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NPG Report No. 1296

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**BORE SURFACE TEMPERATURES IN
THE 3"/70 TYPE E MOD 0 GUN
USING HOT AND COOL POWDERS**



**U. S. NAVAL PROVING GROUND
DAHLGREN, VIRGINIA**

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OCT 7 - 1954

Date: 4 October 1954

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U. S. Naval Proving Ground
Dahlgren, Virginia

Bore Surface Temperatures in
the 3"/70 Type E Mod O Gun
Using Hot and Cool Powders
by

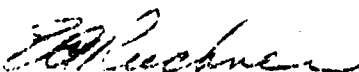
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Armament Department

NPG REPORT NO. 1296

Foundational Research
Project NPG-M-11016-9

4 October 1954

APPROVED: J. F. BYRNE
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Tables:

1. Chemical and Physical Characteristics of Powders Used in Test.
2. Summary of Firing Data.

ABSTRACT

Bore surface temperatures were recorded at the origin of rifling and the base of the cartridge case in the 3"/70 Type E Mod O Gun. Rounds were fired using "hot" and "cool" powders. As a result of this test it is concluded that the bore surface temperatures produced by the "hot" and the "cool" powders are significantly different.

Additional firings were conducted to determine the characteristics of the NPG bore surface thermocouple. It was observed from these tests that:

Two bore surface thermocouples installed at the base of the cartridge case on the same round agreed within 15°C with one another.

The depth of recess of the thermocouple surface from the bore varied from 0.090 to 0.009 with no significant effects on the recorded temperatures.

Response of the NPG bore surface thermocouple is extremely fast. The response time was shown to be below a limiting value of approximately 0.068 milliseconds. The corresponding rate of temperature rise, for the conditions of the test, is 15,000°C per millisecond.

The NPG bore surface thermocouple has been used on 13 single round firings thus far with no evidence of having reached its maximum life.

FOREWORD

The tests reported herein were conducted under the Foundational Research Program of the Naval Proving Ground as authorized by reference (a). This is the second partial report on Foundational Research Project NPG-M-11016-9, Bore Surface Temperature Measurements.

The firings reported in this paper were conducted during October - November 1953.

This report was reviewed by:

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INTRODUCTION

In the development of new weapons and propellants, the bore surface temperature histories are of special interest. The processes of gun erosion, thermal stress and heat transfer depend upon the transient temperatures at the bore surface.

An extremely rugged fast-responding bore surface thermocouple was developed by the Naval Proving Ground during 1952-1953 and a complete description of it is contained in reference (b).

The primary objective of this project was to record the bore surface temperatures at the origin of rifling and at the base of the cartridge case for both "hot" and "cool" propellants fired in the same gun under similar conditions. Included in this report are the recorded bore surface temperature-time curves, along with reproductions of the original temperature oscillograms and simultaneous pressure-time records.

A secondary objective of this test was to determine more accurately the characteristics of the NPG bore surface thermocouple. Such characteristics as (1) response of two thermocouples at the same axial location in the gun on the same round, (2) effects of varying the distance between the thermocouple surface and the bore wall, (3) thermocouple response rate and (4) the durability of the thermocouple design were determined and the results of these tests are also included in this report.

DESCRIPTION OF MATERIAL

Gun

The 3"/70 Type E Mod O Gun was used for this test. The gun dimensions, gauge hole, projectile and cartridge case dimensions are contained in reference (c).

Powder

Two types of powders were used in this test; SPDN-10114 and EX 6586. The physical and chemical characteristics of these powders are contained in Table 1. The calculated flame temperatures of these powders are 2391°K and 2065°K respectively. These particular powders were chosen because they had the widest range in calculated flame temperatures among the available powders for the test gun at the time of these firings.

DESCRIPTION OF TEST EQUIPMENT

A brief description of the construction of this thermocouple is contained below.

A strip of metal foil, approximately 1/8" wide and 0.0002 thick, is sandwiched between the flat surfaces of a split cylinder of another metal. Two thin sheets of mica (3-6 microns thickness) are used for insulation between the two elements. The two metals comprising the thermocouple may be made of any thermo-electric combination; however, it is best to use for the split cylindrical sections the same material as the metal wall whose temperature is to be recorded. In this way the flow of heat through the split cylinder approaches the heat flow pattern of the wall itself. Nickel and steel were chosen for the elements of this thermocouple.

