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RESEARCH INSTITUTE

"INVESTIGATION OF SEVERAL HIGH TEMPERATURE REACTIONS  
INVOLVING CYANOGEN AND LIKE COMPOUNDS AS  
HIGH BRIGHTNESS CHEMICAL PYROTECHNIC SOURCES"



FOR

DEPARTMENT OF THE ARMY  
ARMY MATERIEL COMMAND  
PICATINNY ARSENAL  
FELDMAN RESEARCH LABORATORY  
DOVER, NEW JERSEY 07801

SUMMARY REPORT

ON

EXPERIMENTAL USE OF CHEMICAL SYSTEMS  
FOR PULSE LASING SOLID-STATE LASERS

AUGUST 1, 1968

S.

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## I. INTRODUCTION

In early 1963 discussions were held between Picatinny Arsenal and Research Institute personnel regarding the possibility of using high temperature producing chemical reactions as a light source to pump a solid-state laser. A program was undertaken to investigate this possibility. With the background of previous research carried out at Picatinny Arsenal, FRL, and a close cooperative effort by both sponsor and contractor, studies were initiated on several systems with the main one being the cyanogen-oxygen gaseous detonation system. As the program progressed, this system showed more and more promise as one that would be capable of pumping a ruby solid-state laser. The program went in several directions concurrently, maximum light output of the cyanogen-oxygen system, development and fabrication of pumping fixtures, and studies on other systems that might prove useful as chemical sources. This summary report describes the research and studies which lead to the successful pulse-pumping of both neodymium and ruby solid-state lasers.

## II. INSTRUMENTATION

### A. TEMPERATURE DETECTION EQUIPMENT

#### 1. Photodiode System

The method for measuring the brightness temperatures in the experiments described herein was identical with one developed at the Picatinny Arsenal Pyrotechnics Laboratory<sup>(1)</sup>. The image of the detonation wave front, the brightness temperature of which was to be measured, was projected onto a plane immediately in front of a plate which had an 1/8" hole. A light detector provided with appropriate filters was located behind this plate so that it saw a portion of the image through the 1/8" hole. The diagram of this system is shown in Fig. 1. The output signal from the detector was fed into a Teletronix Type 533 or 545 oscilloscope. The sweep was triggered directly by the signal. Two Polaroid cameras were used to make permanent records. A Philco type L-4413 silicon P-N junction photosensor was used as the detector. The diagram of the photosensor, the cathode follower, and the power supply is shown in Fig. 2. Figure 3 shows the spectral sensitivity of the L-4413 photosensor.

#### 2. Photomultiplier System

In later experiments the projection of the image with a lens was found impractical. The image hole size was decreased to 5/64" and, since the detector had to remain at about the same location, the photosensor

(1) Smith, Chester L., Kisatsky, Paul J., "An Investigation Into The Feasibility of a Pyrotechnics Laser Pump", Technical Rep. 3102, Picatinny Arsenal, Pyrotechnics Laboratory.



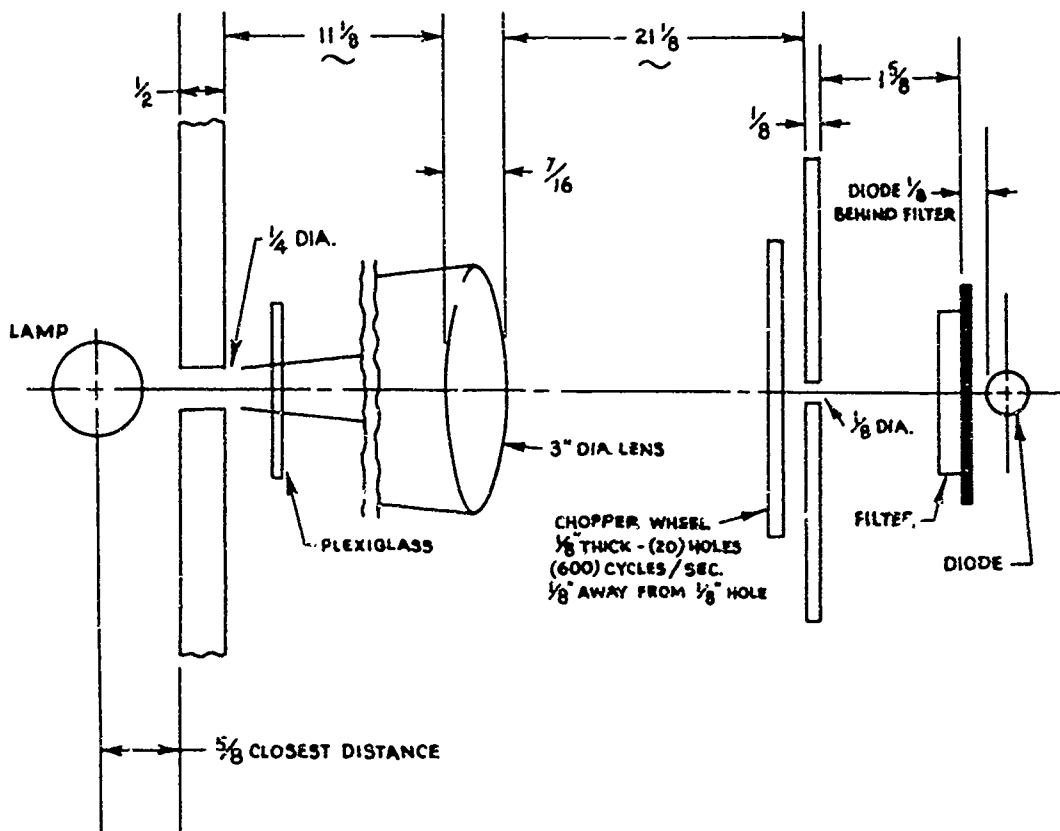


FIGURE 1  
OPTICAL SYSTEM



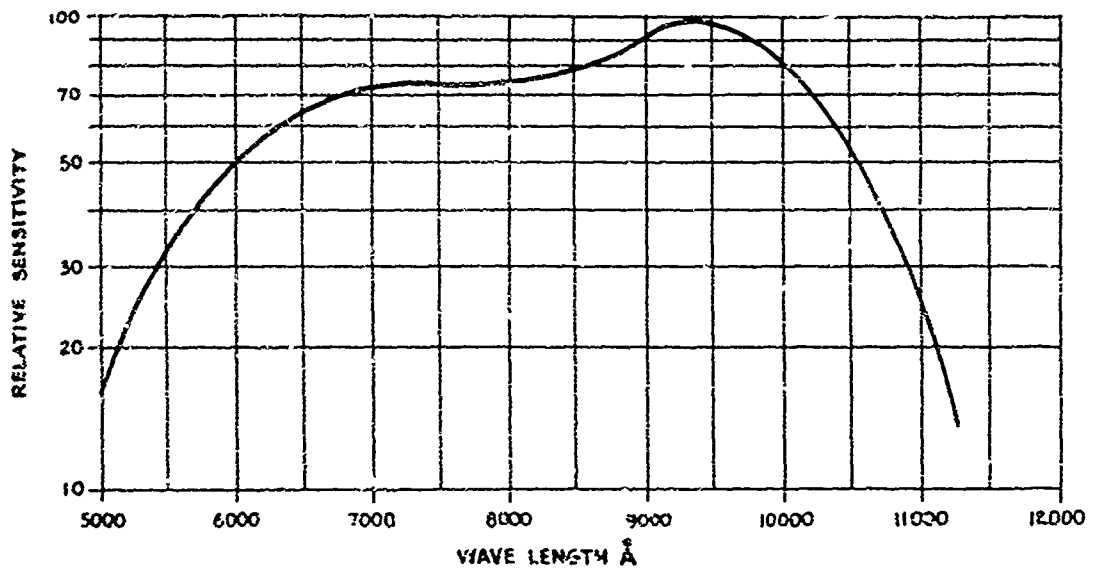


FIGURE 3  
SPECTRAL SENSITIVITY OF L-4413 PHILCO DIODE

was changed to a sensitive 931A photomultiplier tube which has a spectral response as shown in Fig. 4. The schematic of this detector is shown in Fig. 5. The low power consumption of the photomultiplier tube permitted the use of a battery power supply with its inherent simplicity, low noise, and no ripple. However, due to the bulkiness of the battery pack, an AC power supply was constructed, as shown in Fig. 6.

### 3. Filter Data and Ratio Curves

Two filters were used for the detector systems. One was a narrow band interference filter peaking at 582 millimicrons with a band width of 14 millimicrons. With this filter, both systems, photosensor and photomultiplier, peak at 582 millimicrons because of the filter's narrow band width. The other was a broad band filter with a wave length range of 480 millimicrons to 600 millimicrons ("M" Filter). Using this filter, the Philco photosensor peaked at 575 millimicrons and the photomultiplier (Type 931A) at 550 millimicrons. In order to facilitate the reduction of data quickly, curves were calculated for brightness temperature versus "R", which is the ratio of the output of a 2400°K tungsten band lamp and the experimental item. These curves are based on the use of Plank's Equation<sup>(1)</sup>. Three curves are presented:

- (1) T vs R for 582 millimicron filter, Fig. 7
- (2) T vs R for "M" filter Philco photosensor, peaking at 575 millimicrons, Fig. 8
- (3) T vs R for "M" filter + 931A photomultiplier peaking at 550 millimicrons, Fig. 9

(1) Smith, Chester L., Kisatsky, Paul J., "An Investigation Into The Feasibility of a Pyrotechnics Laser Pump", Technical Rep. 3102, Picatinny Arsenal, Pyrotechnics Laboratory.

