozen earth or similar materials can severely restrict or make grading operations impossible.

(5) Electric System. Components include a 24-volt system and starter batteries, 40 amp alternator, transistorized voltage regulator, and an ether starting aid. The batteries are the weak link of the system during severe weather conditions. During periods of low temperature, the batteries must be kept fully charged. The engine should be run for at least 1 hour to fully mix the electrolyte solution if water is added to the batteries. In extremely hot weather, the electrolyte level should be checked daily. Electrolyte should be somewhat diluted from the normal specific gravity; and the level should be kept above battery plates to prevent damage to batteries. If the grader is to stand idle for several days, the batteries should be removed and stored in a cool place.

(6) Wheel and Tires. The JD670A generally uses six 13.00-24, 8 PR tires with grader 10-inch rims. Weight distribution is 7,728 pounds to the front and 18,252 pounds to the rear. In cold weather (below freezing), the grader should be parked on high ground and under cover if possible. A footing of planks or loose brush is needed under the wheels to insure that they do not freeze to the ground. The wheels should be blocked and the parking brake released. Blocks must be placed under the blade to prevent it from freezing to the ground. All mud, snow, and ice should be cleaned from the grader. If parked outdoors, the equipment should be covered with a tarp, but ends of the tarp must not touch the ground.

(7) Cab. The ability to use the grader under a variety of ambient conditions clearly depends on whether or not a cab is available. The JD670A comes with a fully enclosed cab with rollover protection and heater, front and back windshield wipers, and defroster. This may not be true of all graders in the USAF inventory. The environmental conditions in which the grader can operate will depend on the ability of the operator to resist the impact of ambient conditions.

d. Truck, Dump, 5-Ton

AF Regulation 93-2 requires approximately 15 dump trucks to accomplish repairs to three small craters. Most repair techniques and processes require more than that number of dump trucks. Most military standard dump trucks are made by Continental and are Models LDS-461-1 or -1A.

Most military dump trucks currently in use by the Air Force, as well as the Army, are given the military designation of M51A2 Model. Reference 17 describes the major components or systems as being:

(1) Engine;

(2) Electrical system;

(3) Lubricants, fuels and air intake systems;

(4) Cooling system;

(5) Exhaust system;

(6) Transmission and power takeoff systems;

(7) Transfer and power takeoff systems;

(8) Propeller and drive shaft systems;

(9) Steering system;

(10) Brake system; and

(11) Axles, wheels, tires, and hubs.

Each system is described briefly and the effects of environment on the component are described.

(1) Engine. The M51A2 is equipped with the LDS 465-1 and 465-A1 six-cylinder, in-line, liquid-cooled multifuel engine. The multifuel engine uses the fuel injection compression ignition principle which permits the use of various grades of fuel. Permissible fuel grades are discussed under "fuel and air intake systems."

In extremely cold weather, it is necessary to allow the engine sufficient warmup time before movement. An arctic winterization kit is provided for use in temperatures of from -25°F to -65°F. This consists of an engine compartment cover. Installation of the engine compartment cover is done at direct support maintenance level. The radiator brushguard cover is designed to cover the radiator opening to keep cold air out of the engine compartment. The aperture flap must be opened and tied in the open position when engine temperature is above 180°F. If engine temperature continues to rise above 180°F, the entire engine compartment cover should be removed by loosening the lashing cover ropes and pulling off the cover. The engine cover should be replaced and the aperture flap secured during standby periods and overnight.

The dump truck is equipped with a hot water personnel heater kit. The engine must be warmed up to use the kit. The kit allows warm air to flow into the cab compartment or onto the windshield. In ice, snow, or 0°F weather, do not let hot air flow directly to the windshield until the passenger compartment has warmed up. Sudden temperature changes can damage the glass. The truck is equipped with fuel-burning personnel and power plant heaters. Refer to the operator's manual for use of these heaters. The fuel-burning power plant heater should be used to keep the power plant warm when the truck is not in use. It should never be used while operating the truck. A HI-LO switch is provided for both heaters. Normally, the LO position on the power plant heater is suitable for lengthy standby periods.

When the truck is to remain outdoors in cold weather overnight or for long periods of time, the following actions are essential. The truck should be parked in a sheltered area, if possible. If no shelter is available, it should be parked so that the engine faces away from the wind. All levers should be placed in neutral position to preclude freezing in gear caused by water condensation. The truck should be parked on level ground so that the body does not twist. Other special actions to protect tires, batteries, cooling system, and other components, are described later. The power plant heater should be on in either HI or LO position. When ready, start engine and let it warmup thoroughly (check engine temperature gauge). Turn off fuel burning power plant heater. Place front transmission gearshift level in position 1. Place transfer case lever to LO position. Drive truck at lowest possible speed for 100 yards being careful not to stall engine. This should heat gears and tires sufficiently for normal operations.

During operations in extremely hot weather always watch for overheating, especially during continuous operation of truck at high speeds or during long hard pulls in low gear ratios on steep grades or in soft terrain.

(2) Electrical System. In extremely cold weather, freezing of batteries can keep them from supplying enough current for starting. If the truck does not have an arctic winterization kit and is to be left exposed to the elements, organizational maintenance must remove the batteries and store them in a warm area. This is for temperatures from 0°F and below.

In extremely hot climates, it is necessary to check the level of electrolyte in the battery cells daily. If low, add water using this priority:

- Distilled water;
- Rain or drinking water;
- Water with high mineral content.

While use of water with a high mineral content can damage batteries, it does less damage than letting the electrolyte level drop below the battery plates. A dry battery has a short service life. If the truck is to remain unused for several days, it is best to remove the batteries and store them in a cool place.

(3) Fuel and Air Intake Systems. The impact of cold and hot temperatures on lubricants and coolants is significant. A variety of oils are available to meet different functional requirements and to perform in

different environmental ranges. These are segregated by function and by environmental usage below. In general, oils have a tendency to become thick at low temperatures. This consequently retards the flow through the oil pump to places where it is needed for lubrication. Thickened oils also increase the drag on the entire engine, thus making it more difficult to turn over.

The grade of oil is classified in terms of viscosity (fluidity or flow ability) and is identified by OE, OES, GO, and GOS. OES and GOS are more fluid and flow more readily than OE and GO oils.

To determine if the oil in the compartments will flow in cold weather, remove the oil level gauge or dip a finger or clean rod into the oil before starting, and if the oil will flow off, the oil is fluid enough to circulate properly.

The GOS oil used for cold weather operations should be drained and replaced with GO oil at the end of the cold season.

The oil specification chart will aid in the proper oil grade selection for the various compartments. The proper grade of oil to select is determined by the atmospheric temperature at which the machine is started. However, during operation, OES oil can be used successfully in the diesel engine crankcase when atmospheric temperatures are as high as 70°F.

Components of the fuel system include the intake manifold flame heater; air cleaner; fuel tanks; fuel supply pump; primary, secondary, and final fuel fitters; injection pump; and hand throttle.

Permissible fuel grades for this engine can be found in Reference 17. In cold weather fuel may not vaporize and mix with the air to form a combustible mixture. This can be overcome by use of the proper types of fuel, and by insuring proper drainage of fuel filters. It is especially important to drain water from primary, secondary, and final fuel fitters immediately after operation and before the fuel system cools below the freezing point. Refueling should also take place immediately after operations, and any water should be drained just prior to refueling. When operating in muddy or icy conditions, it is important to frequently clean off the radiator grill and fins to insure that debris does not freeze to these areas and impede the proper flow of air.

(4) Cooling System. This is a sealed system made up of the radiator, fan, drive belts, thermostat, water pump, temperature gauge, and pressure filler cap.

In extremely cold weather, it is essential to check this system frequently to insure that the proper levels of antifreeze are available. If approved antifreeze solution is not available, organizational maintenance must drain the radiator and block it when the truck is not in operation.

Proper levels and types of liquid and coolant are also essential in hot weather. It is important to frequently check the following:

- Proper coolant level in radiator;

- Hose connections for leaks;

- Proper fan belt tension;

- Cracked or leaking hose lines; and

- Radiator fins and core and air cleaner intake (clean with compressed air to eliminate sand, dust, and insect accumulation).

It is also important to provide proper cooling liquid. Corrosive-inhibiting compound should be used, especially in high temperatures where rust and scale develop quickly. Avoid water that contains alkali; rain water is a good liquid to use. When the temperature is below freezing, sufficient antifreeze should be used in the cooling system to prevent freezing. Various antifreeze mixtures such as ethylene glycol, denatured ethyl alcohol, methanol (synthetic wood or methyl alcohol) and glycerine are all suitable for use. Alcohol can be used successfully, but because it readily evaporates at the normal operating temperature of the diesel engine, the solution should be tested frequently - even daily - and kept up to correct strength. This loss by evaporation is objectionable, but the temperature regulator should not be removed. Doing so might make the solution run cooler and save the alcohol, but is not desirable for good performance. It is essential, therefore, that the coolant be tested frequently to assure adequate protection. Without the proper level of coolant, water freezes and expands. While it is expanding in a restricted space (as in an engine), it has tremendous power, enough to crack the toughest of iron. When engine temperature is above 180F, extreme caution should be used in removing cooling system filler cap, as severe injury can result. Also, adding coolant to a hot engine can result in damage to the engine unless it is running when the coolant is added.

(5) Exhaust System. Exhaust gases from the engine pass through the turbo-supercharger and then into the exhaust pipe assemblies. Horizontal and vertical exhaust systems are available, but normally the dump truck will have the horizontal system. This consists of three sections that extend along the right side of the truck, exiting in front of the right rear tandem wheels.

Normally, extreme environmental conditions have little effect on the exhaust system. The truck can ford to a depth of 30 inches without the use of special equipment. It can ford up to 72 inches when prepared with use of the special deep water fording kit.

(6) Transmission and Transmission Power Takeoff. The transmission is a manually-operated synchromesh type that supplies five forward and one reverse speed. The dump truck has a double-ended transmission power take-off unit. In general, the effects of environmental conditions do not seriously degrade this system. It is important to keep all control and shift levers in neutral when vehicle is parked for long periods in cold weather. Failure to place them in neutral may cause freezing in gear due to water condensation.

(7) Transfer and Transfer Power Takeoff Systems. The transfer is a two-speed synchromesh unit driven by the transmission through a propeller shaft. The transfer drives propeller shafts to the front and rear wheels. The transfer power takeoff supplies power to the truck's auxiliary equipment.

(8) Propeller and Drive Shaft Systems. A number of axle-driving propeller and drive shafts as well as auxiliary equipment propeller shafts are used to supply power to the wheels and auxiliary equipment items. These are all of the double universal type. Adverse weather has limited effect on these items.

(9) Steering System. The steering system consists of a hydraulically assisted steering gear with pitman arm, hydraulic oil reservoir and pump, steering linkage and steering wheel. In cold weather, it is important to properly lubricate the hydraulic pump, and to allow the hydraulic fluid to properly warm up before normal operation.

(10) Brake System. The brake system includes the hand brake, service brake, and compressed air systems. The braking systems are operated using cable, air, hydraulic, or combined air-hydraulic systems. In general, adverse weather has little effect on these systems.

(11) Axles, Wheels, Tires and Hubs. When properly maintained, the components of this system are not highly impacted by adverse climates. Tires and general mobility of the vehicle, however, can be affected by adverse climates. In cold weather, the truck should be parked on high ground and in firm soil. If that is not possible, it may be necessary to park the truck on a bed of planks, brush, or chock blocks, to preclude wheels freezing to the ground. If parked overnight or for long standby periods, an extra 20 pounds of air above normal should be put into the tires. The excess air should be released before tires are hot. In deep snow or mud, it may be necessary to let air out of tires to prevent spinning. The correct tire pressure should be restored as soon as possible

afterward. Proper tire inflation guidance should be used at other times, as shown below. Tire pressure should be checked when tires are cold.

- Highway 70 psi

- Cross-Country 35 psi

- Mud, Snow, and Sand 25 psi.

After operating in a muddy or snowy environment, clean ice, snow, and mud from wheels, axles, steering knuckles, and steering arms.

It may become necessary to use chains when negotiating snow or mud. Never drive with tire chains on only one wheel of a driving axle as this may result in damage to the tire, power train, or both.

In hot environments, it is important not to park the truck in the sun for long periods of time. Heat and sunlight shorten tire life.

e. Truck Tractor, Equipment Transporter

A number of equipment transporter trucks are required for RRR. These vehicles are used for bringing engineer equipment, AM-2 mat, FOD cover, and other equipment and materials to the work place. The cab is made by the AM General Corporation, engine by Cummins, transmission by Caterpillar, and axles by Rockwell. The principal truck tractors of concern are:

- Light Equipment Transporter, M916;

- Medium Equipment Transporter, M920; and

- Concrete-Mobile® Mixer Truck, M919.

All models of this truck are capable of operation in temperatures of from -25°F (-32°C) to 125°F (52°C). With arctic kit installed, the vehicle can withstand cold down to -50°F (-45.6°C). Major components of the vehicle are:

(1) Engine;

(2) Electrical system;

(3) Fuel and air intake system;

(4) Cooling system;

(5) Exhaust system;

(6) Transmission;

(7) Transfer;

(8) Steering system;

(9) Brake system;

(10) Axles, wheels, tires, and hubs; and

(11) Winch.

The effects of the environment are briefly discussed with regard to each system component in the paragraphs that follow. Most of the information is drawn from Reference 18.

(1) Engine. This series of trucks is powered by the Cummins NTC-400, four-stroke, in-line diesel six-cylinder engine. The engine has a displacement of 855 cubic inches or 14 liters, and generates a maximum of 400 horsepower at 2100 rpm. It has a full-flow, replaceable oil filter element with a 46-quart oil capacity.

If it is necessary to shut down the truck engine in extreme cold weather, it should be parked in a sheltered area facing away from the wind. The truck should be cleaned of snow, ice, and mud as soon as possible after shutting it down.

The truck is authorized an arctic winterization kit when assigned to cold areas. This kit protects the truck from freeze damage and enables faster starting. The kit consists of:

- Engine coolant heater;
- Engine oil heater;
- Transmission heater; and
- Battery heater.

Any standard 110-volt ac (45 amp capacity) electrical outlet will provide the necessary power to operate the winterization system. A 25-foot auxiliary cable is provided to connect the outlet to the truck receptacle. The auxiliary cable contains a ground wire which grounds the system to the ac source ground when it is connected. Each heater is turned on by a circuit breaker located in the waterproof circuit breaker box next to the receptacle. The engine oil heater and the transmission heater are immersion-type while the battery heater is a coil-type system. All but the transmission heater are thermostatically controlled. The heaters then function automatically until the system is turned off. To turn on the system, the truck is parked within 25 feet of a 110-volt ac electrical outlet while it is still warm from operations. The engine coolant heater shutoff valve is placed in the open position. The four winterization kit circuit breakers are placed in the OFF position until the cable is connected, then the four circuit breakers are placed in the ON position.

For cold-weather engine starting, the operator should follow all normal starting procedures, plus depress the ETHER QUICK-START button for 4-5 seconds and release while cranking the engine. This will automatically inject a set amount of ether into the intake manifold. At temperatures below 0F, it may be necessary to repeat this operation several times. Before operation, the operator should check that the engine alcohol evaporator is between full and two-thirds full of 188-proof pure methyl alcohol. At above freezing temperatures, the evaporator bottle should be kept empty. After engine starts, the operator should maintain an idle speed of 580-650 rpm until normal engine oil pressure is reached. Engine oil temperature should read between 120 and 140°F. Start driving slowly. Be alert to indications that tires may be frozen to the ground or frozen in the shape of flat spots, or that a brake shoe may be frozen and require preheating. Drive very slowly for 100 yards, giving truck fluids and components extra warmup time.

When operating the truck in extremely hot weather, pay especially close attention to the water temperature gauge. Also check the oil level, cooling system, air cleaner, and radiator fins more frequently. Shorten differential oil change intervals. When possible, park the truck under cover from direct sunlight. If cover is not available, arrange tarps around the engine compartment and over the radiator to provide some cooling effect.

(2) Electrical System. A 12-volt (24-volt cranking) system is used to provide electrical power, consisting of four 12-volt batteries connected in series-parallel. Battery capacity is 950 cold-cranking amps at 0F at 24 volts. If available, be sure to use the coil-type battery heater in extreme cold (-10°F and below). If the truck is to be parked for long periods of time, the batteries should be removed and placed in a warm location. Battery servicing in either cold or hot weather conditions should provide few problems as maintenance-free batteries are available on this vehicle.

(3) Fuel and Air Intake Systems. These trucks have a diesel fuel system with a 118-gallon fuel tank and a diesel injection fuel system. One dry element type air cleaner is used. The main problem encountered during cold weather is condensation in fuel filters. These should be checked and water drained out frequently. In hot weather, it is important to check the air cleaner for dust, insects, etc. more frequently. An air filter restriction indicator is available, and it will show red if air flow is restricted. Organizational maintenance support is required to clean the filter.

(4) Cooling System. The main component of the cooling system is the radiator. It has a refill capacity of 65 quarts. It is important to maintain the proper quantity and quality of coolant in the radiator at all

times. In extremely cold weather, the engine coolant heater of the winterization kit is used to keep coolant temperature at the proper level.

In extremely hot weather, check the cooling system frequently, especially for proper coolant level and for leaks. Level is checked by using the radiator sight glass. If low, add a mixture of ethylene glycol antifreeze and clean water, at the proper ratio for prevailing temperatures.

(5) Exhaust System. This system is not expected to offer problems in different environmental extremes. The trucks have a vertical exhaust system. Fording depth is set at 20 inches.

(6) Transmission. The transmission is a Caterpillar D-7155 overdrive 16-speed semiautomatic with remote air control power shift. There are 5.5 gallons of transmission oil. It is equipped with strip heaters to warm the transmission during cold weather. These heaters are thermostatically controlled for automatic operation at temperatures below 5°F. Indicator lights on the cab console light up when the strip heaters are on. The transmission should not be operated until the lights go off. This component is in addition to the immersion type transmission heater that is included in the winterization kit. When parking in cold, icy, or slushy weather conditions, leave transmission in neutral and block tires instead of using the parking brake. This prevents the gears and brake from freezing in position.

No special care of the transmission is required for hot weather conditions.

(7) Transfer. The transfer case is an Oshkosh 18,000 Series F-U29, with a ratio of 1:1. In general, the transfer is not expected to have problems as a result of extreme environmental conditions.

(8) Steering System. The Ross Integral Power with Assist Cylinder is used. A Hydraulic Power Booster provides actuation, and an Eaton B165R power steering pump is used. The power steering system incorporates a cooler designed to reduce power steering fluid temperatures during normal or warm conditions. This cooler becomes restrictive in cold weather and must be bypassed. Organizational maintenance must perform this in order to prevent over pressure and possible rupture of the cooler. Bypass is required when 0°F temperature or lower is expected.

(9) Brake System. This truck series uses an air-mechanical-actuation system for the brakes. When first starting out after the truck has been sitting in cold weather, check to insure that one or more brake shoes have not frozen. If truck is parked for a long shutdown period in cold weather, chocks should be used in place of the parking brake. After fording or emerging from water, it is important to apply the brakes a few times to help dry out brake linings.

(10) Axles, Wheels, Tires and Hubs: The M916, M919, and M920 use Budd No. R49210 wheels with bias play on/off highway tires of 11- by 24-inch sizes. Each wheel with tire weighs 326 pounds and has a rated single on-highway capacity of 6,040 pounds. The correct air pressure (cold) is 100 psi on the front and 90 psi on the rear tires.

If parking for long periods in cold weather, find a fairly high, dry spot so that tires will not freeze into the mud, slush, or soil. Planks, brush, or chock blocks should be used to make a raised and relatively dry surface. Correct tire pressure is extremely important in cold weather.

In extremely hot weather, check tire pressures more frequently. However, be sure to wait until tires are cool before adjusting tire pressure.

(11) Winch: The M916 and M920 models are equipped with a full hydraulic winch mounted on the frame behind the cab. The winch operates at 2,100 psi from a dual pump driven by a power takeoff from the transmission. Rated winch capacity is 45,000 pounds. When operating the winch at temperatures of below -25°F, it is necessary to warm up the hydraulic system by engaging the PTO and operating the tractor engine at fast idle for 30 minutes. After warmup, operate the winch in a no-load condition by paying out 100 feet of wire rope at low speed. Then, take up the wire rope at low speed. This prepares the winch for normal operations.

f. Concrete-Mobile® Mixer

The Concrete-Mobile® mixer is manufactured by the Daffin Mobile Products Division of Barber-Greene Company. The mixer is mounted on on M919 truck tractor, a description of which was given in the preceding section. Accordingly, this section will describe only the effects of the environment on the Concrete-Mobile® Mixer, most of which is taken from Reference 19.

The mixer is a combination materials transporter and concrete mixing plant. The mixer body is mounted on the M919 truck chassis. The mixer carries sufficient unmixed material to produce fresh concrete in any quantity up to 8 cubic yards (6.12 $m^3$). The concrete is mixed at the site and, since the unit has been precisely calibrated, mixes can be produced that meet or exceed American Concrete Institute and American Association of State Highway and Transportation Officials standards for design strength. The unit can be used on an intermittent or continuous basis, however, continuous operation is dependent on the availability of raw material at the site. Some control settings for the mix operations vary from truck to truck and from site to site.

Each mixer is calibrated at the factory and settings are provided on a permanent plate in the control area. Choice of settings will depend on your truck as well as on a number of other factors. The principal components of the mixer and a brief explanation of each follow:

(1) Water Tank. The water tank holds 400 gallons of potable (drinkable) water. The water flow is adjusted by a control valve for use in the mix operation. Water in this tank is also used for cleanup after mixing operations.

(2) Sand and Stone Bins. The sand bin and stone bin are actually two compartments of the same vessel. The sand bin portion (left side), holds 40 percent of the total aggregate carried by the mixer. The stone bin portion (right side), holds 60 percent of the total aggregates. Since damp sand has a tendency to bridge over the conveyor, the bins have a shaker system to break up packed sand. The main conveyor belt carries sand and stone from the bottom of the bins to the mixing trough.

(3) Cement Bin. The cement bin holds 63 cubic feet (1.78 $m^3$) of dry cement for mixing up to 8 cubic yards (6.12 $m^3$) of cement. The bin contains an aerator system for "fluffing" the cement. Fluffing is necessary because cement has a tendency to pack, especially during transport. The bin also has an auger and a feeder. The auger conveys cement to a rotary type feeder. The feeder dispenses cement onto the main conveyor belt.

(4) Electric Winch. The electric winch raises and lowers the mixing trough, and supports it during cement production.

(5) Mixing Trough. The mixing trough mixes dry and wet ingredients (sand, stone, cement, water, and admixtures). They are mixed into concrete by an auger located in the trough. The auger also conveys the mixed concrete to the chute for placement.

(6) Control Area. Mixer controls are clustered at the left rear of the unit. This allows the operator to see the mixing process as he runs the machine. From the control area the operator can adjust ingredient proportions, position the mixing trough, and start or stop the mixing operation.

(7) Hi-Flow Liquid Admix Tank. The hi-flow admix tank holds 42 gallons of admixture solution for injection into the mix.

(8) Low-Flow Liquid Admix Tank. The low-flow admix tank holds 12 gallons of admixture solution for injection into the mix. This tank serves the same purpose as the hi-flow tank but is used when smaller quantities of admixture are needed.

(9) Dry Admix Bin. The dry admix bin holds 2.35 cubic feet (0.66 $m^3$) of powdered admixture. Augers in the bin guide the powder into a feeder shaft. The feeder delivers the admixture to the main conveyor belt. The dial setting on the bin determines the delivery rate.

(10) Hydraulic Reservoir. The hydraulic reservoir stores 32 gallons of hydraulic fluid to operate the hydraulic system.

Because of the close relationship between the components in the production of concrete, the components will be discussed as an entirety instead of breaking each one out as was done in Sections A-E. Instead, this section is divided into the relevant ambient environmental conditions.

(1) Cold Weather. The mixer is capable of producing concrete at temperatures as low as -50°F (-47°C). The following guidelines should be followed at the job site whenever the mixer is being operated in cold weather (below 32°F or 0°C).

The mixer water must be heated to 180°F prior to loading it on the mixer. The higher temperature of the water compensates for heat loss when transferred into the heat tank so as to maintain an average temperature of 140°F when entering the mixing trough. The mixer should be kept in a protected area long enough to raise the temperature of the metal parts of the mixer to 35°F. It may be necessary to wrap water lines with thermal tape to meet temperature requirements. The water shutoff valve and gauge valves must be in the closed position while the heated water is loaded into the tank and while the mixer is enroute to the job site.

When the mixer arrives at the job site, the water shutoff valve is opened. If water has frozen in the lines ahead of the shutoff valve, use a small heating torch to warm up water lines, valves, and pumps, as needed, between the water shutoff valve and the water discharge nozzles. When all water lines are warmed sufficiently to prevent flash icing (above 40°F), the frozen lines between the water tank and the shutoff valve are heated until water flows freely to the water discharge nozzles. The gauge valve remains closed at all times during subfreezing weather to prevent the water sight gauge frame from freezing or rupturing.

The sand and stone bins of the mixer equipment must also be heated to a temperature of not less than 35°F, just as the other metal parts were heated. This can be accomplished in a heated sheltered area, or by covering with a tarp and blowing in heat from a hot air heater. When ambient temperatures are below 32°F, it is necessary to heat the sand and stone components of the aggregate as well. This can be done with a tarp and hot air heater, or as an alternative, the aggregate can be stockpiled over a series of empty oil drums and a fire built in the drums or hot air blown into the drums. Covering the stockpile with a tarp will conserve the heat. If heating is not possible, bin screens must be available to insure that frozen lumps are removed and that the aggregate is dry and flowing freely. Spread and secure the tarp after loading the sand and stone into the appropriate mixer bins in order to retain the greatest possible amount of heat.

The liquid admix system can be heated in the same manner as the water and then loaded into the mixer system. Production of the concrete using the dry admix system proceeds the same way as it would in normal weather.

Cleanup in cold weather is essential to avoid damage from freezing moisture that can damage lines and valves. Moisture must be blown out of the water system and the admix system at the end of the day or if long delays are expected on the job site. This involves opening the vents and draincocks on the flowmeters, sight gauges, fill caps, and air gate valves. When no more admix comes from the draincocks and drains, the air gate valves can be closed. Then empty the aggregate bins to prevent moist aggregate from freezing into chunks in the bins. When all aggregate has been dumped, use the washout hose to clean the mixing trough. Then drain and blow moisture from the water system by removing a water tank fill cap and the eight draincocks. Finally, blow air into the air fittings until no more water comes from the draincocks. If available, 10-25 drops of antifreeze or alcohol should be injected into the air fittings and then blown into the water system using compressed air in order to prevent frosting and freezing of water pumps and valves.

(2) Hot Weather. During mixer operations in hot weather, keep a tarp over the sand and stone bins to keep the aggregates from drying out. It may also be necessary to increase water settings during concrete production. Clean up immediately after operations because concrete sets faster in warm weather and may harden on mixer components.

(3) Humid Weather Conditions. When working in humid conditions, be sure that the cement bin cover fits tightly over the bin. Empty the bin at the end of the day's operation. Use the fluffer valve to fluff the cement frequently.

g. Vibratory Roller

A wide variety of types and models of vibratory rollers or compactors are available. The RRR kit requires three such rollers or compactors, and specifies that they should: weigh at least 19,000 pounds, have a minimum frequency of 1,200 vibrations per minute, have a minimum drum width of 80 inches, have a minimum centrifugal or dynamic force of 25,000 pounds, and have a minimum static weight of the vibratory drum of 130 pounds per inch of drum width. The Galion VOS 84A and VOS D84A are very similar vibratory rollers that meet all the requirements stated above. The Raygo Model 400 can also be used. Should a variable-weight tandem roller be used for RRR applications, the principal environmental consideration pertains to draining the sprinkler tank as soon as the day's work is over to prevent it from freezing up. Also, the tank on a variable-weight tandem roller should not be filled with water ballast until the engine has been started and some heat reaches the tank. This is not of concern to the vibratory rollers which are discussed below.

In general, vibratory rollers or compactors are not equipped with cabs. Either ROPS or enclosed ROPS (EROPS) can be purchased from the manufacturer, as well as cabs and canvas covers for the operator, depending on expected environmental conditions. Other available options that pertain to environmental conditions are heater and defroster, windshield wiper, engine hoodsides, starting aids, air cleaner and cleaner service indicator, instrument panel cover, vandalism kit, driving and working lights, drum drive, dual amplitude control, and finally, smooth-tread, flotation-diamond, or ground-grip lug tires.

The standard VOS D84A is described below. The major components or assemblies are:

(1) Engine and fuel system,

(2) Cooling system,

(3) Electrical system,

(4) Steering and brakes, and

(5) Vibratory roller and roller engine.

(1) Engine and Fuel System. The VOS D48A is powered by a Detroit Diesel engine that provides the ability to travel at speeds up to 9.3 mph. In extreme cold weather, use the proper grade lubricants to provide adequate warmup time. Do not operate the roller at full speed until all temperature and pressure gauges have a reading in the normal range. The fuel tank should be refilled to the maximum level as much of the time as possible to prevent moisture from condensing in the tank. Fuel filters should be checked and water drained off frequently.

In hot or humid weather, watch the temperature gauges closely to avoid overheating the equipment components. The proper grade of lubricants for hot weather is also essential.

(2) Cooling System. In cold weather, ensure that the proper level and type of coolant is used in the radiator. Also check for proper coolant level during hot weather. Remove any accumulations of trash, leaves, or other material from the radiator and keep fins clean by using compressed air or water under pressure.

(3) Electrical System. In general, the electrical system is not impacted by changes in environmental conditions. Wiring should not be moved during freezing weather as it may become stiff and brittle. Water should not be added to batteries unless the engine is to be operated for

several hours immediately afterward. When unmixed with the electrolyte, the water may freeze and break battery cases.

(4) Steering and Brakes. The compactor is rubber tired in the rear with a large steel rolling cylinder in the front. The powertrain is mounted over the rear tires. Steering is hydraulically actuated and controlled by two steering cylinders just behind the roller. In cold weather, allow the machine time to warm up prior to conducting operations. Park the compactor on a solid, dry surface when it is to be left out overnight in low temperatures.

