



**Technical Report 186**  
**APPLICATION OF METHOD**  
**FOR PREDICTING THERMAL ERROR**  
**IN MEASUREMENT**  
**OF GROUND TEMPERATURE**

by  
**Warren M. Rohsenow**

**MAY 1967**

Conducted for  
**CORPS OF ENGINEERS, U.S. ARMY**  
by

**U.S. ARMY MATERIEL COMMAND**  
**COLD REGIONS RESEARCH & ENGINEERING LABORATORY**  
**HANOVER, NEW HAMPSHIRE**

**Contract DA-19-016-ENG-3204**

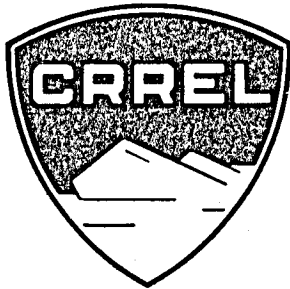


~~RESTRICTED - Special Agent~~  
~~CONFIDENTIAL - Special Agent~~  
~~CONFIDENTIAL - Special Agent~~

*Distribution limitation now removed*

Error - USA CRREL Technical Report 186

p. 5, Fig. 8: In note on this figure change 0.25" to 0.025."



**Technical Report 186**

**APPLICATION OF METHOD  
FOR PREDICTING THERMAL ERROR  
IN MEASUREMENT  
OF GROUND TEMPERATURE**

by  
**Warren M. Rohsenow**

**MAY 1967**

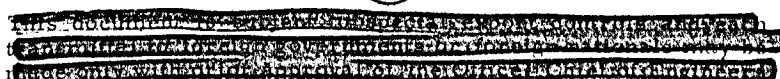
Conducted for  
**CORPS OF ENGINEERS, U.S. ARMY**

by  
**U.S. ARMY MATERIEL COMMAND  
COLD REGIONS RESEARCH & ENGINEERING LABORATORY  
HANOVER, NEW HAMPSHIRE**

**Contract DA-19-016-ENG-3204  
DA Task IV025001A13001**



*Distribution limitation now  
removed*



## PREFACE

Authority for the investigation reported herein is contained in FY 1955 Instructions and Outline, Military Construction Investigations, Engineering Criteria and Investigations and Studies, Studies of Construction in Areas of Seasonal Frost; Correlation Studies.

The study was conducted for the Engineering Division, Directorate of Military Construction, Office, Chief of Engineers. The program was administered by the Civil Engineering Branch (Mr. T.B. Pringle, Chief). Dr. W.M. Rohsenow and Dr. J.A. Clark, Department of Mechanical Engineering, Massachusetts Institute of Technology, performed this study under Contract DA-19-016-Eng-3204 awarded by the former Arctic Construction and Frost Effects Laboratory (ACFEL)\* of the U. S. Army Engineer Division, New England. This report, authored by Dr. Rohsenow, presents one phase of the contractual study. Other contractual phases are reported in: Technical Report 187 (May 1967), "Transient Temperature Distribution Within Thermal Sensing Elements," J.A. Clark; Technical Report 188 (May 1967), "The Properties of Thermistors," J.A. Clark and Y. Kobayashi; and Internal Report 5 (Sept 1966), "The Effect of Temperature Level on Various Thermocouple Circuit Components," J.A. Clark.

Investigations were performed under the general supervision of Mr. K.A. Linell, Chief, Experimental Engineering Division, USA CRREL (Formerly Chief, ACFEL) and the direct supervision of Mr. E.F. Lobacz, Chief, Construction Engineering Branch, USA CRREL (Formerly Coordinator, ACFEL). Mr. W.C. Sayman was the ACFEL project leader and Mr. G.D. Gilman of the Construction Engineering Branch was responsible for the coordination of the final report.

Lt. Colonel John E. Wagner was Commanding Officer/Director of the U. S. Army Cold Regions Research and Engineering Laboratory during the publication of this report, and Mr. W.K. Boyd was Chief Engineer.

USA CRREL is an Army Materiel Command laboratory.