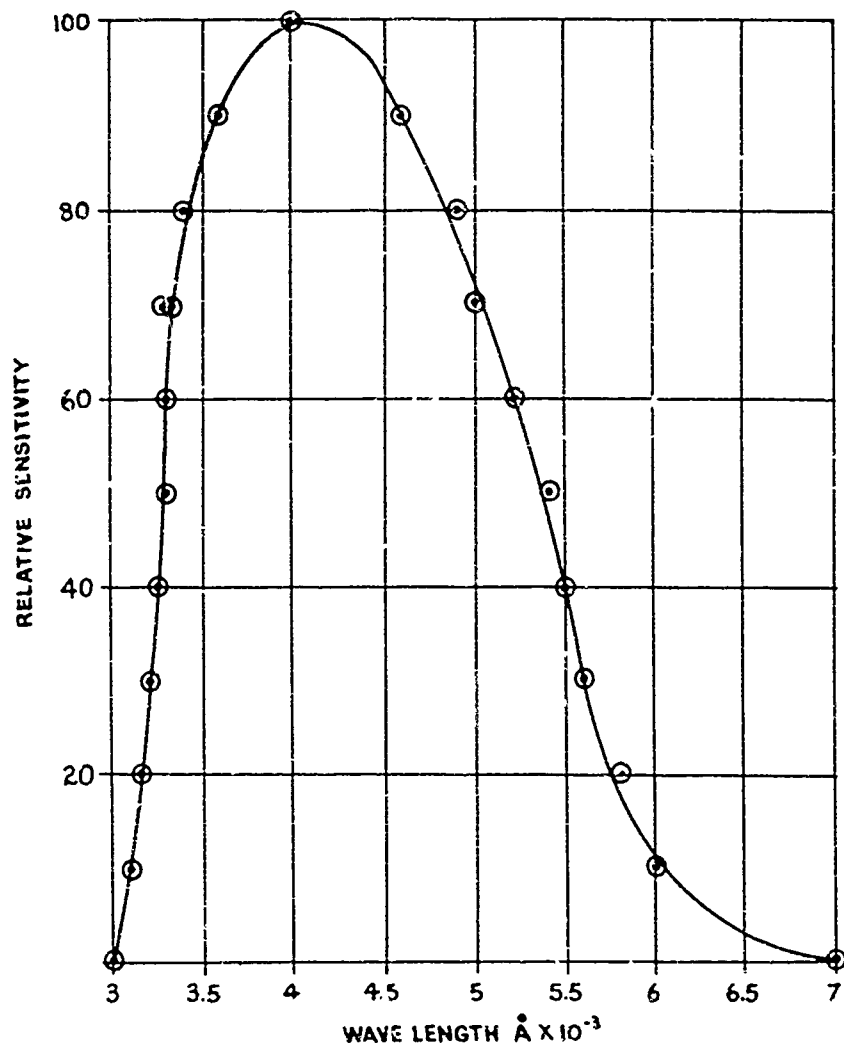


FIGURE 4  
SPECTRAL SENSITIVITY OF 931A RCA PHOTOMULTIPLIER TUBE

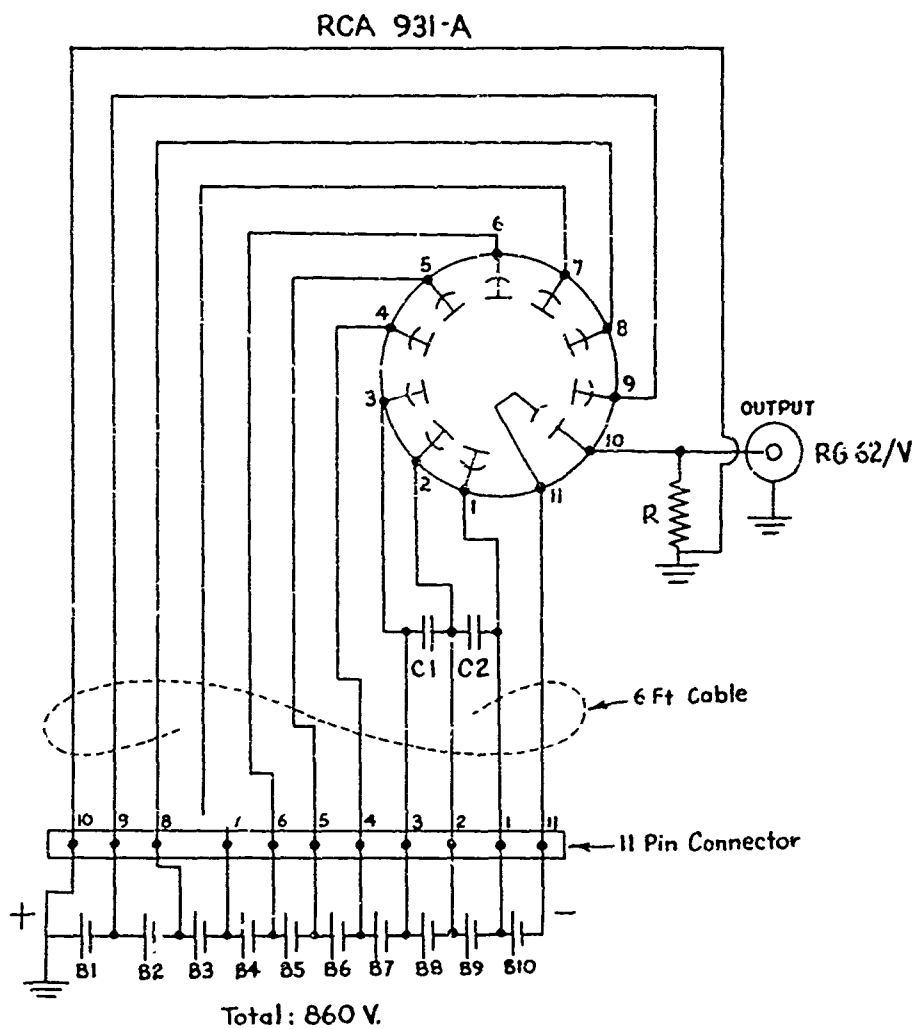


FIGURE 5  
PHOTOMULTIPLIER SYSTEM

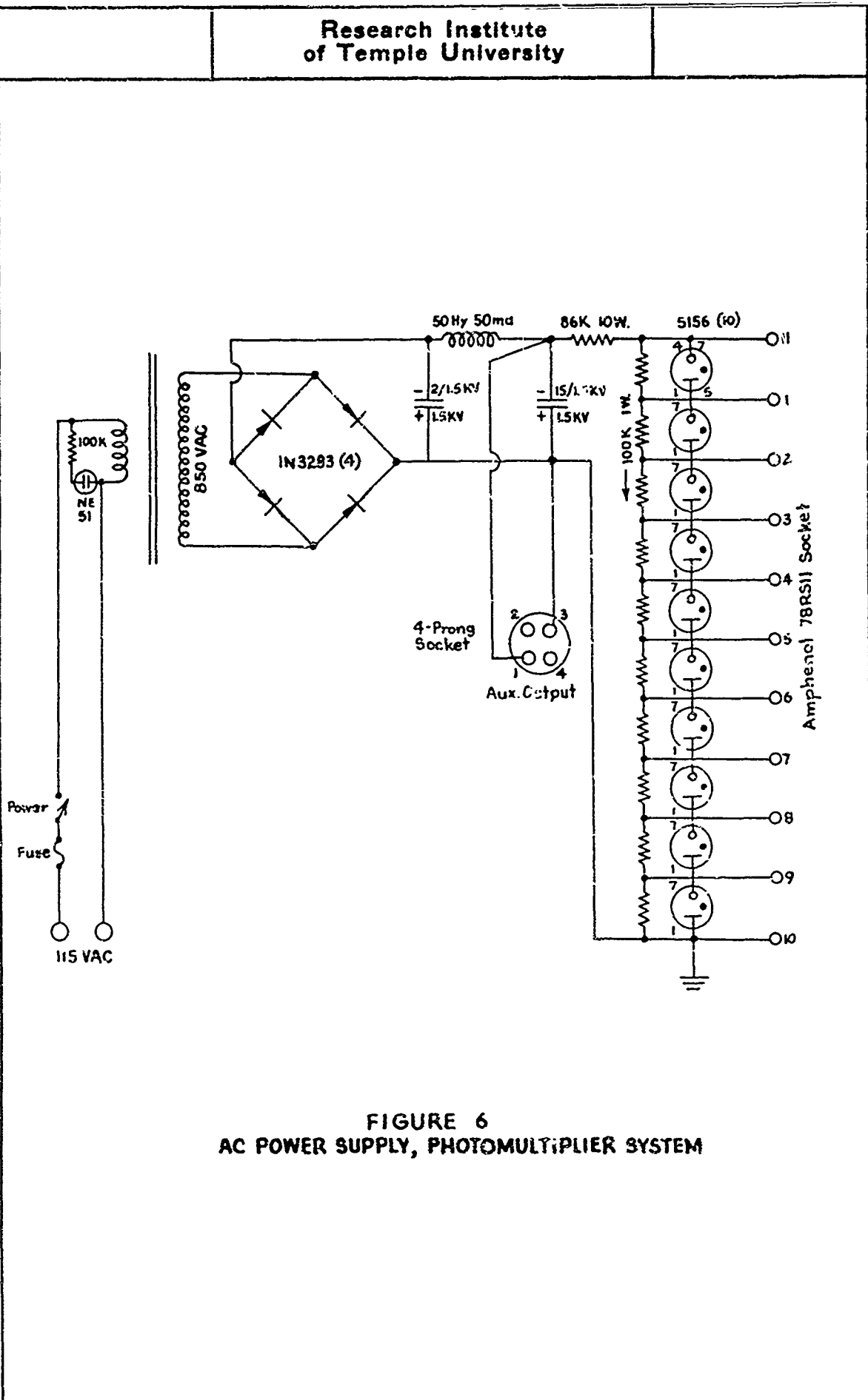


FIGURE 6  
AC POWER SUPPLY, PHOTOMULTIPLIER SYSTEM

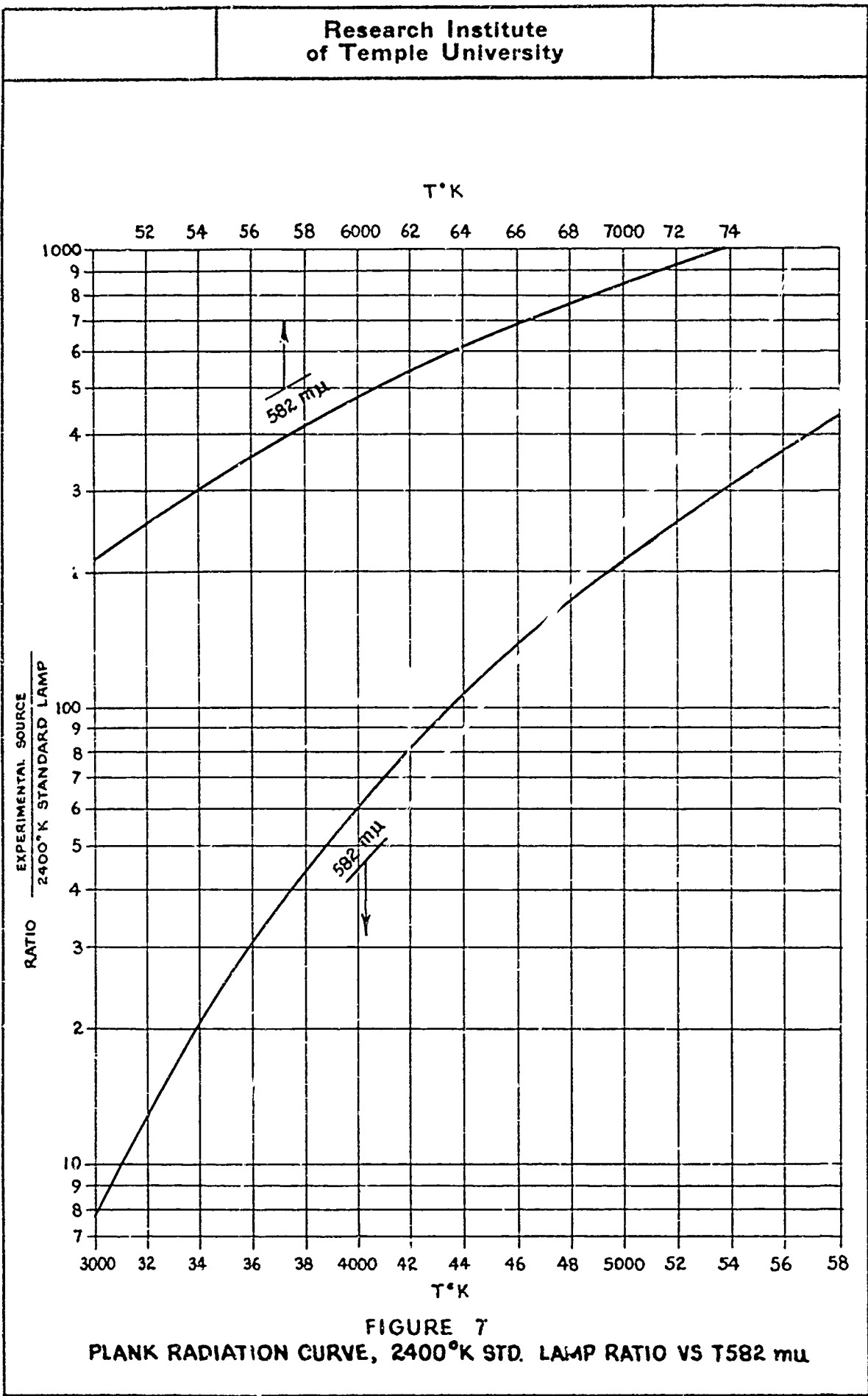


FIGURE 7  
PLANK RADIATION CURVE, 2400°K STD. LAMP RATIO VS T582 mμ



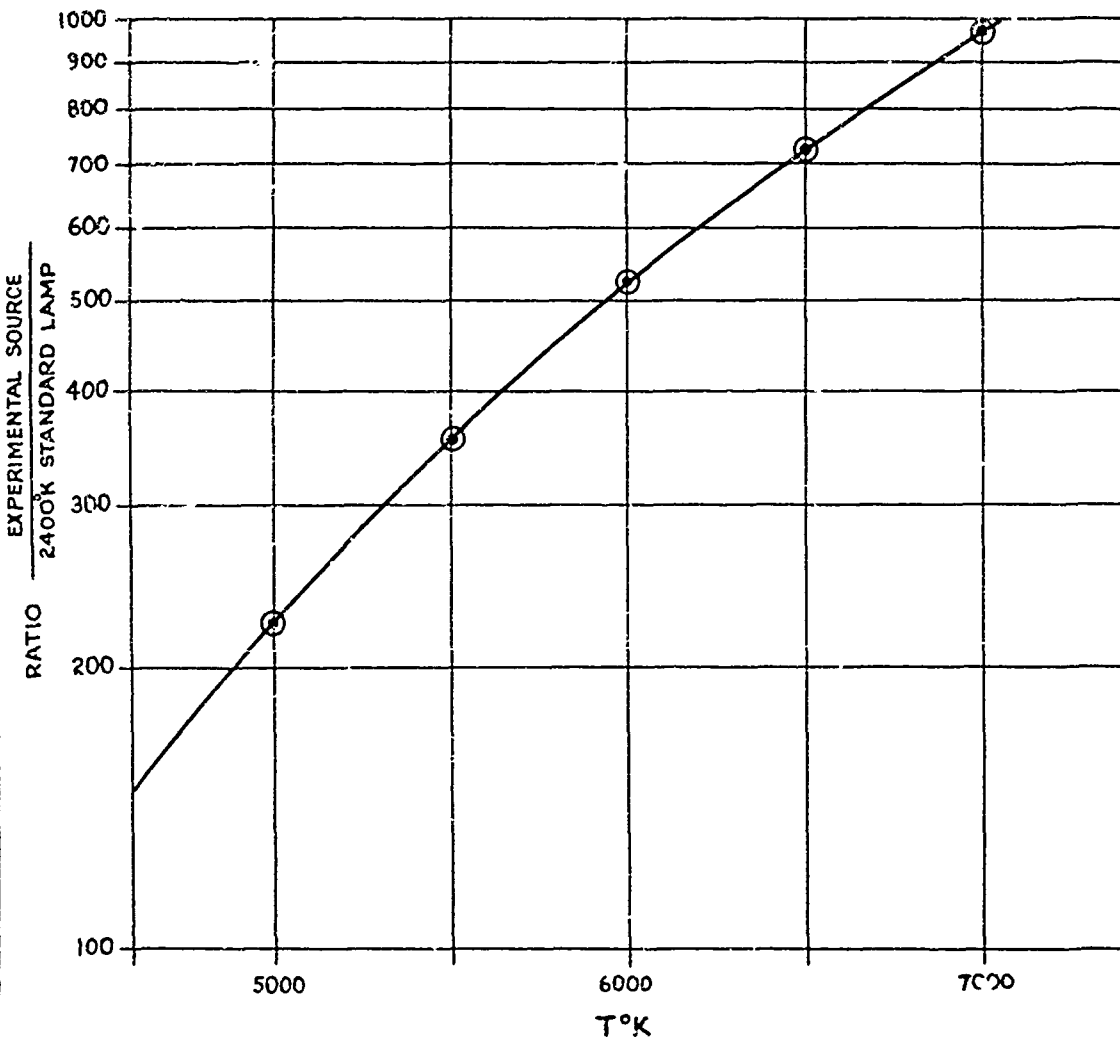


FIGURE 8  
PLANK RADIATION CURVE, 2400°K STD. LAMP RATIO VS T575 mu

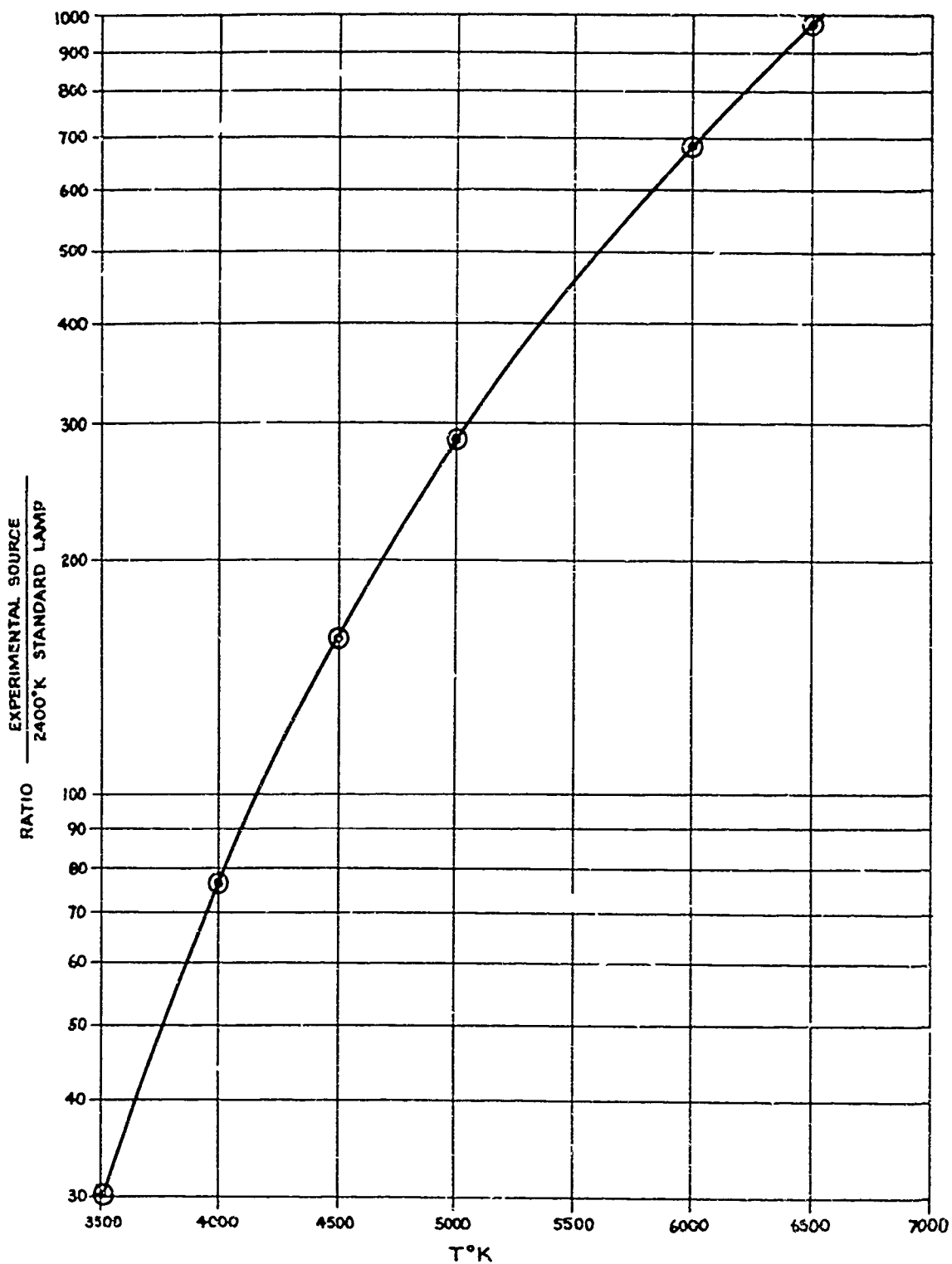


FIGURE 9  
PLANK RADIATION CURVE, 2400°K STD. LAMP RATIO VS T 550 mμ

The light intensity appearing at the detectors was varied by means of neutral density filters to keep the photodiode and the photomultiplier within their linear operating range.

## B. LASER DETECTION EQUIPMENT

### 1. Diode Type

The same unit as described in Section A, Part 1, above, The L-4413 Philco detector (see Fig. 2) was separated from the lens system and placed directly in the laser beam path. By using an appropriate filter, this diode detector was adequate for detecting lasing pulses from both ruby and neodymium crystals.

### 2. Photomultiplier Type

Similarly, the photomultiplier system, as shown in Fig. 5, was used for the detection of lasing pulses from ruby crystals using appropriate filters. Since the 931A photomultiplier is not responsive on the infrared (see Fig. 4), it could only be used for ruby lasing detection.

### 3. Filters Used for Laser Detection

#### a. Neodymium Doped Crystals

A Corning type 7-56 infrared transmitting visible absorbing filter was used on detectors for all neodymium crystal lasing experiments. This filter transmits from 0.9 to below 2.7  $\mu$ . Neodymium doped glass laser emits at 1.06  $\mu$ .

b. Ruby Crystals

An interference filter of 693 mu was used on all detectors for monitoring the lasing of ruby crystals. The lasing wave length of ruby crystals is 693.4 mu.

C. RADIATION PROBES

It was of interest, particularly in the case of the pumping fixture, to determine the energy level covering the area where a laser would be placed during pumping experiments. To facilitate this, a series of radiation probes were constructed of the general type shown in Fig. 10. These probes were made small enough to fit into a 1/2" I.D. hole in the Lucite laser holding tubes. A Type L-4413 Philco photodiode was used as the pick-up which was fed directly to an oscilloscope. With a load resistor of 500 or 1000 ohms, the linear range of the diode went up to 200 millivolts and the output was kept in this range by use of neutral density filters. Three types of probes were constructed using different filters.

1. Infrared filter. Corning Type 1-69 transmission

Transmission 400 mu to 700 mu

2. Blue or Blue-Green Filters

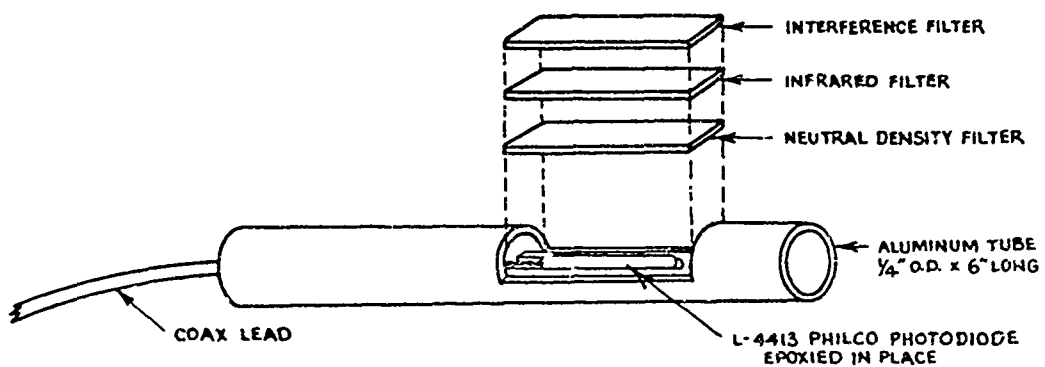
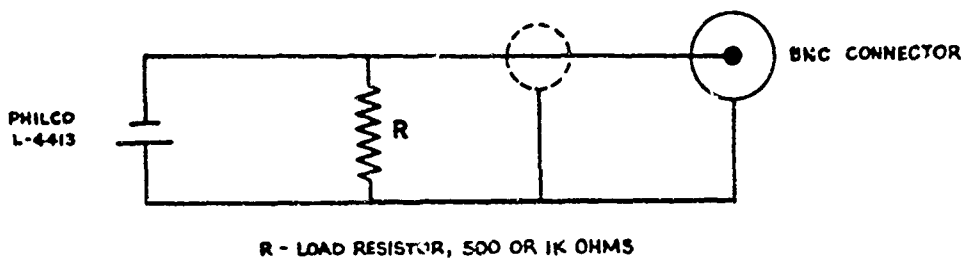
Corning type transmission

Corning type transmission

3. Interference filters

565 mu, 14 mu band width

431 mu, 14 mu band width



FILTERS TAPED IN PLACE. PROBE COVERED WITH  
ALUMINUM FOIL LEAVING WINDOW  $\frac{1}{8}$ " x  $\frac{1}{2}$ " AT  
PHOTODIODE.

FIGURE 10  
RADIATION PROBE CONSTRUCTION

Type 3 probes using the interference filters proved to be the most reliable. By calibration against a series of AG-1 flash bulbs, brightness temperatures could be estimated.

#### D. SPECTROGRAPHIC INSTRUMENTATION

In the spectrographic studies, a Bausch and Lomb 1.5 meter spectrograph was used. TRI-X film was used to record the emission spectra of the system investigated and the exposure was controlled by the distance of the fixture used from the entrance slit of the spectrograph. The TRI-X film was analyzed by use of a modified Applied Research Laboratory Model B5400A Densitometer coupled to a Minneapolis Honeywell millivolt recorder which produced an intensity versus wavelength trace.

#### E. LUCITE WINDOW LIGHT ATTENUATION

Since Lucite windows approximately 1 1/4" thick are used in several of the fixtures, it was of interest to determine the light attenuation or brightness temperature attenuation of these windows and also the effect on the optical system. Using the standard 2400°K tungsten band lamp, an attenuation of 25% was obtained with the 1 1/4" Lucite window. Fifteen tests were made using AG-1 flash bulbs with and without the window. The temperatures of the AG-1 flash bulbs were 200° lower with the Lucite in place as compared to the flash bulbs alone; however, using the standard lamp millivoltage with the Lucite plug in place, the temperatures obtained for the flash bulbs with the Lucite plug were the same as those without the plug. These experiments show that the system can be calibrated with the Lucite plugs included and that no adverse effect on the optical system occurred with their use.