(5) Vibratory Roller and Roller Engine. The main vehicle powertrain is located over the rear tires; however, the vibratory action of the compactor is accomplished by a separate, smaller engine located in the roller arms. In general, the same provisions apply to this smaller engine as applied to the main engine in different ambient environmental circumstances.

h. Excavator

A variety of types and sizes of excavators are available for use with the RRR team. Manufacturers include Caterpillar, John Deere, Liebherr, and other firms. The equipment described in this section is the Caterpillar Model 225, which is both U.S.- and Europe-sourced. The U.S.-sourced machine has engine model #3208 with 135 horsepower or 101 kW. Principal components are:

(1) Engine, fuel and cooling systems,

(2) Hydraulic system,

(3) Tracked undercarriage,

(4) Control and swing system,

(5) Drive and brake system, and

(6) Cab.

(1) Engine, Fuel and Cooling System. The Caterpillar 225 is powered by a Caterpillar four-stroke-cycle, V-type 3208 diesel engine with eight cylinders and a displacement of 636 cubic inches (10.4 liters). The engine generates a flywheel horsepower of 135. Vehicle engine equipment includes fan, air cleaner, fuel pump, water pump, lubricating oil pumps, muffler, and alternator. In cold weather, it is important to keep the fuel tanks filled as much as possible, and to top off the vehicle after each day's operation. Insure that temperature and pressure gauges register in the normal zone before placing a full load on the system. A low-temperature starting system and an ether starting aid are both available as

optional equipment. For hot-weather operations, supplemental cooling options are available. A 10-gallon cooling system is standard equipment.

(2) Hydraulic System. The major components of the system are: diesel engine to power the pumps, twin variable-displacement piston pumps, a single-section fixed displacement gear pump, piston motors for the tracks, hydraulic hoses and heavy steel tubings, pilot control valves, hydraulic cylinders, and an 80-gallon hydraulic tank. The system requires a total of 152 gallons of hydraulic fluid. In general, this system is not severely impacted by weather conditions. It is important to insure that there are no obstructions in front of the oil-to-air hydraulic cooler which is mounted in front of the engine radiator.

(3) Tracked Undercarriage. The tracked undercarriage includes a reinforced box-section track roller frame, sealed tracks, lifetime lubricated rollers and idlers, hydraulic track adjusters, and triple grouser shoes. The overall track length is 12 feet, 6 inches, and the ground contact area is 5,628 square inches. The undercarriage and track systems are fairly impervious to extreme weather conditions. An exception to this general rule, as is the case for the other tracked vehicles, is that the excavator must be parked on a bed of logs or planks if it is to be left outdoors for extended periods in subfreezing temperatures.

(4) Control, Steering and Swing Systems. The excavator operator manipulates the boom, stick, bucket, and swing by using two joystick hand levers. The right lever is moved forward and backward to raise and lower the boom. It is moved right and left to control bucket curl and dump. The left is moved forward and backward to move the stick in or out. It is moved left and right to control swing direction. The steering system is designed so that it can provide gradual pivot or counterrotational spot turns. The swing mechanism is splash lubricated with case-hardened drive gears. The swing drive and swing gear have 7.5 and 3 gallons of lubricants, respectively. In general, these systems do not require special attention in periods of temperature extremes. However, it is important to allow the systems to warm up completely in cold weather conditions before large loads are placed on the systems. Lubrication for swing gear and swing drives should be serviced more frequently in hot, humid, or dusty work conditions. These normally require greasing only once every 50 service meter hours.

(5) Drive and Brake System. Drive is full hydrostatic with each track driven by an independent hydraulic motor. The final drives are triple-reduction, spur-gear, fully enclosed, and splash-lubricated. The hydraulic motors develop 36,800 pounds of drawbar pull each, which provides a travel speed of 2.3 mph for the vehicle. There are two (7-inch diameter) oil disk brakes on the final drive input shafts. These are spring-applied and hydraulically released. Brakes set automatically when the machine is stationary and disengaged when the travel pedals are depressed simultaneously. Each final drive requires three gallons of lubricant. In general, environmental extremes have little effect on these systems.

(6) Cab. The all-weather operator cab comes as standard equipment with the excavator. It includes defroster, interior lights, instrumentation and electric hour meter, adjustable seat and seat belts, dual windshield wipers with washers, and safety glass or Lexan® in windows and skylights. A cab heater is available as an option.

i. Paint Striper

Paint stripers or pavement marking systems are available from a variety of manufacturers, the most important being Kelly-Creswell. One is required to implement the crushed stone method for small crater repair. The paint striper is used to provide markings on the Minimum Operating Strip (MOS) surface as repairs are being completed to provide pilots with an effective means of guidance for takeoffs and landings. The markings may require some form of camouflaging to prevent use as an aiming point during subsequent threat attacks.

Paint stripers come in a variety of sizes and models for a variety of different purposes. Some are self-propelled while others are pushed by the operator. The paint striper discussed below is the Kelly-Creswell Model B-4. It is normally a double line striper but can be modified for airport striping by changing the size of the air curtain attachments and adding new bead dispensing attachments. The B-4 for airport striping is discussed below. Its principal systems are:

(1) Material container,

(2) Self-propulsion system,

(3) Spray and cleaner system, and

(4) Control and guide system.

Optional equipment for this model includes mechanical or electrically activated intermittent line mechanism, transport trailer, positive chain and sprocket drive with differential, air-actuated clutch, and hydraulic disk brakes. It should be noted that larger models, such as the Kelly-Creswell Model WV-4 Multiliner, can provide such environmentally oriented features as paint heating equipment, windshield and cover for operator protection, and the ability to apply fast-dry, hot line marking materials. Such larger models can also travel at speeds up to 60 mph, have a capacity of up to 120 gallons of paint, and can carry from one to six personnel. The sections below outline the climatic considerations applicable to the different systems of the B-4 under a variety of environmental conditions.

(1) Material Container. The B-4 paint striper has a 17-gallon, 150 psi steel tank with a large 10-inch ASME lid assembly. It comes with either a swirl or paddle-type agitator. A twin-cylinder, 18.5 cfm compressor is used to propel the paint agitator. The compressor has force feed

lubrication to all bearings. Cold weather (below 32°F) requires special formulations of paint, or requires that the paint be heated prior to loading and used quickly afterwards. Temperatures considerably below freezing may preclude use of any paint as this model does not have a paint tank heater. Wet surface conditions (including ice, snow, or sleet) will normally also make painting impossible.

(2) Self-Propulsion System. The B-4 is powered by an air-cooled engine developing 12 hp. A governor provides constant traction for going up or down hills. There is a variable speed throttle. Electric starter, generator, and battery are optional items. The standard model has air-actuated drive rolls. Hand and foot brakes are provided. In cold weather, the equipment should be stored indoors.

(3) Spray and Cleaner System. The spray system consists of paint lines and hoses, spray guns, and paint guide plates. The spray guns are air-controlled, diaphragm-operated, adjustable-volume high-speed types. These provide for uniform application and distribution of the paint. The paint line widths are variable, or a 12-inch runway width can be mounted as standard equipment. Exhaust gas from the engine is used to maintain a keen-edged line. In general, the spray system should not be impacted by climatic extremes, provided that paint and condensation is not allowed to form in lines or on components during storage or when otherwise not in use. Paint must be drained from material container when it will not be used for several days or when temperature drops below freezing. After draining paint, the cleaner equipment must be used to clear out all lines, hoses, and spraying guns. Cleaner equipment consists of a 1/2-gallon automatic pressure cleaner mechanism with atomizing head. This can be used to flush fluid lines and clean the spray head assembly of the guns.

(4) Control and Guide System. Each spray gun is controlled by a separate control valve. In addition, a master control valve can be used to control both guns simultaneously. The guns are separately regulated by all brass solvent-resisting regulators. An adjustable telescopic guide arm is provided. In general, extremes of ambient environmental conditions should have little or no effect on these components.

j. Sweeper

AF Regulation 93-2 indicates a requirement for a towed rotary sweeper and a self-propelled vacuum sweeper to implement the crushed stone method for crater repair. The towed rotary sweeper is not expected to encounter difficulties under conditions of varied climates provided that it is properly maintained. The only difficulty is that no provisions are made for operator protection from the elements on the towed sweeper. The sections which follow provide a brief description of the FMC Model 707, Runway Vacuum Sweeper, and the ability of the sweeper to handle various environmental conditions. Another major manufacturer of sweepers is the Athey Products Corporation, which produces the Mobil Sweeper product line.

The main components and systems of the Wayne® Runway Vacuum Sweeper (Model 707) are:

(1) Sweeper chassis,

(2) Engine,

(3) Clutch and transmission,

(4) Fuel and cooling systems,

(5) Electrical system,

(6) Auxiliary fan drive system,

(7) Vacuum system, and

(8) Cab, instruments and controls.

(1) Sweeper Chassis. The chassis is an International Harvester S-series, Model 1724, with a maximum gross vehicle weight rating of 26,500 pounds, and steel leaf spring suspension (with auxiliary springs in the rear). A hand brake and a hydraulic service brake with vacuum booster are available. The vehicle operates on single front and dual rear tires. Cold conditions are expected to have little impact on the sweeper chassis. However, it is wise not to park the vehicle on wet, soft ground for long periods under freezing weather conditions, nor to set the parking brake at such times. Careful driving practices are required when operating with slippery surface conditions.

(2) Engine. The Model 707 is powered by an International V-345 eight-cylinder gasoline engine (diesel is available as an option). It has a full-flow oil filter with a capacity of 9 quarts. Proper maintenance and operation should permit use of the engine at all environmental extremes.

(3) Clutch and Transmission. A single-plate 13-inch clutch and a five-speed synchromesh manual transmission is used. The transmission should not be left in gear when parked for long periods in cold weather.

(4) Fuel and Cooling Systems. The vehicle has a 30-gallon fuel tank under the cab with a dry air cleaner. The cooling system uses a permanent type antifreeze which protects to -20°F. In cold weather, it may be necessary to increase the level of antifreeze protection.

(5) Electrical System. A 12-volt, 77 amp battery is used on the vacuum sweeper. The fuse panel is behind the driver's seat. In low temperatures, the battery should be removed and stored in a protected, heated area if the truck is to be left outdoors.

(6) Auxiliary Fan Drive System. The vacuum impeller fan is driven by a separate eight-cylinder gasoline engine (International MV-446) with a displacement of 446 cubic inches. This engine has a separate cooling system with a 25-quart capacity. A diesel engine is available as an option. The environmental constraints that apply to the vehi e propulsion engine apply to this engine.

(7) Vacuum System. In addition to the auxiliary fan drive engine, the vacuum system also includes the power train, fan, pickup nozzle, air ducts, material separator, dust filter system, and a hydraulic debris dumping hopper (4 cubic feet). The vacuum system is of the nonrecirculating air type. The vacuum sweeper has a cleaning capacity of 1,000,000 square feet per hour at a speed of 25 mph. It lifts and retains all particles ranging in size from fine dust (10 microns) to 2-inch diameter stone, solid steel cylinders 1 inch in diameter by 3 inches large, and a variety of miscellaneous materials such as common size finishing nails, flat washers, bolts, and hexagon nuts. Deflectors inside the suction hood guide the heavier particles into the heavy-particle intake nozzles. A dual suction blower and nozzle system insures that the greatest possible mix of potential foreign object damage (FOD) particles are removed from the runway surface. This system meets the requirements of M16-C-27464A (USAF) and Amendment Number 2. An 88-inch wide agitator broom also enhances vacuum effectiveness by breaking loose packed debris and flicking it forward into the vacuum airstream. Another feature of the Wayne• Model 707 permits sweeping either wet or dry surfaces. This is a diverter located near the dust filter screening system. The diverter changes the direction of the air to bypass the filters when sweeping under wet conditions. The effects of extreme heat and cold on the vacuum system are expected to be minimal, and, as described, provisions are made for sweeping in wet conditions.

(8) Cab, Instruments and Controls. A steel operator cab with heater and defroster, electric windshield wipers, windshield washers, sun visor, and safety glass is standard. This cab provides the sweeper operator good protection against most ambient environmental conditions.

k. Pickup Truck

Two pickup trucks are required to implement the crushed stone method of small crater repair, according to AF Regulation 93-2. The standard military pickup is four-wheel drive with a manual transmission. It is 16.7 feet long and has a curb weight of approximately 4,650 pounds. It is powered by an eight-cylinder gasoline engine, and has a 20-gallon fuel capacity and a dual circuit service brake system. The military standard pickup is designated the M880 and is manufactured by the Chrysler Corporation. The principal components and systems of the pickup truck are:

(1) Engine and engine cooling system,

(2) Fuel system,

(3) Electrical system,

(4) Steering and brakes,

(5) Wheels, tires, and suspension, and

(6) Cab.

Each of the main systems is described below, with information provided on the effects of environmental extremes on the system.

(1) Engine and Engine Cooling System. The M880 is powered by an eight-cylinder, V-type, overhead valve engine with a displacement of 318.3 cubic inches. It generates 150 horsepower at 4,000 rpm. Cooling is accomplished with a radiator system with a capacity of 18 quarts, 6 quarts of crankcase lubricant, 6 pints of rear differential lubricant, and 4 pints of front differential lubricant.

In extremely cold weather, it is important to allow the engine to warm up for at least 5 minutes before operation. This permits congealed lubricants to warm and become viscuous, as well as warming up other systems and components of the vehicle. After the warmup period, drive the truck slowly for a short distance as a test run while watching all instruments carefully. This should tell you if there are problems with the engine thermostat, hoses, or other components. If the vehicle is to be parked in cold weather for long periods, face the engine away from the wind. If high, dry ground is not available, prepare a footing of brush or planks to park on and chock the truck in place. Clean snow, ice, and mud from the vehicle so that it does not freeze on important vehicle components. Protect the engine and accessories from loose, drifting snow which could melt and then refreeze on or near engine components. If possible, cover the truck with a tarp. Insure that the antifreeze solution in the cooling system is adequate for the expected temperatures. If not, and no antifreeze is available, open the radiator draincock, remove the radiator cap, and drain the coolant. Make sure that the drain hole is not obstructed and that all coolant has been drained. Then, put the following note on the steering wheel: "DO NOT OPERATE! Radiator empty. Refill before using." Leave radiator cap on the driver's seat.

If operating in designated areas of extreme cold, insure that the Arctic Winterization Kit is available and properly used. It consists of: a Swingfire heater, a 24-volt personnel heater, cab heavy-duty motor and core, cargo box bowing and insulation, hood and cab insulation, and engine compartment rework. The Swingfire heater is used to preheat vehicle engine coolant and batteries in temperatures of down to -50°F. Refer to the vehicle Technical Manual for specific operations/instructions for kit components.

The principal potential problem in hot weather is overheated engines. Be especially alert for overheating when making long, hard pulls in low gear up steep grades, driving slowly (stop and go), hauling heavy loads, or operating over soft terrain. Pull over for a cooling-off period if needed. When halted, park in shade or under cover, or cover the vehicle with tarps, covering window glass and engine compartment first, especially in dusty areas.

The truck is protected for fording up to 16 inches of water, provided that proper fording procedures are used and that the required after-fording maintenance instructions are followed closely. Be sure that the truck does not exceed the 16-inch limit or the starter motor may need replacement. Do not let engine stall while fording.

(2) Fuel System. The components of the fuel system are: 20-gallon fuel tank, fuel pump, two fuel filters, a two-barrel carburetor, and fuel and vacuum lines. In extremely cold weather, it is important to take special care with fuels, especially gasoline. Condensation or vapor residue should be drained off frequently, especially where rapid temperature changes cause condensation. In cold climates, gasoline will not freeze but becomes more difficult to vaporize. Since only vapor will burn, combustion of gasoline inside an engine is more difficult, and unburned gasoline dilutes the oil in the crankcase, contributing to the formation of sludge.

Other environmental conditions have limited effect on the fuel system, provided that the fuel components remained sealed against humidity, precipitation, and dust.

(3) Electrical System. The vehicle uses a 10-volt electrical system with negative ground. A 50 amp alternator is provided as standard equipment, but kits are available to upgrade to either a 60 amp/24-volt or 100 amp/24-volt system. The same basic principles apply to the pickup as applied to the other vehicles: do not leave batteries in cold; do not add water to batteries unless vehicle is to be operated for several hours afterwards.

(4) Steering and Brakes. The vehicle has a manual steering system. The service brake system includes front disk brakes, rear drum brakes, a dual master cylinder, and a vacuum-assisted power booster. The parking brake is cable-operated using the rear service brake assemblies. In extremely cold weather, the operator must be careful to insure the brake shoes have not frozen to the brake drums, especially where vehicle has been left in the cold for extended periods. After fording or driving through deep water puddles, depress the brake pedal lightly while moving the truck. This will dry out the brakes. The parking brake cable may freeze if the brake is engaged and the vehicle left in the cold for long periods. Normal warmup procedures will normally permit the brake cable to thaw out.

(5) Wheels, Tires, and Suspension. The pickup truck is equipped with 16.5 x 6.75 drop center rim wheels. Tires are on- and off- road design radials. Tire size for all models of the M880 series truck is 9.50R16.50.

Proper tire inflation pressure is 45 psi for the front tires and 55 psi for the rear tires and the spare. Vehicles with the arctic winterization kit have wide-tread snow tires and tubes. The vehicle operates on four double-acting shock absorbers, one at each wheel. Leg springs are used on the front and rear axles. Extreme cold weather can affect the tires if the vehicle is left standing for long periods. The truck should be parked on brush or planks if it is to be left in place for long periods and high, dry ground is not available. When starting after leaving the vehicle in the cold for long periods, let the vehicle warm up for at least 5 minutes before moving. Then, drive the truck slowly for a short distance. This should permit tires that have frozen into the shape of flat spots to thaw out and regain their normal configuration.

(6) Cab. The operator's cab is normally equipped with windshield wiper/washer for wet weather, air vents for hot weather, and heater and defroster for cold weather. As described earlier, the Arctic Winterization Kit may be issued with the vehicle depending on the geographic area in which it is used. This includes a heavy-duty heater motor and core to replace the standard heater for heating the cab area, as well as a 24-volt personnel heater and insulation to protect personnel in the cargo area.

## 3. EQUIPMENT SURVEY RESULTS

As a part of the data gathering effort on equipment efficiencies, the questionnaire is shown in Figure C-1. The high standard deviations show that the responses varied greatly. This was necessarily the case, as the survey recipients were asked to give estimates to reflect their experience and not to report the result of any specifically described experiment.

| | Activity<br>Mean (Standard Deviation) | 60°F Clear | 0°F Dry | 100°F High Humidity | Light Drizzle | Heavy Rain | Medium Snow Fall | Icy Sur-face | Heavy Fog | Wind 30 mph |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Conditions | | | | | | | | |
| 1. | Equipment Movement Speed (Wheeled Vehicle) | 99 ( 2) | 71 (24) | 84 (16) | 82 (19) | 61 (21) | 56 (23) | 38 (22) | 47 (28) | 85 (15) |
| 2. | Pushing Large Debris w/Crawler Dozer | 99 ( 3) | 74 (20) | 82 (16) | 85 (14) | 59 (20) | 69 (27) | 51 (33) | 72 (26) | 86 (15) |
| 3. | Excavating using Excavator or Backhoe on Concrete | 99 ( 2) | 70 (20) | 81 (18) | 86 (15) | 64 (20) | 70 (29) | 59 (30) | 76 (23) | 77 (28) |
| 4. | Site Grading & Clearing with Motor Grader | 100 ( 1) | 60 (23) | 79 (20) | 73 (21) | 42 (22) | 52 (29) | 26 (15) | 65 (22) | 82 (15) |
| 5. | Loading Aggregate/ Dirt from a Stock-pile into Trucks w/Front End Loader | 99 ( 2) | 69 (22) | 84 (14) | 83 (13) | 52 (34) | 69 (24) | 45 (27) | 73 (19) | 82 (13) |
| 6. | Backfilling Craters w/Aggregate w/Dump Truck or Front End Loader | 99 ( 2) | 78 (16) | 79 (20) | 87 ( 9) | 50 (22) | 62 (29) | 42 (26) | 70 (23) | 86 (12) |
| 7. | Breaking/Cutting Concrete Pavement w/Bulldozer or Front End Loader Ripper | 94 (17) | 69 (24) | 79 (22) | 69 (37) | 49 (25) | 56 (34) | 46 (27) | 71 (26) | 83 (19) |
| 8. | Mixing/Pouring Concrete from On-site Mobil | 99 ( 3) | 56 (38) | 86 (12) | 87 ( 8) | 33 (29) | 50 (31) | 51 (39) | 84 ( 8) | 77 (16) |
| 9. | Compacting Crushed Stone w/Vibratory Roller | 100 ( 1) | 67 (34) | 84 (14) | 89 (13) | 36 (29) | 46 (35) | 56 (37) | 79 (30) | 88 (10) |

Figure C-1. Equipment Survey Results.

## APPENDIX D

## WEATHER EFFECTS ON MATERIALS

### 1. GENERAL

This section provides the detailed examination and analysis of each material item that is essential for the repair of runways.

### 2. SPECIFIC MATERIALS ANALYZED

The following materials are examined:

- Crushed Stone
- Polymer Concrete
- Silikal®
- AM-2 Mat
- FOD Cover
- Paint
- Lead-Sulfur Compound.

a. Crushed Stone

Crushed stone is used in bomb damage repair for backfilling the craters. Generally, a 24-inch deep layer of well-graded crushed stone aggregate is required. The material is well-graded to facilitate compaction during the repair in accordance with the requirements of AF Regulation 93-2. A complete list of specifications for the crushed stone appears in AF Regulation 93-2. The crushed stone is normally kept in sheltered stockpiles near the runway.

A variety of environmental conditions can affect the ability of crushed stone to produce an acceptable runway surface. One is the amount of fine material in the stockpile. Wind and rain can segregate the stockpile. Segregation is the tendency of the smaller stones to migrate to the center and bottom of the stockpile. If this happens, much of the stockpile would not be well-graded material. The result of this would be inferior compactability of the aggregate because the smaller components of the aggregate necessary to fill voids in the craters are missing. A great amount of segregation would be necessary to make the crushed stone ineffective. This degree of segregation would only occur if the aggregate is exposed for long periods of time (months to years). Solutions to this problem could include placing the crushed stone in sheltered areas, or by occasionally replacing or mixing the crushed stone. These alternatives provide fairly acceptable and inexpensive solutions to the problem of aggregate segregation.

A more serious problem involves the effects of moisture on crushed stone, especially its impact on compactability. The inherent characteristics of crushed stone aggregate make it very sensitive to moisture content. Optimal, acceptable, and unacceptable levels of moisture can be determined with regard to compaction. The definition of proper water content levels varies depending on the requirement that the aggregate is fulfilling.

Aggregate is used in both the crushed stone with FOD cover and the concrete cap repair techniques. Aggregate requirements differ for the two cases. For crushed stone repairs, it is necessary to use a well-graded crushed limestone or silica aggregate that produces a high degree of sheer strength as a result of compaction. The FOD cover acts only to eliminate the possibility of aggregate chips being ingested into the jet engines of the aircraft, and provides little or no strength to the system. This cohesive crushed stone is very sensitive to moisture content. Absorbed water within the aggregate particles is not a problem. Internal moisture plus excess moisture on the order of 2-3 percent normally aids in compaction. Moisture content above this level results in an inability of the graded crushed particles to fill in void areas and to achieve an adhesive effect to one another. In such cases, the compactive blows rebound off noncompressible water-filled voids in the aggregate. This degradation of compactive effort reduces the shear strength levels that can be achieved by the fill material.

The concrete cap repair method places less demand on the postcompaction performance of the aggregate since the concrete cap provides the majority of the required flexural strength. The aggregate only provides the general support required to underlay the cap surface. For this type of repair, a lower quality crushed stone and a decreased compactive effort is permissible, to the point that noncohesive materials may be used. Poorly graded gravel is a good example of a noncohesive material in which water content is of less concern especially where the quantity of gravel provides sufficient void space to accommodate the water. Later, as water drains or as the water table is lowered, the percolation of the water from the gravel will not adversely affect the ability of the aggregate to support the cap.

The sections which follow explore the issue of weather content in more detail. For cohesive materials, water content is normally measured by drying and weighing a sample before and after the water has been added. A nuclear density gauge can be used to determine the moisture content in a field sample. However, it only provides moisture content in relation to the compaction effort; therefore, is not an absolute measure of aggregate moisture.

The determination of the compactability of crushed stone or other aggregate depends on its moisture content. Moisture content for a specific material in a specific location is dependent on a wide variety of data elements. Information on the airbase and its setting is essential. It may include the depth to the water table and the types, depths, and thicknesses of the soil layers beneath the pavement. Information on precipitation events is also needed to determine the intensity-duration values of the precipitation as well as drainage characteristics and runoff hydrographs of the area. Rainfall intensity-duration curves are discussed in another section. When used in conjunction with ground cover and ground storage information, it becomes possible to determine the rainfall excess and its routing to produce the needed runoff hydrograph (water flow versus time).

Rainfall excess can be computed with knowledge of ground cover, ground storage, and precipitation. Given the relatively impermeable nature of the runway surface, ground cover can be estimated as being between 97-100 percent impermeable. (Paved parking lots, roofs, driveways, streets, and roads are 98 percent impermeable.) Runoff curve numbers (CN) are derived from the percent of impervious area. These are provided for a variety of circumstances in a variety of references (see Reference 20 for an example). Figure D-1 provides the rainfall excess for given rainfall rates, wherein the runoff curve number for the airfield pavement can be set at about 95.

The RRR repair crew must consider the water table, the rate of rainfall, and the drainage into the crater in assessing the ability of the crushed stone to adequately repair the damage. The location of the crater in relation to the runway crown can have impact where the slope allows falling precipitation to run into the crater. The depth of the crater and the depth to ground water for the particular airbase interact with drainage characteristics to yield the total amount of water in the crater. This total amount or level of water is used to determine the moisture content. This information can be combined with information on weather conditions and probabilities to determine the feasibility of crushed stone repairs in a variety of environmental circumstances.

It has been clearly established that well-graded crushed stone used in the compacted crushed stone and FOD cover repair technique is highly sensitive to moisture content. If the aggregate is very dry (less than approximately 2 percent moisture content), then a small amount of water must be added to the crushed stone before it is placed and compacted (Reference 21). There is also a serious problem when there is too much water present. Current guidelines specify that the crushed stone stockpile must be constructed in such a way that the maximum water content will not exceed 5 percent. This can usually be accomplished by allowing the stockpile to drain naturally (Reference 20). Field tests conclude that this is an acceptable moisture content for compaction of crushed stone (Reference 2). Oftentimes, however, the crater itself will become filled with water or the repair will have to be done under rainy conditions and steps must be taken to keep the moisture content of the aggregate from becoming too high.

The investigations conducted in Reference 22 found severe problems with compaction of well-graded crushed stone at moisture contents of above 4.5 percent. The recommended range of moisture content is in the 3-3.5 percent range, excluding the water that is absorbed in the aggregate particles. Load cart testing found the failure point in the crushed stone

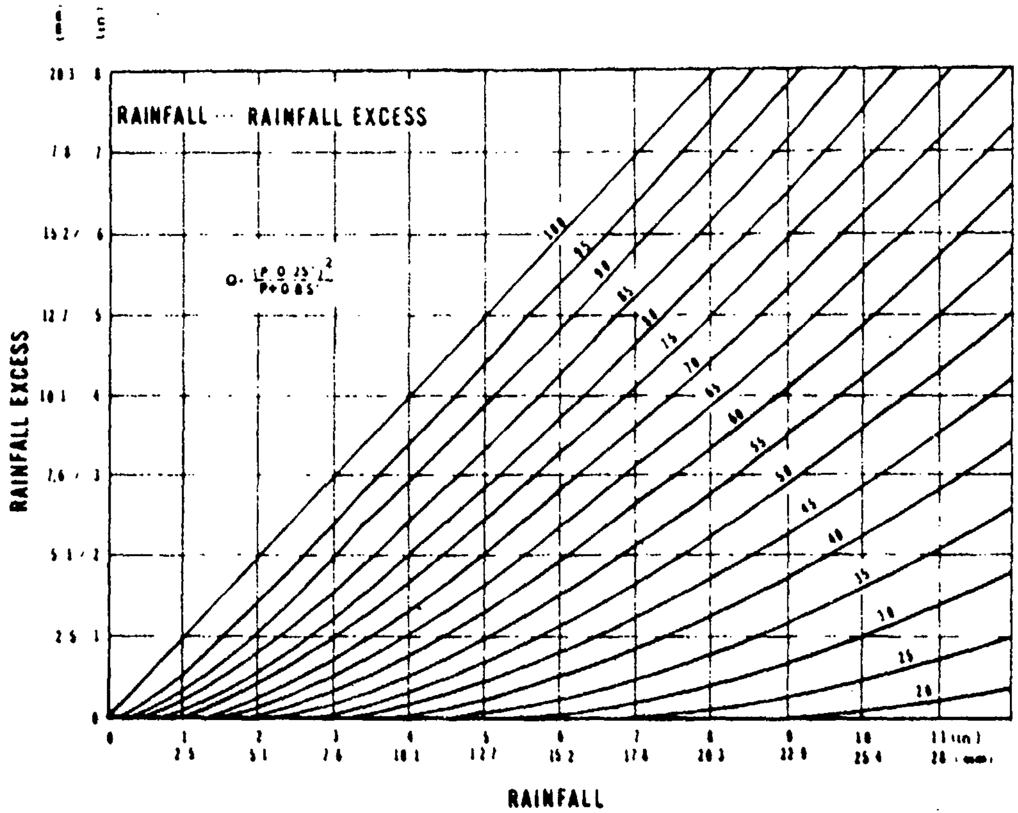



Figure D-1. Rainfall Excess-CN Curves.

repair at 5.4 percent moisture content. The report investigated the relative effects of gradation versus moisture content.

A good estimate of the optimum moisture content for crushed stone would lie between 3-3.5 percent. This represents the values between OMC and b along the line of optimums on Figure D-2. This provides the maximum dry unit weight at the most economical level of compaction effort. As stated earlier, problems with compaction take place at around 4.5 percent moisture content, and failure in pavement shear strengths as a result of load cart testing have been observed at moisture contents above 5.4 percent. This is typical of the low moisture content curves associated with materials of fairly high dry unit weight, such as crushed stone, thus reducing the moisture content within the crushed stone. The amount of single-sized aggregate required to retain the water could be calculated by estimating the volume of water and the volume of void space within a given quantity of aggregate. More research and testing of this potential solution are needed.

The relationship between water content and either standing water or precipitation does not appear to require a detailed amount of analysis since the acceptable moisture content levels are in the very low range for crushed stone. In general, if the crater has measurable standing water or if precipitation is in the moderate to heavy range, one can assume that the compacted crushed stone repair procedure is not feasible.