---

\*ACFEL was merged with the former Snow, Ice, and Permafrost Research Establishment (SIPRE) in 1961 to form the Cold Regions Research and Engineering Laboratory (USA CRREL), Hanover, New Hampshire.

## CONTENTS

	iii
	Page
Preface-----	ii
Summary-----	iv
Introduction-----	1
Thermal errors in ground temperature measurement-----	1
Errors in temperature measurement by probe inserted in a pit wall-----	2
Conditions assumed-----	2
Transient ground temperature due to cooling at pit wall-----	2
Sensing element transient after insertion in ground-----	3
Time interval for valid readings-----	5
Closure-----	5

## ILLUSTRATIONS

### Figure

1. Temperature distribution in side of pit as a function of time after excavation-----	1
2. Temperature distribution in instrument and ground as a func- tion of time after insertion-----	2
3. Probe tip details-----	2
4. Transient temperature distribution vs depth; pit wall in ice -	3
5. Transient temperature distribution vs depth; pit wall in soil-	4
6. Transient temperature distribution vs depth; pit wall in heavy snow-----	4
7. Transient temperature distribution vs depth; pit wall in light snow-----	4
8. Error in reading vs elapsed time after probe insertion-----	5

## TABLES

### Table

I. Properties of ground materials-----	3
II. Time interval for valid readings-----	5

## SUMMARY

This report illustrates the use of generalized charts in estimating the thermal error in measurement of ground temperature in the case of a probe inserted in a pit wall. The word "ground" includes snow and ice as well as soil materials. Two major sources of error, other than instrument error, are inherent in this type of measurement. If the air temperature differs from the ground temperature, heat will be exchanged between the air and side walls of the excavation as soon as the pit is opened. The ground temperature must be read before appreciable heat transfer occurs. A second error is introduced upon insertion of the temperature sensing element if the element temperature differs from the ground temperature.

# APPLICATION OF METHOD FOR PREDICTING THERMAL ERROR IN MEASUREMENT OF GROUND TEMPERATURE

by

Warren M. Rohsenow

## INTRODUCTION

Generalized charts for estimating errors in temperature measurement in a variety of situations were developed under a previous contract.\* This report illustrates the use of these charts in estimating the thermal error in measurement of ground temperature in the case of a probe inserted in a pit wall. In this report the word "ground" includes snow and ice as well as soil materials.

## THERMAL ERRORS IN GROUND TEMPERATURE MEASUREMENT

One method of measuring ground temperature consists of excavating a pit or trench and inserting temperature measuring devices, such as thermometers or thermocouples, into the faces at various depths. In order to estimate the true undisturbed temperature, it is necessary to know how the reading of the temperature sensing element, subsequent to insertion, compares with the actual undisturbed temperature.

Two major sources of error, other than instrument error, are inherent in this type of measurement. If the air temperature differs from the ground temperature, heat will be exchanged between the air and side walls of the excavation as soon as the pit is opened. Figure 1 schematically represents the temperature distribution as a function of time after the excavation of a pit if the temperature of the air is lower than that of the ground. Thus a temperature sensing instrument inserted to

a finite depth  $X$  must be read before the ground temperature at that point has changed appreciably due to heat transfer with the air at the pit wall. Allowable time between excavation and reading increases with insertion depth.

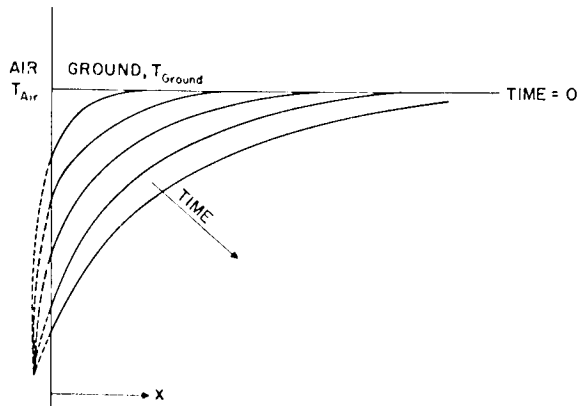


Figure 1. Temperature distribution in side of pit as a function of time after excavation.

ment from  $T_{\text{air}}$  to  $T_{\text{ground}}$  must be diffused to the ground. The instrument and initial ground temperatures will not become equal in finite time, but their difference approaches zero with increasing contact time. As stated above, this reading error is zero if  $T_{\text{air}}$  equals  $T_{\text{ground}}$ , or if the probe could be pre-heated or pre-cooled to  $T_{\text{ground}}$  before insertion.