The assembly containing the split cylinder, mica and nickel foil is threaded into an appropriate steel housing. Set screws and a press-fit ring are then used to keep the unit together tightly. Finally, the end surface of the assembly is ground flat and polished with a fine abrasive. The direction of grinding and polishing is perpendicular to the slit between the halves of the plug. A number of thermo-electric junctions are thus formed on the exposed surface. A sketch of the thermocouple is contained in Figure 1. The same thermocouple used in the preliminary firings contained in reference (b) was used for this test. Additional thermocouples, of similar design, were constructed for use at the base of the cartridge case.

TABLE 1

CHEMICAL AND PHYSICAL CHARACTERISTICS OF POWDERS USED IN TEST

CHEMICAL CHARACTERISTICS

Powder Index	Nitrocellulose	Dinitrotoluene Dibutylphthalate	Diphenylamine	Centralite	Dibutylphthalate	Total Volatiles	Total Ash
SPN 10114	82.63	14.63	.98			1.76	.07
EX 6586	20.33		Picrite	2.09	7.94	.20	.04

PHYSICAL CHARACTERISTICS

Powder Index	Diameter (D) (In.)	Diameter of Perf. (d) (In.)	Web (In.)	Inner	Outer	Avg.	Length (L) (In.)	Web Var.	L/D	D/d	Form	No. of Grs. /lb.	No. of Perf.	S.G.	Calc. Flame Temp. °K	Nominal Flame Temp. °K
SPDN 10114	.2511	.0243	---	.0445	.0445	.0445	.6087	--	--	--	Cyl.	648	7	--	2391	2500
EX 6586	.1425	.0132	.0248	.0266	.0257	.0257	.3500	7.0	2.45	10.8	Cyl.	3326	7	1.58	2065	2100