Several techniques are available to help protect the aggregate from excessive moisture. A tarp can be hung between two trucks or vehicles to protect small-to medium-sized craters from the rain. The adverse impact of this solution on the efficient use of vehicles and on the ability of personnel and other equipment to maneuver about the crater makes it almost infeasible to use this technique. Water pumps could be used to remove standing water from the bottom of the crater. Considerable research and testing should be conducted to ensure that this technique is feasible. A more feasible solution is to place some quantity, perhaps a 23-inch lift, of single-sized or poorly graded aggregate, into the crater before placing the crushed stone. This solution may be useful in areas where the water table is close to the surface, or for other reasons it is difficult to remove all the moisture from the crater. The single-sized aggregate would retain the standing water within its void spaces.

b. Polymer Concrete Cap Repairs for Small Craters

Two materials are currently being investigated to provide the cap in the concrete cap method of crater repair. These materials are polyurethane and acrylic concrete. The acrylic concrete is a compound of various substances and known by the acronym HEMA. It is a variant of the DOMA concrete investigated earlier in the research and development process.

The goal of the research and development effort is to select a concrete cap material that can be placed and cured within the material

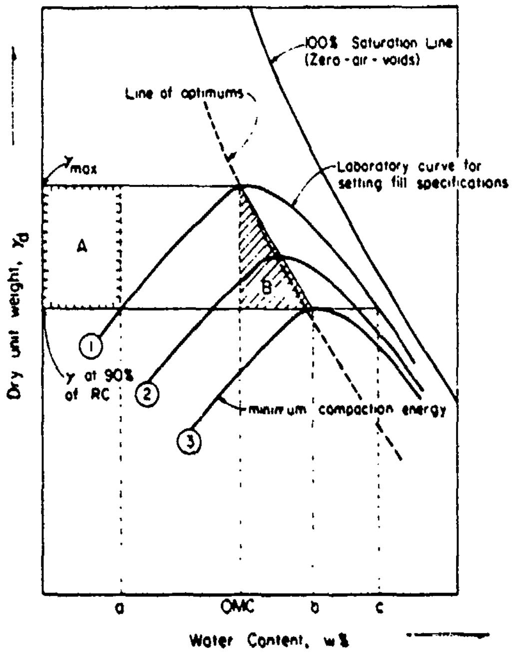



Figure D-2. Dry Unit Weight vs. Water Content.

temperature range of from $5^{o}$-$110^{o}F$, and within the ambient environmental (or cure) temperature range of from $-25^{o}$-$125^{o}F$. The material must be capable of curing within 1 hour after placement, using either wet or dry aggregate, and must develop a minimum flexural strength under the required conditions. The minimum design strength desired is 700 psi for the polyurethane and 500 psi for the acrylic cement. This design criterion is independent of ambient environmental conditions with the temperature ranges given above.

The results of the limited tests and experiments conducted on the materials to date are summarized in Table D-1. The six environmental conditions account for the cure or air temperature at the repair site, as well as the temperature of the material. Material temperature is normally expected to be well inside the extreme ranges of ambient temperatures as it will be stored indoors or at least enclosed within packing materials which provides some mitigation of temperature extremes due to its mass and volume. As noted, the polyurethane must be treated with Silane to achieve the strengths shown. Otherwise, it is more susceptible to moisture and can be expected to lose 300-350 psi at any temperature level when using wet aggregate.

Prototype small-scale mixing and dispensing systems have been developed by the subcontractor. This was demonstrated at Tyndall Air Force Base in September 1982. The prototype equipment provided a mixing and dispensing rate of 20 gallons per minute, while the expected rate of production equipment is to be approximately 300 gallons per minute. More information on the performance of these materials is expected to be developed and published soon.

c. Repair of Scabs with Silikal• Polymer Concrete

The principal area of application of polymer concrete is in the repair of scabs. A specific brand of polymer concrete, Silikal• R7/$B_W$, is currently used for scab repair. Silikal• is a proprietary product of Karl Ullrich & Company of Germany. Several licensees produce this material in the United States and Germany.

Silikal• is a methyl methacrylate-based polymer mortar. It is made by mixing dry sand and powdered polymer with liquid hardener. Silikal• R7/$B_W$ is a special formulation of Silikal• produced for the German military for airbase scab repair. U.S. Air Force tests have shown this material provides for fast and effective repair system for scabs, under certain environmental conditions. Packaging for Silikal• R7/$B_W$ consists of the following:

- 1 bag of powder mixture, 15 kg; and
- 1 can of hardener liquid, 2 liters.

TABLE D-1. CONCRETE CAP MATERIAL STRENGTHS.

| CONDITION (TEMPERATURE IN °F) | AVERAGE FLEXURAL STRENGTH (psi) POLYURETHANE | ACRYLIC |
|---|---|---|
| 5° Material, -25° Cure Wet Aggregate | 850 | 710 |
| 5° Material, -25° Cure Dry Aggregate | 1325 | 535 |
| 70° Material, 70° Cure Wet Aggregate | 720 | 595 |
| 70° Material, 70° Cure Dry Aggregate | 1620 | 815 |
| 110° Material, 125° Cure Wet Aggregate | 855 | 605 |
| 110° Material, 125° Cure Dry Aggregate | 1355 | 815 |

NOTES: The flexural strength is measured 1 hour after mixing of the components. Beam strength tests are conducted at the temperature the beam reached as a result of the curing process, to include effects of exothem. The polyurethane is treated with Silane (chemical that makes the aggregate less susceptible to the effects of moisture) (Source: Conversation with P. Boyer, BCL, September 28, 1982).

The bag is a four-layer paper bag with a waterproof polyethylene liner. In the bag on top of the powder are enclosed:

- A white paper bag containing 235 g of powdered catalyst (benzoyl peroxide); and

- A polyethylene mixing bag.

One bag of Silikal® R7/$B_W$ will provide .27 cubic feet of polymer mortar. The addition of 42 pounds of gravel produces slightly more than 1/2 cubic foot of polymer concrete. Although scab size varies, cannon-produced scabs average about this size (AF Regulation 93-2).

There is a 3/4-inch deep false bottom in the can containing a low-temperature accelerator. This accelerator makes the cure time a nearly constant 20 minutes (approximately) for all ambient temperatures (Reference 2). The temperature range guaranteed by the manufacturer is -4° to 104°F. Tests using TTEGDA (tetraethylene glycol diacrylant) as an accelerator demonstrated that adequate strength could be obtained from the cured concrete at temperatures as low as -25°F (Methyl Methacrylate Polymer - Concrete for RRR: Phase I Report).

A variety of studies have been made to assess the merits of polymer repair materials to the RRR process. Problem areas of this repair material include cost, shelf life, and the complexity of use for unskilled laborers, in addition to its variable environmental effects. However, its high strength, excellent bonding properties, and low cure time still make polymer materials a likely candidate.

The principal environmental condition which affects polymer repair materials is moisture. The sensitivity of polymer materials to environmental conditions results from their need for carefully controlled transformation to the polymer state from their component monomers and additives. Anything which affects this transformation, such as extreme temperature or moisture, generally has a severe effect on the strength of the cured concrete.

As with most polymer concrete, Silikal® R7/$B_W$ is very sensitive to moisture. Moisture affects scab repair with Silikal® in two ways. First, the moisture interferes with the polymerization of the monomer mix. Tests performed by AFESC have shown that a modest water content of 2 percent in the Silikal® reduces the strength of the cured concrete by 50 percent. The second way that Silikal® is sensitive to moisture is when the scab has water in it. Any moisture in the scab when the concrete is placed severely degrades the bonding between the Silikal® and the original runway pavement. Current RRR guidelines require that the scab be air-dried before concrete placement (AF Regulation 93-2).

The two ways that Silikal® is affected by moisture combine to make the Silikal® very sensitive to precipitation. Any significant precipitation will degrade scab repair with Silikal• to such a great extent that an alternative method will have to be used. Even if scab repair is postponed until after the storm, the scab needs to be completely dried before work can continue. To overcome the problems with moisture in Silikal• spall repairs, it is necessary to dry out the scab, protect the scab from precipitation, or both. An alternative for scab repair is described next.

d. Scab Repair Using Steel Plates

A potential method of overcoming adverse environmental conditions in the repair of scabs is to use steel plates. Reference 23 provides some history and a detailed discussion of this technique. It modifies the British Royal Engineer's method by filling in the scab with concrete before installing the steel plate. The British method consists of the following four steps:

- The scab area is cleared of debris and swept clean;
- A steel plate is laid over the scab, overlapping to provide a good key for the Rawl bolts;
- A drilling and bolting crew, using four Kango hammer drills from a 6-kVA generator trailer, drilled holes in the pavement and bolted down the plates with Rawl bolts; and
- The area is swept clean to remove any foreign object damage hazard.

The British estimate that 7 minutes are required using this method on concrete pavement and 10 minutes on bituminous. Three sizes of plates are available. Figure D-3 shows the design of the small scab plate. A U.S. Army Engineer Battalion experimenting with this technique was unable to match the British repair times. Problems were encountered with the types of organic equipment available to the unit (drills and drill bits), and with making the bolt holes match the steel plate. Additional research and training is needed for this alternative repair technique to work. However, it demonstrates a potential method for overcoming problems with precipitation and moisture in scab repair.

e. AM-2 Mat

When using the AM-2 mat repair technique, the crater is backfilled with coarse aggregate while the mat is assembled to the side of the crater. The backfill used for the AM-2 mat repair technique is not of the same quality as that used for the FOD cover repair technique. AM-2 mat crushed stone should be a dense grade, cohesionless, crushed aggregate with less than 10 percent fines (passing No. 200 sieve with 100 percent passing a 1 1/2-inch sieve). The fines should be nonplastic. Sand or naturally

## SCAB PLATE-SMALL

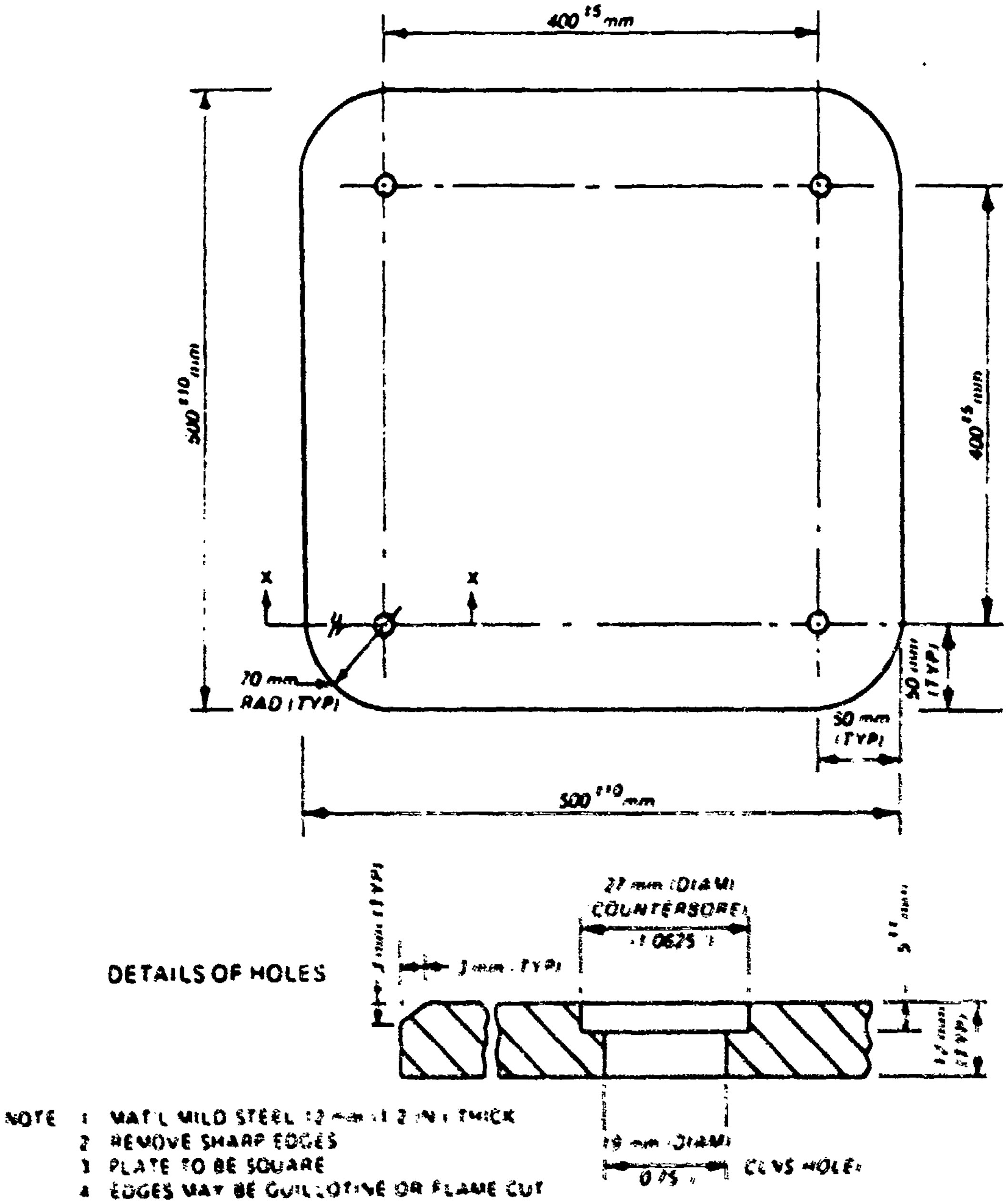



Figure D-3. Scab Plate-Small.

occurring well-graded gravel are acceptable alternate select fill materials where crushed aggregate is not available.

The required thickness of the select fill base course to ensure emergency operating conditions should be adjusted as follows:

| Subgrade Soil | Moisture | Thickness (in.) |
|---|---|---|
| Noncohesive | Any | 12 |
| CL, ML* | Low | 12 |
| | High | 24 |
| CH, MH,* Organic | Any | 24 |

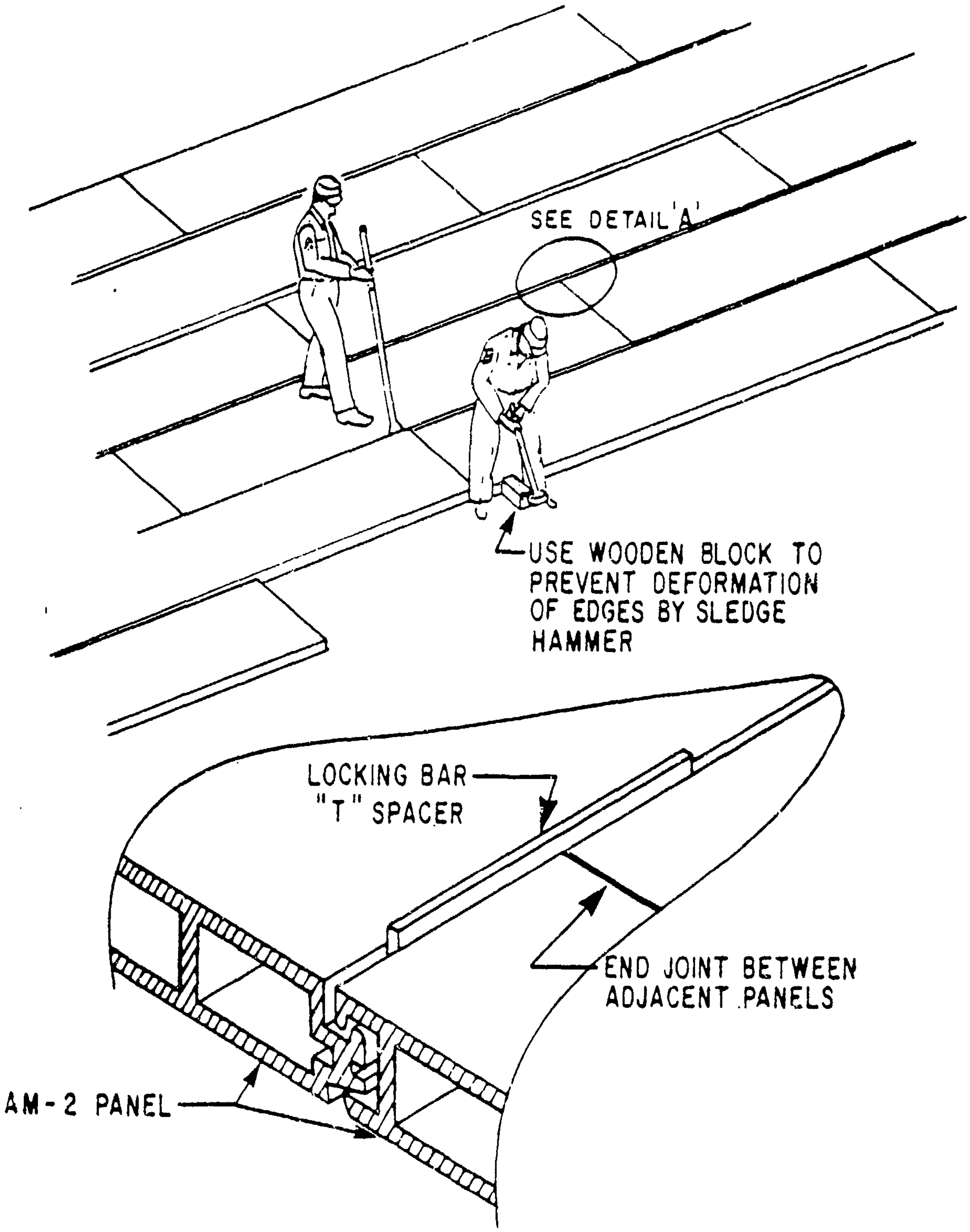
(Source: AF Regulation 93-2, Appendix 1, Annex B)

The crushed stone backfill is leveled and slightly compacted, then the assembled AM-2 mat patch is towed over the crater using dozers, loaders, or other equipment items as needed. The AM-2 mat patch is then bolted to the runway. In summary, the procedure consists of five steps, not counting the initial step involving the aggregate or the final step of bolting the mat to the runway. These are: select the mat assembly area, assemble the keylock, assemble the towing tubes, assemble the patch, and finally, attach the towing cable and tow the patch into position over the crater.

AM-2 mat consists of interlocking rows of aluminum panels. A complete AM-2 mat patch found in the RRR set consists of 140 full mats (12 feet by 2 feet) and 35 half mats (6 feet by 2 feet). In addition to the mats and the other equipment found in the RRR set, a Patch Kit contains all the tools and the accessory items required to fabricate a mat patch. Each full mat weighs approximately 100 pounds. The mats are delivered in bundles on the trailer or lowboy and are loaded and offloaded using fork-lifts, normally after the Patch Kit has been delivered and the keylock and towing tube frame has been assembled. Assembly of keylock, towing tubes, and mats is conducted in accordance with the instructions found in AF Regulation 93-2.

Mat attachment requires the use of the pry bar, sledgehammer, wooden block, and 3/16-inch locking pins or T-spacers. The locking pin or T-spacer provides the necessary spacing between mats when assembling the patch (see Figure D-4). The main weather condition that can affect the AM-2 mat repair process is freezing rain, and it affects the connection of one mat to another. Freezing rain can fill the joints and crevices in

* Soil classification by Unified Soil Classification System.




DETAIL A

Note: Locking bar is used as a spacer between panels while the patch is being assembled.

Figure D-4. Use of Locking Bar in Assembling Patch Correction of Mat Misalignment.

either the male or female connectors on the AM-2 mat, making it difficult or impossible to connect mat sections. This has been verified by actual experience of PRIME BEEF elements in the course of mat assembly.

The AM-2 mat is not directly affected by other weather conditions in the sense of material degradation. However, as discussed in Section V of this report, weather conditions may affect the ability of personnel to manipulate the mat. For example, wind above 30 mph increases the difficulty of positioning and assembling mat sections, rain or high humidity makes holding mat sections more difficult, and high or low temperatures may require gloves to avoid burning or freezing hands while manipulating the aluminum surfaces of the mat.

As described earlier, once the mat is assembled, it is towed into place over the crater. The bolting of the AM-2 mat to the runway is described in terms of weather effects on the lead-sulfur compound, in Part h of this appendix.

f. FOD Cover

A foreign object damage (FOD) cover is used in the crushed stone repair procedure. This insures that no pieces of aggregate are dislodged or chipped from the crushed stone bed which could be ingested into the aircraft engines. The FOD cover is prepared prior to the start of bomb damage repair or RRR activities. For a standard repair, the cover is constructed to the dimensions shown in Figure D-5. The strips are connected, using liquid adhesive. After the cover has been prepared, it can be rolled or folded for storage.

The most common form of FOD cover in use is called T-17. This is a neoprene-coated, two-ply nylon membrane with reinforcing strips attached, as shown in Figure D-5. When installed over the crater, the reinforcing strips are on the bottom of the cover. The cover is attached to the runway using end anchor plates and either side plates or some form of cable system that is anchored to the end plates in order to hold the sides firmly to the runway surface. The end plates are anchored by drilling holes of 3/4-inch diameter to a depth of 7 inches into the pavement.

Extremes in ambient environmental temperatures do not degrade the effectiveness of the FOD cover. Tests at Battelle Columbus Laboratories have shown that FOD cover strength and resistance to elongation change less than 5 percent in the temperature range of from -20°F to 125°F. Even high-temperature testing such as reported in Reference 24 showed that FOD cover samples that had been heated to 300°F (simulation of jet blast) responded much like the unheated samples after they had cooled to normal room temperatures. Elongation appeared to be similar and fracture occurred at a point outside the heated area. For heated specimens under load, the FOD cover fracture occurred in the heated area.

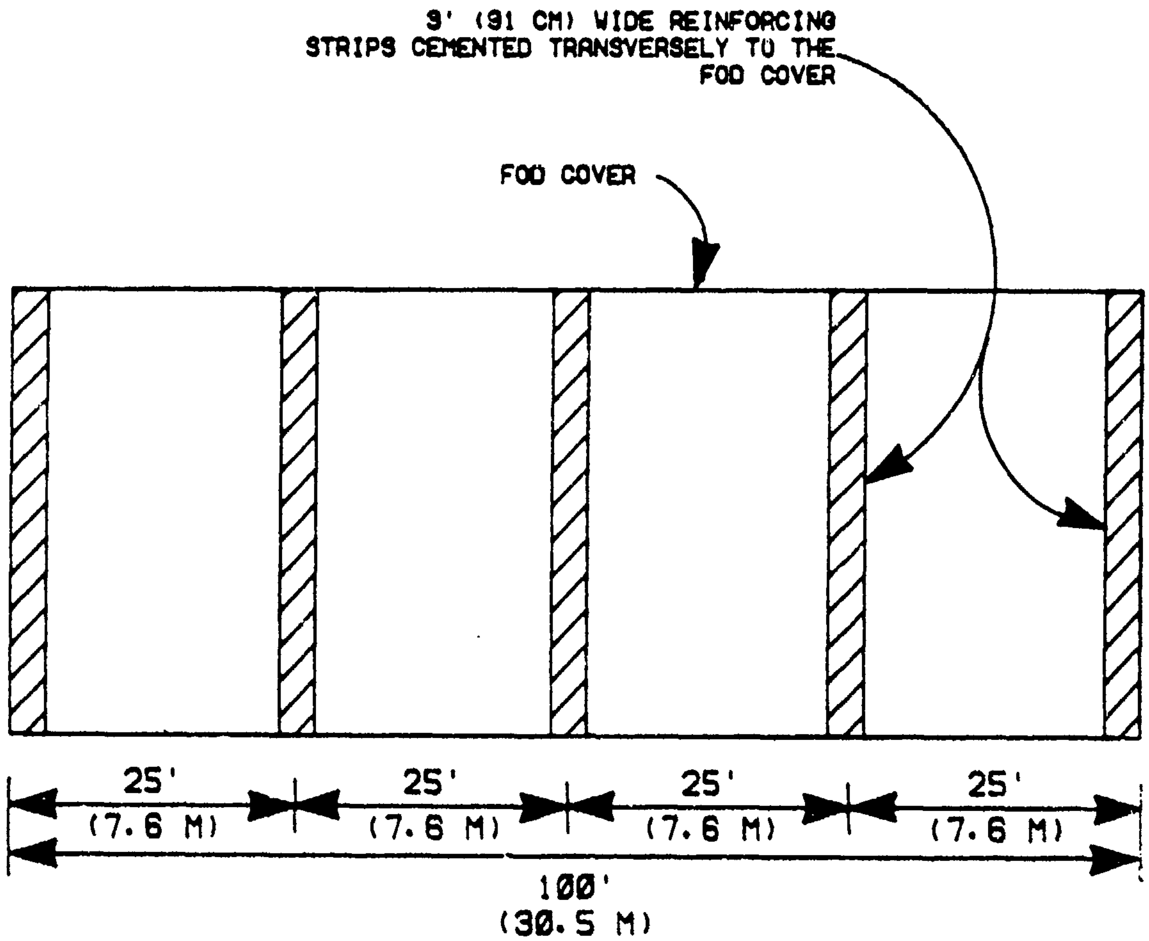



Figure D-5. FOD Cover Preparation (Not to Scale).

Precipitation and moisture do not appear to affect the FOD cover. The cover is impermeable, and the effects of moisture on the adhesive that connects the strips to the cover appear to be negligible. High winds or winds gusting to 20 or 30 mph or higher can be expected to have an impact on the process of placing and anchoring the FOD cover. This is a process problem, however, and should have no adverse impact on the cover material.

g. Paint

The last activity in the restoration of an airfield is the painting of a centerline down the center of the Minimum Operating Strip (MOS). This centerline is critical since it cannot be assumed that the MOS is parallel to the runway. This section briefly outlines the effects of the environment on paint.

Common construction practice is to paint only in temperatures greater than 50°F (Reference 5). There is, therefore, limited information on the effects of cold weather on paint. Local paint companies have suggested that an oil-based paint may be used at temperatures below 32°F for expedient repairs. Although the quality of the job would be poor, it would serve its purpose as a runway marker. The temperature where runway marking is impossible is difficult to estimate, but at 10°F the paint would probably become too viscous to place. Water-based paints are useless at temperatures less than 32°F.

Precipitation has a severe effect on painting. Even a light rain makes centerline painting impossible. Although there is a lack of experience in this area, small amounts of snow probably would not halt centerline painting for expedient repairs. The centerline would need repainting, but it would be visible.

Heat has little effect on paint. Humidity greatly affects the time required for paint to dry. Nevertheless, this is not a critical factor in centerline construction and can, therefore, be dismissed.

h. Lead-Sulfur Compound

The lead-sulfur compound is used to provide a solid anchor for the bolts used to pin the repair patch or cover to the runway surface. In the AM-2 mat method, end ramps are attached at the end of the mat sections and then bolted to the runway. In the FOD cover method, the anchor plates are placed over the FOD cover and then anchored to the runway.

It is necessary to drill 3/4-inch diameter holes to a depth of 7 inches to provide a solid anchor. While the holes are being drilled, the lead-sulfur compound is heated. The holes are then blown clear of dust and moisture using compressed air, then filled 3/4 full of the molten lead-sulfur compound. It is necessary to insert each bolt immediately after pouring the molten compound into its hole and pushing the bolt head down with washer and nut already attached, and holding it there until the lead-sulfur hardens (see Figure D-6). Goggles and gloves are necessary to protect workers during this process.

Temperature is not expected to affect the lead-sulfur compound except that additional time may be required for the melting pot warmer to sufficiently melt the lead-sulfur compound. This small amount of extra time will not be of significance to the overall repair process.

Moisture is expected to have a more severe impact, yet even this is not significant because of the effects of the compressed air and the small diameter and depth of the drilled hole. The drilled hole must be dry to achieve an adequate bond between the pavement and the lead-sulfur compound. However, it seems easy to protect the hole from water in the short time between its being drilled and the placement of the compound and the bolt using some form of cover or plug. Even that precaution is probably not necessary except in periods of very heavy precipitation, since the compressed air will dry any small to moderate amounts of moisture in the hole.

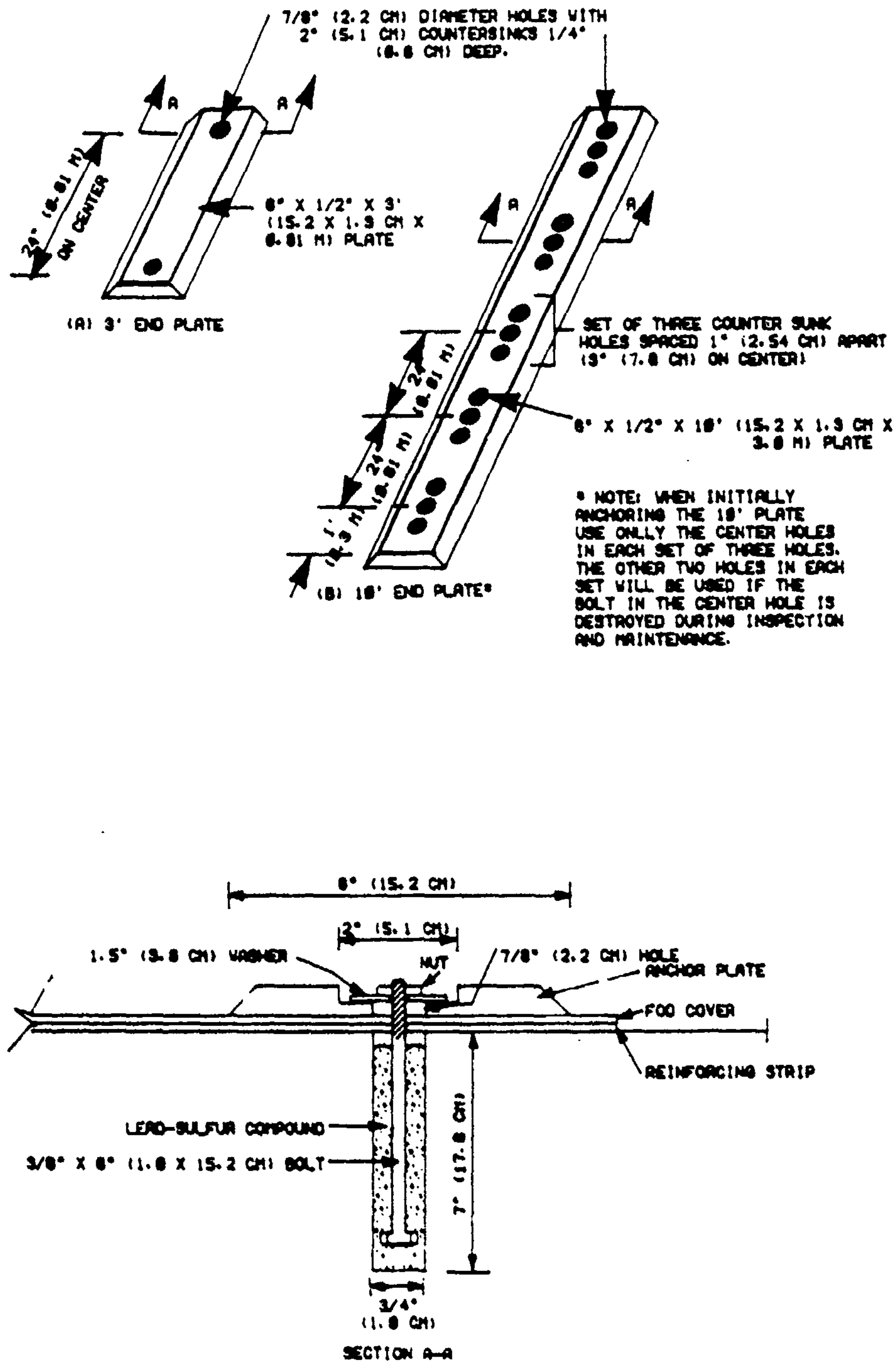



Figure D-6. End Anchor Plates for FOD Cover.