A second error is introduced upon insertion of the temperature sensing element if the element temperature differs from the ground temperature. Upon insertion, an element at a different temperature (generally the existing air temperature) begins to change temperature by diffusion of heat through the ground. Figure 2 schematically represents the temperature distribution in the instrument and surrounding ground as a function of time after insertion. In order to bring the instrument temperature to the initial ground temperature, heat equal to the internal energy change of the instru-

\* Rohsenow, W.M.; Clark, J.A.; and Van Alstyne, P.C. (1954) An analysis of errors in ground and air temperature measurement, New England Division, Corps of Engineers, Arctic Construction and Frost Effects Laboratory, Technical Report 52.

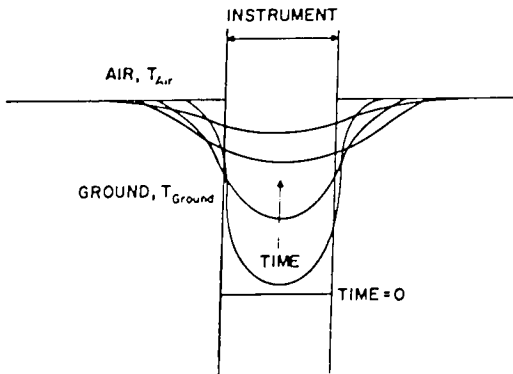


Figure 2. Temperature distribution in instrument and ground as a function of time after insertion.

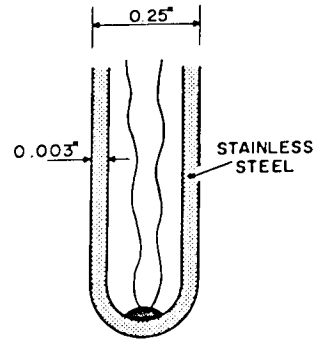


Figure 3. Probe tip details.

#### ERRORS IN TEMPERATURE MEASUREMENT BY PROBE INSERTED IN A PIT WALL

General mathematical and graphical solutions for determining thermal errors for a variety of cases of ground temperature measurement by probe insertion in a pit wall are given in ACFEL TR 52. A detailed solution for one specific case is given in this report. This method may be used to solve many other specific cases.

##### Conditions assumed

Ground materials of soil, ice, light snow and heavy snow, with properties as given in Table I, will be considered. The arbitrarily selected probe is a stainless steel tube (density = 480 lb/cu ft, specific heat = 0.11 Btu/lb°F), outside radius 0.25 in., wall thickness 0.003 in., with a thermocouple inside the tube to measure the tip temperature (Fig. 3). It will be assumed that the trench is excavated rapidly and that the probe tip is immediately inserted to a depth of 6 in. (Significant time lags between excavation and insertion would necessitate shifting the time-scale on the curves discussed below by the length of the time lag.) It will also be arbitrarily assumed that the ground temperature for all materials, including snow and ice, is 50F prior to excavation and that the probe is at an air temperature of -50F before insertion.

##### Transient ground temperature due to cooling at pit wall

The general solution for the transient temperature distribution in the ground near a pit wall\* applies to any ground material and any magnitude of heat transfer,  $h$ , at the pit wall. An approximate relation for determining the magnitude of heat transfer due to natural convection\* gives a coefficient of  $h$  of 0.85 for a temperature change of 100F as in this considered case. Since there will be some radiation through the top of the pit this is raised to  $h = 1$  Btu/sq ft hr. Radiation between side walls is considered negligible, since all are at approximately the same temperature.

\* op. cit.



Table I. Properties of ground materials.