### III. FIXTURES

#### A. BRIGHTNESS TEMPERATURE MEASUREMENT CELLS

A series of fixtures were constructed to facilitate the measurement of the brightness temperature of various gaseous detonation systems and one for use with a solid system. The following are the various types used.

##### 1. Confined Chamber

Figure 11 shows a configuration of the confined chamber fixture. This unit was fabricated of stainless steel and was used for experiments utilizing solid materials. It had provisions for a squib type ignitor (M1A1, 90/10 or with bridge wire only). A 1/4" Lucite window bolted across the face of the fixture was used to observe the reaction. This unit was utilized for the tetracyanoethylene-potassium perchlorate system.

##### 2. Test Tube Detonation Cell

This fixture is shown in Fig. 12 and utilized a 11 mm diameter x 3" Pyrex test tube, "O" ring sealed to a stainless steel adapter block which contained an AC Type M-8 spark plug which served as ignitor. This unit was used for atmospheric and sub-atmospheric gaseous detonation system experiments utilizing cyanogen-oxygen. In some cases a flat head test tube was used. This unit proved to be very successful for carrying out the brightness temperature measurements of the gaseous detonation system up to 1 Atm. pressure.

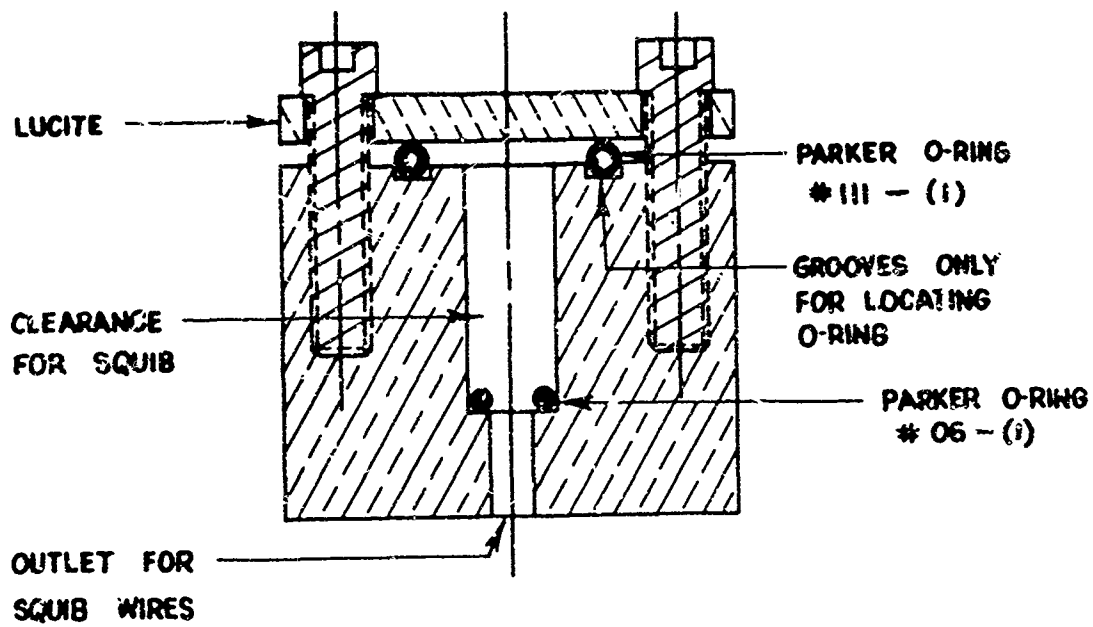


FIGURE II  
CONFINED CHAMBER



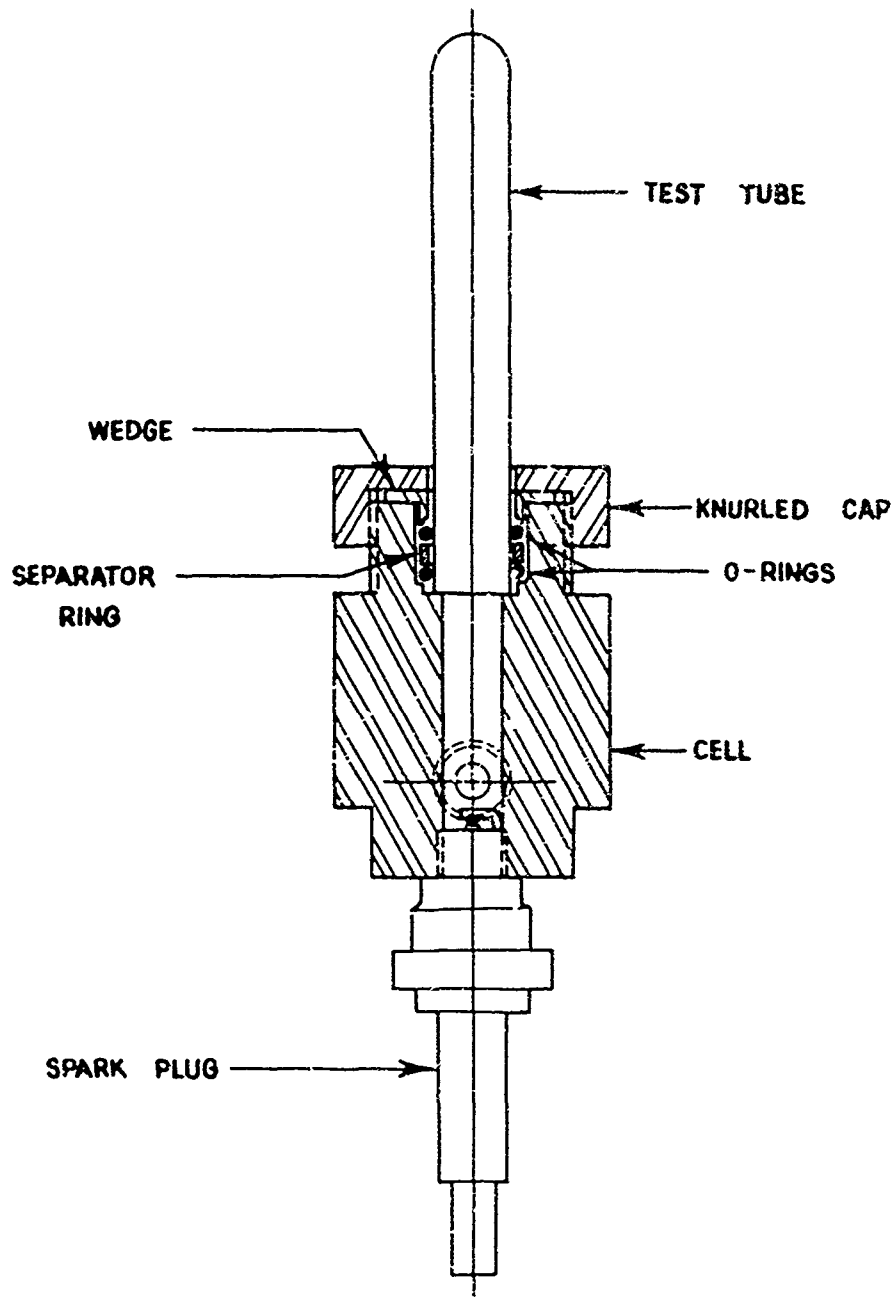


FIGURE 12  
TEST TUBE DETONATION CELL

### 3. Metal Cavity Detonation Cell

Constructed to carry out experiments at high pressures utilizing gaseous detonation systems, a fixture was fabricated as shown in Fig. 13. This unit was made of stainless steel and included windows perpendicular to the axis and also a viewing port at the end. Ignition methods included squib and spark which were facilitated by interchangeable fittings as shown in Fig. 13 and 14. Internal volume of the fixture was a cylinder 1/2" in diameter x 6" long. This fixture was used for a series of gaseous detonation systems and proved highly successful for determining both brightness temperature axially and perpendicularly to the axis, detonation velocity, and effects of pressure on the above parameters.

### 4. Lucite Tube Chambers

By adapting the test tube detonation cell block, various sizes of Lucite tubing were able to be used as confinement chambers, as shown in Fig. 15. These fixtures allowed axially perpendicular viewing of the detonation system under investigation as well as head-on observation. Also it facilitated the use of various internal diameters and lengths to be used for comparative purposes.

### 5. Slit Fixture

Figure 16 shows a drawing of the slit fixture. This apparatus was constructed at Picatinny Arsenal for the purpose of determining the detonation velocity of various gaseous detonation systems. It proved to be highly successful for this purpose. Axial observation of the detonation front was also facilitated by Lucite windows at the end. Spark ignition by an AC Type M-8 spark plug was used.