APPENDIX E

ACTIVITY DESCRIPTIONS

## 1. INTRODUCTION

This appendix contains a list of RRR activities. Each activity is described, a duration formula is developed and the effects of weather on the activity are discussed. The figures for this appendix appear at the end, for ease of reference.

## 2. PREPARE SCABS

### a. Description

Before the polymer concrete can be poured into a scab, the scab must be free of debris and unsound pavement. Men use compressed air jets to blow the debris out of the crater. Picks are used to remove the damaged pavement. This activity model involves the preparation of 15 average-sized scabs in a relatively small area.

### b. Assumptions

(1) A two-man team requires 2 minutes to prepare a scab. The scab zone containing 15 scabs is prepared in 30 minutes.

(2) Two crews are available.

### c. Duration

The time required to prepare the 15 scabs is:

$$30 \text{ minutes}/(E_m \times N_c) = 30 \text{ minutes}/(E_m \times 2) = 15/E_m \text{ minutes.}$$

where $E_m$ = efficiency of the men

$N_c$ = number of two-man crews

The graph of this duration formula is given in Figure E-18.

### d. Weather

(1) Visibility. Preparing scabs is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, preparing scabs is one of those activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is due to difficulty in locating the scabs in the scab area, and coordinating the two teams.

The effect of visibility on the duration of scab repair may be read from Figure E-10. Since duration at maximal efficiency is 15 minutes, enter the graph with K = 15. Then at a visibility of 40 feet for example, duration would be approximately 30 minutes.

Reference to Figure A-214 shows that in the worst month (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to operate the compressed air jets is moderate. Efficiencies for moderate work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-13) with K = 15 to read the duration of preparing the scab at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of scab preparation.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increase the duration to 20 and 45 minutes, respectively.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of high, medium and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation that derives from the moisture coming down and not from temperature or slipperiness. The reduced efficiencies are caused by delay to put in and operate in protective clothing. Entering the duration/precipitation graph with K = 15 gives the duration of preparing the scab at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 20 minutes.

(4) Slipperiness. To use the compressed air jets and picks to prepare the scabs the workers must be able to move about on the surface. Because of the crater debris, any moisture on the ground may combine with dirt creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations calculated by dividing 15 by the efficiency.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and

January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Calculating 15/EM = .25 gives a duration of 60 minutes for scab preparation in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of scab preparation in snowy conditions is 23 minutes.

(5) Wind. Preparing scabs requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 15 gives the durations.

Reference to Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a wind speed of 31 miles per hour gives a worst–case duration for scab preparation of 60 minutes.

3. DRY SCABS

a. Description

When the scabs are wet, a dryer must be used to ensure adequate bonding between the polymer concrete and the existing pavement. This activity inolves the drying of 15 craters. The activity is necessary if it has rained between the time of attack and the time that the scabs are being repaired.

b. Assumptions

(1) The scabs are dryed with a butane-fired infrared heater. A scab can be dryed in 2 minutes with a 5-minute cooling period (Reference 25).

(2) Four men with dryers are available.

c. Duration

The time required to dry a collection of scabs is dependent on the actual drying time and not on the time to cool. The duration is:

$$\frac{30 \text{ minutes}}{E_D \times N_D} = \frac{30}{E_D \times 4} = \frac{7.5}{E_D}$$

where $E_D$ = efficiency of dryer operation

$N_D$ = number of dryers available

Figure E-18 gives the graph of this duration formula.

d. Weather

(1) Visibility. If low visibility accompanies the rain that necessitated the scab-drying activity, the workers' efficiency will be degraded by difficulties in locating the scabs and coordinating the work effort. This is an onsite activity which is only affected by extremely limited visibilities, as shown in Figure E-1. Since duration at maximal efficiency is 7.5 minutes, enter the duration/visibilty graph (Figure E-10) with K = 7.5 to read the duration under various visibility limitations.

Figure A-214 shows that the worst-case situation for visibility gives 3.5 percent occurrence of visibilities of less than 100 meters. Data for shorter distances are not available, but the deduction can be made that visibilities of less than 75 feet are sufficiently rare that extended duration of the scab drying task is not a severe problem.

(2) Temperature. The level of work required to operate the infrared heaters is moderate. Efficiencies for moderate work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-13) with K = 7.5 to read the duration of drying the scab at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of scab drying.

The worst case for heat is 99°F in Germany in July. This temperature is reached 1 percent of the time, increasing the duration to 11 minutes (Figure E-13). Since this activity only takes place after it has rained, the worst case of cold is 32°F, or a duration of 9 minutes.

(3) Precipitation. This activity cannot proceed in periods of precipitation. Work must stop until the precipitation has abated. Because the activity is on the critical path, the duration of the repair will be increased by the duration of the precipitation. Figures A-165 though A-200 give precipitation duration information.

(4) Slipperiness. To use the infrared heaters to dry the scabs the workers must be able to move about on the surface. Because of the crater debris, any moisture on the ground may combine with dirt, creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated by dividing 7.5 by the efficiency.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Calculating $7.5/E_m$ with $E_m$ = .25 gives a duration of 30 minutes for scab drying in icy conditions. It is worth noting here that although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in

Germany in February). The duration of scab drying in snowy conditions is 12 minutes.

(5) Wind. Drying scabs requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 7.5 gives the durations.

Reference to Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a wind speed of 31 miles per hour gives a worst case duration for scab drying of 30 minutes.

4. MIX AND PLACE CONCRETE IN SCABS

a. Description

After the scab has been prepared, it is repaired with Silikal• polymer concrete. The components of Silikal• are placed in a plastic bag and mixed thoroughly. Gravel is added to the concrete and the contents of the bag are mixed thoroughly again. The bag containing the concrete is held over the scab and cut open with a trowel. The concrete is then quickly troweled into the scab. This activity involves the repair of 15 scabs.

b. Assumptions

(1) The time required to mix and place one bag of polymer concrete, cleanup, and move to the next scab is roughly 13 minutes (Reference 25 and observations of runway repair).

(2) Each bag has enough concrete to fill one scab.

(3) Silikal• is assumed to be readily available to the workers. A lowboy brings the concrete from the stockpile and deposits it near scab repair sites at different places on the runway.

(4) Four men are available to mix and place concrete.

c. Duration

The time required to repair 15 spalls with Silikal• is:

$$195 \text{ minutes}/(N_m \times E_m) = 195/4 \times E_m = 48/E_m$$

where $N_m$ = number of men

$E_m$ = efficiency of men

This duration formula is graphed in Figure E-18.

d. Weather

(1) Visibility. Mixing and placing the concrete in the scabs is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, this is one of those activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is from difficulty in locating the scabs in the scab area and moving from the repair sites to the stockpile.

The effect of visibility on the duration of scab repair may be read from Figure E-10. Since duration at maximal efficiency is 48 minutes, enter the graph with K = 48. Then at a visibility of 40 feet, for example, duration would be approximately 85 minutes.

Reference to Figure A-214 shows that in the worst month (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to mix and place the concrete is heavy. Efficiencies for heavy work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-12) with K = 48 to read the duration of mixing and placing the concrete at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of the scab repair.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increase the duration to 55 and 140, respectively.

(3) Precipitation. This activity cannot proceed in periods of precipitation. Work must stop until the precipitation has abated. Because the activity is on the critical path, the duration of the repair will be increased by the duration of the precipitation. Figure A-165 through A-200 gives precipitation duration information.

(4) Slipperiness. To be able to carry and mix the Silikal• and gravel the workers must be able to move about on the surface. Because of the crater debris, any moisture on the ground may combine with dirt to create a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated using $48/E_m$.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). This gives a duration of 192 minutes for scab filling in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of scab filling in snowy conditions is 73 minutes.

(5) Wind. Repairing scabs requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 48 gives the durations.

Reference to Figure A-258 shows that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a wind speed of 31 miles per hour gives a worst-case duration for scab filling of 192 minutes.

## 5. PAINT THE MOS

### a. Description

After the repairs of the runway, a centerline needs to be painted on the MOS. The painting is done with an automatic paint striper which is pulled down the MOS.

### b. Assumptions

(1) The area that requires painting is a 5000-foot by 3-foot stripe down the center of the runway.

(2) The paint rate of the equipment is 200 $ft^2$/minute (Source: Kelly Cresswell Model "C" paint striper data provided by local paint striping companies).

(3) Assume one striper is available.

### c. Duration

The time required to paint the centerline under normal conditions can be expressed in the form:

$$\frac{A}{R \times N}$$

where A = area to be painted

R = rate of painting

N = number of stripers

From the assumptions, the duration is:

$$\frac{5000 \times 3}{200 \times N} = 75 \text{ minutes}/N$$

Under adverse conditions, the formula is:

$$75 \text{ minutes}/(N \times E) = 75/E \text{ minutes.}$$

where N = number of stripers

E = efficiency of the striper (including paint)

The graph of this duration formula is given in Figure E-18.

d. Weather

(1) Visibility. The paint striper is only operated at a rate of 66 ft/min or .75 mi/hr. Hence limited visibility does not cause any loss of efficiency.

(2) Temperature. In temperatures below the 45°-50°F range, paint begins to thicken and clog the striping equipment. Painting cannot proceed at temperatures below 32°F (Climatic Limitations, pp 3-36). Assuming that the efficiency degrades linearly, Figure E-7 gives the paint efficiency curve. Efficiency of the striper is unaffected by high temperatures. The operator however is performing light work, and in the 99°F case his efficiency can be read from Figure E-2, giving a duration of 91 minutes.

(3) Precipitation and Slipperiness. Painting cannot proceed when the runway is covered with rain, snow or ice.

(4) Wind. Wind does not degrade the painting activity.

## 6. PULL MAT INTO PLACE

a. Description

The AM-2 mat has been assembled at the crater repair site and needs to be placed on the crater. The great weight of the mat necessitates the use of heavy equipment to pull the mat. Towing tubes attached to the mat during the mat assembly are connected to two pieces of equipment, usually loaders. The equipment pulls the AM-2 mat into position over the crater.

b. Assumptions

(1) The attach and towing activity requires 10 minutes to perform under ideal conditions (Source: Observations of runway repair at Eglin AFB).

c. Duration

The time required to pull the mat into place is dependent on the men who attach the towing tubes to the equipment. The duration is thus:

$$10 \text{ minutes}/E_M$$

where $E_M$ = efficiency of men

The graph of this duration formula is given in Figure E-18.

d. Weather

(1) Visibility. Pulling the mat into place is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, this is one of these activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is due to difficulty in seeing across the repair site.

The effect of visibility on the duration of this activity may be read from Figure E-10. Since duration at maximal efficiency is 10 minutes, enter the graph with K = 10. Then at a visibility of 40 feet, for example, duration would be approximately 20 minutes.

Reference to Figure A-214 shows that in the worst month (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and, as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to attach the towing tubes is light. Efficiencies for light work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-14) with K = 10 to read the duration of this task at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of pulling the mat into place.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increased the durations to 12 and 34, respectively.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of high, medium, and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation that derives from the moisture coming down and not from temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph (Figure E-15) with K = 10 giving the duration of preparing the scab at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 13 minutes.

(4) Slipperiness. To attach the towing tubes to the mat the workers must be able to move about on the surface. Because of the crater debris, any moisture on the ground may combine with dirt creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Due to the weight of the mat, the effects on the towing equipment will be even more severe. Use Figure E-6 for strongly effected equipment. Durations are calculated using $10/E_m$.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Calculating $10/E_m = .25$ gives a duration of 40 minutes for pulling the mat into place in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of pulling the mat into place in snowy conditions is 22 minutes.

(5) Wind. Pulling the mat into place requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V.

However, the principal part of the time of this activity is spent towing, which is unaffected by high winds.

7. ASSESS DAMAGE

a. Description

Teams of men walk over the damaged airfield. Their path zig-zags across the runway and taxiways as they record the damage that they see on note pads. Every third damage area, the damage assessment team radios the Survival Recovery Center and reports the damage observations.

b. Assumptions

(1) One damage assessment team takes 93 minutes to assess the damage on a 5,000-foot long runway with 100 damages (Source: Manual Damage Assessment Systems Test Report).

(2) The time required to do damage assessment scales linearly with the length of the surface to be assessed.

(3) Assume the runway is 10,000 feet long and that two teams work simultaneously.

c. Duration

The time required to assess the damage on an airfield by one damage assessment team and under ideal conditions can be expressed in the form:

$$\frac{L_S}{5000} \times 93 \text{ minutes}$$

where $L_S$ = length (in feet of surface)

Several teams can work simultaneously, and weather can degrade performance. The duration is, therefore:

$$\frac{L_S}{54 \times N_T \times E_T} = \frac{10000}{54 \times 2 \times E_T} = \frac{93}{E_T} \text{ minutes}$$

where $N_T$ = the number of damage assessment teams

$E_T$ = the efficiency of the damage assessment teams

The graph of this duration formula is given in Figure E-18.

d. Weather

(1) Visibility. Damage assessment is an activity that is sensitive to limited visibilities. Read $E_T$ from Figure E-1, using the UXO and DA curve. The degradation occurs because, using the totally manual technique, damage assessors must report the locations of craters and scab zones and UXO by estimating their relative positions to markers located every 500 feet along the runway.

The effect of low visibility on the duration of damage assessment may be read from Figure E-8. Since duration at maximal efficiency is 93 minutes, enter the graph with K = 93. Then at a visibility of 100 feet, for example, duration would be approximately 175 minutes.

Reference to Figure A-214 shows that in the worst month, (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound, and at 100-meter visibility, the damage assessment task is not degraded.

(2) Temperatures. The level of work required to carry out damage assessment is light. Efficiencies for light work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-14) with K = 93 to read the duration of damage assessment at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of damage assessment. In hot weather, chemical suits will further degrade damage assessment teams' performance.

The worst case for heat is 99°F in Germany in July, which is reached less than 1 percent of the time. The duration is increased to about 113 minutes. The worst case for cold is in Korea in January, where the 1-percent temperature is -8°F. Efficiency at this temperature for light work is given as 35 percent in Figure E-2. This data, however was gathered from the construction industry, which is subject to economic constraints and whose projects last over a period of weeks. With special clothing and greater motivation, an efficiency of 80 percent was assumed for this task at -8°F. This gives a duration of 116 minutes.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of high, medium and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation derived from the moisture coming down and not temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph with K = 93 gives the duration of damage assessment at various precipitation rates.

Table A-2 shows that the worst case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 124 minutes.

(4) Slipperiness. To collect the required data for MOS selection and repair the workers must be able to move about on the airfield surface. Because of the crater debris, any moisture on the ground may combine with dirt creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated using $93/E_T$.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Calculating $93/E_T$ with $E_T$ = .25 gives a duration of

372 minutes for assessing damage in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of damage assessment in snowy conditions is 143 minutes.

(5) Wind. Damage assessment requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 93 gives the durations.

Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a wind speed of 31 miles per hour gives a worst-case duration for damage assessment of 388 minutes.

8. LOAD, DELIVER, UNLOAD FOD COVER, AND RETURN

a. Description

Foreign Object Damage (FOD) covers are delivered to craters by tractor trailers. The cover material is loaded onto the tractor trailer by a forklift. The lowboy then drives to the crater and is unloaded by a forklift. Afterwards, the lowboy returns to the material stockpile.

b. Assumptions

(1) The time required to load or unload the FOD cover is 1 minute (Source: Observation of a Case W24C wheeled loader with a fork-lift attachment).

(2) The lowboy travels over the access roads at 25 mph (Source: Engineering judgment based on observation of vehicle performance).

(3) Assume distance from the stockpile to the crater is 1 mile.

c. Duration

The time required under ideal circumstances to load, deliver, and unload the FOD cover and return to the material stockpile can be expressed in the form:

$$T_L + T_D + T_U + T_R$$

where $T_L$ = time required to load

$T_D$ = time required to deliver

$T_U$ = time required to unload

$T_R$ = time required to return

From the assumption, the duration is:

$$T_D + T_R + 2 \text{ minutes}$$

or

$$(2 \times \frac{D}{25 \text{ mph}}) + 2 \text{ minutes}$$

where D = distance (in miles) between stockpile and crater

Converting units, and considering the degrading effects of weather, the duration is:

$$2 \times \frac{Df}{E_L \times 2200 \text{ ft/minute}} + \frac{2 \text{ minutes}}{E_F} = \frac{2 \times 5280}{E_L \times 2200} + \frac{2}{E_F} = \frac{5}{E_L} + \frac{2}{E_F}$$

where $D_f$ = distance (in feet) between stockpile and crater

$E_L$ = efficiency of the lowboy

$E_F$ = efficiency of the forklift

d. Weather

(1) Visibility. In periods of severely limited visibility, lowboy travel speed will be restricted. Read $E_L$ from the travel curve in Figure E-1. The degradation starts when visibility drops below 150 feet. The forklift will be unaffected by low visibility; that is $E_F = 1$. Hence duration is $\frac{5}{E_L} + 2$. Duration at various visibility may be read from Figure E-8. Enter with K = 5 and add 2 to the result.

Reference to Figure A-214 shows that in the worst month, (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and as 150 feet is less than half this distance, such low visibilities are fairly unlikely to occur.

(2) Temperature and Precipitation. Low temperatures and precipitation do not increase the duration of this task. At high temperatures the equipment operators' efficiency decreases. The lowboy operator performs light work and the forklift work is moderate (See Figure E-2). At the worst-case 99th percentile temperature (99°F at Hahn in July), this gives a duration of 9 minutes.

(3) Slipperiness. In periods of slipperiness the efficiencies of both the forklift and the lowboy will be degraded. As these are both rubber-tired vehicles involved in either travel or lifting, they are strongly affected by a slippery environment. Figure E-6 gives the efficiencies under various degrees of slipperiness. Since the forklift and lowboy are affected to the same degree, the duration formula may be simplified in this case to $\frac{5}{E_L} + \frac{2}{E_F} = \frac{7}{E_C}$ where $E_C$ is the common efficiency.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, $E_C$ = .25 so the duration is 28 minutes for FOD cover delivery in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of delivering the FOD cover in snowy conditions is 11 minutes.

(4) Wind. This activity is only mildly affected by wind. See Figure E-5 under equipment operators to read the duration. In the 31-mile per hour case, duration is not substantially increased (Figure E-15).

9. ASSEMBLE AM-2 MAT

a. Description

The AM-2 cover for the crater is delivered to the crater in bundles of 20 panels each. A frame is constructed for the mat at the mat assembly site. The 2-foot by 4-foot panels are placed into the mat frame and locked into each other to form the AM-2 cover. This is done by a team of men who pry up an end of the mat and put the next panel into place. A mat pin is inserted into each panel to lock it in place.

b. Assumptions

(1) Mat crew personnel are divided into teams of five or seven men. A five-man team can lay a single panel of mat in 45 seconds under ideal conditions. Each team consists of a man using a pry bar, a man inserting the mat pin, a man assembling the mat frame, and two men carrying the panel to be placed. A seven-man crew has two additional panel carriers and works twice as fast (Source: Observations of crater repairs at Eglin AFB).

(2) All repairs require at least nine bundles of AM-2 mat. An additional bundle of mat is required for each 8 feet of repair diameter in excess of 72 feet (Source: AF Regulation 93-2).

(3) Assume 12 men are available, making up a seven- and a five-man crew. Also assume the repair requires nine bundles of mat.

c. Duration

The time required to assemble an AM-2 mat under ideal conditions can be expressed in the form:

$$N_p \times T_c \;/\; N_c$$

where $N_p$ = number of panels to be placed

$T_c$ = time for a crew to place a panel

$N_c$ = number of crews/teams placing mat

From the assumptions, the duration is:

$$20 \times \text{MAX } 9,\ 9 + \text{Least } (D_R - 72 \text{ feet})/8 \text{ feet}) \times T_c/N_c$$

where $D_R$ = repair diameter

"Least" returns the smallest integer greater than the argument

"Max" returns the greater of its two arguments

From the assumptions, a seven-man crew does the work of two five-man crews. In adverse weather conditions, the duration is:

$$20 \times \text{MAX } 9,\ 9 + \text{Least } (D_R - 72 \text{ feet})/8 \text{ feet} \times (.75 \text{ min}/E_m)/(N_{5c} + 2N_{7c})$$

where $N_{5c}$ = number of five-man crews

$N_{7c}$ = number of seven-man crews

$E_m$ = efficiency of men

This reduces to $\frac{20 \times 9 \times .75}{3 \times E_m} = \frac{45}{E_m}$ minutes.

d. Weather

(1) Visibility. Assembling the mat is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, this is one of those activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is due to difficulty in coordinating the crew members at the assembly site.

The effect of visibilty on the duration of mat assembly may be read from Figure E-10. Since duration at maximal efficiency is 15 minutes, enter the graph with K = 45. Then at a visibility of 40 feet for example, duration would be approximately 80 minutes.

Reference to Figure A-214 shows that in the worst month (Oct.) on the worst airbase visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to assemble the mat is strenuous. Each panel weighs 140 pounds and must be moved and maneuvered into place. The locking operation requires precise work which will be hindered in very cold temperatures. Efficiencies for strenuous work are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-12) with K = 45 to read the duration of assembling the mat at various temperatures. It has also been noted that thermal expansion at high temperatures may cause fitting problems when locking the mat together. However, no data are available at this time to quantify this effect.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increase the duration to 85 and 118 minutes, respectively.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of high, medium, and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation that derives from the moisture coming down and not from temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph with K = 45 gives the duration of preparing the scab at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 60 minutes.

(4) Slipperiness. To assemble the mat the workers must be able to move about on the runway surface. Because of the crater debris, any moisture on the ground may combine with dirt, creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. An additional difficulty in assembling mat in icy or snowy condition is that the mat joints may become clogged with slush and have to be cleared. Figure E-4 gives the relevant efficiencies, and durations are calculated, using 45/E.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations

(Figure A-163). Calculating 45/E with E = .25 gives a duration of 180 minutes for assembling the mat in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of mat assembly in snowy conditions is 69 minutes.

(5) Wind. Assembling the mat requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-16 with K = 45 gives the durations.

Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-16 at a wind speed of 31 miles per hour gives a worst-case duration for mat assembly of 187 minutes.

10. DISTRIBUTE FILL

a. Description

The crushed stone fill is placed into the crater after it has been stockpiled near the crater. A loader or a dozer pushes the fill from the stockpile into the crater so that the fill is evenly distributed.

b. Assumptions

(1) A cycle consists of the loader or dozer pushing the fill from the stockpile in the crater and then returning to the stockpile. Each cycle requires 30 seconds (Source: Observation of runway repairs at Eglin AFB).

(2) Twenty-five cubic feet of crushed stone is pushed into the crater every cycle (Source: Observation of runway repairs at Eglin AFB).

(3) Assume two pieces of equipment are available.

c. Duration

The time required to distribute the select fill into the crater under ideal conditions can be expressed in the form:

$$\frac{V_T}{V_C} \times T_C$$

where $V_T$ = total volume of crushed stone to be placed

$V_C$ = volume of crushed stone which is moved in a cycle

$T_C$ = time required for one cycle

The depth of crushed stone required for the repair is 24 inches. The crushed stone volume is therefore nearly disk shaped. From the assumptions, the time in seconds to distribute fill is:

$$\frac{2 \text{ feet} \times 3.14 \times [\frac{D}{2}]^2}{25 \text{ feet}^2 \times N_E} \times 30 \text{ seconds}$$

or, under adverse weather conditions,

$$.125\ D^2/E \times N_E \text{ minutes}$$

where $D$ = crater diameter (in feet)

$E$ = work efficiency of the equipment

$N_E$ = number of pieces of equipment allocated

For a 57-foot crater this gives a duration formula of $\frac{51}{E}$ minutes and for a 31-foot crater the formula is $\frac{15}{E}$. (See Figure E-18 with K = 51 and 15, respectively.)

Similarly, for concrete cap repair, the duration expression:

$$.785\ D^2/E \times N_E$$

The large crater formula reduces to

$$\frac{.052\ D^2}{N_E \times E},$$

which is $\frac{21}{E}$ in the large crater case and $\frac{6}{E}$ in the small crater case. Durations can be read by summing Figure E-18 with K = 21 and K = 6.

d. Weather

Distributing fill is primarily a machine activity and not substantially degraded by low visibility, low temperatures or precipitation. High temperatures will cause the operator, who is performing moderate work, to have a decreased efficiency (see Figure E-2). At the worst case 99th percentile temperature (99°F at Hahn AFB in July), this gives a duration of

22 minutes for the small crater. High winds may also cause loss of efficiency for the operator (Figure E-5), but reference to Figure E-5 shows that at the 99th percentile, efficiency is still 98 percent.

Slipperiness is the only condition which causes serious reductions in equipment efficiency. Loaders and dozers distributing fill are strongly affected by slippery conditions. Figure E-6 gives the relevant efficiencies. Calculating K/E gives the duration of distributing fill under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The following tables give the durations of delivering fill for the four cases treated above.

| | DRY | ICY | SLUSH |
|---|---|---|---|
| LARGE CONCRETE CAP | 21 | 84 | 32 |
| SMALL CONCRETE CAP | 6 | 24 | 9 |
| LARGE CONVENTIONAL | 51 | 204 | 78 |
| SMALL CONVENTIONAL | 15 | 60 | 23 |

11. SWEEP

a. Description

The runway is covered with debris that is too small to be removed by a loader, dozer, or a grader. The runway is swept to dispose of the debris. The sweeper is a rotary sweeper which is towed by a tractor.

b. Assumptions

(1) The entire runway must be swept, but this activity involves the sweeping of a 500-foot by 75-foot area of the MOS.

(2) Observations of a John Deere 3018 tractor pulling a rotary broom of 5-foot effective width at an average work speed of 3 miles per hour gives an effective sweeping rate of 1320 square feet/minute.

c. Duration

The time required (minutes) to sweep a 500-foot by 75-foot section of the MOS is:

$$28/E_s$$

where $E_s$ = efficiency of the sweeper

d. Weather

Sweeping is primarily a machine activity and is not substantially degraded by low visibility, low temperatures or precipitation. High temperatures may cause the machine operator, who is performing light labor, to be less efficient. In the worst-case 99th percentile temperature (99°F at Hahn in July) the duration is increased to 34 minutes. High winds also may cause loss of efficiency for the machine operator (Figure E-5), but reference to Figure E-16 shows that in the 31 mile/hour case, duration is not substantially increased.

Slipperiness is the only condition which causes serious reduction in sweeper efficiencies. Not only will the towing tractor experience traction problems, but the efficiency of the sweeper brushes will be reduced. The efficiency may read from Figure E-6 using the strongly affected line. Calculating 28/E then gives the duration of the sweeping activity under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E = .25, giving a duration of 112 minutes for sweeping in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of sweeping in snowy conditions is 52 minutes.

12. CLEAR DEBRIS

a. Description

Bomb damage on the runway causes debris to be strewn on the runway. This debris is cleared by equipment which can include loaders, dozers, or graders. The rubble is backfilled into the craters and pushed off the MOS.

b. Assumptions

(1) A 500-foot by 75-foot area surrounding each crater must be cleared of debris.

(2) Assume one piece of clearing equipment is available.

c. Duration

The time required under ideal conditions for one piece of equipment to clear the debris from around one crater can be expressed in the form:

$$Ac/Rc$$

where $Ac$ = area to be cleared

$Rc$ = rate at which the area can be cleared

Under adverse weather conditions, the duration is:

$$\frac{Ac}{Rc \times N_E \times E_E}$$

where $N_E$ = number of pieces of equipment clearing

$E_E$ = efficiency of the clearing equipment

Assuming an effective blade width of 8.6 feet, an average clearance speed of 3 miles per hour gives:

$$Rc = 2285 \text{ square feet/minute}$$

From the assumptions, the duration (in minutes) is:

$$16/N_E \times E_E = \frac{16}{E_E}$$

d. Weather

Clearing debris is primarily a machine activity and is not substantially degraded by low visibility, low temperatures or precipitation. High temperatures may cause the machine operator, who is performing light labor, to be less efficiant. In the worst-case 99th percentile temperature (99°F at Hahn in July) the duration is increased to 24 minutes. High winds also may cause loss of efficiency for the machine operator (Figure E-5), but reference to Figure E-17 shows that in the 31-mile/hour case, duration is not substantially increased.

Slipperiness is the only condition which causes serious reduction in debris-clearing efficiencies. The equipment will experience traction problems as it attempts to push heavy loads of rubble over the runway surface. The efficiency may be read from Figure E-6, using the strongly affected line. Calculating 16/E then gives the duration under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E = 0.25, giving a duration of 64 minutes for clearing debris in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of clearing debris in snowy conditions is 35 minutes.

13. PLACE AND ANCHOR FOD COVER

a. Description

The foreign object damage (FOD) cover is delivered to the repair site for use on the crater. The FOD cover is placed over the crater and pulled taut between two end plates that are implanted in the runway surface. The cover is firmly anchored to the runway, using bolts which are placed through the cover and end plates and into the airfield pavement. The bolts are kept in the pavement by pouring a molten lead-sulfur compound into the drilled hole and allowing it to harden with the bolt placed in it. Side plates are installed so that the cover is secured strongly.

b. Assumptions

(1) The time required to prepare the FOD cover to be anchored is 10 minutes. This includes unrolling the FOD cover, placing the FOD cover over the crater, and organizing the bolts and end plates needed (Source: Observations of runway repair at Eglin AFB).

(2) Steel plates are anchored at the ends of the FOD cover and along the sides. Anchoring holes along the end are present every 2 feet. Anchoring holes along the edges are placed every 4.6 feet. The FOD cover length is the least multiple of 25 feet that is equal to or greater than the repair diameter. FOD cover width exceeds the repair diameter by 6 feet to a maximum of 55 feet.