	<u>Soil</u>	<u>Ice</u>	<u>Light snow</u>	<u>Heavy snow</u>
Thermal conductivity, Btu/sq ft hr °F	1.83	1.33	0.0483	0.242
Specific heat, Btu/lb °F	0.195	0.50	0.50	0.50
Density, lb/cu ft	140.0	56.16	6.24	25.0
Thermal diffusivity, sq ft/hr	0.067	0.0475	0.0155	0.0194
Density of snow (% of ice density)			11.0	45.0

Figures 4 - 7 are the results of applying the general solution to the conditions assumed and show transient temperature distribution in the ground at various times after excavation and at various depths in the side walls.

The temperature at any depth must be measured before the temperature at that point is significantly changed by this effect. For example, Figure 4 shows a temperature drop of 1F at a depth of 0.8 ft in 2 hours. Therefore, temperature must be read within that time if the allowable error is 1F.

#### Sensing element transient after insertion in ground

No exact solution for the transient temperature of the tip of a probe inserted in a pit wall is known. The thermocouple measures the tip temperature (Fig. 3). and the transient temperature performance may, therefore, be approximated by that of a spherical shape in an infinite ground. ACFEL TR 52 presents the solution for this performance for a hollow metal probe, and graphical representations of temperature changes vs time for such probes inserted in various ground materials.

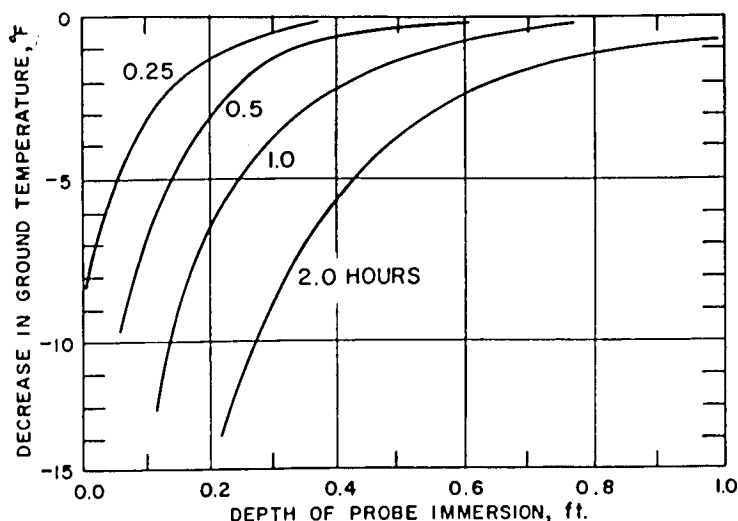


Figure 4. Transient temperature distribution vs depth; pit wall in ice.

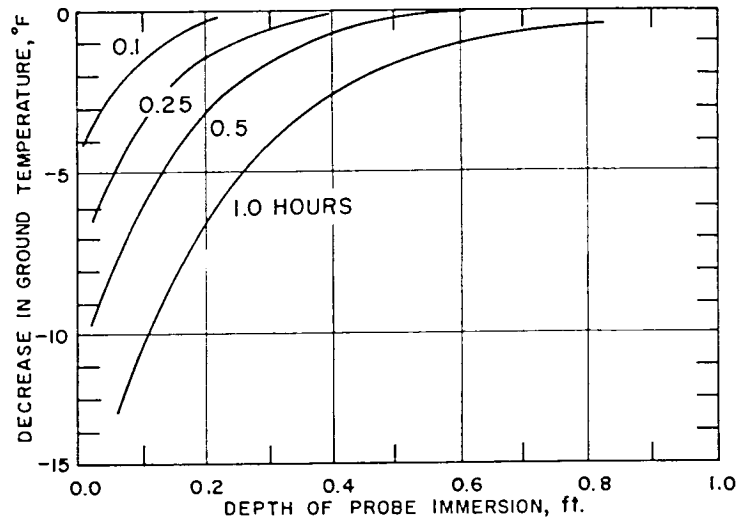


Figure 5. Transient temperature distribution vs depth; pit wall in soil.