WEAPONS SECTION

SKETCH OF THERMOCOUPLE ASSEMBLY

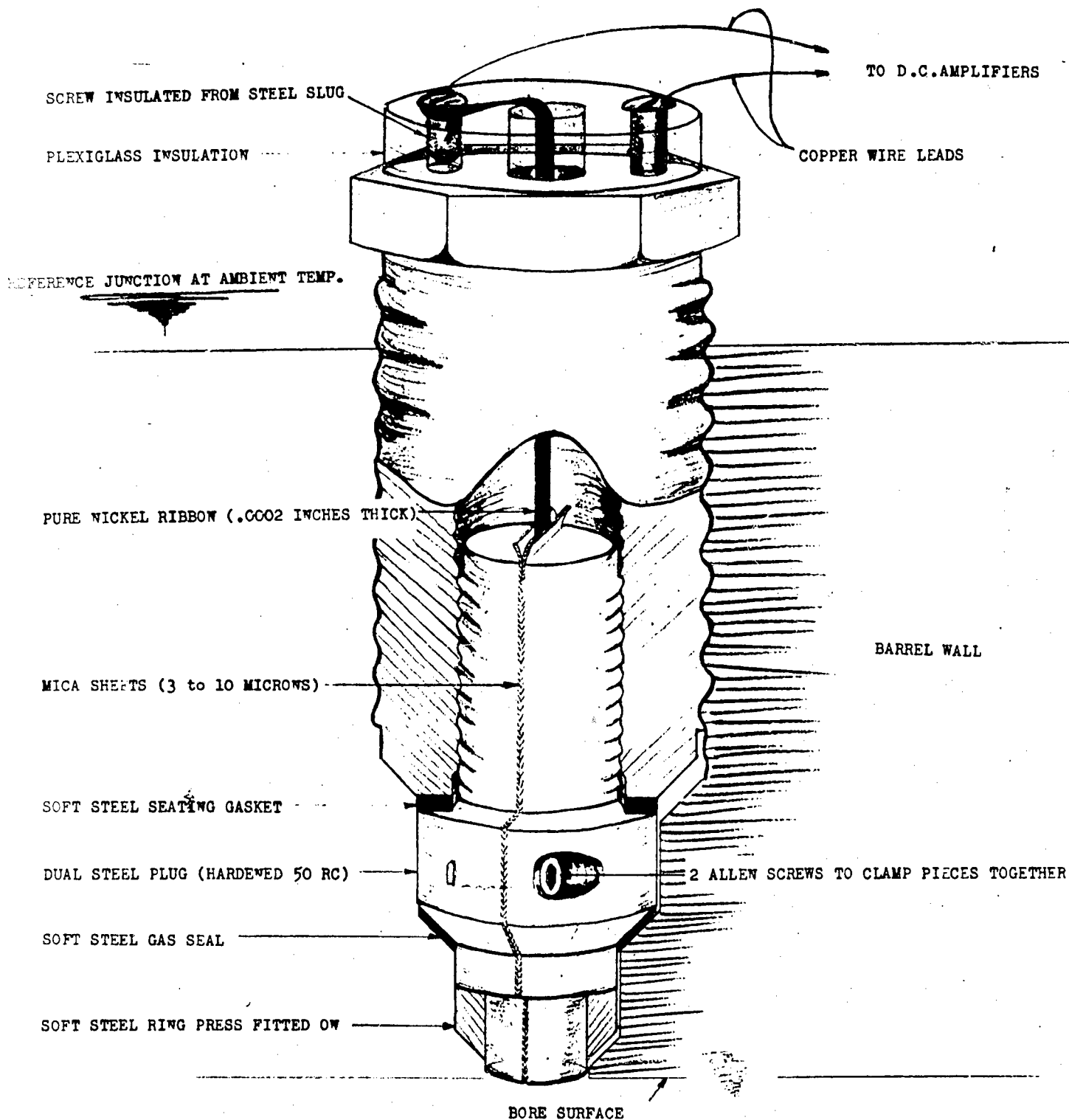


FIG. 1

PROCEDURE

Three rounds with each type of powder were fired in the 3"/70 gun with other firing conditions identical. Pressure and bore surface temperature-time data were recorded at the base of the case and the origin of rifling.

Ejection times were recorded by a strain gauge mounted circumferentially about the barrel 240 from the muzzle. Thus "ejection" represents the instant the after rotating band of the projectile reached the point 240 from the muzzle.

RESULTS AND DISCUSSIONS

Table 2 contains a summary of firing data for each round. Reproductions of original pressure and temperature oscillograms are contained in Figures 2 through 7. Figures 8 and 9 contain the bore surface temperature-time curves obtained on these firings.

Comparison of Temperature Curves

There were significant differences in the bore surface temperatures between the "hot" and "cool" propellants used in this test. The maximum temperatures at the origin of rifling average 1075°C and 980°C for the "hot" and the "cool" powders respectively. Similarly, the maximum temperatures in the case average 370°C and 280°C. Approximately 40 milliseconds after ejection, the bore surface temperatures at the origin of rifling average 350°C and 250°C for the "hot" and "cool" powders respectively.

Consistency of Thermocouple Measurements

The variations in the recorded temperatures from one round to the next, using a given powder, were very slight.

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SUMMARY OF FIRING DATA

TABLE 2

Proj.: EX 11
 Proj. Wt.: 15 lbs.
 Primer: Mk 46

Rd.	Date	Powder Index	Charge Wt., lbs.	Maximum Case Pressure (psi)	Maximum 34"O* Pressure (psi)	Maximum 186"O* Pressure (psi)	Muzzle Velocity (fps)	Recess (in.)**
1	10/8/53	SPDN 11014	8.0	---	60100	11200	3417	.090
2	10/13/53	SPDN 10114	8.0	66000	61600	11000	3392	.090
3	11/10/53	SPDN 10114	8.0	65000	62000	11500	3413	.025
4	10/27/53	EX 6586	8.8	55000	52000	11500	3295	.090
5	11/14/53	EX 6586	8.8	54000	52500	11800	3266	.025
6	11/15/53	EX 6586	8.8	54700	52300	11400	3318	.090

* All distances measured from breech face.

** "Recess" is the radial distance from the groove surface to the thermocouple surface.

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Close of Firing Key

Ejection

1 2 3

Firing Data

Charge : SPDN 10114 , Charge Wt. 8.0 lbs
Primer : Mk. 45
Proj. : EX 11, Projectile Wt. 15 lbs.
Muzzle Velocity : 3417 f.p.s.

Trace Identifications

- 1-Pressure at 3470 from Breech Face
- 2-Pressure at 18670 from Breech Face
- 3-Strain Gauge Ejection
- 4-Thermocouple at Base of Case
- 5-Thermocouple at Base of Case
- 6-Thermocouple at 3470 from Breech Face

10 Milliseconds

ROUND 1

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

October 1953

3770 Type E Mod. O Gun

NP9-63686
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FIG. 2

Close of Firing Key

Ejection

1 2 3 4

Firing Data

Charge : SPDM 10114, Charge Wt. 8.0 lbs
Primer : Mk. 46
Proj: M11, Proj. Wt. 15 lbs.
Muzzle Velocity : 3392 f.p.s.