For a large crater (57-foot repair diameter), this implies 55 anchor bolts in the end plates and 32 anchor bolts along the edges. For a small crater (31-foot repair diameter), these statistics are 38 and 22, respectively.

(3) The time required under ideal conditions for a two-man crew to place one bolt is 45 seconds.

(4) Assume four two-man crews are available.

c. Duration

The time required to place and anchor the FOD cover under ideal conditions can be expressed in the form:

$$T_p + T_a$$

where $T_p$ = time required to place the cover

$T_a$ = time required to anchor the cover

From the assumptions, the time for a two-man crew to place and anchor the mat:

$$10 \text{ minutes} + (N_B \times T_B)$$

where $N_B$ = number of bolts

$T_B$ = time for each bolt

The time required to anchor the FOD cover in weather conditions that may degrade efficiency is:

$$10 \text{ minutes}/E + (87 \times 1.5)/(N \times E) = (10 + 131/8)/E = \frac{26}{E}$$

for a larger crater and

$$10 \text{ minutes}/E + (60 \times 1.5)/(N \times E) = (10 + 90/8)/E = \frac{21}{E}$$

for a smaller crater

where N = the number of men assigned

E = work efficiency of men

d. Weather

(1) Visibility. Placing and anchoring the FOD cover is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, anchoring the FOD cover is one of those activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is due to difficulty coordinating the team members.

The effect of visibility on the duration of this activity may be read from Figure F-10. Enter the graph with K = 27 for a large crater and 21 for a small crater.

Reference to Figure A-24 shows that in the worst month (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and, as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to place and anchor the FOD cover is strenuous. Efficiencies for strenuous work levels are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-12) with K = 27 and 21 for large and small craters respectively to read the duration of placing and anchoring the FOD cover at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not a specific aspect of the activity. It has been noted that at low temperatures, the molten sulphur may cool too quickly to allow the bolts to be placed. No data are available, however, to quantify this observation.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increased the duration as follows:

| | -8° | 99° |
|---|---|---|
| LARGE CRATER | 66 | 51 |
| SMALL CRATER | 51 | 40 |

(3) Precipitation. Figure E-3 gives worker efficiency in periods of light, medium and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation that derives from the moisture coming down and not from temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph with K = 27 or 21 gives the duration of placing the large or small FOD cover at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on F[illegible] E-15, giving worst-case durations for this activity of 36 and 28 m[illegible]

(4) Slipperiness. To pl[illegible] anchor the FOD cover the workers must be able to move about on the runway surface. Because of the crater debris, any moisture on the ground may combine with dirt, creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to

maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated using K/E with K = 27 and 21 for large and small craters, respectively.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-4, E=.25, giving durations of 108 and 84 minutes for large and small craters, respectively, for placing and anchoring the FOD cover in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The durations are 42 and 33 minutes in snowy conditions.

(5) Wind. Anchoring the FOD cover requires work in exposed positions. In addition, the FOD cover can act as a sail to catch strong winds in which case it becomes very difficult to control. Care must be taken and more workers may be required to avoid this.

Read the efficiency for onsite workers from Figure E-5. Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a windspeed of 31 miles per hour gives worst-case durations for FOD placement of 108 and 84 minutes for large and small craters, respectively.

14. LOOSEN LIP

a. Description

Craters on the runway are often surrounded by upheaved pavement. This pavement must be removed in order to meet surface roughness criteria. The first step necessary to removing the cracked lip of the crater is loosening it so that it can be either pushed away or backfilled into the crater. The loosening of the concrete is accomplished by wedging underneath the cracked pavement with a dozer blade or a loader bucket and moving up. This is done from within the crater.

b. Assumptions

(1) Only one piece of equipment can work on this activity at a time (Souce: Engineering judgment and observations of crater repair at Eglin AFB).

(2) A loader or a dozer can loosen 7.5 linear feet of upheaved surface every 45 seconds (Source: Observations of crater repair at Eglin AFB).

c. Duration

Under ideal conditions, the duration has the form:

$L/R$

where $L$ = is the number of linear feet to be loosened

$R$ = work rate of equipment

Generally, lip is removed in one stage for small craters, and in two stages for large craters. That is, for large craters, the dozer or loader working travels the crater circumference twice.

For large craters, then:

$$L = (D_R + D_A) \times 3.14$$

For small craters,

$$L = D_R \times 3.14$$

where $D_R$ = the crater repair diameter

$D_A$ = the crater apparent diameter.

Consequently, the area can be loosened in:

$$(45 \text{ seconds}) \times ((D_R + D_A) \times 3.14)/(7.5 \times E) = \frac{30}{E} \text{ minutes}$$

for a typical large crater with $D_R$ = 57 feet and $D_A$ = 39 feet, and

$$(45 \text{ seconds}) \times D_R \times 3.14/(7.5 \times E) = \frac{10}{E}$$

for a small crater with $D_R$ = 31 feet,

where $E$ = work efficiency of lip loosening equipment.

d. Weather

Loosening the lip is primarily a machine activity and not substantially degraded by low visibility, low temperatures or precipitation. High temperatures may cause the machine operator, who is performing moderate work, to be less efficient. In the worst-case 99th percentile (99°F at Hahn AFB in July), the duration is increased to 45 and 15 minutes for large and small craters, respectively. High winds may also cause loss of efficiency for the operator (Figure E-5), but reference to Figures A-220 through A-258 shows that such conditions are less than 1 percent likely.

Slipperiness is the only condition which causes serious reductions in equipment efficiency. Loaders and dozers loosening the lip are strongly affected by slippery conditions. Figure E-6 gives the relevant efficiencies. Use K/E with the appropriate values for K and E to calculate the duration of distributing fill under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). The durations are 120 and 40 minutes for loosening the lip for large and small craters in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The durations are 67 and 22 minutes in snowy conditions.

## 15. ANCHOR AM-2 MAT

### a. Description

After the AM-2 mat is pulled into place, it must be securely anchored to the runway. Small holes along the perimeter of the mat are used for this purpose. A hand drill is used to make a hole in the runway into which a molten lead-sulfur compound is poured. A bolt is quickly pushed through a hole in the mat and into the drilled hole in the runway. When a bolt is placed through each of the holes and screwed into place the mat is firmly secured on the runway.

### b. Assumptions

(1) Twenty-eight bolts are required to anchor the mat, 14 at each end) (Source: AF Regulation 93-2).

(2) The time required for a team of two men to place one bolt is 45 seconds under ideal conditions (Source: Observations of runway repair at Eglin AFB).

(3) Drills, bolts, and the molten lead-sulfur compound are readily available.

(4) Assume two two-man teams.

c. Duration

Under ideal conditions, the time required to anchor the AM-2 mat can be expressed in the form:

$$\frac{N_B \times D_B}{N_T}$$

where $N_B$ = number of bolts to be placed

$D_B$ = duration of each bolt placement

$N_T$ = number of two-man teams

Considering the degrading effects of weather, this equals:

$$\frac{28 \times (.75 \text{ min}/E_m)}{N_T}$$

or

$$\frac{10.5}{E_m}\text{minutes}$$

where $E_m$ = efficiency of men

d. Weather

(1) Visibility. Anchoring the mat is an onsite activity, hence $E_m$ is read from Figure E-1. As the graph shows, anchoring the mat is one of those activities least affected by low visibility. The degradation that occurs at visibilities of less than 75 feet is due to difficulty coordinating the team members.

The effect of visibility on the duration of this activity may be read from Figure E-10. Since duration at maximal efficiency is 10.5 minutes, enter the graph with K = 10.5.

Reference to Figure A-214 shows that in the worst month, (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and, as 75 feet is substantially smaller than 100 meters, efficiency for this task will probably not be reduced.

(2) Temperature. The level of work required to anchor the mat is strenuous. Efficiencies for strenuous work level are graphed in

Figure E-2. Enter the duration/temperature graph (Figure E-12) with K = 10.5 to read the duration of anchoring the mat at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not a specific aspect of the activity. It has been noted that at low temperatures, the molten sulpher may cool too quickly to allow the bolts to be placed. No data are available, however, to quantify this observation.

The worst cases are 99°F in Germany in July for heat and -8°F in Korea in January for cold. These temperatures were reached less than 1 percent of the time and increased the durations to 40 and 51, respectively.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of light, medium and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation derived from the moisture coming down and not from temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph with K = 10.5 gives the duration of preparing the scab at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 28 minutes.

(4) Slipperiness. To anchor the AM-2 mat the workers must be able to move about on the runway surface. Because of the crater debris, any moisture on the ground may combine with dirt, creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated using 10.5/E.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-4, E = .25, giving a duration of 84 minutes for anchoring the mat in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of scab preparation in snowy conditions is 32 minutes.

(5) Wind. Anchoring the mat requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 10.5 gives the durations.

Figures A-220 through A-258 show that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a wind speed of 31 miles per hour gives a worst-case duration for anchoring the mat of 88 minutes.

16. GRADE

a. Description

A motorized grader levels the partially compacted crushed stone in the crater. The operator moves the level of the grader blade as instructed by an observer who watches the process while standing beside the crater. When the grading is complete, the compaction may be completed.

b. Assumptions

(1) For a 57-foot crater, each pass across the crater takes 30 seconds. Fifteen seconds are also required to maneuver before each pass. The maneuver time is constant for all craters but the time to make the pass scales linearly with the crater diameter (Source: Viewing of films of PRIME BEEF crater repairs).

(2) The portion of the crater which lies on the MOS needs to be covered by the grader three times (Source: Observation of crater repair at Eglin AFB).

(3) The effective blade width of the grader is 8.66 feet (Source: Reference 26 and observation of crater repair at Eglin AFB).

c. Duration Formula

The time required to grade the crushed stone under ideal conditions can be expressed in the form:

$$N_p \times T_p$$

where $N_p$ = number of passes

$T_p$ = time for each pass

The number of passes as a function of crater size, effective blade width, and the required number of coverages:

$$\frac{3 \times D_R \times P_m}{8.66 \text{ ft}} \times T_p$$

where $D_R$ = repair diameter

$P_m$ = portion of crater on the MOS

From Assumption (1), the time required to grade under ideal conditions is:

$$\frac{3 \times D_R \times P_M}{8.66 \text{ feet}} \times (D_R/57 \text{ feet}) \times 30 \text{ seconds} + 15 \text{ seconds}$$

Considering adverse weather conditions, a 57-foot crater totally on the MOS has a duration of:

$$\frac{3 \times 57 \times 1}{8.66} \times \frac{1 \times .5 + .25}{E_G} = \frac{15}{E_G} \text{ minutes.}$$

For a 31-foot crater totally on the MOS the duration formula is

$$\frac{3 \times 31 \times 1}{8.66} \times \frac{(31/47) \times .5 + .25}{E_G} = \frac{5.6}{E_G} \text{ minutes.}$$

where $E_G$ = efficiency of the grader

d. Weather

Grading is primarily a machine activity and is not substantially degraded by low visibility, low temperatures or precipitation. High temperatures may cause the machine operator, who is performing light work, to be less efficient. In the worst-case 99th percentile temperature (99°F at Hahn in July) the duration is increased to 18 and 7 minutes for large and small craters, respectively. High winds may also cause loss of efficiency for the machine operator (Figure E-5), but reference to Figure E-5 shows that such conditions are less than 1 percent likely.

Slipperiness is the only condition which causes some reduction in grader efficiencies. The effect is not a strong one and efficiency may be read from Figure E-6 using the moderately affected line. Use K/E with K = 15 or 5.6 to calculate the duration of the grading activity under slippery conditions for 57-foot and 31-foot craters, respectively.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E=.5, giving a duration of 30 or 11 minutes for large and small craters, respectively. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The durations of grading in snowy conditions are 21 and 8 minutes, respectively.

17. LOAD, DELIVER, UNLOAD AM-2 MAT, AND RETURN

a. Description

AM-2 mat is delivered to the crater by tractor trailers. The trailers are loaded at the materials stockpile with the AM-2 mat needed for a crater. Loading is accomplished by a forklift which lifts the pallets of AM-2 mat. The tractor trailers then drive to the mat assembly area at the repair site. A forklift at the crater unloads the pallets of AM-2 mat. Afterwards, the truck returns to the material stockpile.

b. Assumptions

(1) The forklift can load a pallet of mat, maneuver, set the mat down, and return to the truck in 60 seconds under ideal conditions. Unloading takes 60 seconds also (Source: Observations of a Case W24C wheeled loader with a forklift attachment).

(2) The lowboy travels over the access roads and runway at 25 mph (Source: Engineering judgment based on observation of vehicle performance).

(3) Nine pallets of AM-2 mat are required. (Source: AF Regulation 93-2. Although exceptionally large craters need more AM-2 mat material, the assumption of nine pallets is reasonable because the number of pallets does not greatly impact the duration, and this assumption greatly simplifies the duration formula.)

(4) Assume the distance from the stockpile to the crater is 1 mile.

c. Duration

The time required under ideal conditions to load, deliver, and unload the AM-2 mat and return to the stockpile can be expressed in the form:

$$T_L + T_D + T_U + T_R$$

where $T_L$ = time required to load

$T_D$ = time required to deliver

$T_U$ = time required to unload

$T_R$ = time required to return

From the assumptions, this is:

$$T_D + 18 \text{ minutes} + T_R$$

or

$$(2 \times \frac{Dm}{25 \text{ mph}}) + 18 \text{ minutes}$$

where  Dm = distance (in miles) between stockpile and crater

Converting units yields:

$$\frac{2 \times Df}{2200 \text{ feet/minute}} \times 18 \text{ minutes}$$

where  Df = distance (in feet) between stockpile and crater

Under adverse conditions the duration is:

$$\frac{2 \times 5280 \text{ feet}}{2200 \text{ feet/minute} \times E_L} + \frac{18 \text{ minutes}}{E_F} = \frac{5}{E_L} + \frac{18}{E_F}$$

where  $E_L$ = efficiency of the lowboy

$E_F$ = efficiency of the forklift

d. Weather

(1) Visibility. In periods of severely limited visibility, tractor trailer travel speed will be restricted. Read $E_L$ from the travel curve in Figure E-1. The degradation starts when visibility drops below 150 feet. The forklift will be unaffected by low visibility; that is $E_F = 1$. Hence duration is $\frac{5}{E_L} + 18$. Durationsat various visibilities may be read from Figure E-9. Enter with K = 5 and add 18 to the result.

Reference to Figure A-214 shows that in the worst month, (Oct.) on the worst airbase, visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound and as 150 feet is less than half this distance, such low visibilities are fairly unlikely to occur.

(2) Temperature and Precipitation. Low temperatures and precipitation do not increase the duration of this task. High temperatures will decrease the efficiency of the operators. The lowboy operator performs light work and the forklift work is moderate. At 99°F the task will have a duration of 34 minutes (Figure E-14).

(3) Slipperiness. In periods of slipperiness the efficiencies of both the tractor trailer and the lowboy will be degraded. As these are both rubber-tired vehicles involved in either travel or lifting, they are strongly affected by a slippery environment. Figure E-6 gives the efficiencies under varying degrees of slipperiness. Since the forklift and tractor trailer are affected to the same degree, the duration formula may be simplified in this case to $\frac{5}{E_L} + \frac{18}{E_F} = \frac{23}{E_C}$ where $E_C$ is the common efficiency. Durations may be calculated using 23/E.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E = .25, giving a duration of 92 minutes for AM-2 mat delivery in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of delivering the FOD cover in snowy conditions is 35 minutes.

(4) Wind. This activity is unaffected by wind.

## 18. PLACE POLYMER CONCRETE

### a. Description

This activity is still under development. Trucks will pump polymer onto the loose aggregate which fills the upper 10 inches of the crater. The ploymer will percolate downward through the aggregate and cure. The volume of the polymer required will be approximately 25 percent of the final volume of the concrete cap. Although many of the details of this procedure are unclear, duration formula modeling is straightforward because the concrete cure time will be constant.

### b. Assumptions

(1) The concrete must cure in 10 minutes, else the repair will have failed.

(2) Polymer can be pumped at 40 $ft^3$ per minute.

### c. Duration

Duration will equal

$$T_P + T_C = V/R_P + 10 \text{ minutes}$$

where $T_P$ = time to pump

$T_C$ = time to cure

$V$ = volume to be filled

$R_p$ = pumping rate

For a 57-foot crater this gives

$$3.14 \times (57/2)^2 \times (10/12)/40 + 10 = 53 + 10 = 63 \text{ minutes}$$

For a 31-foot crater

$$3.14 \times (31/2)^2 \times (10/12)/40 + 10 = 26 \text{ minutes}$$

d. Weather

Placing polymer concrete is primarily a materials activity and is not substantially degraded by low visibility or high winds. The temperature range at which it cures satisfactorily is -4°F to 104°F. Reference to Figure A-16 and A-20 shows that less than 1 percent of the observations of maximum temperatures were over 99°F worldwide, so that high temperatures should pose no substantial problems to polymer concrete placement and cure. Figure A-18 gives the 1-percent level for minimum temperature at Korean bases as -8° which is somewhat below the manufacturer's specifications for polymer concrete. However when using an accelerator, as discussed in Section VI, adequate strengths have been obtained from concrete cured at temperatures as low as -25°F.

The principal environmental condition which affects polymer concrete is moisture. In the case of a concrete cap repair, however, adequate strengths have been achieved with the addition of Silane to the polymer concrete. In this case, precipitation slows workers, but the repair is not stopped. The durations for a large and small concrete cap repair in heavy precipitation are 84 and 34 minutes, respectively.

19. CURE CONCRETE

a. Description

After the concrete is placed in the scabs, time is required for the concrete to harden.

b. Assumptions

The Silikal* requires 20 minutes to cure sufficiently to support aircraft traffic (Reference 2).

c. Duration

20 minutes.

d. Weather

Curing Silikal® in scabs is primarily a materials activity and is not substantially degraded by low visibility or high winds. The temperature range at which it cures satisfactorily is -4°F to 104°F. Less than 1 percent of the observations of maximum temperatures were over 99°F worldwide, so that high temperatures should pose no substantial problems to polymer concrete placement and cure. The 1-percent level for minimum temperature at Korean bases is -8° which is somewhat below the manufacturer's specifications for polymer concrete. However when using an accelerator, as discussed in Section VI, adequate strengths have been obtained from concrete cured at temperatures as low as -25°F.

The principal environmental condition which affects polymer concrete is moisture. In the case of a scab repair, this deficiency can be addressed by adding the activity of dry scab to the activity network. If precipitation continues during the repair process the scab repair must stop.

The worst base in the worst [illegible] for precipitation duration is Hahn in December. Ninety-nine percent of the periods of precipitation here have a duration of less than 17 hours.

20. COMPACT

a. Description

After the crushed stone is placed into the crater, it must be firmly compacted. The compacting is done by a vibratory roller which rolls over the crater in strips. Any crater which is not entirely on the MOS needs to be compacted only on the section that is.

b. Assumptions

(1) The roller makes 32 coverages for FOD cover repair of the crater (Source: AF Regulation 93-2), and 24 coverages for AM-2 mat repair of a large crater.

(2) A roller takes 14 seconds to traverse a 57-foot crater. Traversal times for other craters scale linearly with this (Source: Viewing of films of crater repair).

(3) The effective width of a roller after overlap between passes is 6 1/4 feet (Source: Observation of crater repair at Eglin AFB.)

c. Duration

The time necessary to compact the fill under ideal conditions can be expressed in the form:

$$N_p \times T_p$$

where $N_p$ = number of passes over the crater

$T_p$ = time for each pass over the crater

From the assumptions for small crater repair, this is:

$$\frac{32 \times D_R}{6.25 \text{ feet}} \times T_P$$

where $D_R$ = repair diameter

Since the time for each pass scales linearly with diameter, the duration is:

$$\frac{32 \times D_R}{6.25 \text{ feet}} \times \frac{D_R}{57 \text{ feet}} \times 14 \text{ seconds}$$

Under adverse conditions, the duration for a 31-foot crater is:

$$\frac{.021\ D_R^{\ 2}}{E_R} \text{ minutes} = \frac{20}{E_R} \text{ minutes}$$

where $E_R$ = work efficiency of compactor.

Similarly, for large crater repair using AM-2 mat, the duration is:

$$\frac{24 \times D_R}{6.25 \text{ feet}} \times \frac{D_R}{57 \text{ feet}} \times \frac{14}{60} \text{ minutes}$$

For a 57-foot crater this gives

$$\frac{.016\ D_R^{\ 2}}{E_R} \text{ minutes} = \frac{51}{E_R} \text{ minutes.}$$

d. Weather

Compacting crushed stone is primarily a machine activity and is not substantially degraded by low visibility, low temperatures or precipitation. High temperatures may cause the machine operator, who is performing light labor, to be less efficient. In the worst-case 99th percentile temperature (99°F at Hahn in July) the durations are increased to 24 and 62 minutes for small and large craters, respectively. High winds also may cause loss of efficiency for the machine operator (Figure E-5), but reference to Figures A-220 through A-258 show that such conditions are less than 1 percent likely.

Slipperiness is the only condition which causes serious reduction in equipment efficiency. The vibratory roller is moderately affected by slippery conditions. Figure E-6 gives the relevant efficiencies. Entering using K/E with the appropriate values for K and E gives the durations of distributing fill under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E=.5, giving durations of 102 and 40 minutes for compacting large and small craters, respectively, in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The durations of compaction in snowy conditions are 73 and 29 minutes, respectively.

The presence of precipitation can cause problems in compacting crushed stone. If too much moisture is present the stone will not adequately compact. A possible method for avoiding this problem is to include a layer of poorly graded stone between the compacted debris and the select fill. No data are available at this time, but as the volume to be filled is not increased, the time for the crushed stone repair should also not substantially increase with the addition of this activity. Assuming that the drainage problem can be resolved, compaction efficiency will not decline in periods of precipitation.

21. LOAD AND DELIVER FILL

a. Description

Crushed stone from the material stockpile is transported to the crater repair site by dump trucks. A front-end loader at the stockpile loads the trucks with the crushed stone. The trucks are then driven to the crater. An area has already been cleared in the debris near the crater for the select fill. The dump trucks dump their loads in the cleared area and return to the materials stockpile. This activity is repeated as many times as necessary to fill the crater to the appropriate height with crushed stone.

b. Assumptions

(1) The loading of the dump truck is done by a loader picking up some fill, maneuvering to the truck, dumping the crushed stone into the truck, and returning to the crushed stone pile. Each cycle takes 24 seconds (Reference 26).

(2) The dump truck is a 5-ton dump truck with a load volume of 200 cubic feet. The truck is overloaded during the emergency repairs so that the volume is the limiting factor in select fill transport. The truck travels over access roads and the runway at 25 mph. The dump truck takes 1 minute to unload the fill (modeled after an International Harvester 2275 5-ton dump truck).

(3) The effective bucket size of the loader is 50 cubic feet (loader modeled after the Case W24C wheeled loader).

(4) The portion of the crater which needs the select fill is the top 24 inches. The crushed stone fills a disk-shaped volume. The concrete cap repair requires 10 inches of select fill (Source: AF Regulation 93-2 and conversations with concrete cap repair developers).

(5) Assume the distance to be traveled is 1 mile, and five dump trucks are available.

d. Duration Formula

The time required to load and deliver the select fill to a crater for one dump truck under ideal conditions can be expressed in the form:

$$N_R \times (T_L + T_D + T_U + T_R)$$

where $N_R$ = number of dump truck loads required

$T_L$ = time required to load the truck

$T_D$ = time required to deliver the crushed stone

$T_U$ = time required to unload the crushed stone

$T_R$ = time required to return to the stockpile

The time to travel between the stockpile and the crater is the same regardless of direction, so $T_D + T_R = 2 \times T_D$. From the assumptions, the duration is:

$$N_R \times ([2 \times T_D] + T_L + 1 \text{ minute})$$

The time to travel is a function of the distance and speed. The time to load is a function of truck size, loader bucket size, and loading speed.

$$N_R \times \left(\left[2 \times \frac{D}{25 \text{ mph}}\right] + \left[\frac{200 \text{ ft}^3}{50 \text{ ft}^3} \times 24 \text{ seconds}\right] + 1 \text{ minute}\right)$$

where D = distance needed to travel in miles

With D = 1 mile, changing the units to minutes gives:

$$N_R \times (4.8 + 2.6) \text{ minutes}$$

As the travel time will generally be much greater than loading and unloading times, and trucks can travel at the same time, the duration formula can be approximate as:

$$\text{Leastint } (N_R/N_A) \times (4.8 + 2.6) \text{ minutes}$$

where $N_A$ = number of trucks available

"Leastint" returns the least integer greater than or equal to the argument

This duration can be increased by certain weather conditions. Thus, for concrete cap repairs, the duration is:

$$\text{Leastint } \left(3.14 \times \frac{[\frac{D}{2}R]^2 \times .83 \text{ ft}}{200 \text{ ft}^3} / N_A\right) \times ([4.8/E_T] + [2.6/E_L]) \text{ minutes}$$

or

$$\text{Leastint } \left(\frac{D_R{}^2}{306 \times N_A}\right) \times ([4.8/E_T] + [2.6/E_L]) \text{ minutes}$$

With five trucks this gives

$$3 \times \left(\frac{4.8}{E_T} + \frac{2.6}{E_L}\right) = \frac{14}{E_T} + \frac{7.8}{E_L}$$

for a 57-foot crater and for a 31-foot crater.

$$\frac{4.8}{E_T} + \frac{2.6}{E_L}$$

The duration formula for repairs requiring 24 inches of material is:

$$\text{Leastint } (D_R^2/127 \times N_A)) \times ([4.8/E_T] + [2.6/E_L]) \text{ minutes}$$

or

$$6 \times (\frac{4.8}{E_T} + \frac{2.6}{E_L}) = \frac{28.8}{E_T} + \frac{15.6}{E_L}$$

for a 57-foot crater and

$$2 \times (\frac{4.8}{E_T} + \frac{2.6}{E_L}) = (\frac{9.6}{E_T} + \frac{5.2}{E_L})$$

for a 31-foot crater

where $E_T$ = efficiency of dump trucks

$E_L$ = efficiency of loader

$D_R$ = crater repair diameter

d. Weather

(1) Visibility. In periods of severely limited visibility, dump truck travel speed will be restricted. Read $E_T$ from the travel curve in Figure E-1. The degradation starts when visibility drops below 150 feet. The loader will be unaffected by low visibility; that is $E_F = 1$. Hence, for example, duration is $\frac{9.8}{E_T} + 5.2$ for the small crater concrete cap. Durations at various visibilities may be read from Figure E-9. Enter with K = 9.6 and add 5.2 to the result.

Reference to Figure A-214 shows that in the worst month (Oct.), on the worst airbase (Hahn), visibility is less than 100 meters in 3.5 percent of the observations. Data for shorter distances are not available. However, the 3.5 percent does act as an upper bound, and as 150 feet is less than half this distance, such low visibilities are fairly unlikely to occur.

(2) Temperature and Precipitation. Low temperatures and precipitation do not increase the duration of this task. High temperatures degrade the efficiency of the machine operators, who are performing light work. In the worst-case 99th percentile temperature (99°F at Hahn in July) duration for the small concrete cap would be 9 minutes.

(3) Slipperiness. In periods of slipperiness the efficiencies of both the dump trucks and the loader will be degraded. As these are both rubber-tired vehicles involved in either travel or lifting they are

strongly affected by a slippery environment. Figure E-6 gives the efficiencies under various degrees of slipperiness. Since the dump trucks and loader are affected to the same degree, the duration formula may be simplified in this case. For example the small crater concrete cap formula would be $\frac{9.6}{E_T} + \frac{5.2}{E_L} = \frac{15}{E_C}$ where $E_C$ is the common efficiency. Duration may then be calculated with the appropriate value for $E_C$.

Another problem that may arise is that if recent weather patterns have included numerous freeze/thaw cycles and periods of precipitation, an unprotected crushed stone stockpile may freeze solid and be difficult for the loader to manipulate. Bases experiencing such weather cycles should protect their crushed stone stockpiles.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E = .25, giving a duration of 60 minutes for loading and delivering fill in icy conditions for a small conventional crater. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of loading and delivering fill in snowy conditions is 23 minutes.

(4) Wind. This activity is unaffected by wind.

## 22. COMPACT DEBRIS

### a. Description

Debris pushed into the crater during the repair must be compacted before the select fill is added to guarantee repair stability. This compaction is done by a loader or a dozer which goes into the crater and moves over the debris many times. For smaller craters, the loader or dozer gets into the crater and rocks back and forth. Compaction is done in stages with lip removal between stages.

### b. Assumptions

(1) Only one piece of equipment can compact at a time because there is little space in the crater (Source: Engineering judgment comparing equipment size and typical crater size).

(2) The compact debris activity is a series of passes over the debris with equipment. The time to make a single pass in the crater scales linearly with the crater diameter. A single pass of a 48-foot crater takes 5 seconds and 90 passes are necessary to adequately compact the debris (Source: Observation of runway repair at Eglin AFB).

(3) The difference between the repair diameter and the apparent diameter is the length of upheaved pavement around the crater. Each

10 feet of this length causes the crater to require an additional series of passes due to the added debris (Source: Observation of runway repair at Eglin AFB).

c. Duration Formula

The time required to compact the debris under ideal conditions can be expressed in the form:

$$N_p \times D_p$$

where $N_p$ = number of passes necessary to compact

$D_p$ = duration of each pass

From the assumptions, the number of passes is a function of diameter such that the duration under adverse weather conditions is:

$$90 \times \left(1 + \frac{D_R - D_A}{10 \text{ feet}}\right) \times \left(\frac{D_R + D_A}{96 \text{ feet}} \times \frac{5 \text{ seconds}}{E_e}\right)$$

where $E_e$ = efficiency of the equipment

$D_A$ = crater apparent diameter

$D_R$ = crater repair diameter

For a crater with $D_R$ = 57 and $D_A$ = 39 this gives a duration formula of:

$$\frac{21}{E_e} \text{ minutes.}$$

For a smaller crater with $D_R$ = 31 and $D_A$ = 20 the duration formula is $\frac{8}{E_e}$ minutes.

d. Weather

Compacting debris is primarily a machine activity and is not substantially degraded by low visibility, low temperatures or precipitation. High winds may cause loss of efficiency for the machine operator (Figure E-5), but references to Figures A-220 through A-258 show that such conditions are less than 1 percent likely. High temperatures will decrease the efficiency of the operator, who is performing moderate work. At 99°F the task will have durations of 31 and 12 minutes for large and small craters, respectively.