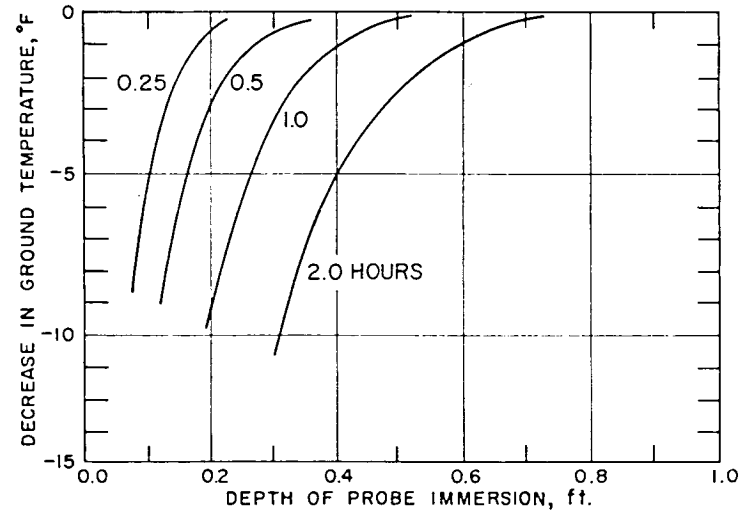


Figure 6. Transient temperature distribution vs depth; pit wall in heavy snow.

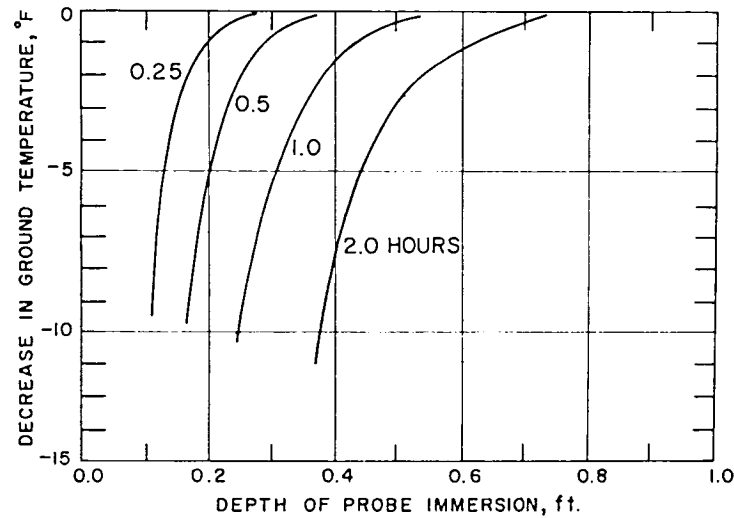


Figure 7. Transient temperature distribution vs depth; pit wall in light snow.

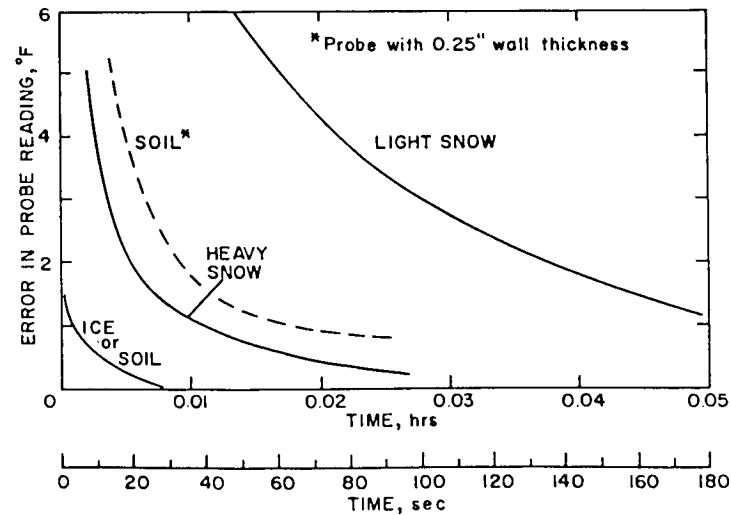


Figure 8. Error in reading vs elapsed time after probe insertion.