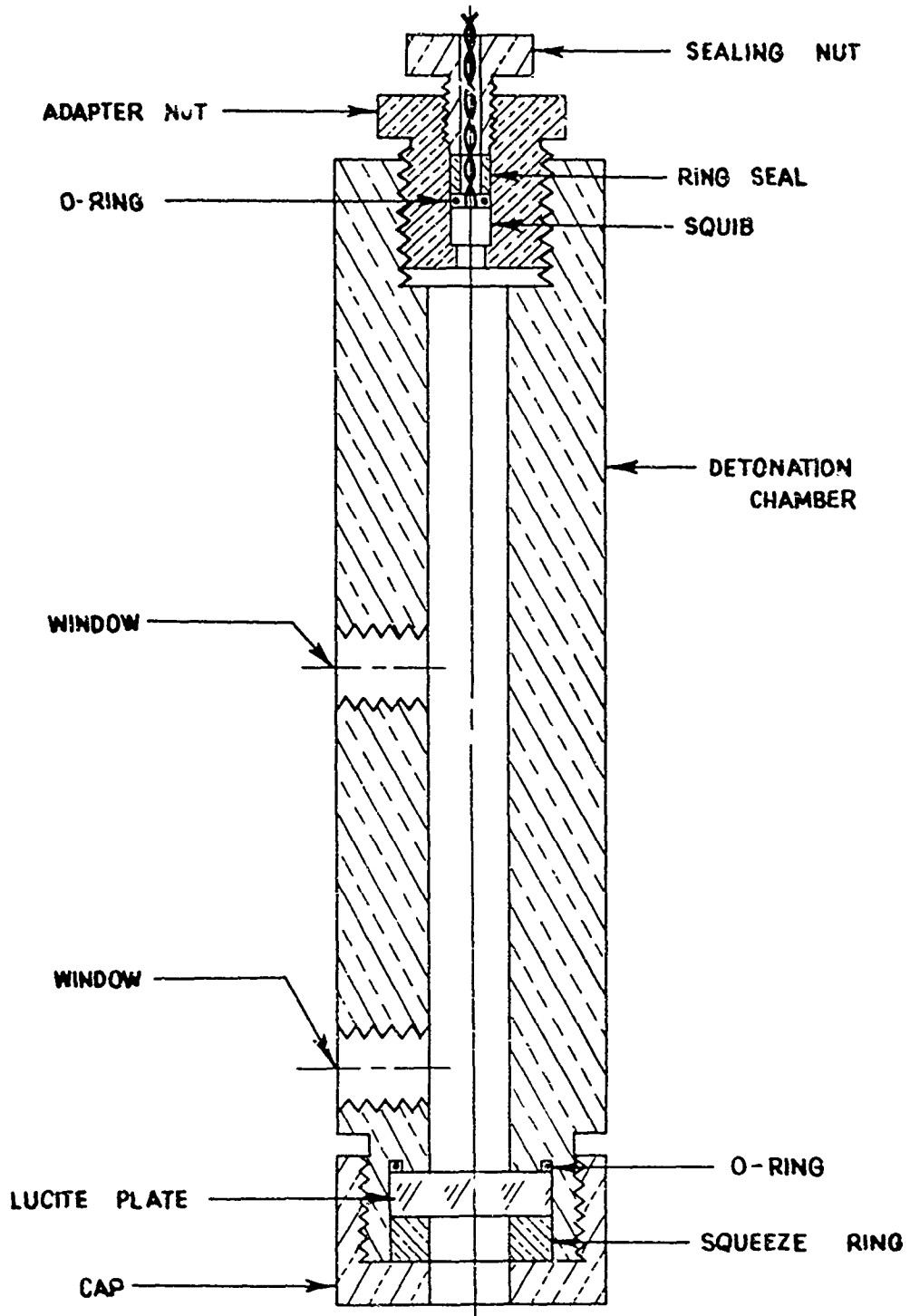


FIGURE 13  
METAL CAVITY DETONATION CELL

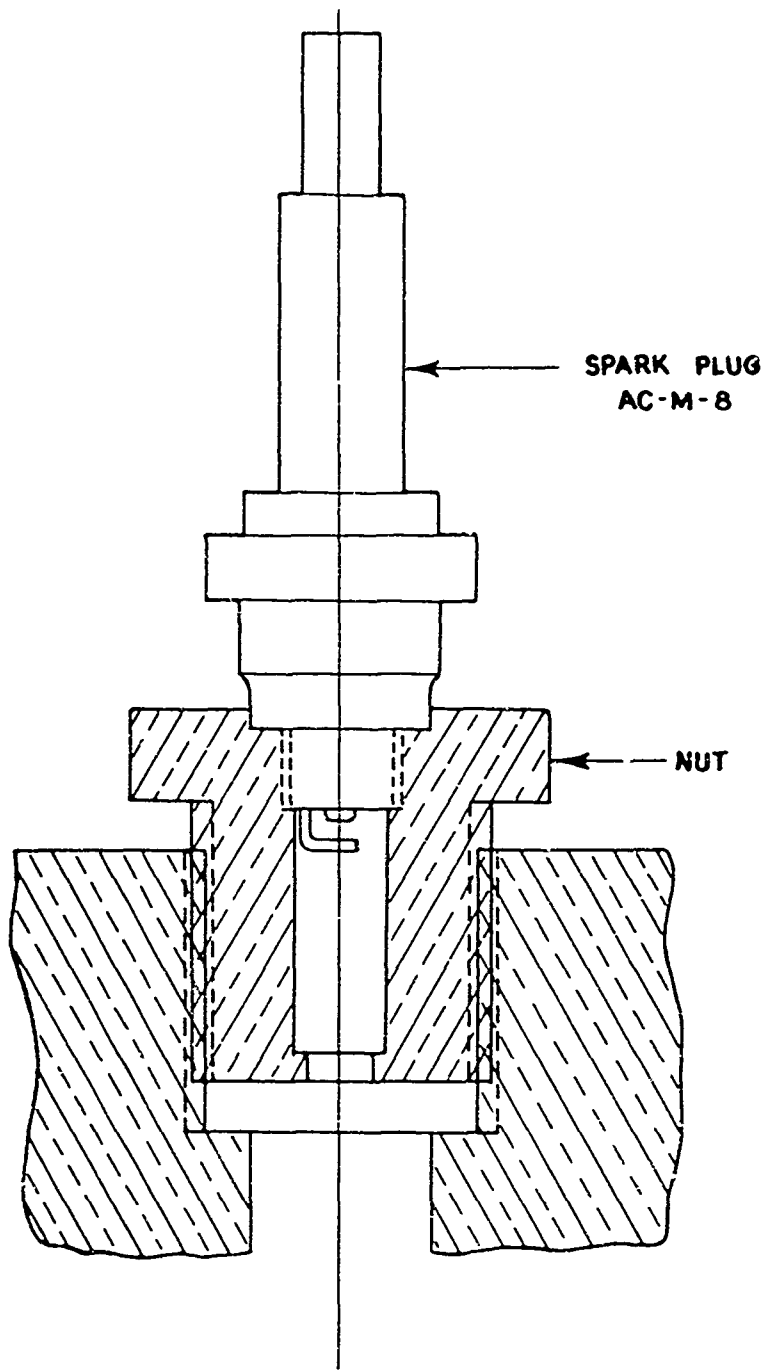


FIGURE 14  
SPARK PLUG ADAPTER

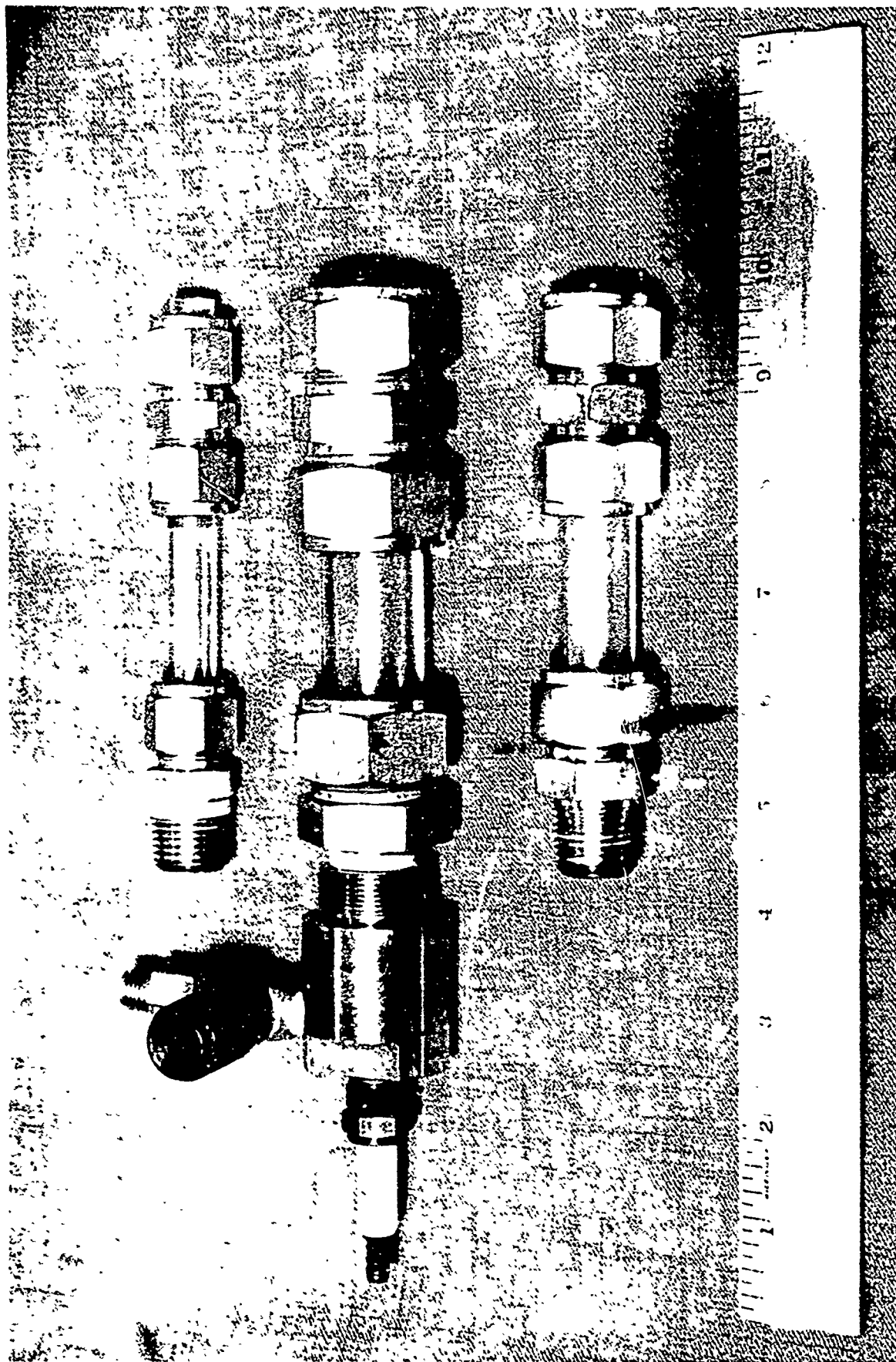


FIGURE 15  
LUCITE TUBE CHAMBER

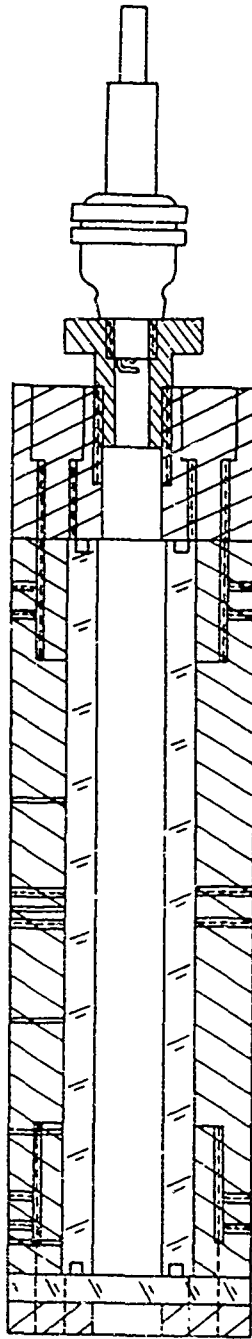


FIGURE 16  
SLIT FIXTURE

## B. PUMPING FIXTURES

### 1. Coaxial Chamber

A coaxial pumping chamber was fabricated of stainless steel and is shown in Fig. 17 and 18. This unit was used both for pumping experiments and temperature measurement and had Lucite observation windows in the side and front of the fixture. Spark ignition was facilitated by an AC Type M-8 spark plug mounted on the side or at one end. A Lucite tube, 1" in diameter and 9" long, was placed on the center axis of the fixture where either probes or a laser could be mounted.

### 2. Multi-pass Pumping Fixture

This fixture utilized the principle of passing a detonation front axis to a laser by channeling the detonation wave by means of several Lucite tubes as shown in Fig. 19. This fixture proved to be unsuccessful since in all cases the Lucite tubes were destroyed. In subsequent experiments the Lucite channel tubes were removed and a cone was placed at one end with single spark plug ignition which facilitated the axis initiated detonation front to travel past the center section of the fixture which held the laser or probe. The cone configuration is shown in Fig. 20.

### 3. "T" Pumping Fixtures

It was of interest to increase the resonance time of the detonation front with regards to the laser rod or probe. This was done by use of a "T" pumping fixture as shown in Fig. 21 and the cone ignition neck in Fig. 22. Figure 23 shows a photograph of the "T" fixture. The detonation was initiated by a single spark plug mounted in the cone