Slipperiness is the only condition which causes serious reduction in equipment efficiency. The loader or the dozer is affected by slippery conditions. Figure E-4 gives the relevant efficiencies. Using K/E entering with the appropriate values for K gives the durations of distributing fill under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E=.5, giving a duration of 42 minutes for compacting debris into large crater in icy conditions. Although the slush produced by snowy conditions does not create as much of a delay, it does occur more often (15.7 percent of the observations in Germany in February). The duration of debris compacting for a large crater in snowy conditions is 30 minutes.

23. REMOVE BOMBLETS

a. Description

The runway must be cleared of bomblets. These are pushed off the edge of the runway with a dozer. There is room for one dozer for each 100 feet of zone length.

b. Assumptions

A 200-foot by 300-foot zone is cleared of bomblets. Two dozers are available. The area is cleared by making a series of passes across the width of the rectangle. A 15-second maneuver time is assumed for each cycle. The effective blade width of the dozer is 9 feet. The dozer travels 5 miles per hour while making each pass.

c. Duration

The duration formula considering degrading weather conditions takes the form

(number of passes) x (time per pass)/(number of dozers) x (dozer efficiency)

where

number of passes = length of zone/blade width

time per pass = width of zone/speed of dozer + maneuver time

Substituting the assumptions above gives a duration formula of

(300 feet/9 feet) x (200 feet/440 feet per minute + .25 minutes)/(2xE) or 16/E

where E is dozer efficiency.

d. Weather

Clearing bomblets is primarily a machine activity and is not substantially degraded by low visibility or low temperatures. High temperatures may cause the machine operator, who is performing medium labor, to be less efficient. In the worst-case 99th percentile temperature (99°F at Hahn in July) the duration is increased to 24 minutes. High winds also may cause loss of efficiency for the machine operator (Figure E-5), but reference to Figure E-16 shows that in the 31-mile/hour case, duration is not substantially increased. During heavy precipitation efficiency is .75, giving a duration of 21 minutes.

Slipperiness is the condition which causes the most serious reduction in dozer efficiencies. The efficiency may be read from Figure E-6, using the strongly affected line. Calculating 16/E then gives the duration of this activity under slippery conditions.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). From Figure E-6, E=.25, giving a duration of 64 minutes for this activity in icy conditions.

24. DISARM BOMB

a. Description

A 750-pound bomb is neutralized and removed from the runway surface.

b. Assumptions

The activity is composed of a single cycle. The cycle time is assumed to be 20 minutes.

c. Duration

The duration formula under adverse weather conditions is

20/E

where E is the EOD team efficiency.

d. Weather

The conditions affecting the disarm bomb activity are temperature and precipitation. From Figure E-3 the efficiency in heavy precipitation is .75, giving a duration of 26 minutes.

The level of work required to disarm bombs is light. In the 99th percentile worst-case high temperature (99°F) the duration will be 24 minutes (see Figure E-2). The 99th percentile worst-case low-temperature duration is 66 minutes. Because of the stationary nature of this task, it was not judged to be degraded by slippery conditions, low visibility or wind.

25. SURVEY

a. Description

The MOS must be surveyed to mark the new centerline.

b. Assumptions

The time to survey a 1000-foot strip of MOS is 4 minutes. The MOS is 5000 feet in length. One survey team is available.

c. Duration

Since weather conditions may decrease the efficiency, the duration formula has the form

(4 minutes) x (MOS length/1000 feet)/E

where E is the survey team efficiency. This reduces to

20/E minutes

under the assumptions given above.

d. Weather

(1) Visibility. Surveying the MOS is an activity that is sensitive to limited visibilities. Read E from Figure E-1, using the surveying curve. Figure A-214 shows that in the worst case, visibility is less than 100 meters (or 328 feet) in 3.5 percent of the observations. Data for shorter distances are not available. Duration at this visibility is 63 minutes.

(2) Temperatures. The level of work required to carry out surveying is light. Efficiencies for light work level are graphed in Figure E-2. Enter the duration/temperature graph (Figure E-14) with K = 20 to read the durations of damage assessment at various temperatures. The degradation here is attributable to general effects of heat and cold on workers and not to a specific aspect of damage assessment. It should be noted here that in hot weather, chemical suits will further degrade performance.

The worst case for heat is 99°F in Germany in July, which is reached less than 1 percent of the time. The duration is increased to about 24 minutes. The worst case for cold is in Korea in January, where the 1-percent temperature is -8°F. Efficiency at this temperature for light work is given as 35 percent in Figure E-2. These data however were gathered from the construction industry, which is subject to economic constraints and whose projects last over a period of weeks. With special clothing and greater motivation, an efficiency of 80 percent was assumed for this task at -8°F. This gives a duration of 25 minutes.

(3) Precipitation. Figure E-3 gives worker efficiency in periods of high, medium and heavy precipitation. The graph is designed to characterize both rain and snow, and to treat only the degradation that derives from the moisture coming down and not temperature or slipperiness. The reduced efficiencies are caused by delay to put on and operate in protective clothing. Entering the duration/precipitation graph with K = 20 gives the duration of surveying at various precipitation rates.

Table A-2 shows that the worst-case 4-hour rainstorm in Korea had an average intensity of 2.6 inches per hour. The worst-case 4-hour snowfall (from the same table) is 6.8 inches per hour. These correspond to heavy precipitation on Figure E-15, giving a worst-case duration for this activity of 26 minutes.

(4) Slipperiness. To accomplish the surveying task the workers must be able to move about on the airfield surface. Because of the crater debris, any moisture on the ground may combine with dirt, creating a muddy surface that will slightly degrade efficiency. In the extreme case, ice storms will produce a surface on which it is extremely difficult to maneuver equipment or even to walk. Figure E-4 gives the relevant efficiencies, and durations are calculated using $20/E_T$.

Freezing rain which produces icy surfaces causes the longest delays from slipperiness. In Germany, in the worst months of December and January, freezing rain occurred in 1.4 percent of the observations (Figure A-163). Calculating $20/E_T$, with $E_T = .25$, gives a duration of 80 minutes for assessing damage in icy conditions.

(5) Wind. Surveying requires work in exposed positions. Workers are subject to the general debilitating effects of wind discussed in Section V. The relevant efficiency curve appears in Figure E-5. Figure E-17 with K = 20 gives the durations.

Reference to Figures A-220 through A-258 shows that winds higher than 27 knots, or 31 miles per hour are experienced in less than 1 percent of the observations at all bases in all months. Entering Figure E-17 at a windspeed of 31 miles per hour gives a worst-case duration for surveying of 83 minutes.

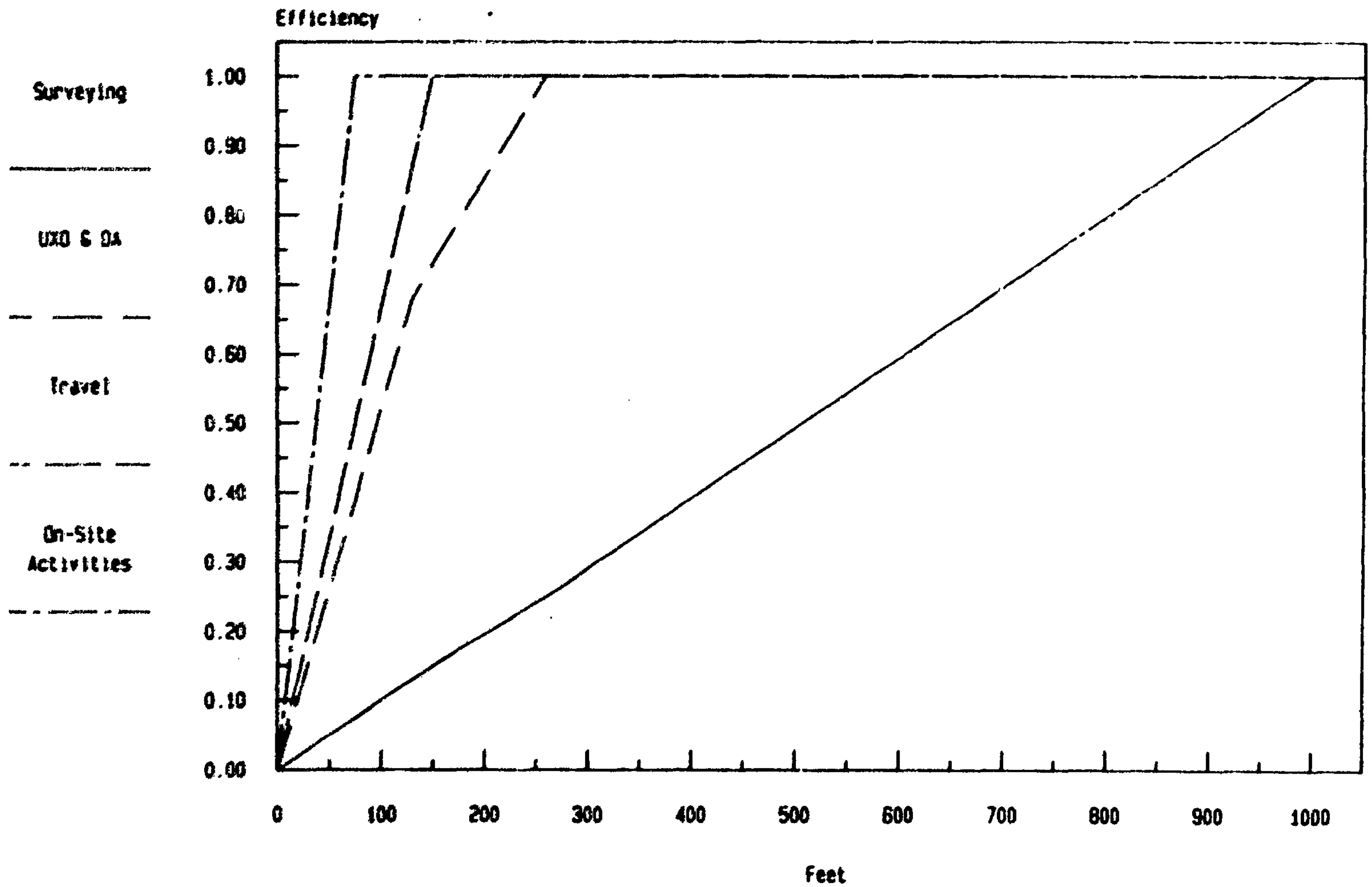



Figure E-1. Human Efficiency (Effects of Visibility).

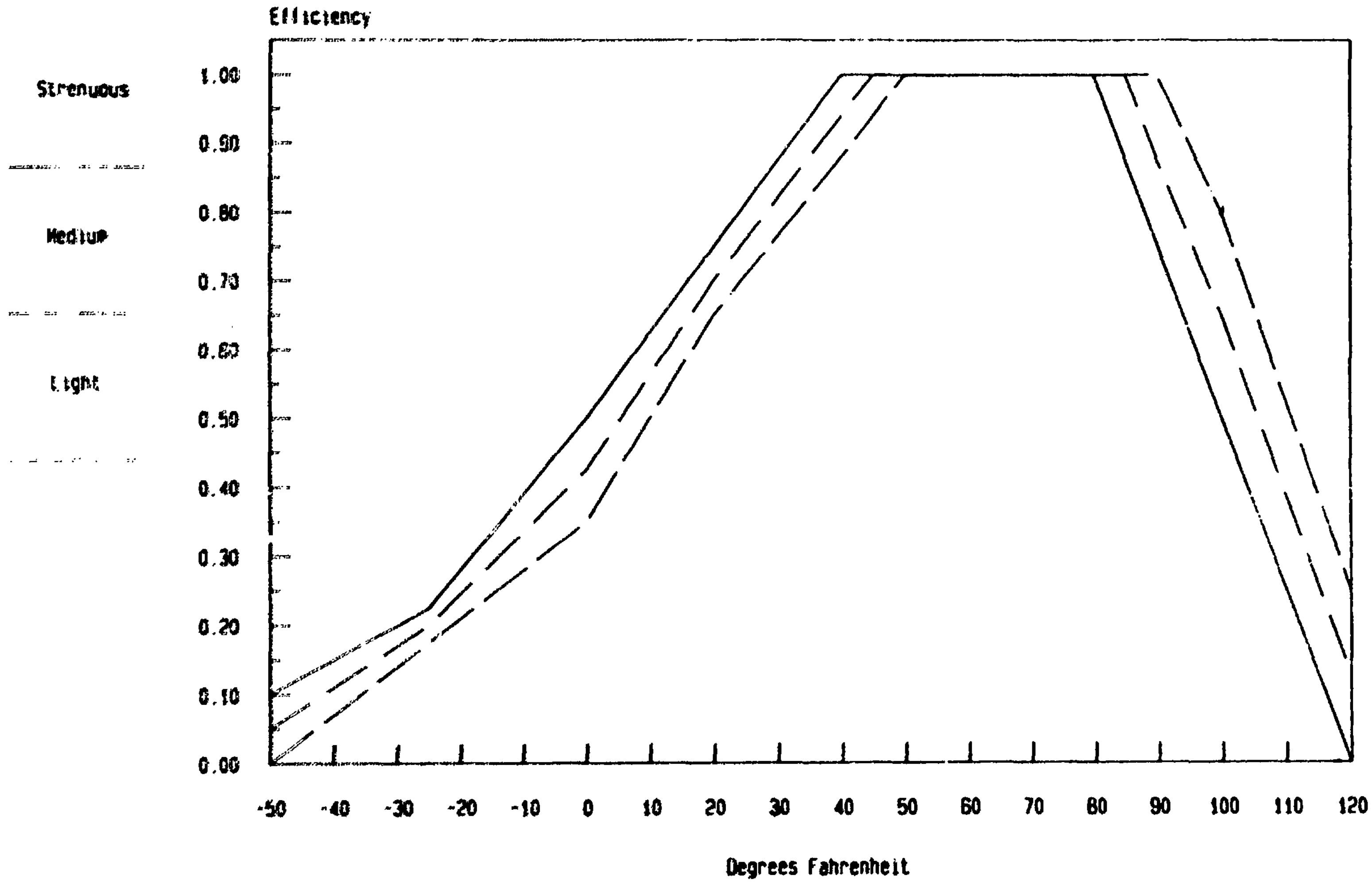



Figure E-2. Human Efficiency (Effects of Temperature).

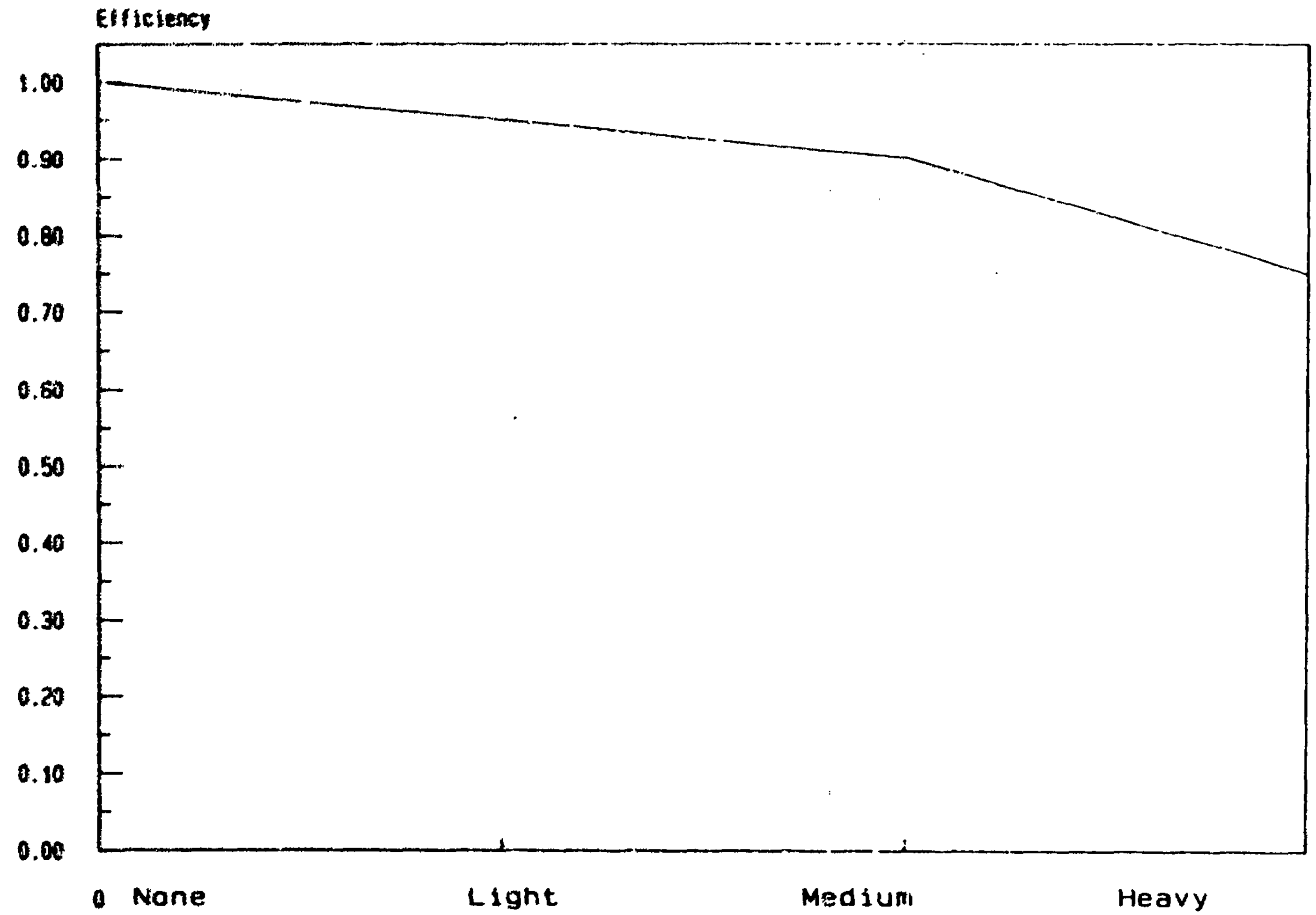



Figure E-3. Human Efficiency (Effects of Precipitation).

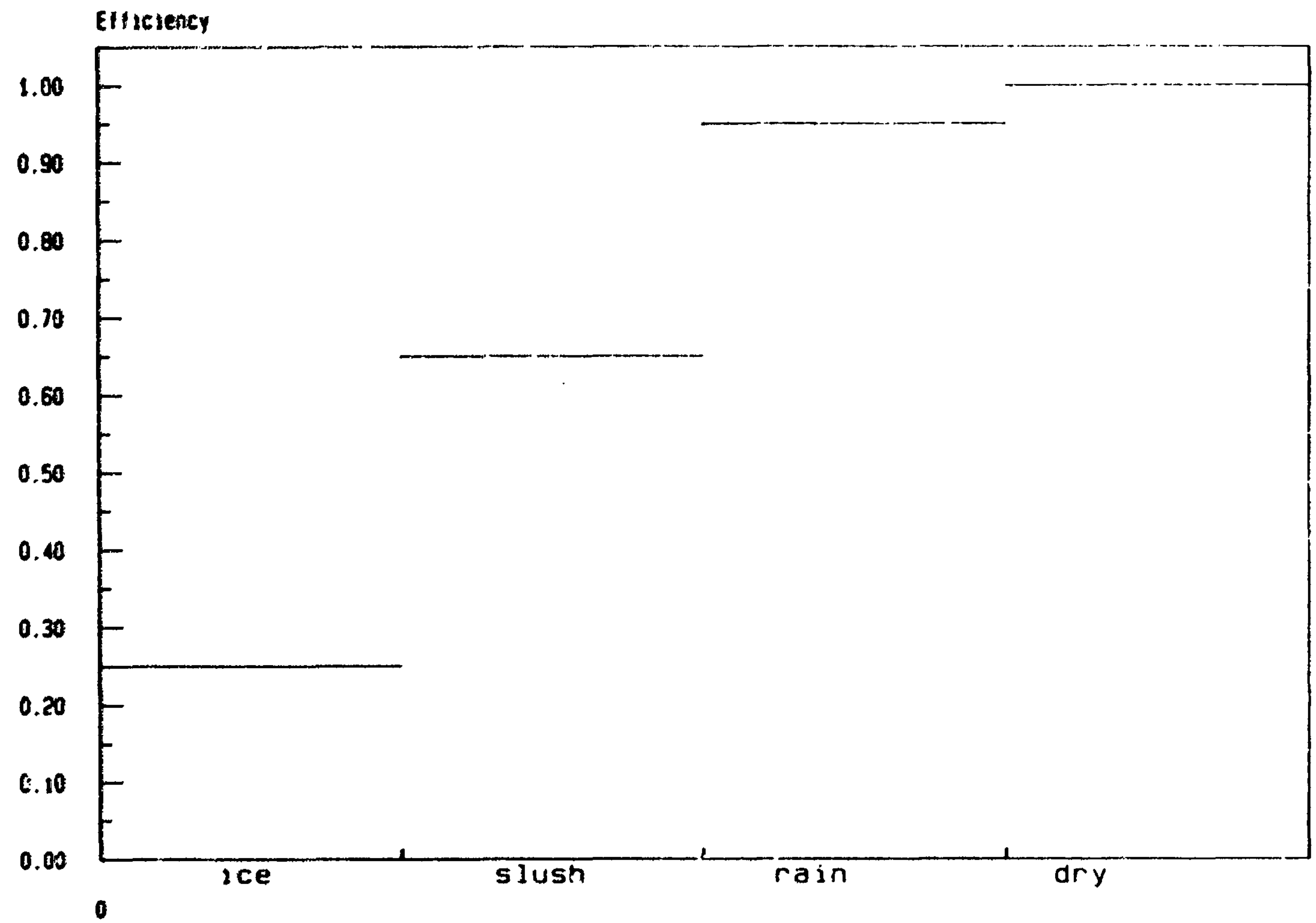



Figure E-4. Human Efficiency (Effects of Slipperiness).

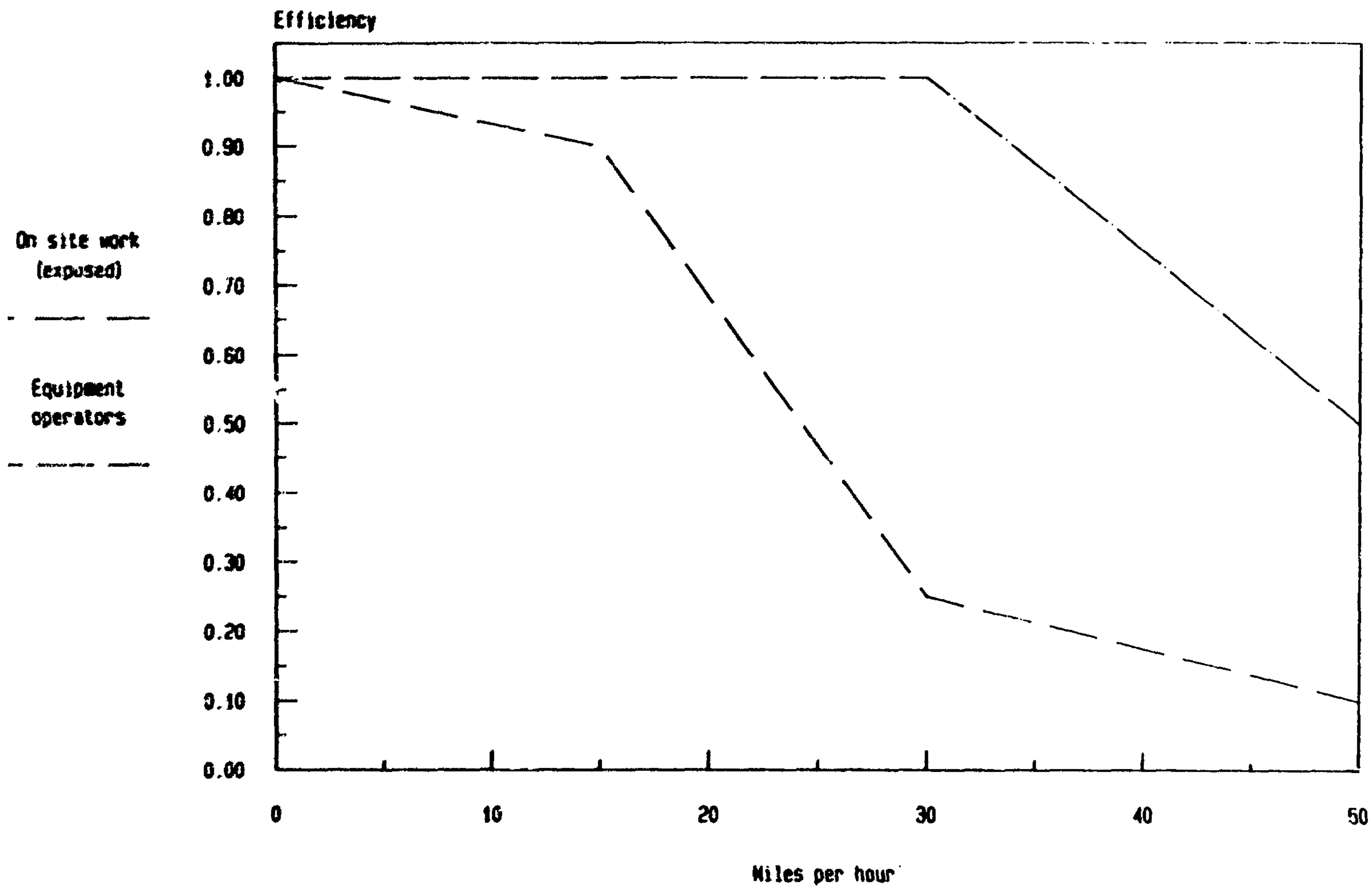



Figure E-5. Human Efficiency (Effects of Wind).

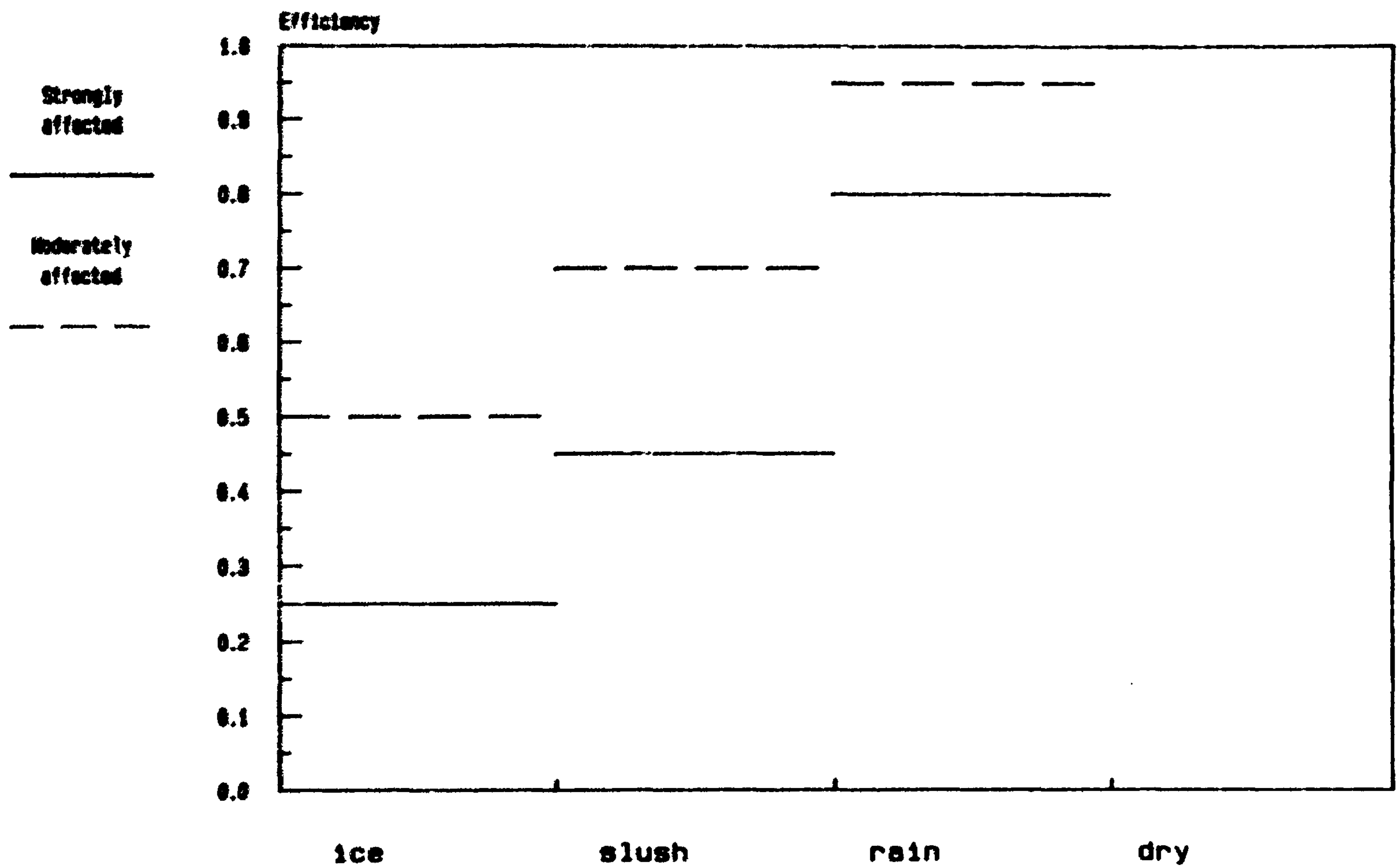



Figure E-6. Equipment Efficiency (Effects of Slipperiness).