Figure 8, which gives minimum elapsed time after probe insertion vs error in reading for the specific probe and conditions being considered, was prepared by application of these conditions to the general solution\*. For example, to keep the error below 1°F, Figure 8 shows that the minimum time lapse should be approximately 0.001 hr (3-4 sec) in ice or soil, 0.01 hr (36 sec) in heavy snow and 0.05 hr (3 min) in light snow. In actual practice these time increments should be multiplied by two or three to account for departure from the idealized spherical shape for which these analytical solutions were obtained.

#### Time interval for valid readings

The measurement of ground temperature by insertion of a thermocouple probe into the side wall of a pit involves waiting until the probe approaches the original ground temperature as prescribed by Figure 8, but the reading must be taken before the temperature at the immersion depth is changed by the heat transfer to the air at the pit wall surface as prescribed by Figures 4 through 7. Table II summarizes the time interval for valid readings for the specific case being considered. The upper limiting time values are taken from Figures 4 through 7 and the lower limit values are three times the magnitudes read from Figure 8.

Table II. Time interval for valid readings.

<u>Ground</u>	<u>Time interval, hr</u>
Ice	0.003 - 1.0
Soil	0.003 - 0.8
Heavy snow	0.03 - 1.4
Light snow	0.15 - 1.3

#### CLOSURE

The upper time limits in Table II are determined by the type of ground material and the air and ground temperatures involved. The lower limits are determined by the material and by the probe dimensions. The probe considered here has a 0.003-in. wall thickness which is structurally adequate for insertion in snow but is

\* op. cit.

## 6 THERMAL ERROR IN MEASUREMENT OF GROUND TEMPERATURES

probably too weak for soil or ice measurements. The effect of probe dimension on lower time limit is illustrated by the dashed curve on Figure 8 which is based on the same conditions as the "Ice or Soil" curve except that the probe wall thickness used was 0.025 in. Thus a probe with greater effective volumetric heat capacity - heavier, thicker or with higher specific heat - will have a slower response to temperature change. It is therefore emphasized that the results in Table II are applicable only to the conditions stated in this report and should not be used for any other conditions or probe geometry.

## DOCUMENT CONTROL DATA - R&amp;D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H.		2a. REPORT SECURITY CLASSIFICATION Unclassified
		2b. GROUP
3. REPORT TITLE APPLICATION OF METHOD FOR PREDICTING THERMAL ERROR IN MEASUREMENT OF GROUND TEMPERATURE		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report		
5. AUTHOR(S) (Last name, first name, initial) Rohsenow, Warren M.		
6. REPORT DATE May 1967	7a. TOTAL NO. OF PAGES 10	7b. NO. OF REFS 1
8a. CONTRACT OR GRANT NO. DA-19-016-ENG-3204	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report 186	
b. PROJECT NO.		
c. DA Task 1VO25001A13001	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.	Distribution limitation now removed	
10. AVAILABILITY/LIMITATION NOTICES <del>This document is subject to special export controls and its release to foreign governments or foreign nationals may be made only with prior approval of the Office, Chief of Engineers. This document is available to U.S. government agencies and their contractors from Defense Documentation Center.</del>		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office, Chief of Engineers Directorate of Military Construction Engineering Division Civil Engineering Branch	
13. ABSTRACT This report illustrates the use of generalized charts in estimating the thermal error in measurement of ground temperature in the case of a probe inserted in a pit wall. The word "ground" includes snow and ice as well as soil materials. Two major sources of error, other than instrument error, are inherent in this type of measurement. If the air temperature differs from the ground temperature heat will be exchanged between the air and side walls of the excavation as soon as the pit is opened. The ground temperature must be read before appreciable heat transfer occurs. A second error is introduced upon insertion of the temperature sensing element if the element temperature differs from the ground temperature.		

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Frozen ground--Temperature--Measurement Snow cover--Temperature--Measurement Ice--Temperature--Measurement Thermometry Probes (Thermal conductivity)						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through \_\_\_\_\_."
- (4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through \_\_\_\_\_."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through \_\_\_\_\_."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS), (S), (C), or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.