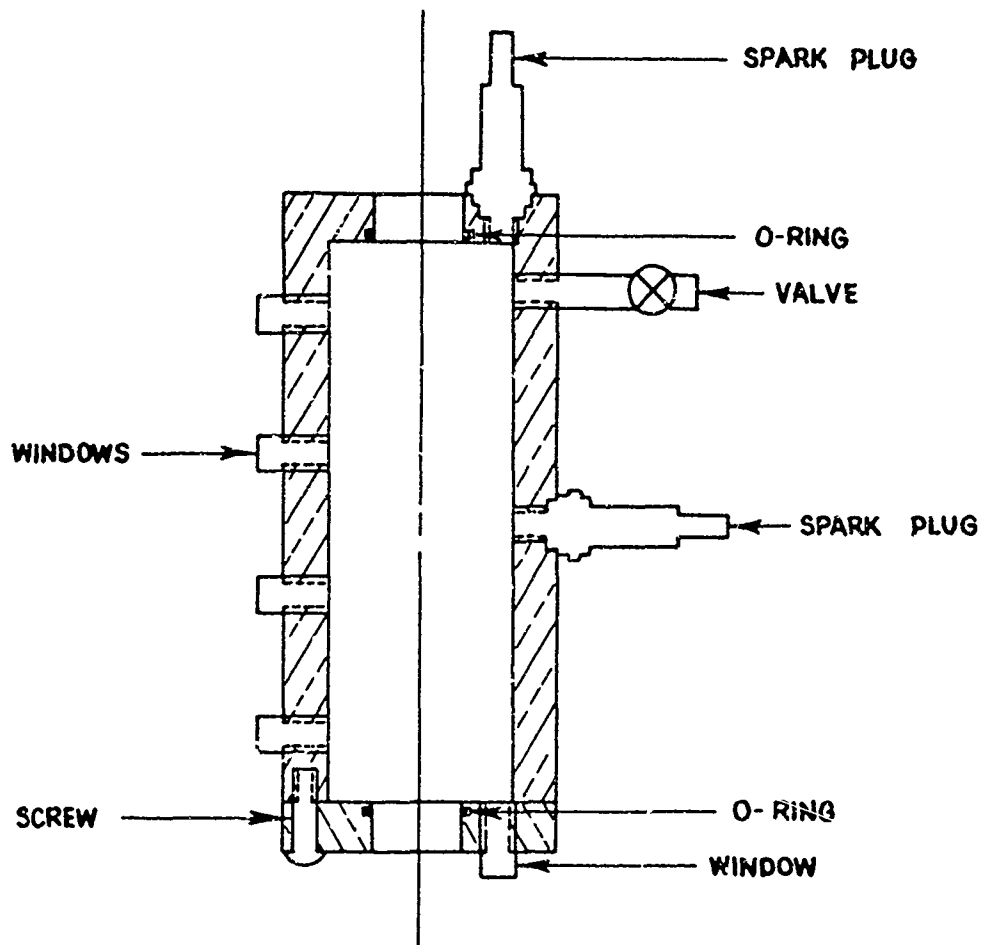


FIGURE 17  
COAXIAL CHAMBER



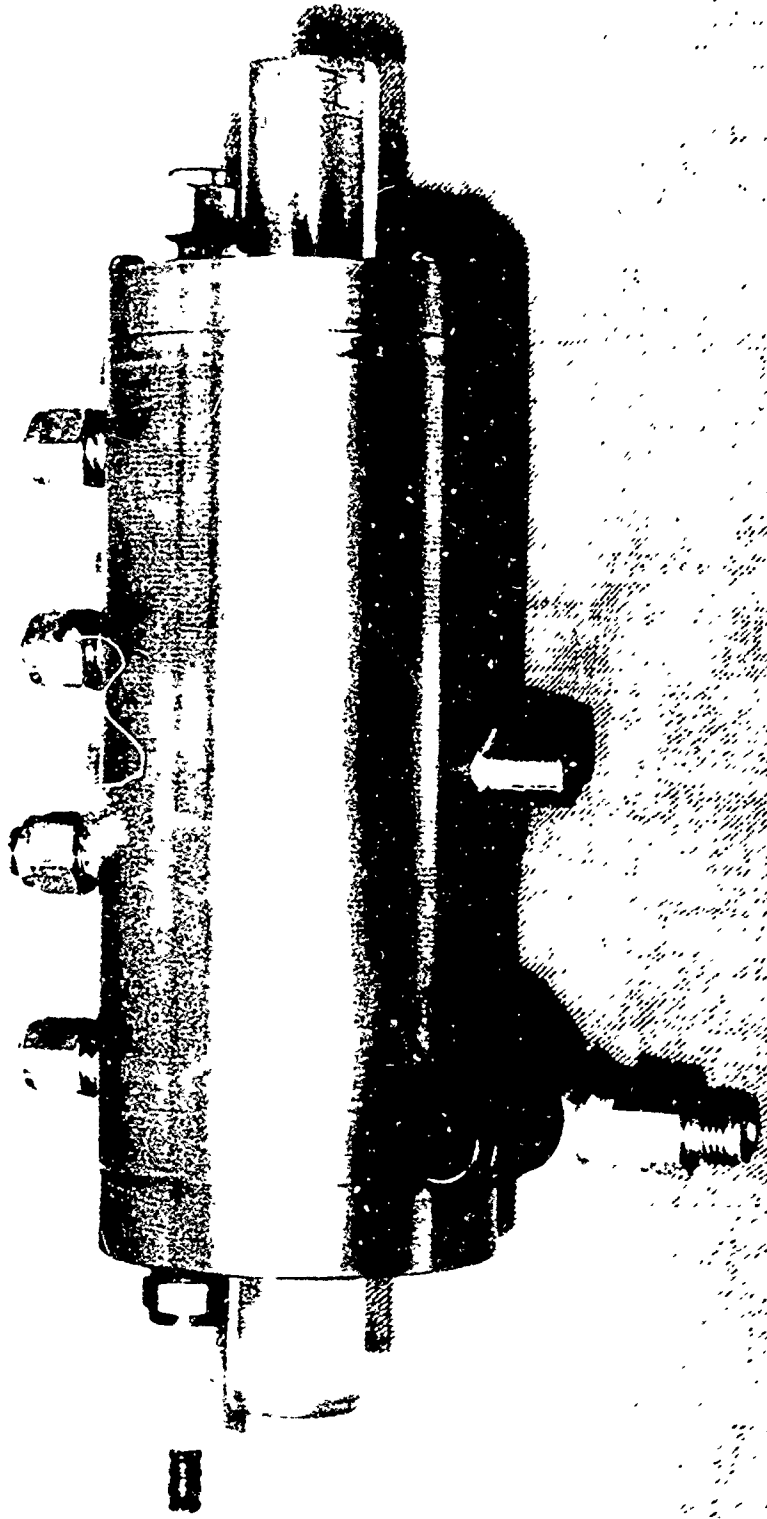


FIGURE 18  
COAXIAL CHAMBER

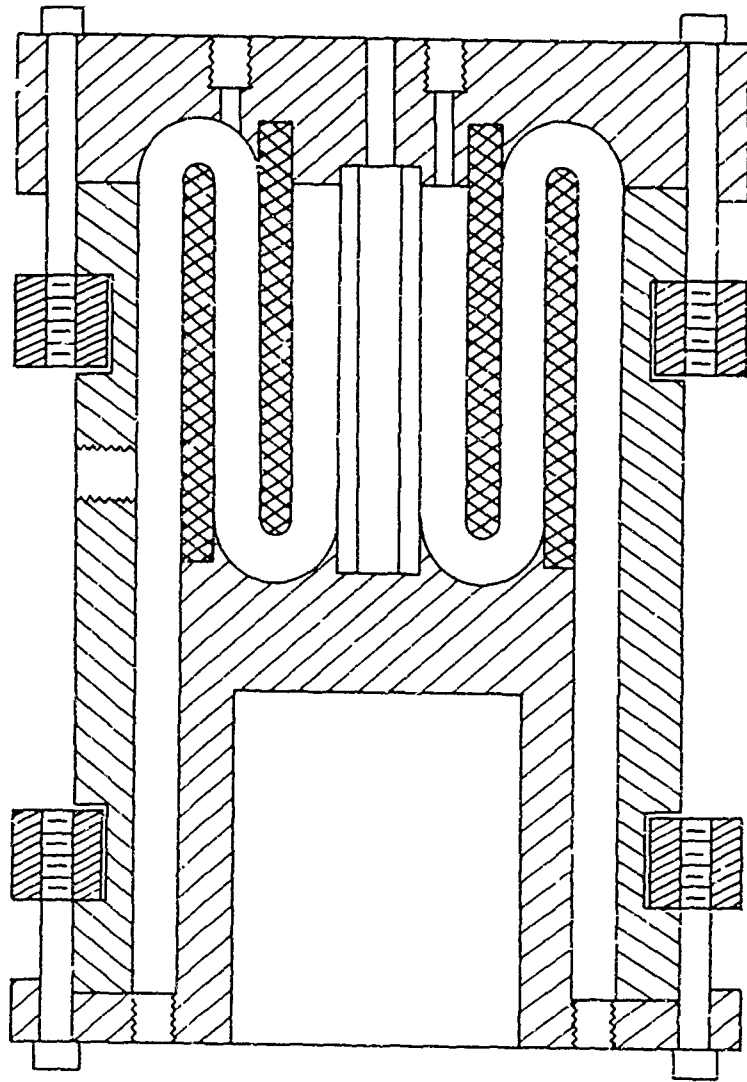


FIGURE 19  
MULTIPASS PUMPING FIXTURE

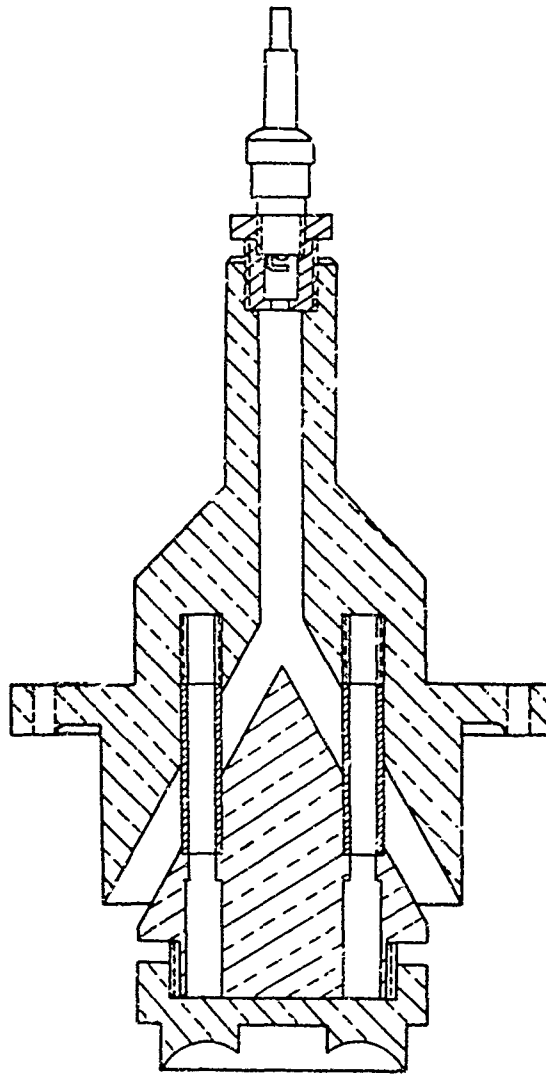


FIGURE 20  
CONE ADAPTOR, MULTIPASS PUMPING FIXTURE

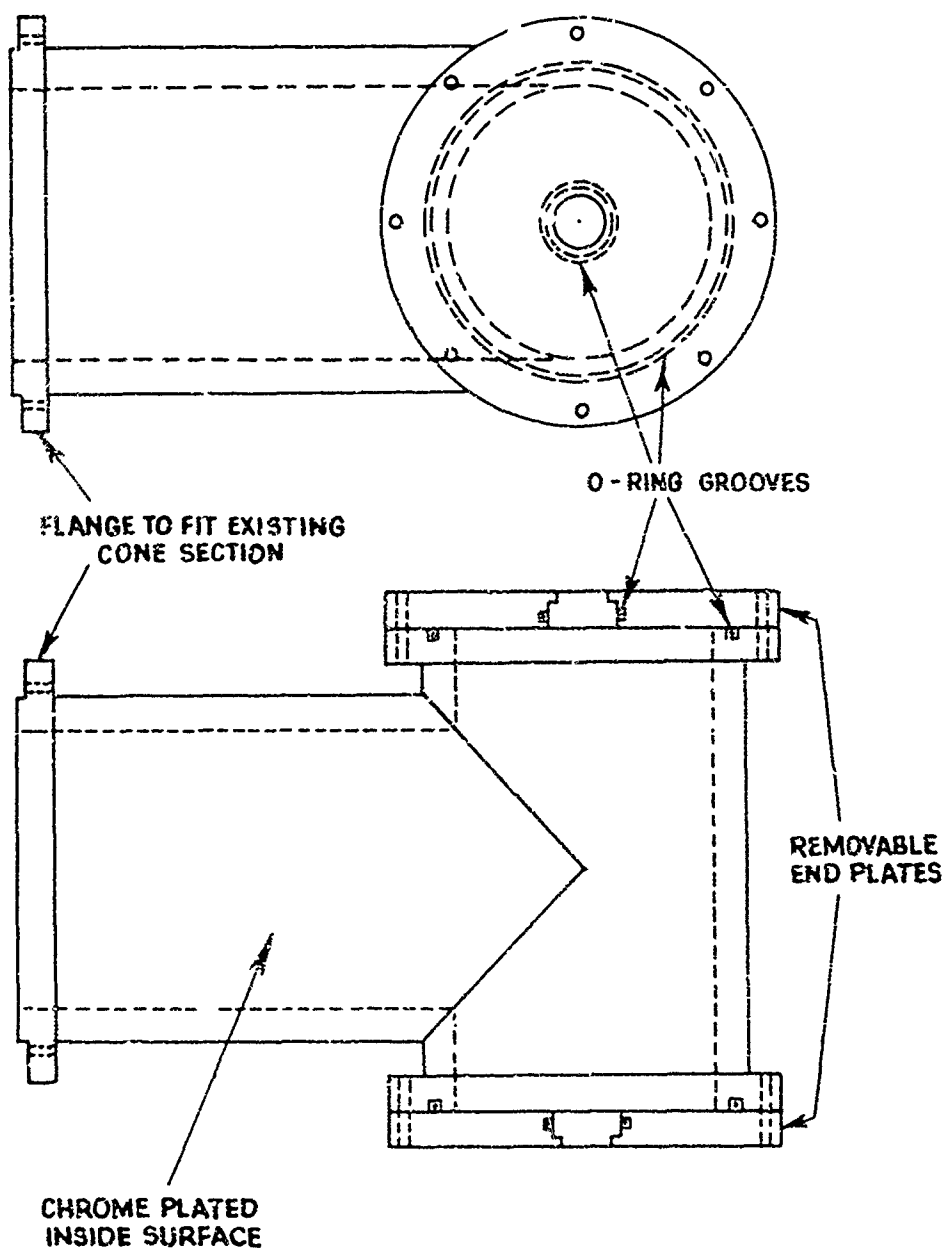


FIGURE 21  
"T" PUMPING FIXTURE

0 1 2  
INCHES

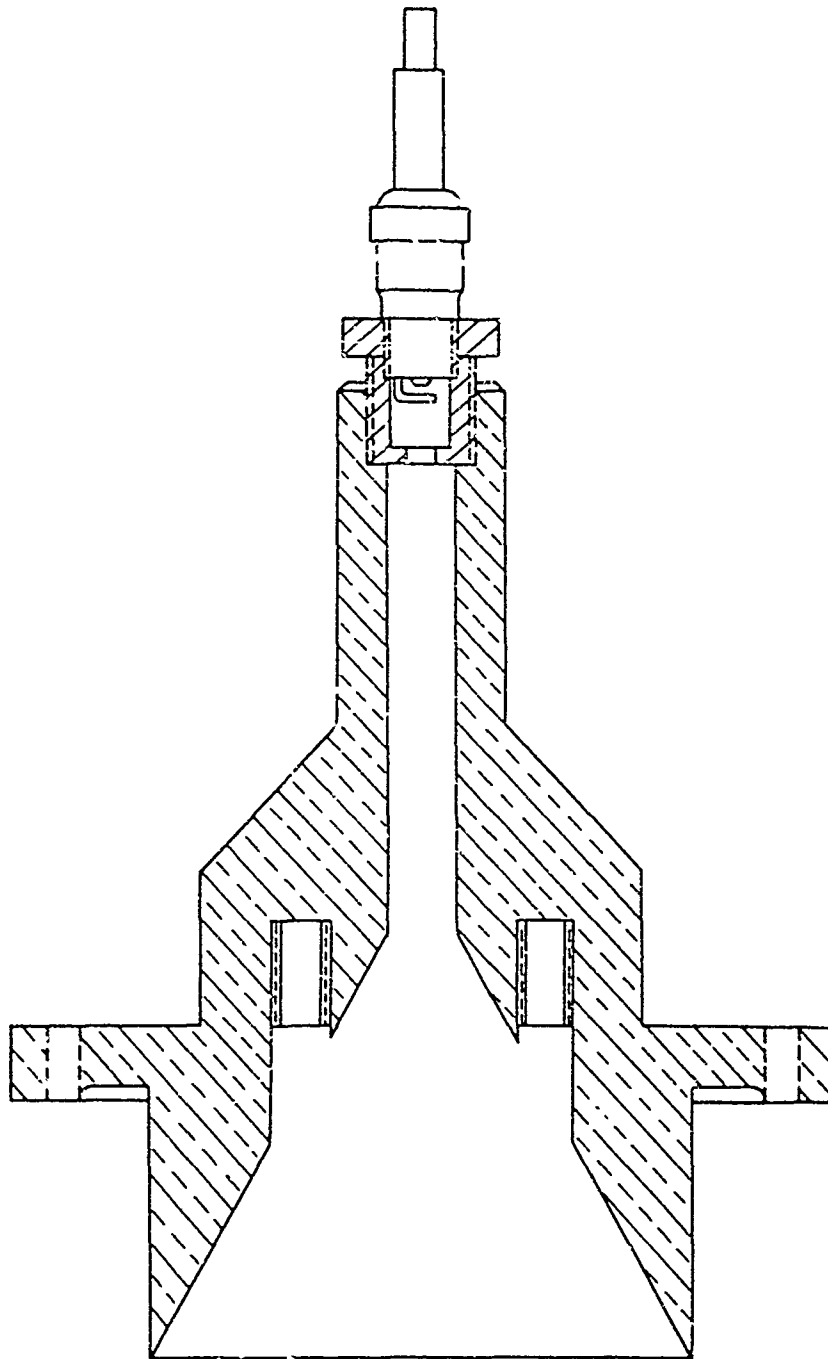


FIGURE 22  
CONE IGNITION NECK

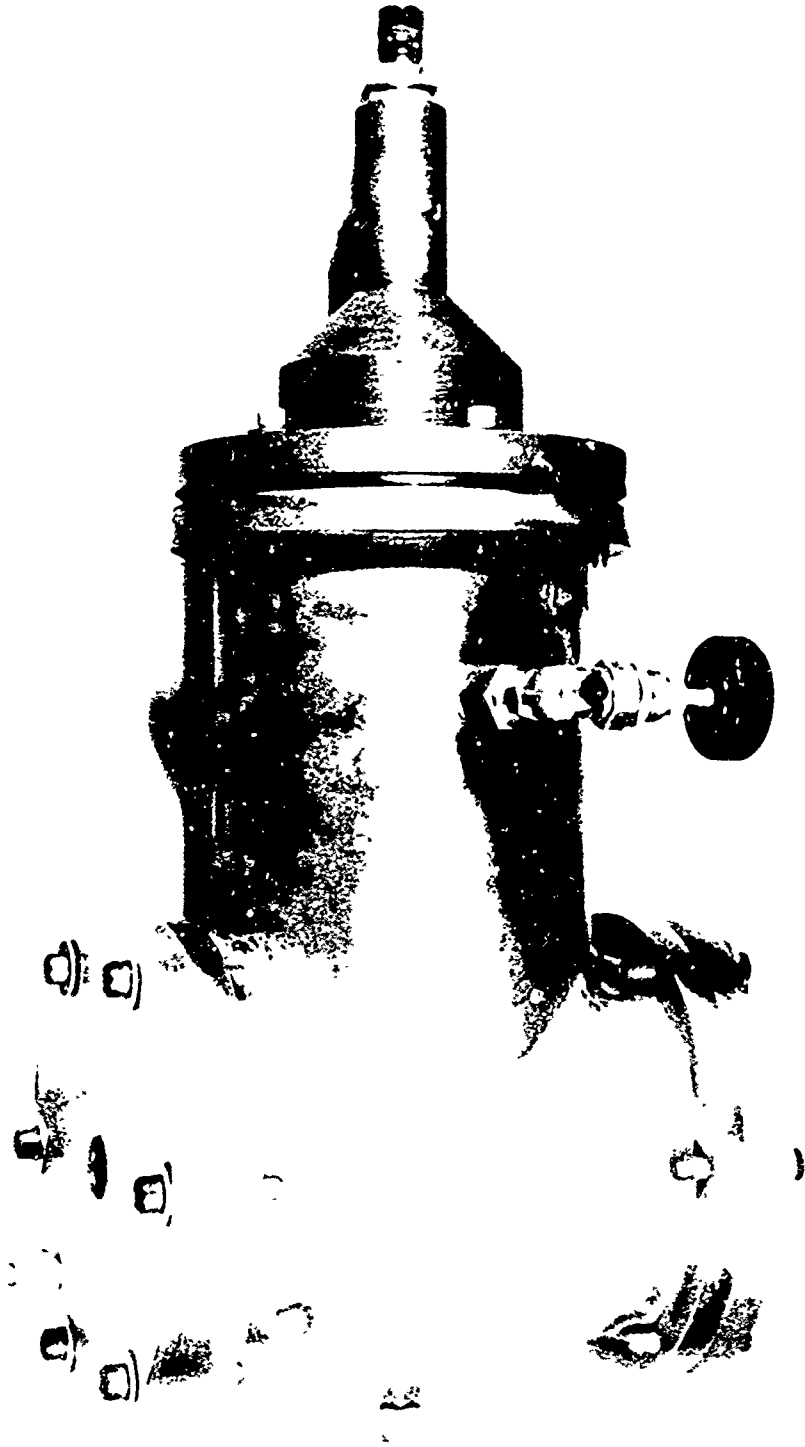


FIGURE 23  
"T" PUMPING FIXTURE

section of the multi-pass pumping fixture and this cone unit adapted to the "T" fixture. The Lucite tube holding the laser was mounted perpendicularly to the initiation point and the interior of the fixture was chrome plated and highly polished. The viewing ports for temperature determination were located at a point on the center line of the fixture and also on one end plate.

#### 4. Implosion Pumping Fixture

It was determined late in the program that a special type of fixture should be constructed for use in the pumping experiments. This fixture utilized the principle of circumferential initiation of the detonable mixture whereby the wave front would travel in towards the Lucite tube holding the laser or probe. It is shown in Figs. 24 and 25. Initiation could be accomplished by either 4, 8, or 12 M-8 spark plugs. It was also provided with rings which could expand the interior by either 1" or 2". These rings were placed on the center axis perpendicular to the Lucite tube. The interior of this fixture and its expansion rings were chrome plated and highly polished to provide most efficient light coupling.

#### C. VOLUMES OF VARIOUS FIXTURES USED

<u>Fixture</u>	<u>Vol. cc</u>	<u>Fixture</u>	<u>Vol. cc</u>
Metal Cavity	21	Implosion	1660
Coaxial	232	Implosion + 1" ring	3510
Multi-pass (no liner)	1700	Implosion + 2" ring	5460
"T"	2700		

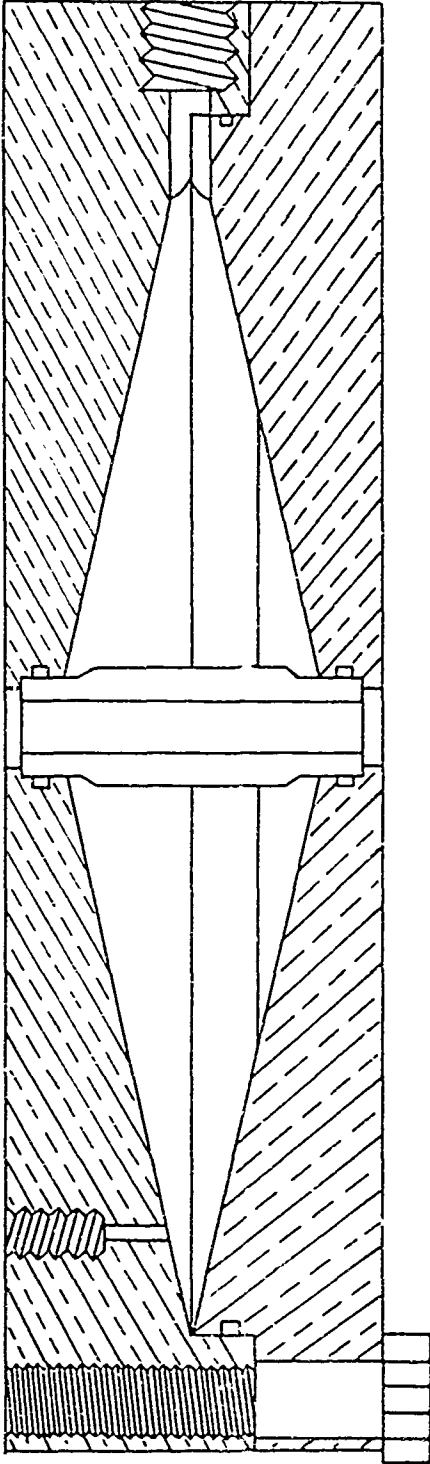


FIGURE 24  
IMPLOSION FIXTURE



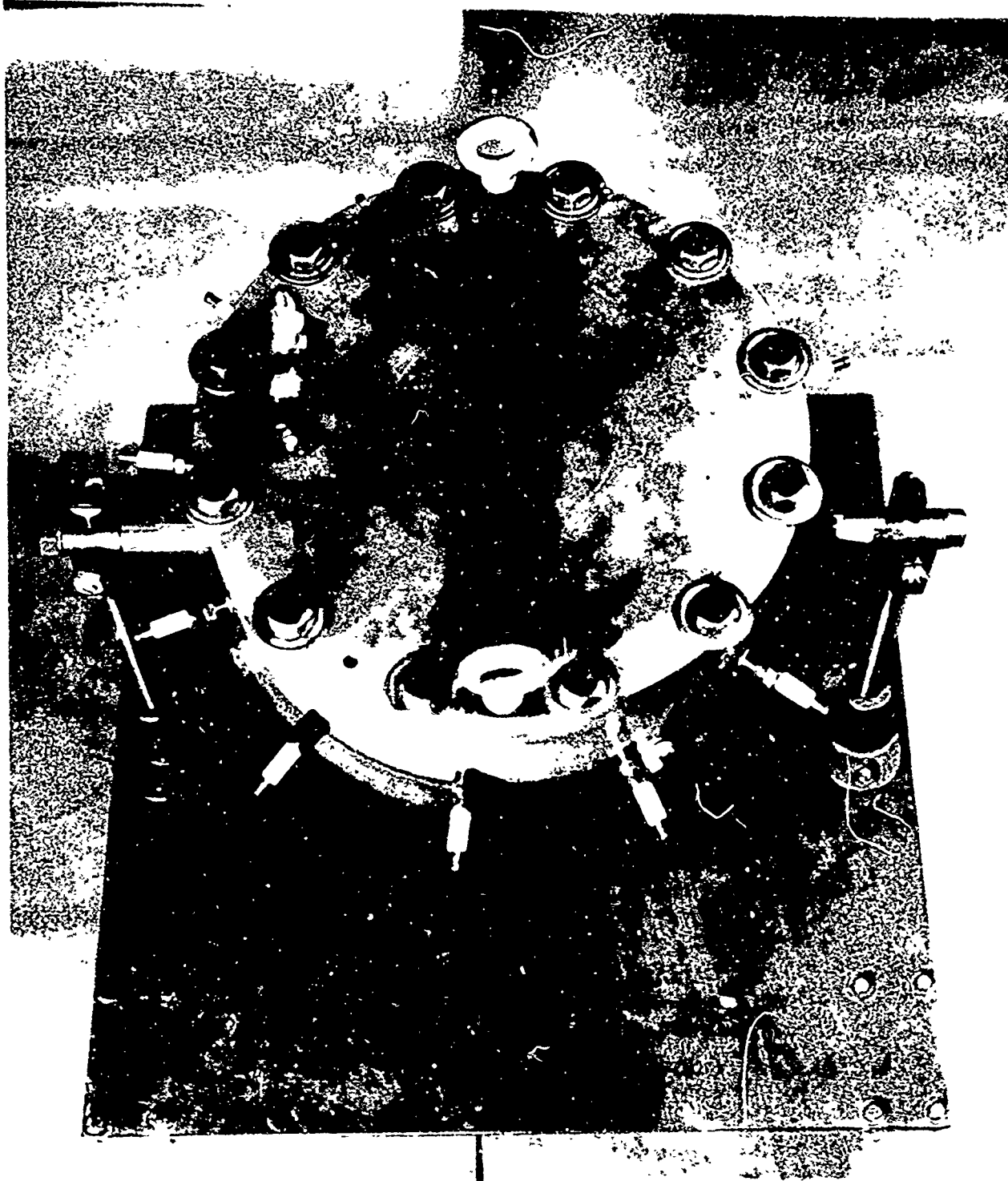


FIGURE 25  
IMPLOSION FIXTURE

#### IV. TEMPERATURE MEASUREMENT DATA

##### A. TETRACYANO ETHYLENE-POTASSIUM PERCHLORATE SYSTEM

Small amounts of tetracyano ethylene ( $C_6N_4$ ) and potassium perchlorate ( $KClO_4$ ) were ground separately to fine powders and mixed in various ratios from fuel rich to oxidizer rich. Approximately 0.1 to 0.2 grams were placed in the confined chamber as shown in Fig. 11. The mixture was ignited with either an electric match or an M1A1 squib. Of the 20 experiments carried out under varying degrees of confinement, no measurable brightness temperatures were obtained. The  $C_6N_4 - KClO_4$  system apparently does not react readily as powders.

##### B. CYANOGEN-OXYGEN SYSTEM

###### 1. Test Tube Detonation Cell Experiments

A detonation cell was fabricated as shown in Fig. 12 for use with the gaseous cyanogen-gaseous oxygen system. The cell was evacuated and then the cyanogen was admitted to a predetermined pressure. Oxygen was then added until the pressure in the cell was 1 Atm. Mixture ratios were varied from 45% to 50% cyanogen by volume. Over 100 tests were carried out. Several different types of glass tubes were used:

- a. Standard 3" long, round bottom test tube
- b. Standard 3" long test tube with bottom cut off and either 1/8" Plexiglass or 3/32" glass plate cemented on end
- c. 11" long, round bottom test tube

All tests were ignited with a spark by discharging a 5000 V. - 0.1 mfd capacitor.

The results of these experiments are shown in Fig. 26 and Table I. The maximum average brightness temperature was 6100°K at 52% C<sub>2</sub>N<sub>2</sub> for the round bottomed 3" test tubes. The maximum temperature obtained was 6400°K for a single experiment.

The flat bottomed test tubes showed an average maximum of 5520°K at 52% C<sub>2</sub>N<sub>2</sub>. The difference between the two types of tubes is probably due to the fact that the flat bottom tubes are not as strong mechanically, and, therefore, the full pressure wave is not developed. The 11" round bottom tubes did not give as high results because they burst part way from the initiator.

Typical oscillograph trace is shown in Fig. 27.

## 2. Metal Cavity Detonation Cell Experiments

Using metal cavity fixture, Fig. 13, a series of experiments were made using cyanogen-oxygen mixtures at constant composition, 52% cyanogen and 48% oxygen, and varying the initial pressures. A second series was studied holding the pressure constant at 3 Atm. and varying the composition from 40 to 60% cyanogen. The results of the constant composition experiments made at initial chamber pressures of 3, 4, and 5 Atm. are given in Table II and shown graphically in Fig. 28. Both head on and side temperature measurements were made utilizing either the Philco diode system or the 931A photomultiplier detector. These detonations were initiated by discharging 0.1 mfd capacitor charged to 5 Kv. across the spark gap. The 5 Atm. and some 4 Atm. detonations cracked the single 1/4" thick Lucite window. Subsequently, two windows were used in all remaining tests.