Trace Identifications

- 1-Pressure at Base of Case
- 2-Pressure at 3450 from Breach Face
- 3-Pressure at 16650 from Breach Face
- 4-Strain Gauge Ejection
- 5-Thermocouple at Base of Case
- 6-Thermocouple at 3450 from Breach Face

10 Milliseconds

5 6

ROUND 2

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

October 1953

NP9-62536

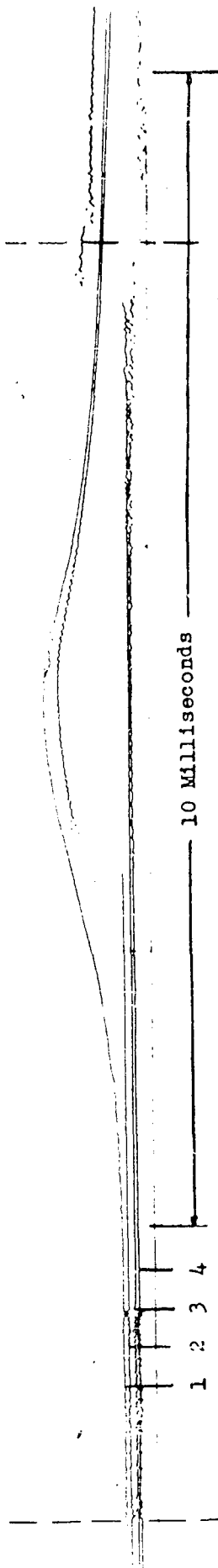
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3"/70 Type E Mod. O Gun

FIG. 3

Close of Firing Key

Ejection



Firing Data

Charge : SPDN 10114, Charge Wt. 8.0 lbs.
Primer : Mk. 46
Proj: EX 11, Proj. Wt. 15 lbs.
Muzzle Velocity : 3413 f.p.s.

Trace Identifications

- 1-Pressure at Base of Case
- 2-Pressure at 3470 from Breech Face
- 3-Pressure at 18670 from Breech Face
- 4-Strain Gauge Ejection
- 5-Thermocouple at 3470 from Breech Face
- 6-Thermocouple at Base of Case

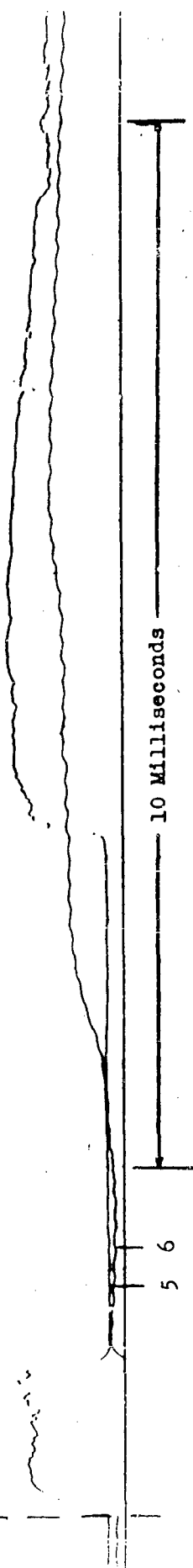


FIG. 4

ROUND 3

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

November 1953

NP9-65687
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3"/70 Type E Mod.O Gun

Ejection

Close of Firing Key

1 2 3 4

Firing Data

Charge : KI 6586 , Charge Wt. 8.8 lbs.
Primer : Mk. 46
Proj : KI 11, Proj. Wt. 15 lbs.
Muzzle Velocity: 3295 f.p.s.