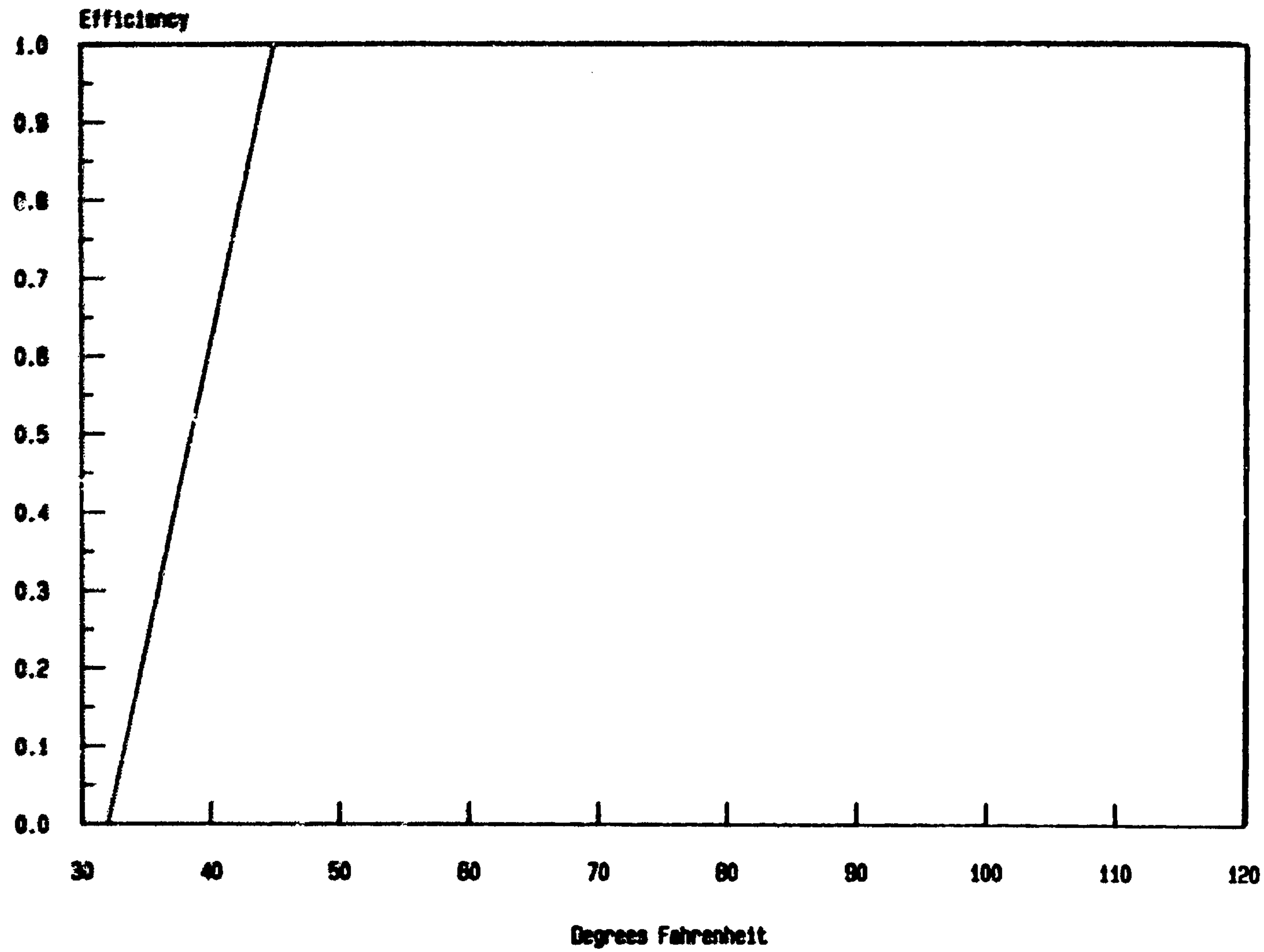



Figure E-7. Paint Efficiency (Effects of Temperature).

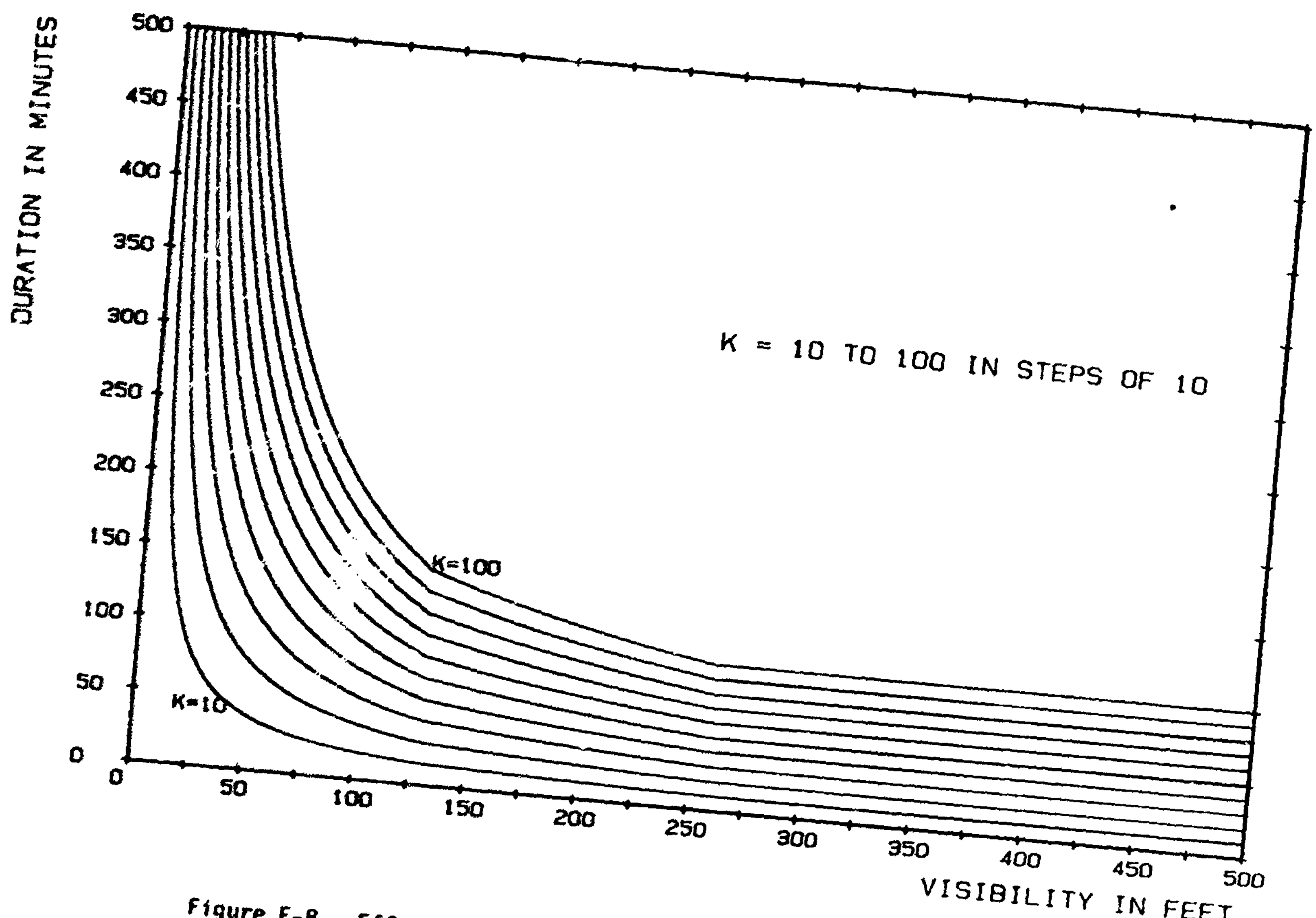



Figure E-8. Effects of Visibility on Duration of EOD and DA.

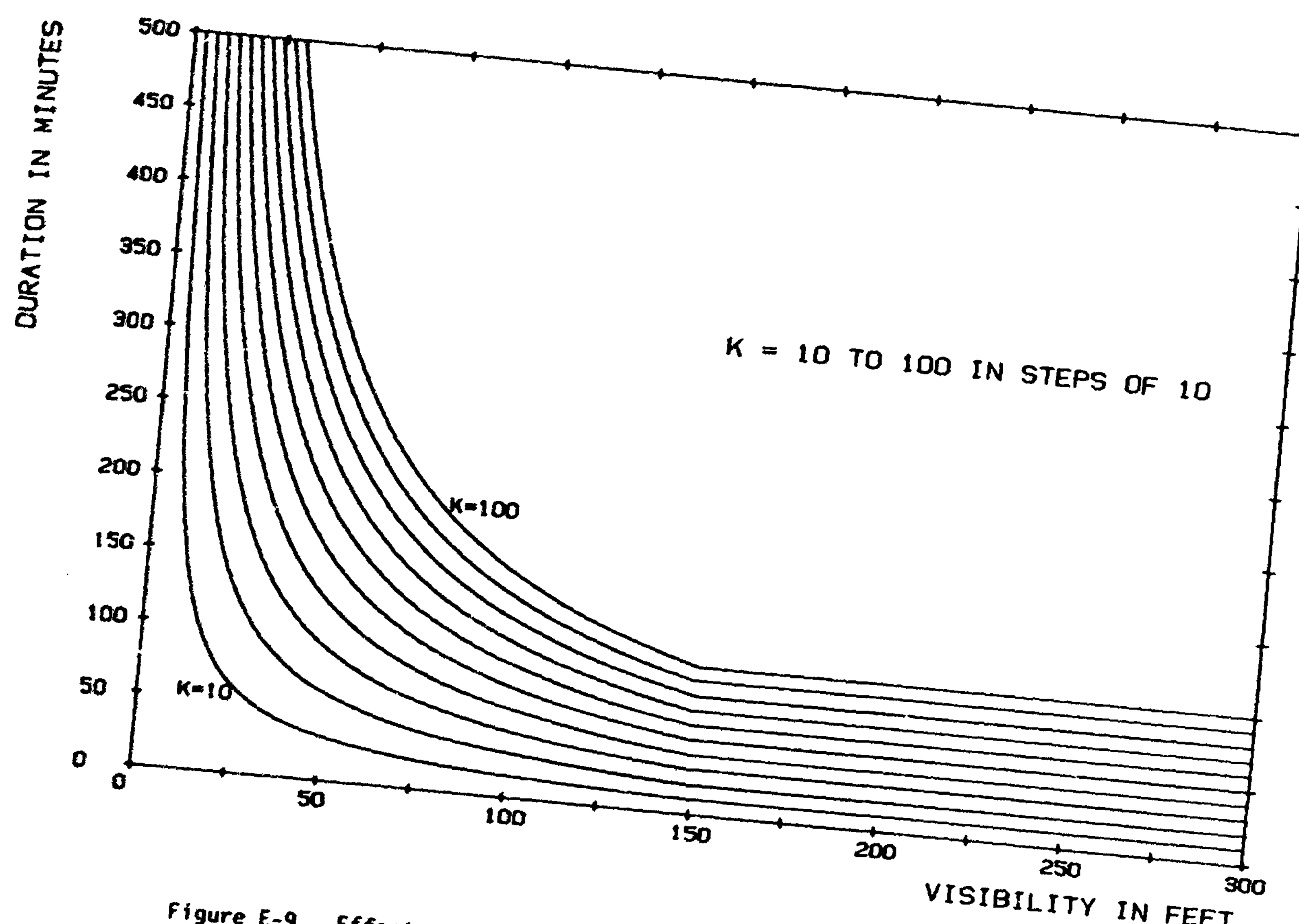



Figure E-9. Effects of Visibility on Duration of Travel Activities.

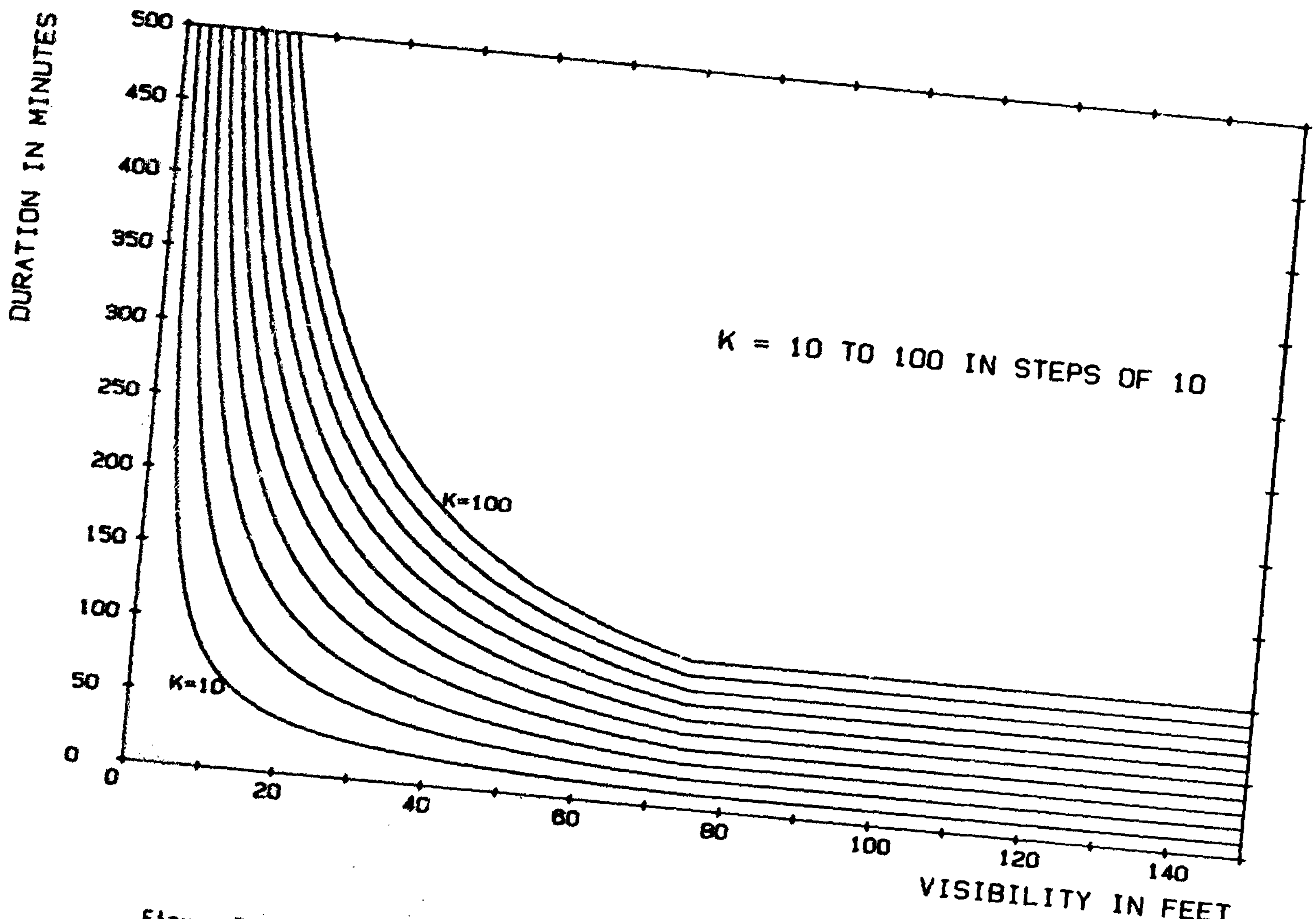



Figure E-10. Effects of Visiblity on Duration of Onsite Activities.

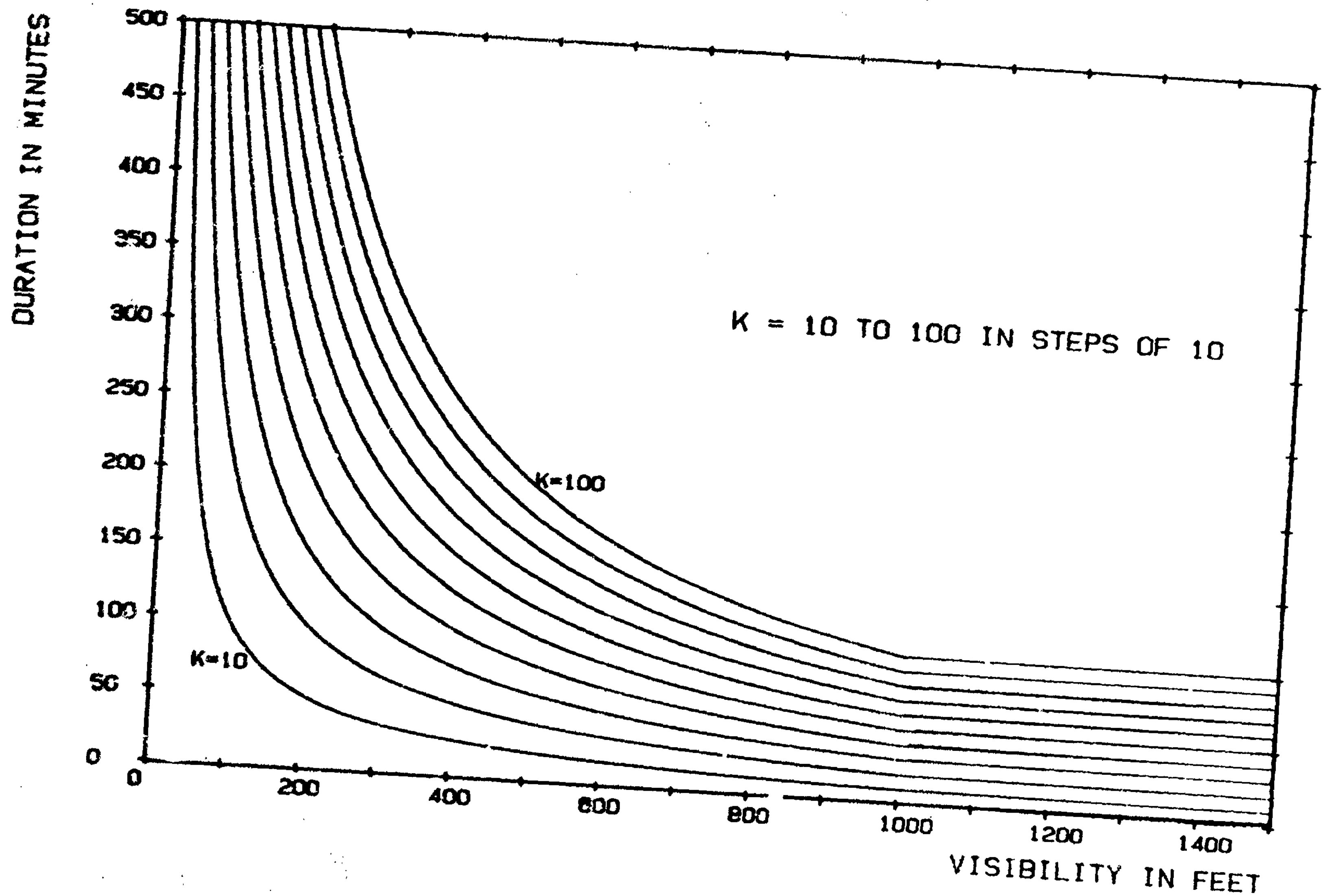



Figure E-11. Effects of Visibility on Duration of Surveying Tasks.

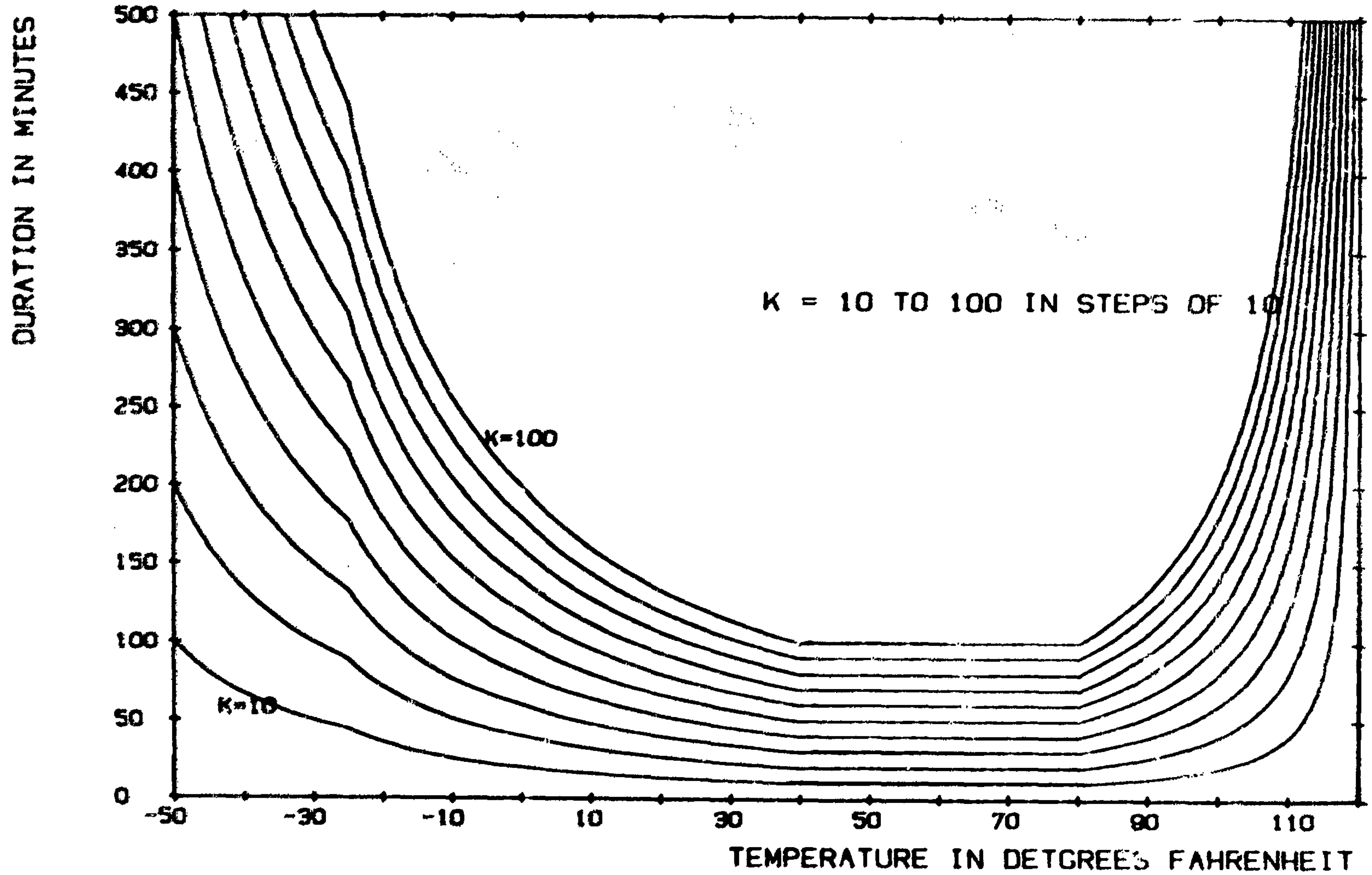



Figure E-12. Effects of Temperature on Strenuous Labor.

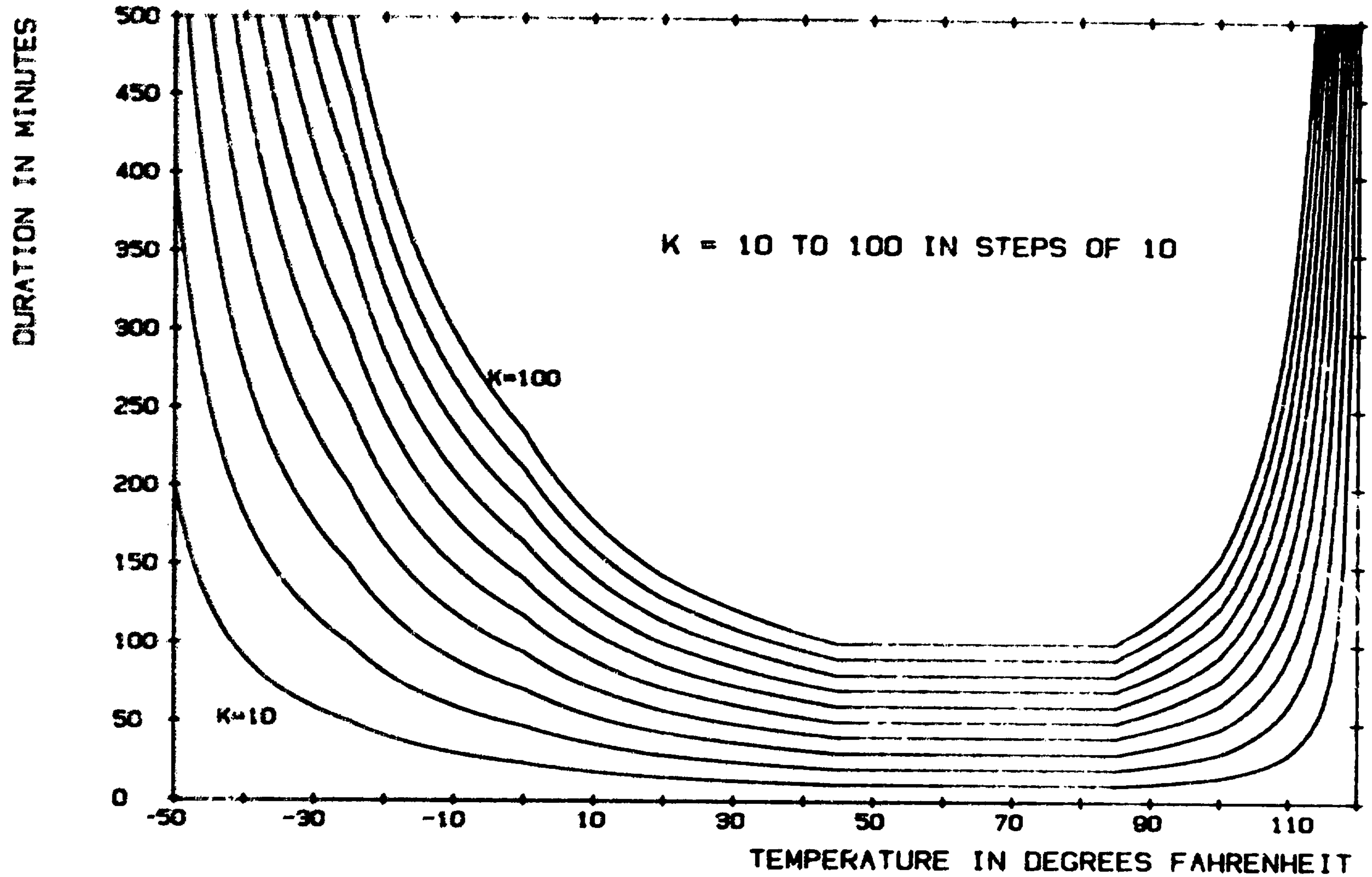



Figure E-13. Effects of Temperature on Medium Labor.

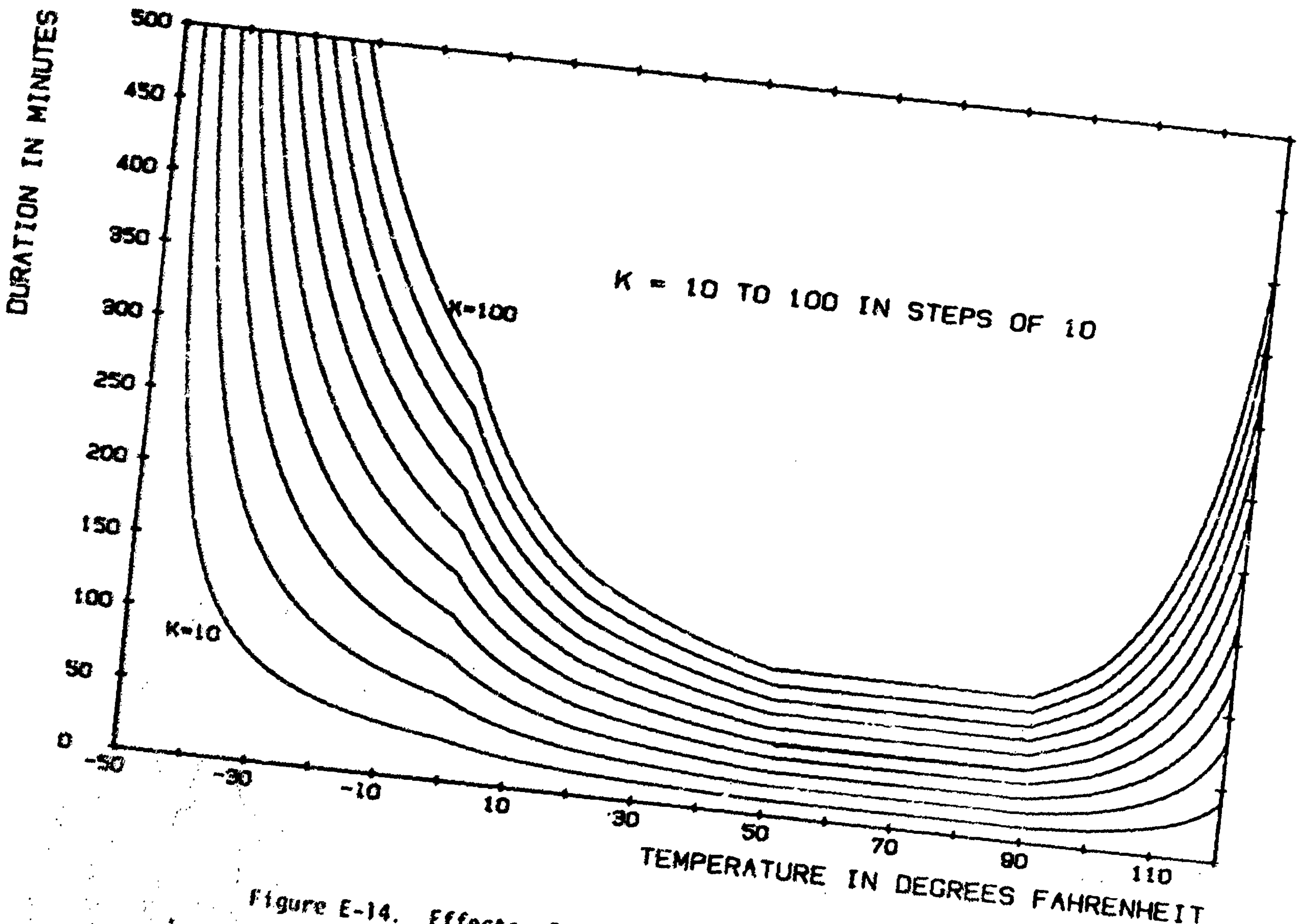



Figure E-14. Effects of Temperature on Light Labor.