TEST TUBE DETONATION CELL  
INITIAL PRESSURE VS TEMP. CYANOGEN-OXYGEN SYSTEM

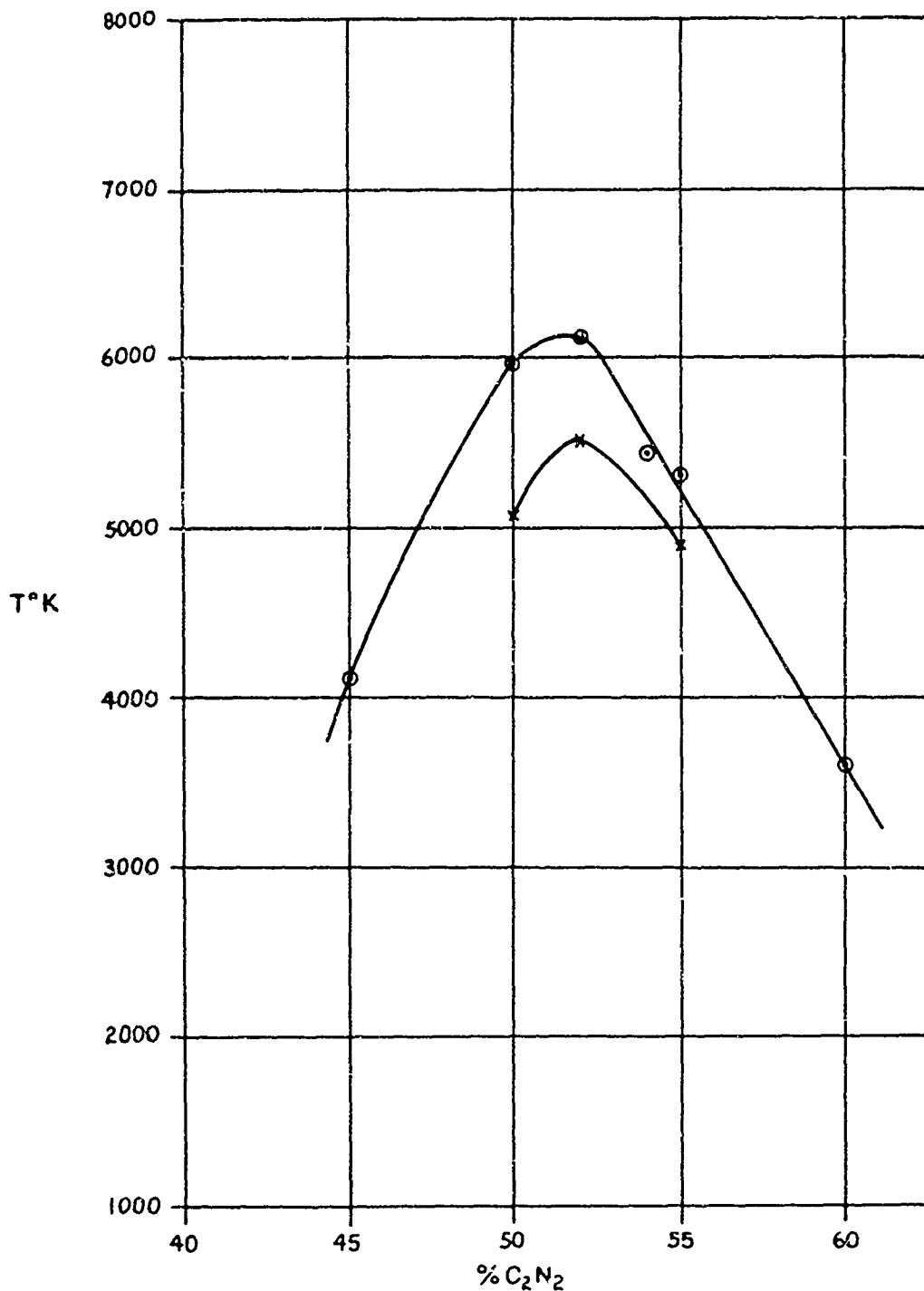


FIGURE 26

TABLE I  
TEST TUBE DETONATION CELL - (CN)2-02 DATA

<u>MIXTURE</u>	<u>P ATM</u>	<u>DETECTOR TYPE</u>	<u>IGNITION</u>		<u>VIEWING POSITION</u>	<u>T°K</u>	<u>NO. OF RUNS</u>
			<u>TYPE</u>	<u>ENERGY</u>			
45% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	4125	4
50% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	5521	14
50% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	5260	5
51% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	5836	5
52% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	6042	14
54% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	5564	15
54% C2N2	1/2	Philco L-4413	Spark	.1 ufd-5Kv	End-on	4442	5
54% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	Upright	4731	12
55% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	5204	11
60% C2N2	1	Philco L-4413	Spark	.1 ufd-5Kv	End-on	3600	2

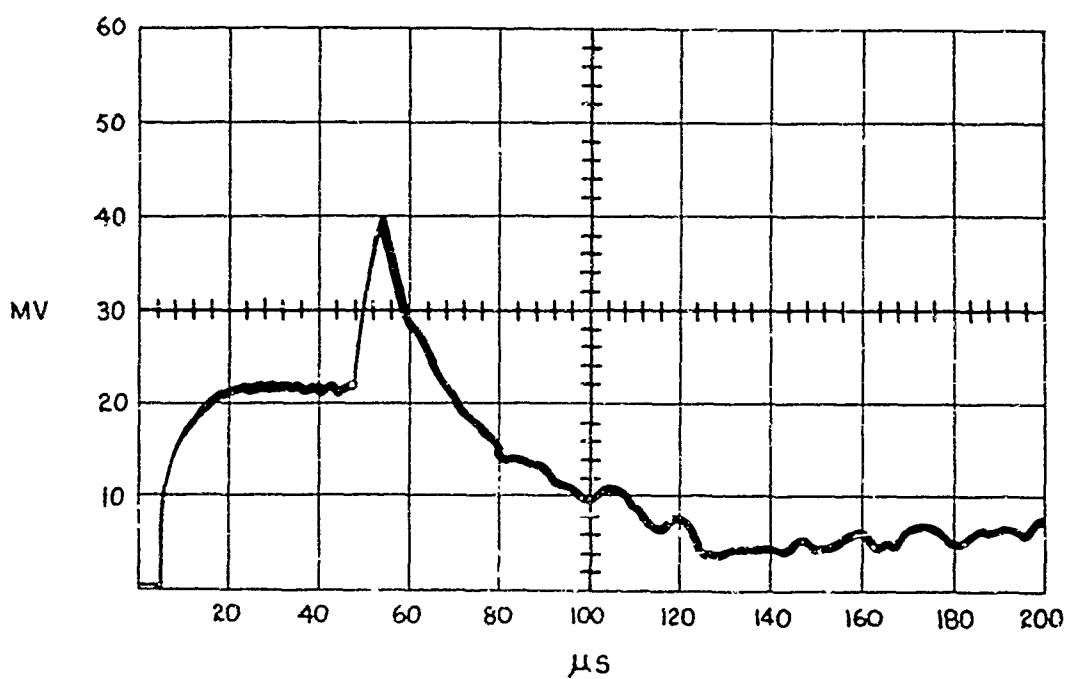


FIGURE 27  
TEST TUBE DETONATION CELL  
OSCILLOGRAM TRACE  $(CN)_2 + O_2$  SYSTEM

TABLE II

## METAL CAVITY DETONATION CELL - (CN)2-02 INITIAL PRESSURE DATA

MIXTURE	P ATM	DETECTOR TYPE	IGNITION		VIEWING POSITION	TK	NO. OF RUNS
			TYPE	ENERGY			
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco 6 931A	Spark	.1 ufd-5Kv	Head-on	6009	28
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	4	Philco	Spark	.1 ufd-5Kv	Head-on	6415	4
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	5	Philco	Spark	.1 ufd-5Kv	Head-on	6423	9
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	MLAl Sq.	-	Head-on	5960	4
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	4	Philco	MLAl Sq.	-	Head-on	6006	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	5	Philco	MLAl Sq.	-	Head-on	5970	2
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	MLAl Sq.	-	Side Front	5780	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	MLAl Sq.	-	Side Midway	556C	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	90-10 Sq.	-	Head-on	6205	2
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	4	Philco	90-10 Sq.	-	Head-on	6200	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	90-10 Sq.	-	Side Front	5920	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	90-10 Sq.	-	Side Midway	5640	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	3	Philco	XM-70 Det.	-	Head-on	5843	9

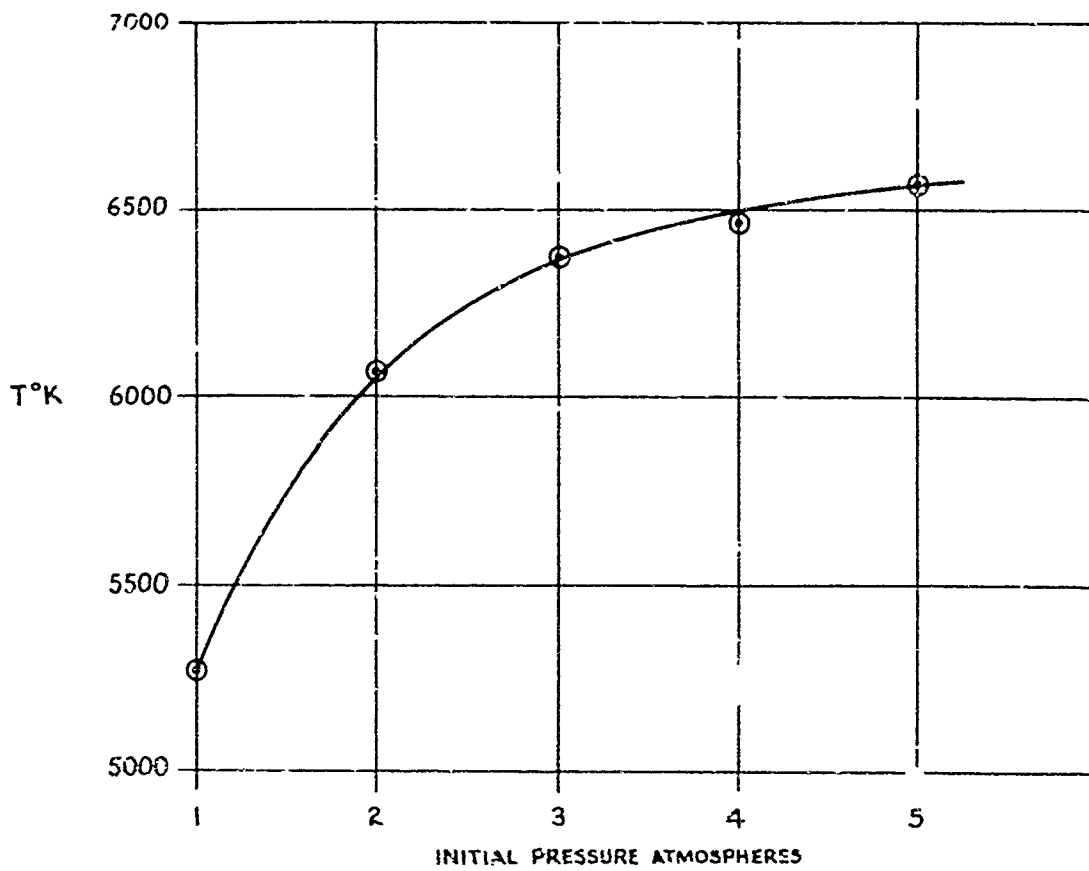


FIGURE 28  
METAL CAVITY DETONATION CELL  
INITIAL PRESSURE VS TEMP.  $(CN)_2 + O_2$  SYSTEM



As can be seen from Fig. 28, the optimum pressure range for the cyanogen-oxygen detonation using the metal cavity type fixture is from 3 to 5 Atm.; an increase of approximately 200° is achieved by raising the pressure from 3 to 5 Atm.; however, raising the pressure from 1 to 3 Atm. increases the temperature approximately 1100°K showing, therefore, that this system should be run at pressures greater than 3 Atm. for maximum brightness temperature. The 1 and 2 Atm. data was taken on the test tube detonation cell described in the previous section.

A second series of runs were made using the metal cavity fixture and varying the constants of the reactants from 40 to 60% cyanogen. The results of these tests are given in Table III and shown in Fig. 29.

As can be seen from Fig. 29, the maximum temperature is produced at 52% cyanogen - 48% oxygen for the head on view and approximately 51.5% cyanogen - 48.5% oxygen for the side view. These results coincide with those reported above using the test tube detonation cell fixture.

### 3. Squib and Detonator Initiated Detonations

Squib initiation of cyanogen-oxygen mixtures at pressures up to 5 Atm. were also carried out utilizing the same metal cavity chamber. For these experiments the adapter-fitting containing the spark plug was removed and a special squib holder fitting inserted (see Fig. 13). The squib itself was initiated with a 6.3 volt, 10 amp. filament transformer. Twenty-three runs were made - 5 using a 90-10 squib; 9 using an M1A1; and 9 using an XM-70 detonator (see Table II). In all cases the cyanogen-oxygen mixture (52% cyanogen) was initiated and gave brightness temperatures

TABLE III

## METAL CAVITY DETONATION CELL - (CN)2-O2 MIXTURE RATIO DATA

MIXTURE	P ATM	DETECTOR TYPE	TYPE	IGNITION ENERGY	VIEWING POSITION	T°K	NO. OF RUNS
40% C <sub>2</sub> N <sub>2</sub> + 60% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	4765	3
45% C <sub>2</sub> N <sub>2</sub> + 55% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	5019	4
47.5% C <sub>2</sub> N <sub>2</sub> +52.5% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	6175	1
50% C <sub>2</sub> N <sub>2</sub> + 50% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	5942	4
52.5% C <sub>2</sub> N <sub>2</sub> +47.5% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	6500	1
55% C <sub>2</sub> N <sub>2</sub> + 45% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	6200	1
57.5% C <sub>2</sub> N <sub>2</sub> +42.5% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	6125	1
60% C <sub>2</sub> N <sub>2</sub> + 40% O <sub>2</sub>	3	931A	Spark	.1 ufd-5000V	Head-on	4650	1
40% C <sub>2</sub> N <sub>2</sub> + 60% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	4800	3
45% C <sub>2</sub> N <sub>2</sub> + 55% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	4657	4
47.5% C <sub>2</sub> N <sub>2</sub> +52.5% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	5580	1
50% C <sub>2</sub> N <sub>2</sub> + 50% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	5735	4
52.5% C <sub>2</sub> N <sub>2</sub> +47.5% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	5710	1
55% C <sub>2</sub> N <sub>2</sub> + 45% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	5350	2
57.5% C <sub>2</sub> N <sub>2</sub> +42.5% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	5320	1
60% C <sub>2</sub> N <sub>2</sub> + 40% O <sub>2</sub>	3	Philco	Spark	.1 ufd-5000V	Side	4560	1

METAL CAVITY DETONATION CELL  
TEMPERATURE VS % CYANOGEN, CYANOGEN-OXYGEN SYSTEM

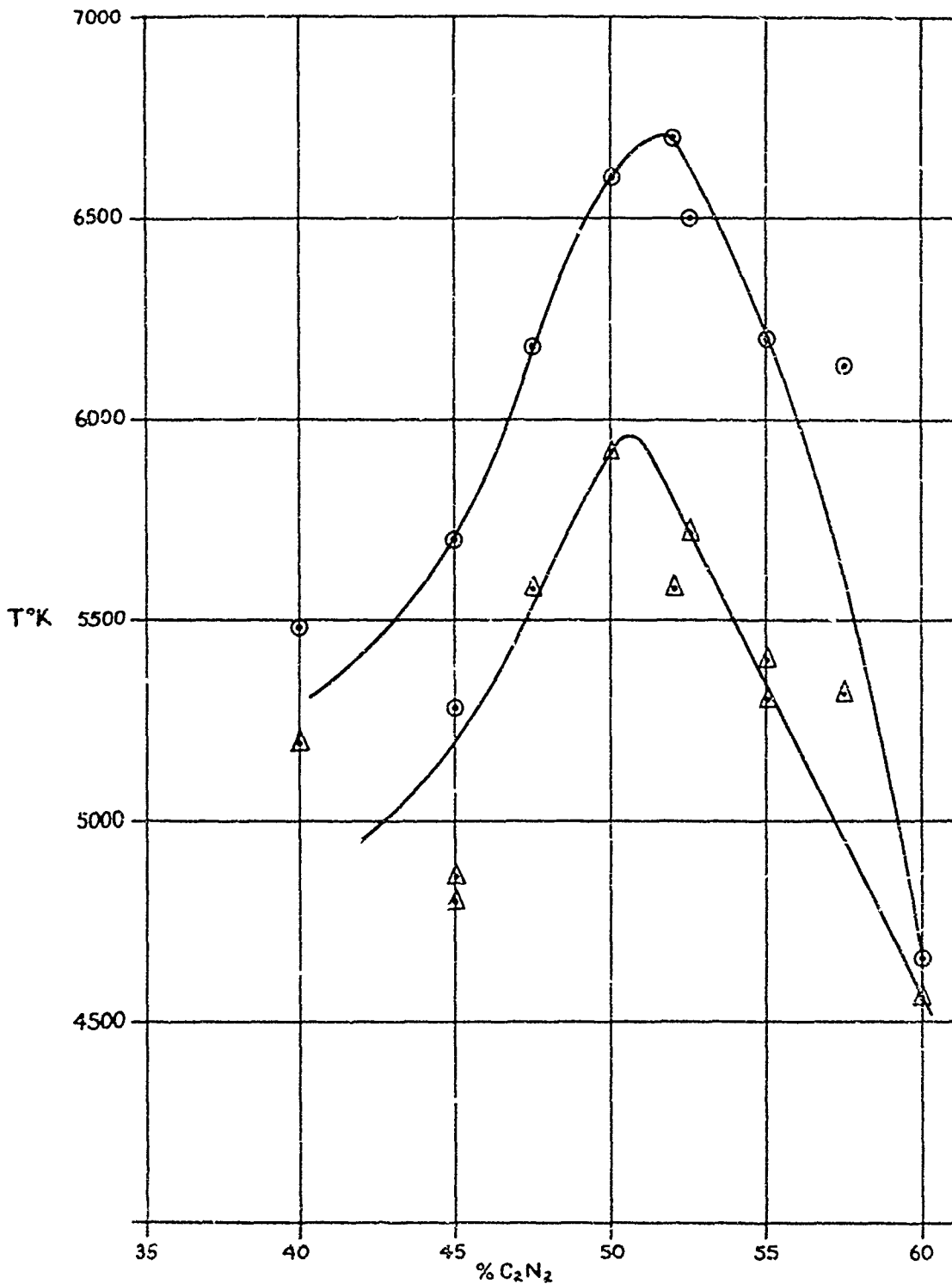


FIGURE 29

similar to those of the spark initiation series. Initial pressures were either 3 or 4 Atm. The average temperature achieved at 3 Atm. was 6150°K. It should be noted that no difference was seen by the use of the two different squib initiators or the XM-70 detonator. Squib initiation is entirely feasible for the gaseous nitrogen-oxygen system as is XM-70 detonator ignition.