Trace Identifications

- 1-Pressure at Base of Case
- 2-Pressure at 3430 from Breech Face
- 3-Pressure at 18630 from Breech Face
- 4-Strain Gauge Ejection
- 5-Thermocouple at Base of Case
- 6-Thermocouple at 3430 from Breech Face

10 Milliseconds

5 6

ROUND 4

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

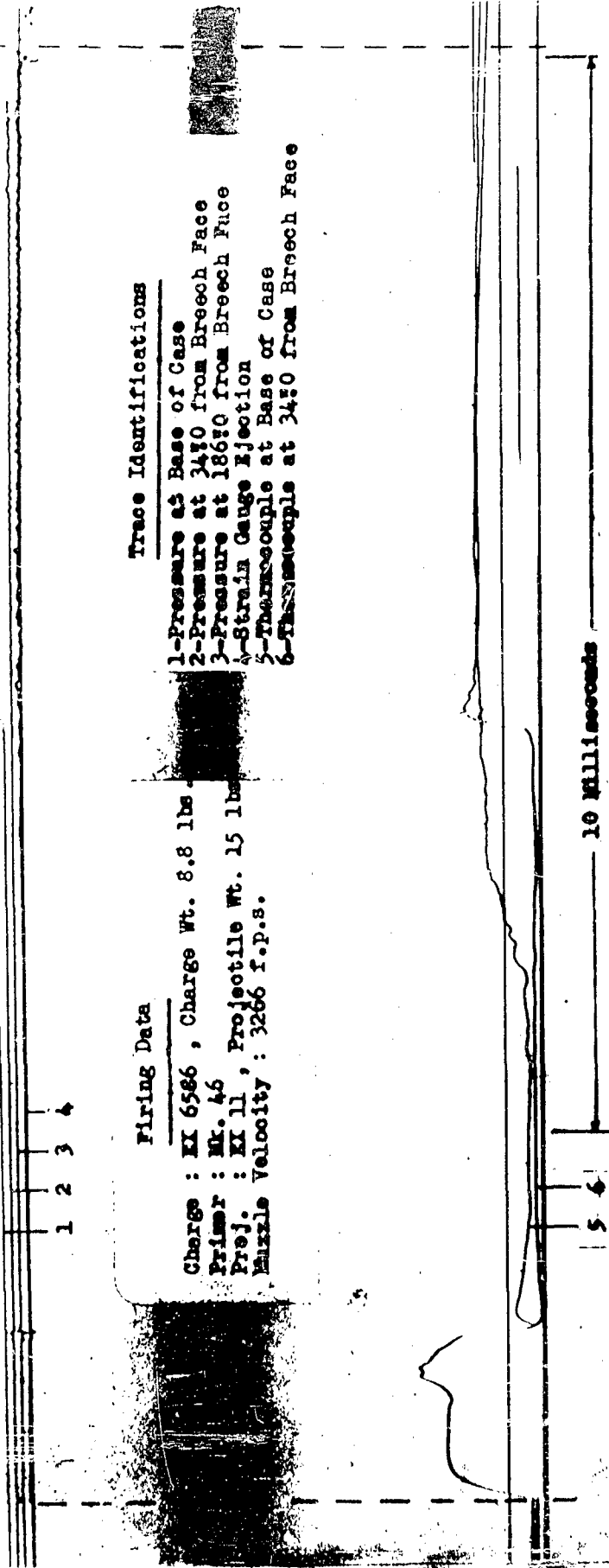
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3770 Type E Mod. O Gun

FIG. 5



ROUND 5

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

NP9-62537
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No. number 1953
3770 Type E Mod. C Gun

1 2 3 4

Firing Data

Charge : KI 6586 - Charge Wt. 8.8 lbs.
 Primer : Mk. 46
 Proj. : KI 11, Proj. Wt. 15 lbs..
 Muzzle Velocity: 3315 f.p.s.

Trace Identifications

- 1-Pressure at Base of Case
- 2-Pressure at 3470 from Breech Face
- 3-Pressure at 18670 from Breech Face
- 4-Strain Gauge Ejection
- 5-Thermocouple at Base of Case
- 6-Thermocouple at 3470 from Breech Face

10 Milliseconds

ROUND 6

PRESSURE & BORE SURFACE TEMPERATURE OSCILLOGRAMS

November 1953

3770 Type E Mod O Gun

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U.S. NAVAL PROVING GROUND
3770 TYPE E MOD 0 GUN