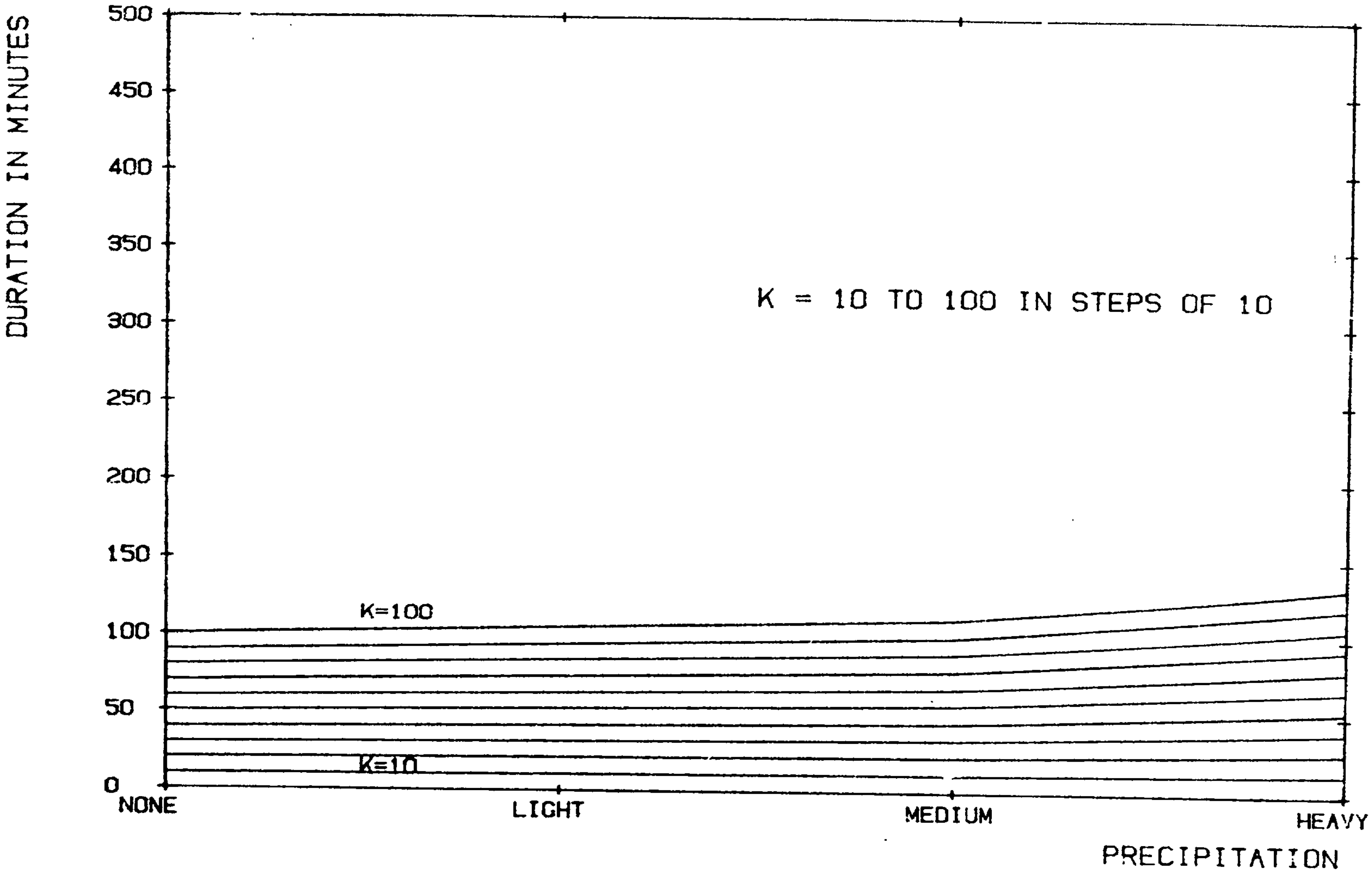



Figure E-15. Effects of Precipitation on Men.

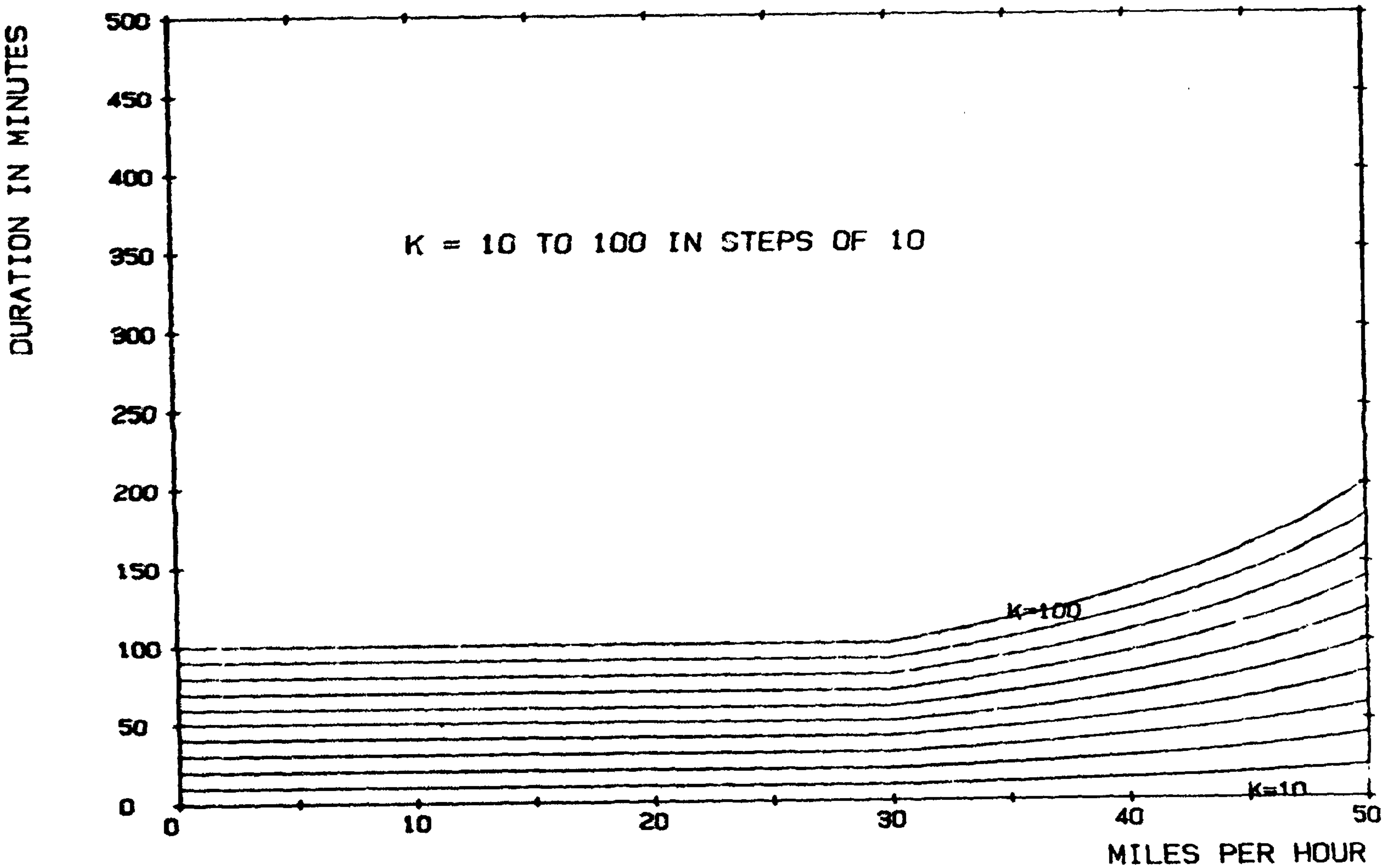



Figure E-16. Effects of Wind on Equipment Operators.

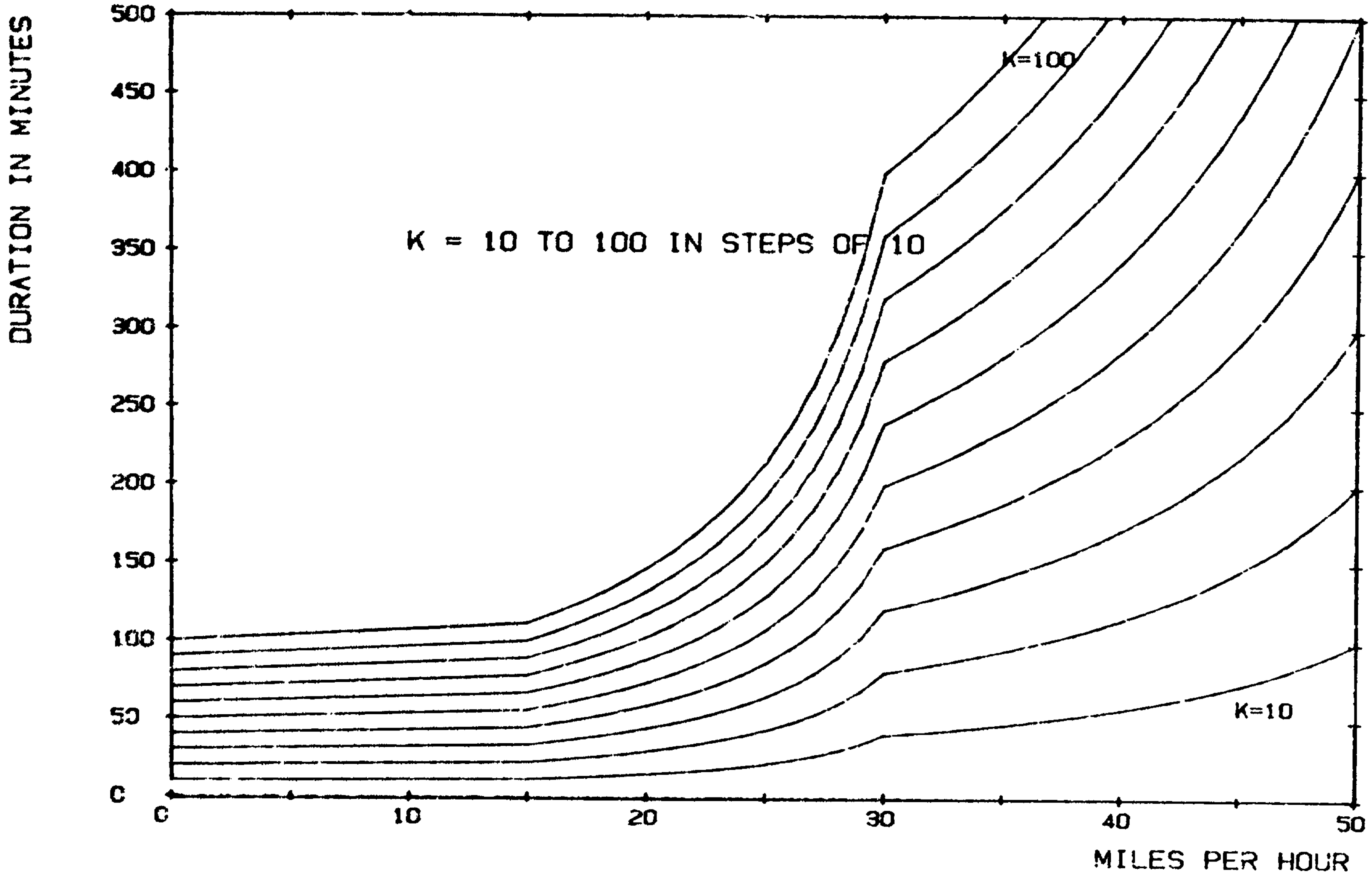



Figure E-17. Effects of Wind on Onsite Activities.

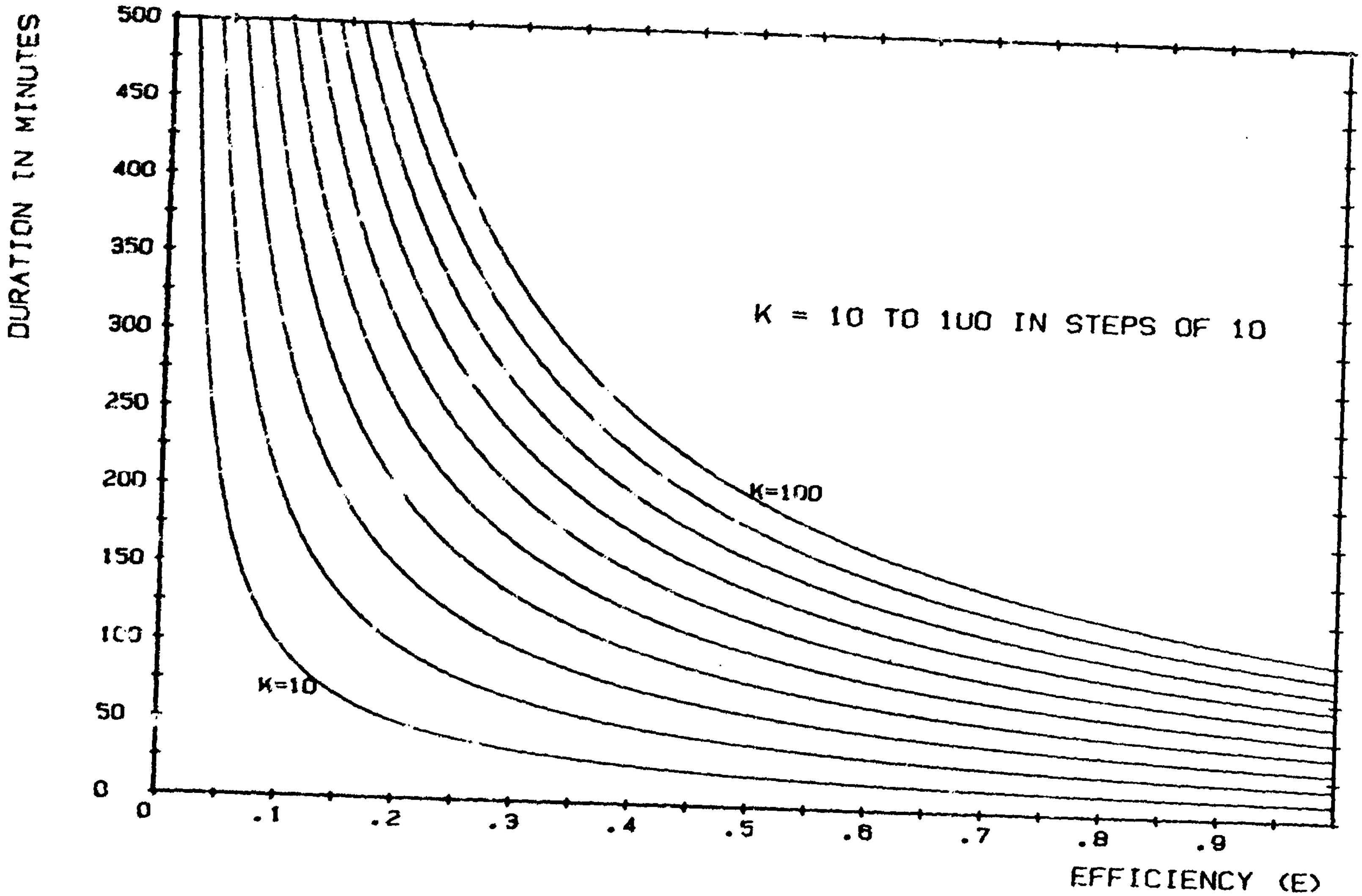



Figure E-18. Duration Formulas of the Form K/E.

## LIST OF REFERENCES

1. The BDM Corporation, Post Attack Requirements Study, BDM/W-81-126-TR, 30 October 1981.

2. Knox, Kenneth J., Small Crater Expedient Repair Test, ESL-TR-80-42, August 1980.

3. Lee, Stephen Mead, "An Approach to Modeling Weather Data by Means of Markov and Semi-Markov Chains," Ph.D. Thesis, Arizona State University, September 1973.

4. Barrington, L. P., "Human Factors in Planning for Climate Control," Climatic Criteria for Building Construction, edited by Paul Siple, 1965.

5. Waters, John W. (University of Illinois, Department of Geography), "Climatic Criteria Defining Efficiency Limits for Certain Industrial Activities," undated (approximately late 1950s).

6. Headquarters Department of the Army, Technical Bulletin 255-3, Construction of Runways, Roads, and Buildings on Permanently Frozen Ground, August 1950.

7. Mather, John R., "Climatology: Fundamental and Applications," McGraw-Hill, New York, 1974.

8. Headquarters, Department of the Army, FM 5-35, Engineers' Reference and Logistical Data, April 1971.

9. The BDM Corporation, Computer Model for Bomb Damage Repair Times, BDM/W-81-737-TR, 16 February 1982.

10. Brookhaven National Laboratories, Upton, New York, "Compatible Polymer Concrete Materials for Use in Rapid Runway Repair Systems for Airport Runways," Monthly Report 1-7, March-October 1980.

11. Sargent, Frederick II, and Tromp, Solco W., editors (World Meteorological Organization), "A Survey of Human Biometeorology," Geneva, Switzerland, 1964.

12. National Academy of Science, Building Research Advisory Board, "Weather and the Building Industry: A Research Correlation Conference on Climatological Research and Its Impact on Building Design, Construction, Materials, and Equipment," Research Conference Report No. 1, January 11-12, 1950, Washington, D.C., April 1950.

13. Life Support Systems, Inc., "Cool Head," Sales Brochure, Mountain View, California, undated.

14. Lowry, William P., Weather and Life: An Introduction to Biometeorology, Academic Press, New York, 1969.

15. Goldman, R. F., and Staff (U.S. Army Reserach Institute of Environmental Medicine), "CW Protective Clothing; the Nature of Its Performance Degradation and Some Partial Solutions," a paper presented to the Thirteenth Commonwealth Defence Conference on Operational Clothing and Combat Equipment, Malaysia, 1981.

16. Headquarters, Department of the Army, TM 5-2410-209-12, Organizational Maintenance Manual: Tractor, Full-Tracked, Low Speed (Allis-Chalmers Model HD16M), September 1965.

17. Headquarters, Department of the Army and the Air Force, Technical Order (TO) 36A12-1C-421-1, Truck, Dump: M51A2, September 1980.

18. Headquarters, Department of the Army, TM 9-2320-273-10, Operator's Manual, Truck Tractor, Light Equipment Transporter Through Truck Chassis for Concrete-Mobile® Mixer Truck, May 1980.

19. Headquarters, Department of the Army, TM 5-3895-372-10, Operation Instructions: Concrete-Mobile Mixer® Body M919, Model 8CM-24/F, undated.

20. Wanielista, Martin P., Stormwater Management: Quantity and Quality, Ann-Arbor Science Publishers, 1978.

21. McNerney, Michael, Interim Report of Field Test of Expedient Pavement Repairs; Items 16-35, AFESC, Tyndall AFB, FL.

22. Wu, G. Y., Permeability and Strength Charcteristics of Graded Crushed Stone for Use in RRR, ESL-TR-80-54, CEL, Port Hueneme, California, September 1980.

23. Breckenridge, J. R., and Goldman, R. F., "Effects of Clothing on Bodily Resistance Against Meteorological Stimuli," Progress in Biometeorology: Volume I, Pathological Biometeorology, Amsterdam, 1977.

24. Rollins, R. S., Laboratory Evaluation of Expedient Pavement Repair Materials, CEEDO-TR-78-44, June 1978.

25. The BDM Corporation, Bomb Damage Repair to Airfield Pavements - Small Crater and Spall/Scab Repair, BDM/W-80-719-TR, 9 March 1981.

26. Caterpillar Tractor Company, Caterpillar Performance Handbook, Edition 11, Peoria, Illinois, October 1980.

# BIBLIOGRAPHY


1. Barrington, L.P., "Human Factors in Planning for Climate Control," Climatic Criteria for Building Construction, edited by Paul Siple, 1965.

2. Bilello, M.A. and Appel, G.C., Analysis of the Midwinter Temperature Regime and Snow Occurrence in Germany, CRREL Report 78-21, Cold Regions Research and Engineering Laboratory, U.S. Army Corps of Engineers, Hanover, New Hampshire, September 1978.

3. Bowler, Joseph E., Physical and Geotechnical Properties of Soils, McGraw-Hill Book Company, New York, 1979.

4. Breckenridge, J.R., and Goldman, R.F., Effects of Clothing on Bodily Resistance Against Meteorological Stimuli, Progress in Biometeorology: Volume 1, Pathological Biometeorology, Amsterdam, 1977.

5. Brookhaven National Laboratories, Upton, New York, Compatible Polymer Concrete Materials for Use in Rapid Runway Repair Systems for Airport Runways, Monthly Report 1-7, March-October 1980.

6. Caterpillar Tractor Company, Caterpillar Performance Handbook, Edition 11, Peoria, Illinois, October 1980.

7. Caterpillar Tractor Company, Caterpillar Product Line, and other Sales Brochures, Peoria, Illinois, undated.

8. Deere and Company, Factors in Earthmoving, undated.

9. Deere and Company, John Deere Construction Equipment Sales Brochures, Moline, Illinois, undated.

10. Fiat-Allis Sales Brochures.

11. Friedman, E.A., "Problems Encountered in Winter Stripping of Open Pit Mines in Northern Minnesota," Minnesota Engineer, April 1953.

12. Gaylord, E.H., Jr., and Gaylord, C.N., Structural Engineering Handbook, McGraw-Hill Book Company.

13. Global Atmospheric Research Program (GARP), Report of the JOC Study Conference on Climate Models: Performance, Intercomparison and Sensitivity Studies, Washington, D.C., December 1979.

14. Goldman, R.F., and Staff (U.S. Army Research Institute of Environmental Medicine), "CW Protective Clothing; The Nature of Its Performance Degradation and Some Partial Solutions," a paper presented to the Thirteenth Commonwealth Defence Conference on Operational Clothing and Combat Equipment, Malaysia, 1981.

15. Goldman, R.F., "Clothing Design for Comfort and Work Performance in Extreme Thermal Environments," Transactions of the New York Academy of Sciences, Series II, Volume 36, No. 6, pp. 531-544, June 1974.

16. Headquarters, Department of the Air Force, Air Force Regulation (AFR) 93-2, Special Civil Engineering: Base Recovery Planning, 1 December 1980.

17. Headquarters, Department of the Army and the Air Force, Air Force Manual No. 88-5, Chapter 1, Surface Drainage Facilities for Airfields and Heliports, Washington, D.C., 1 April 1977.

18. Headquarters, Department of the Army and the Air Force, Technical Order (TO) 36A12-1C-421-1, Truck, Dump: M51A2, September 1980.

19. Headquarters, Department of the Army Field Manual 31-70, Basic Cold Weather Manual," April 1968.

20. Headquarters, Department of the Army, Army Facilities Components Systems User's Guide, October 1979.

21. Headquarters, Department of the Army, Technical Bulletin 255-3, Construction of Runways, Roads, and Buildings on Permanently Frozen Ground, August 1950.

22. Headquarters, Department of the Army, FM 5-35, Engineers' Reference and Logistical Data, April 1971.

23. Headquarters, Department of the Army, Technical Manual (TM) 5-3805-246-12, Grader, Road, Motorized, Diesel Engine Driven, 12 Foot Blade (Caterpillar Model 112F), April 1968.

24. Headquarters, Department of the Army, Technical Manual (TM) 5-3805-249-12, Grader, Road, Motorized, 12 Foot Blade, Caterpillar Model 120, 1971.

25. Headquarters, Department of the Army, TM 5-3895-372-10, Operation Instructions: Concrete-Mobile• Mixer Body M919, Model 8CM-24/F, undated.

26. Headquarters, Department of the Army, TM 9-2320-266-10, Operator's Manual, Truck, Cargo, 1-1/4 Ton, 4x4 and 4x2, M880 through M893, January 1976 (w/Change 7, 12 October 1982).

27. Headquarters, Department of the Army, TM 5-3895-340-12, Operator and Organizational Maintenance Manual: Roller, Motorized, 5-8 Ton, Tandem, 2-Axle, GED (General Steel Tank Model 1504), December 1970.

28. Headquarters Department of the Army, TM 9-2320-273-10, Operator's Manual, Truck Tractor, Light Equipment Transporter through Truck Chassis for Concrete-Mobile• Mixer Truck, May 1980.

29. Headquarters, Department of the Army, TM 5-2410-209-12, Organizational Maintenance Manual: Tractor, Full-Tracked, Low Speed (Allis-Chalmers Model HD16M), September 1965.

30. Headquarters, Department of the Army, Army Regulation (AR) 70-38, Research, Development, Test, and Evaluation of Material for Extreme Climatic Conditions, 1 July 1969.

31. Headquarters, Department of the Army, TM 5-331A, Utilization of Engineer Construction Equipment, Volume A - Earthmoving, Compaction, Grading, and Ditching Equipment, August 1967.

32. Herrington, L.P., "Biophysical Adaptation of Man Under Climatic Stress," Meteorological Monograph 8, 30, American Meteorological Society, Boston, Massachusetts, 1954.

33. Hewson, E.W., and Longley, R.W., Meteorology Theoretical and Applied, John Wiley and Sons, Inc., New York, 1944.

34. Hill, Charles S., Winter Construction Methods, McGraw-Hill, New York 1928.

35. Howell, Gregory, "Construction Productivity Improvement: How to Get Started," Civil Engineer - ASCE, August 1981.

36. Hughes, Patrick, "Weather Climate and Economics," Sea Technology, June 1982.

37. Iampietro, P.F., and Goldman, R.F., "Tolerance of Men Working in Hot, Humid Environments," Journal Of Applied Physiology, Volume 20, No. 1, January 1965.

38. International Harvester Sales Brochures, Truck Division Product Publications, Fort Wayne, Indiana, undated.

39. J.I. Case Construction Equipment Division, Sales Brochures, Racine, Wisconsin, undated.

40. John C. Louis Company, Inc., Sales Service, Rentals of Construction Equipment, Von Hoffman Press, St. Louis, Missouri, 1979.

41. John Deere, Inc., Sample Specifications and Competitive Spec Comparisions, undated.

42. Joy, LTC R.J.T., and Goldman, R.F., "A Method of Relating Physiology and Military Performance: A Study of Some Effects of Vapor Barrier Clothing in a Hot Climate," reprinted from Military Medicine, Volume 133, No. 6, June 1968.

43. Jen-Hu-Chang, Ground Temperature, Volumes I and II, Blue Hill Meteorological Observatory, Harvard University, Milton 86, MA, 21 June 1958.

44. Kinsler, R.E., et al (U.S. Army Ballistic Research Laboratory, Aberdeen Proving Grounds, Maryland), Vulnerability/Vulnerability Reduction Analysis of Selected U.S. Air Force Rapid Runway Repair War Reserve Material, December 1981.

45. Kirkland, J. A., "Thermal Limits for Rapid Runway Repair in Protective Clothing: Assessment of Alternative Solutions," Test Plan, Air Force Engineering and Services Center, Tyndall AFB, FL, July 1982.

46. Knox, Kenneth J., Small Crater Expedient Repair Test, ESL-TR-80-42, August 1980.

47. Lee, S.M., "An Approach to Modeling Weather Data By Means of Markov and Semi-Markov Chains," Ph.D. Thesis, Arizona State University, September 1973.

48. Liebherr Sales Brochures, undated.

49. Life Support Systems, Inc., Cool Head, Sales Brochure, Mountain View, California, undated.

50. Lowry, William P., Weather And Life: An Introduction To Biometeorology, Academic Press, New York, 1969.

51. Mather, John R., Climatology: Fundamental and Applications, McGraw-Hill, New York, 1974.

52. McNerney, Michael, "Interim Report of Field Test of Expedient Pavement Repairs; (Test Items 16-35)," Draft Report, AFESC, Tyndall Air Force Base, FL, August 1980.

53. National Academy of Science, Building Research Advisory Board, "Weather and the Building Industry: A Research Correlation Conference on Climatological Research and its Impact on Building Design, Construction, Materials, and Equipment," Research Conference Report No. 1, January 11-12, 1950, Washington, D.C., April 1950.

54. Onkaram, B., L.A. Stroschein, and R.F. Goldman, (U.S. Army Research Institute of Environmental Medicien), "Three Instruments for Assessment of WBGT and a Comparison with WGT (Botsball)," in the American Industrial Hygiene Association Journal, pp. 634-641, September 1980.

55. Petterson, S., Weather Analysis and Forecasting, 2nd Ed., McGraw-Hill Book Co., Inc., New York, 1940.

56. Rollins, R.S., Laboratory Evaluation of Expedient Pavement Repair Materials, CEEDO-TR-78-44, June 1978.

57. Ross, C.A. (Ross Engineering Associates, Inc.), FOD Cover Analysis for Rapid Runway Repair, ESL-TR-80-59, 30 October 1980.

58. Sargent, Fredrick II, and Tromp, Solco W., editors, (World Meteorological Organization), A Survey of Human Biometeorology, Geneva, Switzerland, 1964.

59. Saucier, K.L., (U.S. Army Corps of Engineers Waterways Experiment Station), High-Strength Cements: Past, Present, Future, May 1979.

60. Shibanov, N., Functional Special Colothing for Builders, (translation from Russian by USA Foreign Science and Technology Center), January 1972.

61. The Travelers Research Center, Inc., The Operational and Economic Impact of Weather on the Construction Industry of the United States, Report No. 7665-163, March 1965.

62. The BDM Corporation, Bomb Damage Repair to Airfield Pavements - Small Crater and Spall/Scab Repair, BDM/W-80-719-TR, 9 March 1981.

63. The BDM Corporation, Computer Model for Bomb Damage Repair Times, BDM/W-81-737-TR, 16 February 1982.

64. The BDM Corporation, Technical Review of Structural Cap Placement Equipment, undated letter.

65. The BDM Corporation, Post Attack Requirements Study, BDM/W-81-126-TR, 30 October 1981.

66. Tighe, D.J., et. al., (Hovey-Sores, Inc.), "An Analysis of Airport Snow Removal and Ice Control," Ottawa, Canada, March 1971.

67. United Nations Educational, Scientific, and Cultural Organization, Climatology: Reviews of Research, Paris, France, 1958.

68. U.S. Army Research Institute of Environmental Medicine, Natick, Massachusetts, Use of a Wetted Cover to Reduce Heat Stress in Impermeable Clothing, October 1980.

69. U.S. Army, Chief of Engineers, Field Reference Document, Airfield Damage Recovery Techniques of 18th Engineer Brigade in Europe, December 1980.

70. U.S. Department of Labor, Bureau of Labor Statistics, Washington, D.C., Seasonality and Manpower in Construction, 1968.

71. U.S. Naval Civil Engineering Laboratories, Polar Weather Limitations on Construction - Preliminary Arctic Survey, June 1965.

72. USAF Air R&D Command, Handbook of Geophysics, 1961.

73. USAF Air Weather Service, An Aid for Using the Revised Uniform Summary of Surface Weather Observations, Scott AFB, Illinois, November 1966.

74. Valvoda, F.R., "Environmental Effects on Journeymen Productivity," Actual Specifying Engineer, pp. 90-100, October 1974.

75. Wanielista, Martin P., Stormwater Management: Quantity and Quality, Ann-Arbor Science Publishers, 1978.

76. Waters, John W. (University of Illinois, Department of Geography), Climatic Criteria Defining Efficiency Limits for Certain Industrial Activities, undated (approximately late 1950s).

77. Wu, G.Y., Permeability and Strength Characteristics of Graded Crushed Stone for Use in RRR, ESL-TR-80-54, CEL, Port Hueneme, California, September 1980.



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