#### 4. Lucite Tube Confinement

The purpose of these experiments was to determine the minimum wall thickness and diameter necessary to confine the detonation in Lucite so that later determinations of the high temperature zone could be made. Swagelok fittings were used to hold the Lucite tube to the stainless steel block which was equipped with a spark plug and a filling valve. A clear Lucite window was attached to the end of the tube by use of Swagelok union and nuts (see Fig. 15). Two detectors were used in some of these tests, looking at both the front and the side of the tube. The spark was used for initiation. The results are tabulated and presented in Table IV.

As can be seen in Table IV, the 1/2" OD by 1/4" ID tubes gave burning and no detonations. In one 5 Atm. run, 6600°K was realized; however, the tube shattered and this experiment could not be repeated in subsequent tries where only burning took place. The 3/4" OD by 3/8" ID tube at 3 Atm. initial pressure gave an average temperature of 5820°K which is about 500°K low for this initial pressure in earlier experiments. Therefore, a 1" OD by 1/2" ID tube was used and in this case the detonation gave a temperature of 6300°K for an initial pressure of 3 Atm.

TABLE IV  
LUCITE TUBE CONFINEMENT USING 52% C<sub>2</sub>N<sub>2</sub>-48% O<sub>2</sub>

<u>Tube Size (in.)</u>		<u>Length (in.)</u>	<u>Initial Pressure Atm.</u>	<u>Ave. Temp. °K (582 mu) Head-on View</u>
<u>OD</u>	<u>ID</u>			
0.5	0.25	6	3	No detonation, burning
			4	No detonation, burning
			5	6600°K tube shattered on detonation or burning
0.75	0.375	6	3	5820
1.00	0.5	6	3	6300
			4	6600 (tube shattered)
			5	6720 (tube shattered)
1.00	0.5	12	3	5900 (tube shattered)

repeatedly. At both 4 and 5 Atm. initial pressure, although the theoretical temperatures were realized, the tube shattered in both cases in all of the experiments tried. It was of interest to determine whether a long tube of 1" OD by 1/2" ID could be used for this containment. It was found repeatedly that a 12" long tube of the above dimensions shattered upon detonation of the mixture and the highest temperature realized was 5900°K.

#### 5. Coaxial Tube Experiments

Since brightness temperatures in excess of 6300°K have been shown to be possible using the gaseous cyanogen-oxygen system, a laser pumping fixture was constructed. Figure 17 shows the detonation cell. The inside diameter of the fixture is 2" and the length is 6". A 1" OD Lucite tube is inserted axially in the fixture leaving a 1/2" circumferential space for the detonating mixture. Two spark plug positions are possible and 4 side windows and 1 front window are included for brightness temperature measurements. The results of several runs are given in Table V. A photograph of the coaxial fixture is shown in Fig. 18.

TABLE V

COAXIAL TUBE EXPERIMENTS USING 52% C<sub>2</sub>N<sub>2</sub>-48% O<sub>2</sub>

Spark Initiated from Rear at 3 Atm. Initial Pressure

<u>Position</u>	<u>Temperature °K</u>	<u>Wave Length of Determination</u>
Front window	6700	582
Front window	6680	582
Front window	6300*	582
1st side window from front	6180	550
	5940	550
	5400*	550

\*Lucite tube broke

Although more experiments must be carried out, the temperatures obtained with this fixture configuration are very encouraging. The temperatures measured from the side are approximately 5% lower than those measured at the front. This is discussed in the next section.

#### 6. Comparison of Axial and Axially Perpendicular Brightness Temperature

Measurements were made of the axially perpendicular or side brightness temperature of the cyanogen-oxygen detonation using the metal cavity detonation cell (Fig. 13), Lucite detonation cell (Fig. 15) and the coaxial detonation cell (Fig. 17). Table VI compares the experimentally determined averaged brightness temperatures observed axially and axially perpendicular using the above fixtures.

TABLE VI

COMPARISON OF AXIAL AND AXIALLY PERPENDICULAR BRIGHTNESS

Temperatures of the 52% C<sub>2</sub>N<sub>2</sub>-48% O<sub>2</sub> System  
at 3 Atm. Initial Pressure

<u>Fixture</u>	<u>Axial Temp.</u>	<u>Axially Perp. Temperature</u>	<u>Side Observation Point</u>		
Metal Cavity (Fig. 13)	6100°K	5850°K	1st window from front		
		5600°K	3rd window from front		
Lucite Tube (Fig. 15) 1" OD x 1/2" ID					
		6" long	6320°K	6260°K	1" from front
		12" long	5870°K	5600°K	1" from front
Coaxial Cell (Fig. 17)	6690°K	6060°K	3/4" from front		

As can be seen from Table VI, all temperatures measured from the side are lower than those of the front. It should be noted that attempts were made to measure the width of the luminous zone. These experiments showed that the highly luminous reaction zone is very thin, 1 millimeter or less; however, a luminous zone exists behind the reaction front, the intensity of which diminishes slowly with the distance from the wave front. This zone is approximately 4 centimeters long. The measurement of the side brightness temperatures are not entirely accurate since this zone does not "fill" the observation window totally at any instant. This problem is not entirely resolved at this writing and requires additional investigation.

### C. CYANOGEN-OXYGEN INERT SYSTEMS

#### 1. Cyanogen-Oxygen-Argon System

Experiments were carried out using mixtures of cyanogen-oxygen-argon at pressures of 3 to 5 Atm. initial pressure. The amount of argon in the system was varied from 5% to 40%. The results of these experiments show that temperatures as high as 74-75°K could be obtained by initiating the mixture with a spark in the metal cavity fixture. The dependence of the temperature of the percent argon added is evident from the plot shown in Fig. 30. Both the head-on and the side temperature were measured and the maximum temperature of approximately 7900°K was obtained at 20% argon. It should be noted that the data plotted in Fig. 30 represents the maximum temperatures measured in any one experiment and Table VII lists the average values over a series of experiments.



METAL CAVITY DETONATION CELL  
TEMPERATURE VS % Ar (CN)<sub>2</sub> + O<sub>2</sub> + Ar SYSTEM

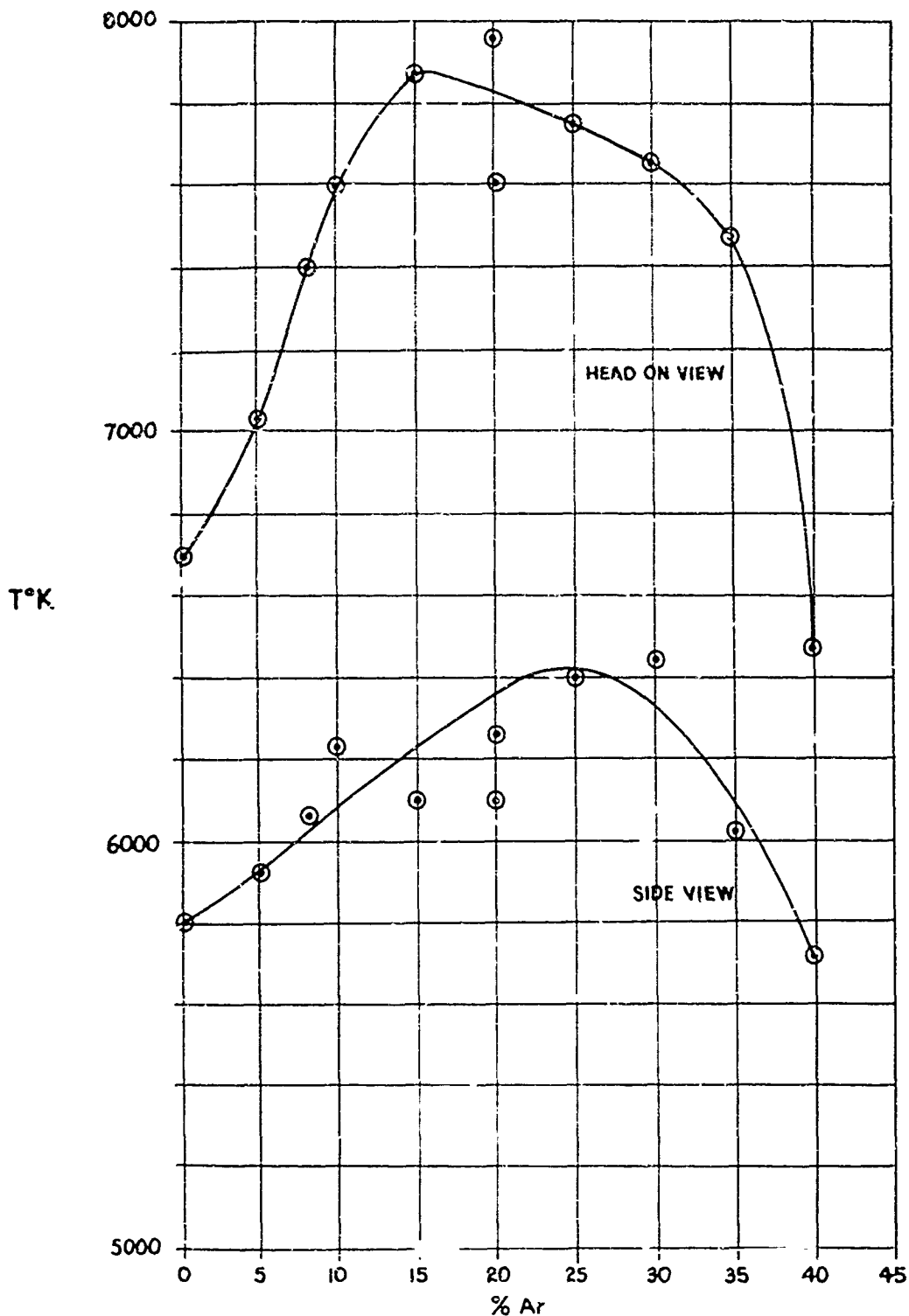


FIGURE 30

TABLE VII

## METAL CAVITY DETONATION CELL (CN)2-02-AR DATA

MIXTURE	P ATM	DETECTOR TYPE	IGNITION		VIEWING POSITION	T°K	NO. OF RUNS
			TYPE	ENERGY			
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 5% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	6300	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 8% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	6300	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 10% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	7240	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 13% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	7100	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 15% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	6912	9
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 20% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	6980	3
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 30% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	6320	1
52% C <sub>2</sub> N <sub>2</sub> + 49% O <sub>2</sub> + 40% Ar	3	931A	Spark	.1 ufd-5Kv	Head-on	5840	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 5% Ar	3.16	931A	Spark	.1 ufd-5Kv	Head-on	7025	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 8% Ar	3.26	931A	Spark	.1 ufd-5Kv	Head-on	7400	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 10% Ar	3.33	931A	Spark	.1 ufd-5Kv	Head-on	6840	4
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 15% Ar	3.53	931A	Spark	.1 ufd-5Kv	Head-on	6916	9
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 20% Ar	3.75	931A	Spark	.1 ufd-5Kv	Head-on	6997	18
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 25% Ar	4	931A	Spark	.1 ufd-5Kv	Head-on	7212	2
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 30% Ar	4.29	931A	Spark	.1 ufd-5Kv	Head-on	7210	3
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 35% Ar	4.62	931A	Spark	.1 ufd-5Kv	Head-on	7475	1
52% C <sub>2</sub> N <sub>2</sub> + 40% O <sub>2</sub> + 40% Ar	5	931A	Spark	.1 ufd-5Kv	Head-on	6475	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 20% Ar	3.75	931A	XM-70Dt.	-	Head-on	5550	4

## 2. Cyanogen-Oxygen-Helium System

Similar experiments were run using the cyanogen-oxygen-helium system as those in 1 above and these showed a maximum temperature of 8000°K at 15% helium, as shown in Fig. 31. The data for these runs is listed in Table VIII.

## 3. Cyanogen-Oxygen-Xenon System

Similar experiments were carried out using cyanogen-oxygen-xenon mixtures as in 1 and 2 above. The data generated from these experiments is listed in Table IX and shows a maximum temperature of 7640°K at 30% xenon.

## 4. Discussion of Cyanogen-Oxygen-Inert Systems

It was not clearly understood at the time the experiments were run just why higher temperatures were obtained using the inerts as diluents in the cyanogen-oxygen detonation than those temperatures measured using the cyanogen-oxygen system alone. Further investigation of the data showed that a very long induction time, that is, the time from the initial spark to the first detection of light, was measured using the diluent systems. These induction times for argon are shown in Figs. 32 and 33 and for helium in Figs. 34 and 35. As can be seen from these curves, Fig. 32 head-on view and Fig. 33 side view, that the induction time varies nearly linearly with the percent argon dilution. Likewise, for helium, Fig. 34 head-on view and Fig. 35 side view, show the same result and are somewhat more linear than the argon results.

Upon reviewing the literature and the experimental data, it was determined that the high temperatures were produced by the production of

METAL CAVITY DETONATION CELL  
TEMPERATURE VS % He  $(CH)_2 + O_2 + He$  SYSTEM

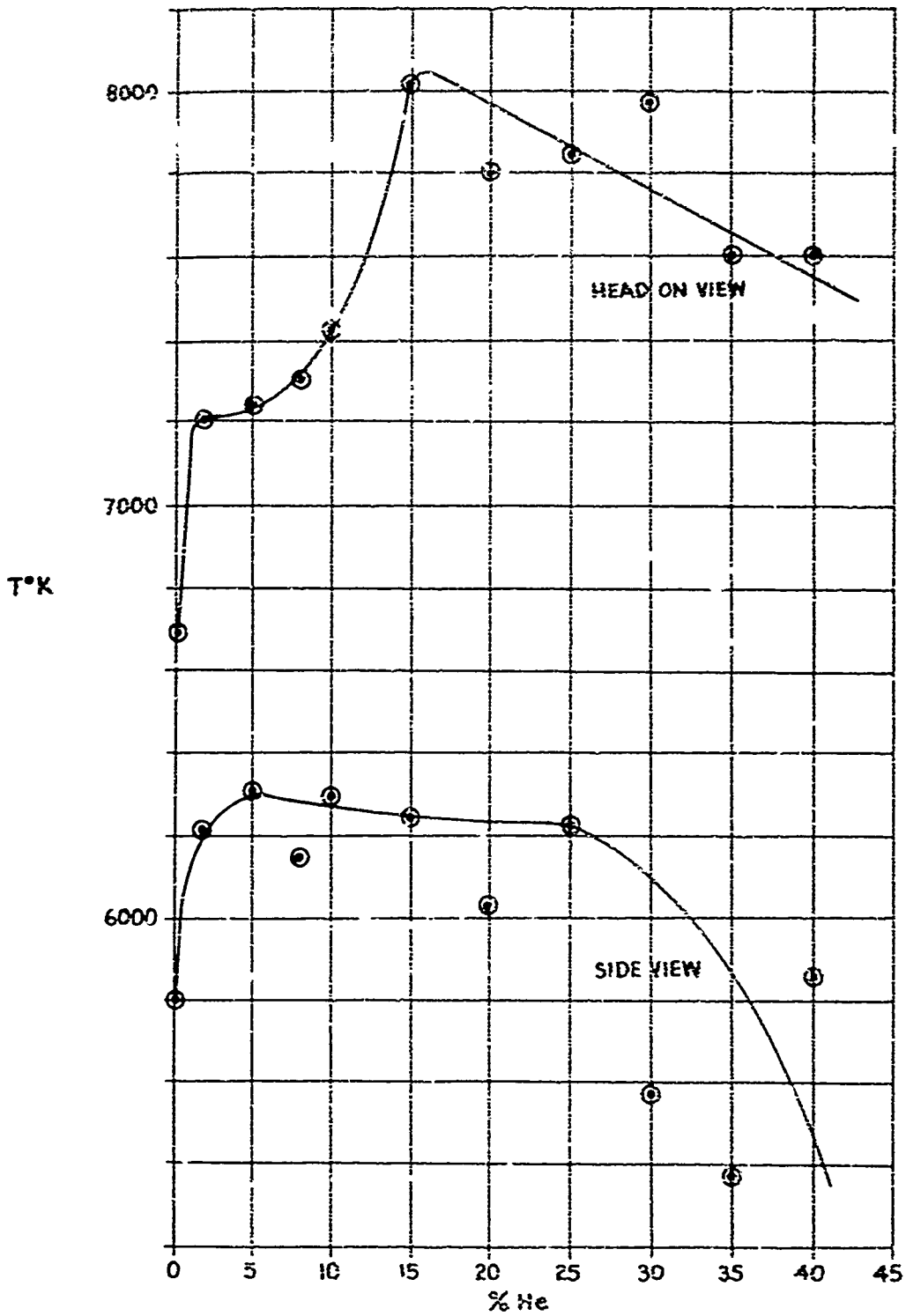


FIGURE 3i

TABLE VIII

## METAL CAVITY DETONATION CELL (CN) 2-02-He DATA

MIXTURE	P ATM	DETECTOR TYPE	IGNITION		VIEWING POSITION	T°K	NO. OF RUNS
			TYPE	ENERGY			
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 2% He	3.06	931A	Spark	.1 ufd-5Kv	Head-on	7200	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 5% He	3.16	931A	Spark	.1 ufd-5Kv	Head-on	7235	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 8% He	3.26	931A	Spark	.1 ufd-5Kv	Head-on	7300	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 10% He	3.33	931A	Spark	.1 ufd-5Kv	Head-on	7425	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 15% He	3.53	931A	Spark	.1 ufd-5Kv	Head-on	8010	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 20% He	3.75	931A	Spark	.1 ufd-5Kv	Head-on	7740	3
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 25% He	4.00	931A	Spark	.1 ufd-5Kv	Head-on	7940	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 30% He	4.29	931A	Spark	.1 ufd-5Kv	Head-on	7975	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 35% He	4.62	931A	Spark	.1 ufd-5Kv	Head-on	7600	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 40% He	5.00	931A	Spark	.1 ufd-5Kv	Head-on	7600	1