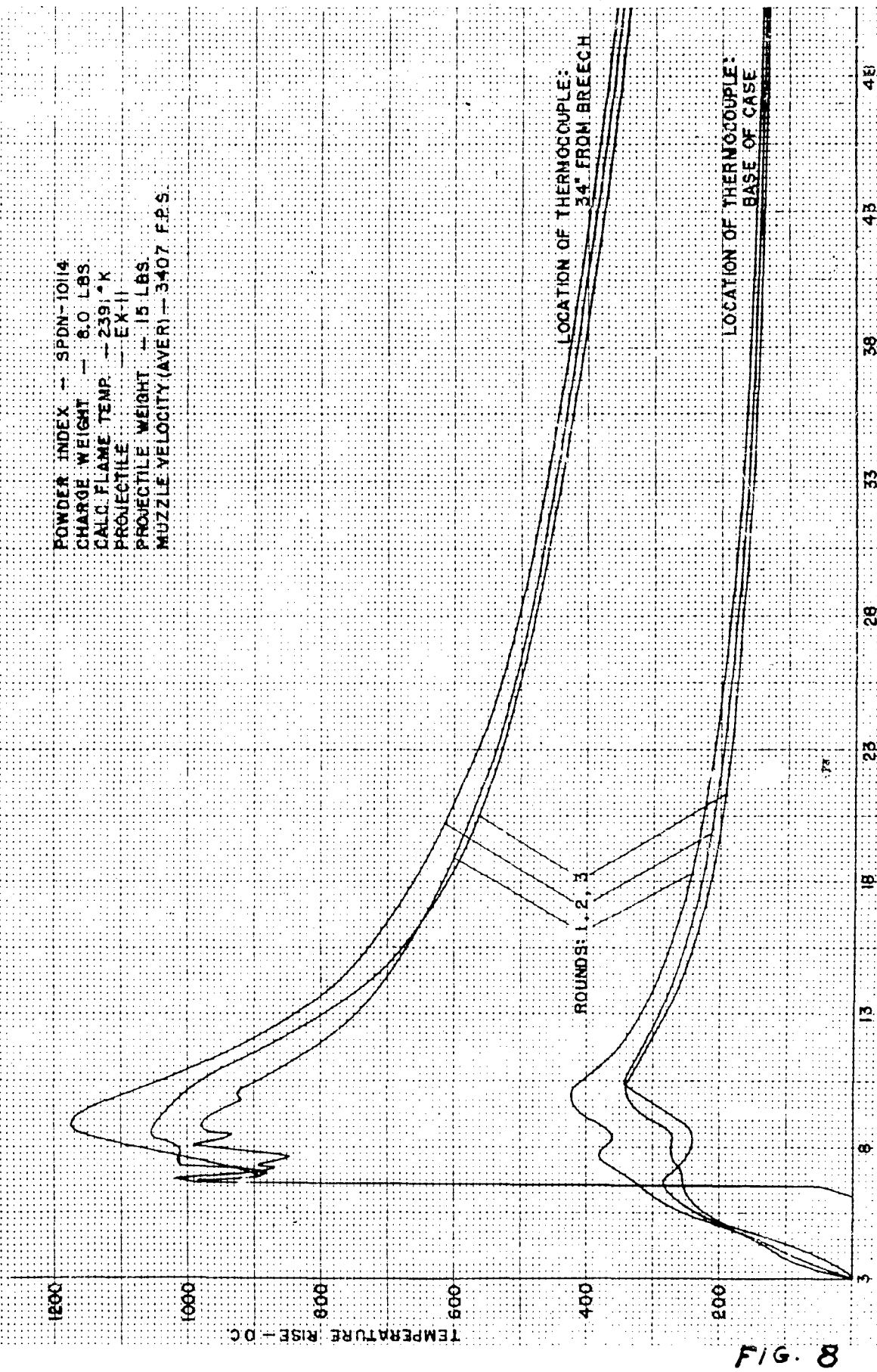
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BORE SURFACE TEMPERATURE-TIME CURVES

QCT-NOV. 1953

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POWDER INDEX - SPDN-1014
CHARGE WEIGHT - 8.0 LBS.
CALC. FLAME TEMP - 2391°K
PROJECTILE - EX-II
PROJECTILE WEIGHT - 15 LBS.
MUZZLE VELOCITY (AVER) - 3407 F.P.S.



U.S. NAVAL PROVING GROUND
3770 TYPE E NDD D BUN

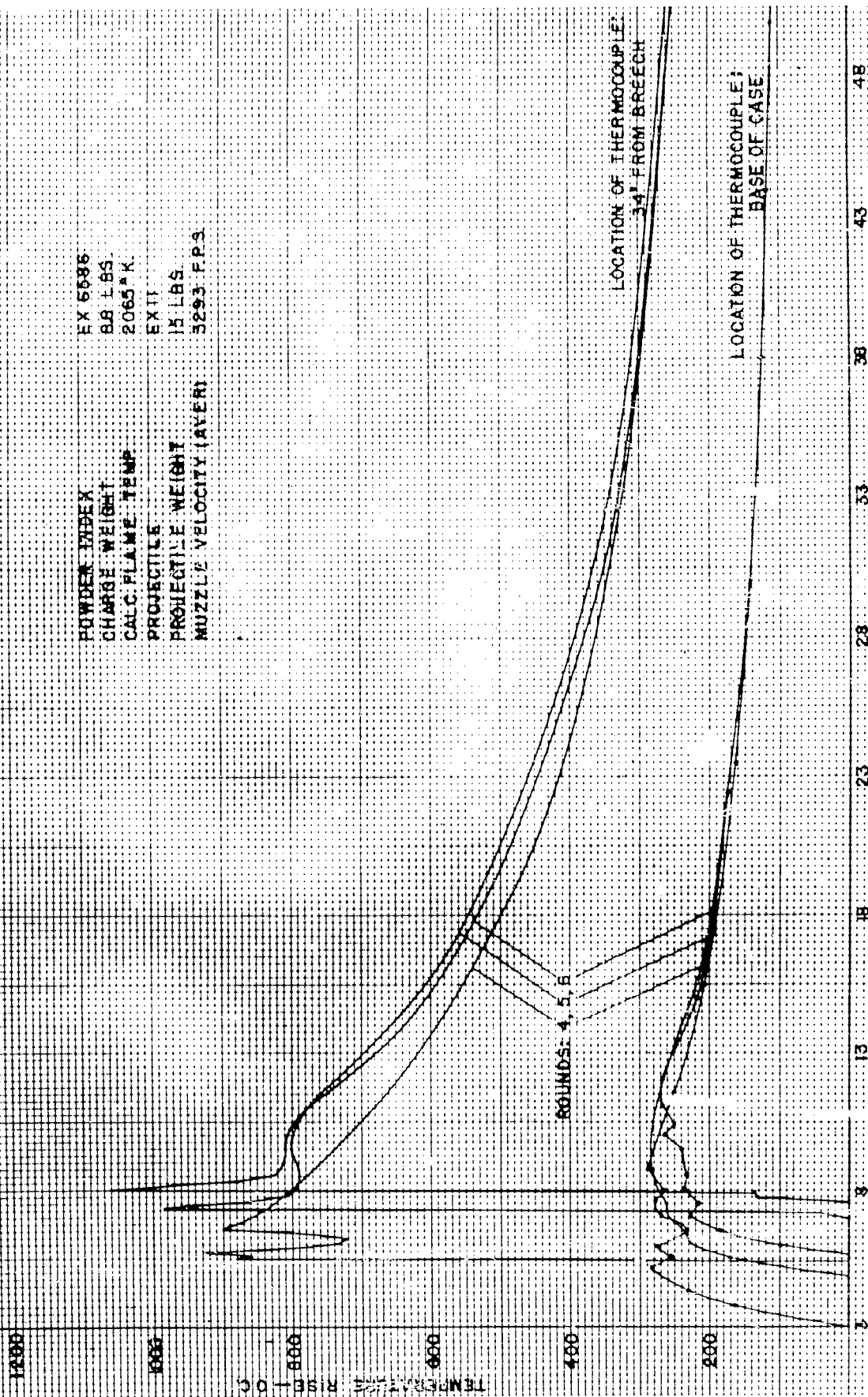
BORE SURFACE TEMPERATURE-TIME CURVES

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NP 1-62430

OCT-NOV-1953

POWDER INDEX EX 6986
CHARGE WEIGHT 88 LBS.
CALC. FLAME TEMP 2065 °K
PROJECTILE EX II
PROJECTILE WEIGHT 15 LBS.
MUZZLE VELOCITY (AVER) 3293 FPS



MILLISECONDS FROM CLOSE OF FIRING KEY

PAPER CROSS SECTION PAPER

FIG. 9

Effect of Varying the Distances Between Thermocouple Surface and Bore Surface

The surface of the thermocouple at the origin of rifling was moved closer to the bore wall by inserting successively thinner seating gaskets when installing the thermocouple. After each installation, the actual location of the thermocouple surface was measured with a star gauge type bore micrometer. The depth of recess of the thermocouple surface from the bore surface was varied from .090 to .009 and no variations were noted in the recorded temperatures.¹ However, as the depth of recess was decreased, the amount of coppering on the thermocouple surface was reduced.

Agreement Between Two Bore Surface Thermocouples at the Same Location on the Same Round

In Round 1, two bore surface thermocouples were installed at the base of the cartridge case. The oscillograms are reproduced in Figure 2. The lead wire of one of the thermocouples was shorted at about the instant of maximum temperature. Up to this instant, the temperature curves from these thermocouples agreed within 15°C with one another.

Temperature of Gases Leaking Ahead of Projectile

Occasionally the bore surface thermocouple at the origin of rifling records a temperature change prior to the passage of the projectile. This is attributed to gases escaping past the rotating band.

Thermocouple Response

An approximate calculation of the rapidity of the thermocouple response can be made if one assumes that the temperature change at the position of the origin of rifling (34.0 from the breech face) is applied in the form of a square wave step function. The response time of the

¹Firings with .009 recess are not included in the data in this report. They will be treated in a later report.

thermocouple is then arbitrarily defined as the time required for the thermocouple to produce 63.2% of its maximum output when this step-temperature change is introduced at the bore surface. The records from the thermocouple located at 3440 from the breech face for rounds 1 and 2 were read under high magnification to determine this response time. The time constant of this thermocouple was thus found to be approximately .068 millisecond. (Measured times were .065 millisecond and .071 millisecond on rounds 1 and 2, respectively.) The corresponding maximum rate of recorded temperature rise was approximately 15,000°C per millisecond.

Clearly, the temperature rise of the bore surface is not a step function. Consequently, the time constant as measured will exceed the true time constant of the thermocouple alone. The significance of the reported value is that it defines a lower limit for the true quality of response. It is reasonable to expect that the true response is appreciably faster.

CONCLUSIONS

As a result of the test conducted, it is concluded that significant differences in the bore surface temperatures exist between "hot" and "cool" powders fired in the 3"/70 Type E Mod O Gun. As would be expected, the bore surface temperature rise is roughly proportional to the difference between adiabatic flame temperature and ambient temperature. Powders with T_0 of 2500°K and 2100°K produced temperature changes of 1075°C and 980°C respectively at the origin of this gun. This temperature change is approximately 50 per cent of the elevation of T_0 above ambient.

REFERENCES

- (a) BUORD ltr Reb-1:mmt NP9 of July 1952
- (b) NPG Conf Report No. 1130 "A Thermocouple to Record Transient Temperatures at the Bore Surface of Guns" 15 July 1953
- (c) NPG Conf Report No. 918 "Interior Ballistic Studies in the 3"/70 Caliber Gun Type E, Mod O, Using Cool Propellants" 21 February 1952

APPENDIX A

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NPG REPORT NO. 1296

Subject: Bore Surface Temperatures in the 3"/70 Type E
Mod O Gun Using Hot and Cool Powders by
J. Nanigian, Armament Department, U. S. Naval
Proving Ground, Dahlgren, Virginia

4 October 1954

ABSTRACT

Bore surface temperatures were recorded at the origin of rifling and the base of the cartridge case in the 3"/70 Type E Mod O Gun. Rounds were fired using "hot" and "cool" powders. As a result of this test it is concluded that the bore surface temperatures produced by the "hot" and the "cool" powders are significantly different.

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ABSTRACT

Bore surface temperatures were recorded at the origin of rifling and the base of the cartridge case in the 3"/70 Type E Mod O Gun. Rounds were fired using "hot" and "cool" powders. As a result of this test it is concluded that the bore surface temperatures produced by the "hot" and the "cool" powders are significantly different.

Additional firings were conducted to determine the characteristics of the NPG bore surface thermocouple. It was observed from these tests that:

Two bore surface thermocouples installed at the base of the cartridge case on the same round agreed within 15°C with one another.

The depth of recess of the thermocouple surface from the bore varied from 0.090 to 0.009 with no significant effects on the recorded temperatures.

Response of the NPG bore surface thermocouple is extremely fast. The response time was shown to be below a limiting value of approximately 0.068 milliseconds. The corresponding rate of temperature rise, for the conditions of the test, is 15,000°C per millisecond.

The NPG bore surface thermocouple has been used on 13 single round firings thus far with no evidence of having reached its maximum life.

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