TABLE IX

METAL CAVITY DETONATION CELL (CN)2-02-X\* DATA

MIXTURE	P ATM	DETECTOR TYPE	IGNITION		VIEWING POSITION	T°K	NC. OF RUNS
			TYPE	ENERGY			
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 10% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	6340	2
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 15% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	7200	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 20% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	6470	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 25% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	5920	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 30% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	7640	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 35% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	6790	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 40% Xe	3	931A	Spark	.1 ufd-5Kv	Head-on	6460	1
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub> + 30% Xe	4.29	931A	Spark	.1 ufd-5Kv	Head-on	7775	1

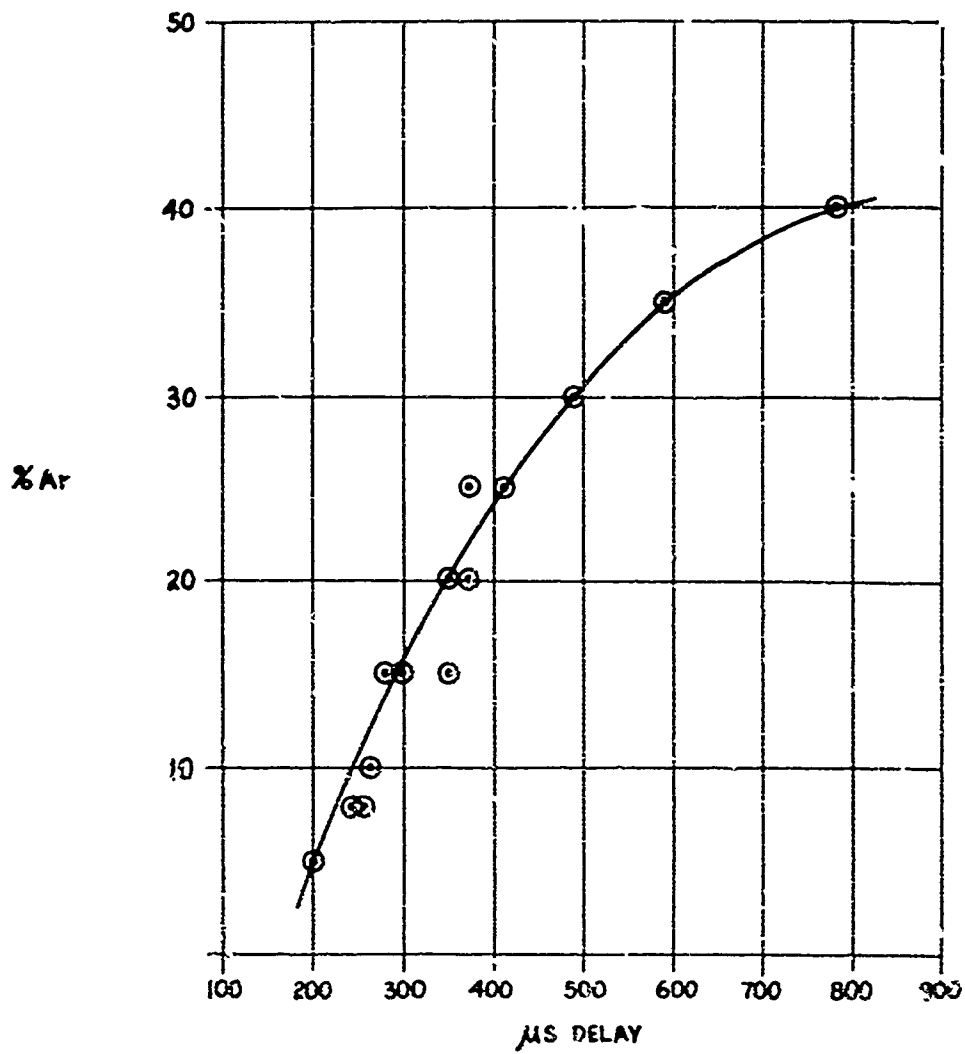


FIGURE 32  
METAL CAVITY DETONATION CELL  
INDUCTION TIME VS % Ar - HEAD ON VIEW -  $(CN)_2 + O_2 + Ar$  SYSTEM

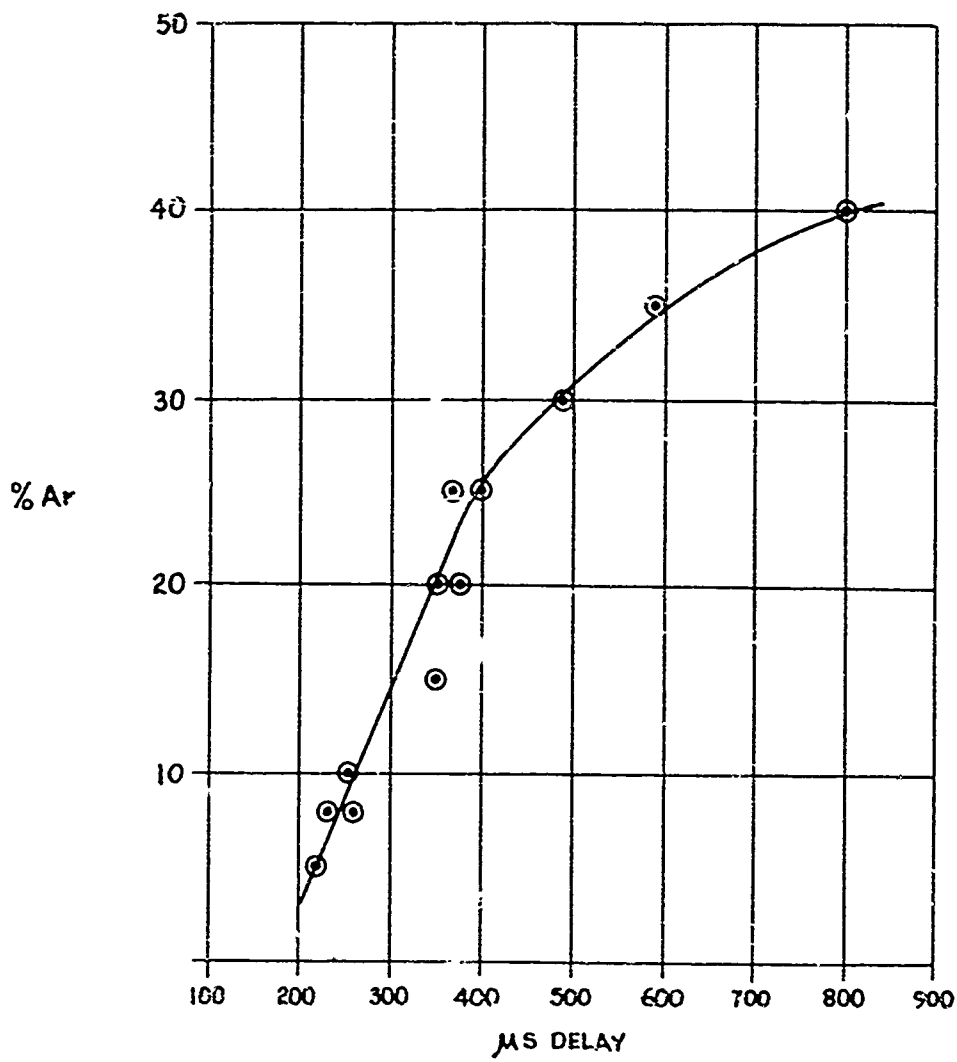


FIGURE 33  
METAL CAVITY DETONATION CELL  
INDUCTION TIME VS % Ar - SIDE VIEW -  $(CN)_2 + O_2 + Ar$  SYSTEM



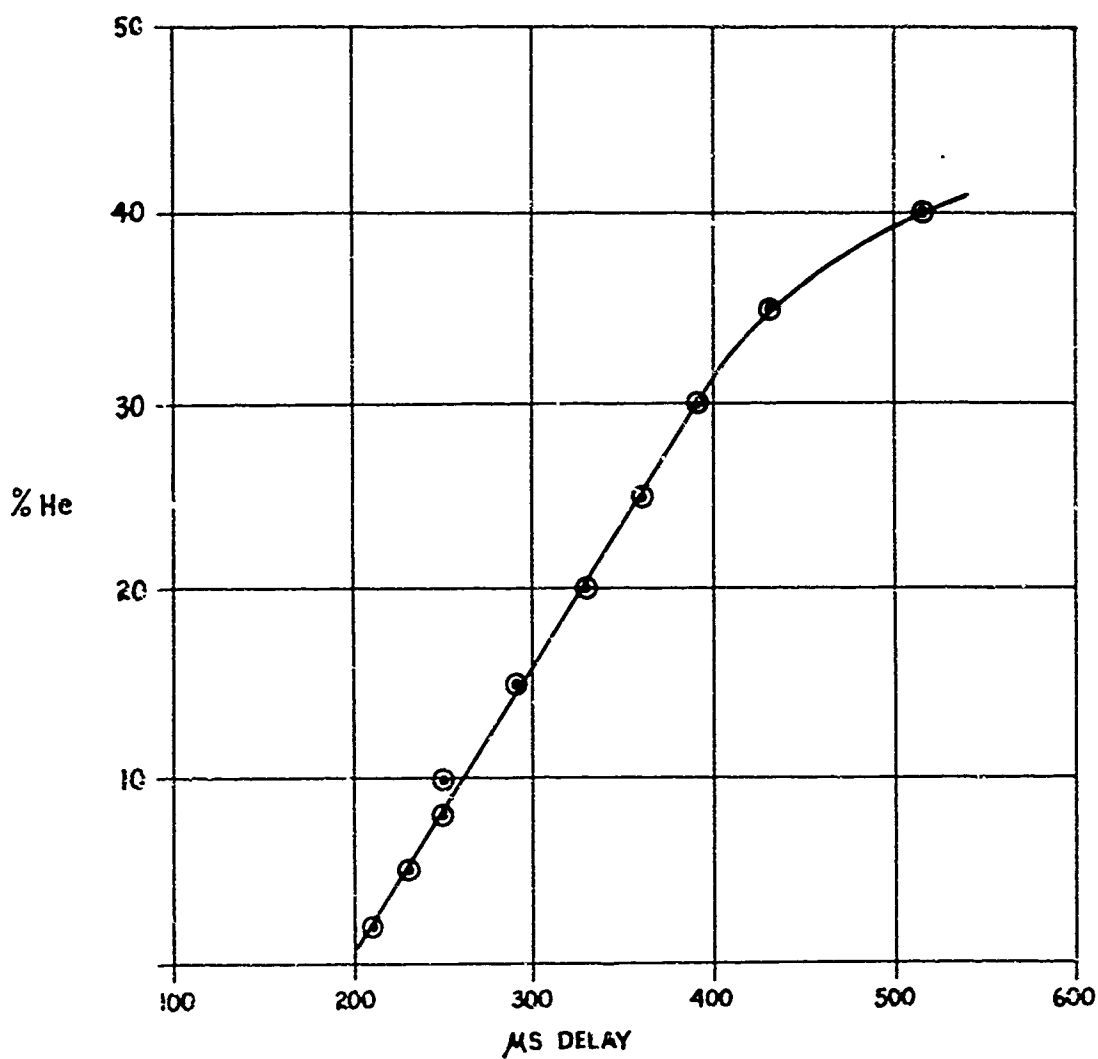


FIGURE 34  
METAL CAVITY DETONATION CELL  
INDUCTION TIME VS % He - HEAD ON VIEW -  $(CN)_2 + O_2 + He$  SYSTEM

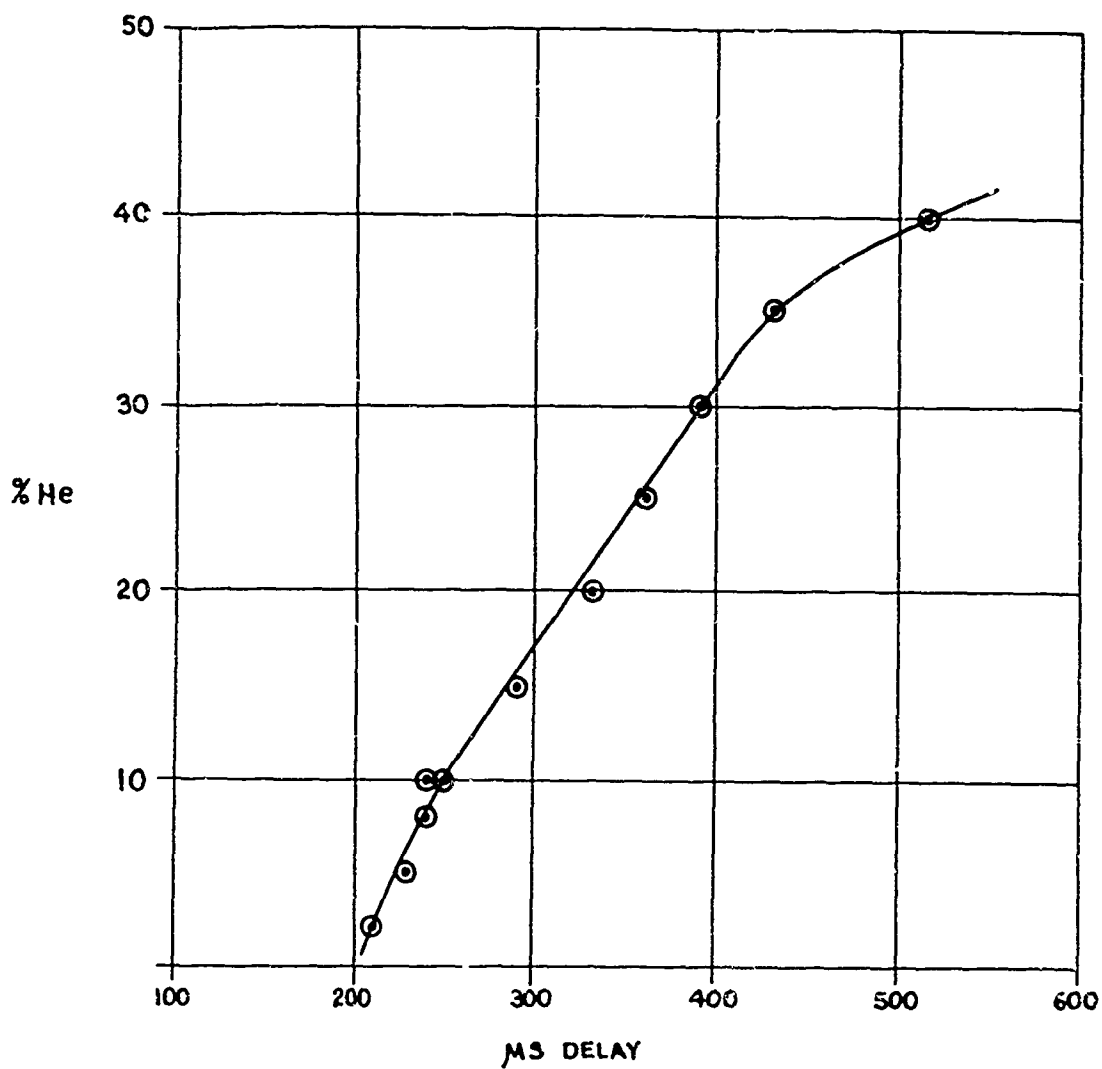


FIGURE 35  
METAL CAVITY DETONATION CELL  
INDUCTION TIME VS % He - SIDE VIEW -  $(CN)_2 + O_2 + He$  SYSTEM

a flame during the induction period which increased the pressure of the confined system. At some point a detonation was initiated in the higher pressure realm and propagated down the remaining length of the chamber. Since the detonation was at a higher initial pressure, the resulting temperature measurement showed an increase. The induction time for the systems was reproducible and increased in time with increased concentrations of inert gas addition. The conclusion drawn before for this system is borne out by several experiments discussed later in the report. One, which is listed on Table VII, is the initiation of an argon system using a XM-70 detonator whereby initiation of the detonation front occurs with no induction period. In this case the temperature measured was lower than that of a pure cyanogen-oxygen system, as would be expected, since the inert in this case was just acting as a diluent. It should be noted that spectra and velocity measurements were made using a 20% argon-cyanogen-oxygen system and the spectra showed no difference between the system without the diluent. The velocity measurements showed lower velocities than the cyanogen-oxygen system without dilution which in light of the above, should be true. Further discussion of these points is made in the sections on velocity measurements and spectral measurements.

#### D. CYANOGEN-NITRIC OXIDE SYSTEM

It has been shown that the cyanogen-nitric oxide system has slightly higher adiabatic flame temperature than the cyanogen-oxygen system<sup>(2)</sup>. Experiments were run using the metal cavity chamber with cyanogen-nitric oxide in varying ratios. The results of these experiments are shown in Table X and Fig. 36. The maximum temperature measured was 6570°K using a

(2) Stokes, C.S., Werner, R.P.G., Smith, W.F.R. & Cahill, J.A., IND&ENG CHEM. 52, 75(1960)

TABLE X

METAL CAVITY DETONATION CELL (CN)2 - NO DATA

<u>MIXTURE</u>	<u>P ATM</u>	<u>DETECTOR TYPE</u>	<u>IGNITION TYPE</u>	<u>IGNITION ENERGY</u>	<u>VIEWING POSITION</u>	<u>T°K</u>	<u>NO. OF RUNS</u>
30% C <sub>2</sub> N <sub>2</sub> + 70% NO	3	Philco	Spark	.1 ufd-5Kv	Head-on	5320	1
33% C <sub>2</sub> N <sub>2</sub> + 67% NO	3	Philco	Spark	.1 ufd-5Kv	Head-on	6305	4
35% C <sub>2</sub> N <sub>2</sub> + 65% NO	3	Philco	Spark	.1 ufd-5Kv	Head-on	6570	2
40% C <sub>2</sub> N <sub>2</sub> + 60% NO	3	Philco	Spark	.1 ufd-5Kv	Head-on	4680	1

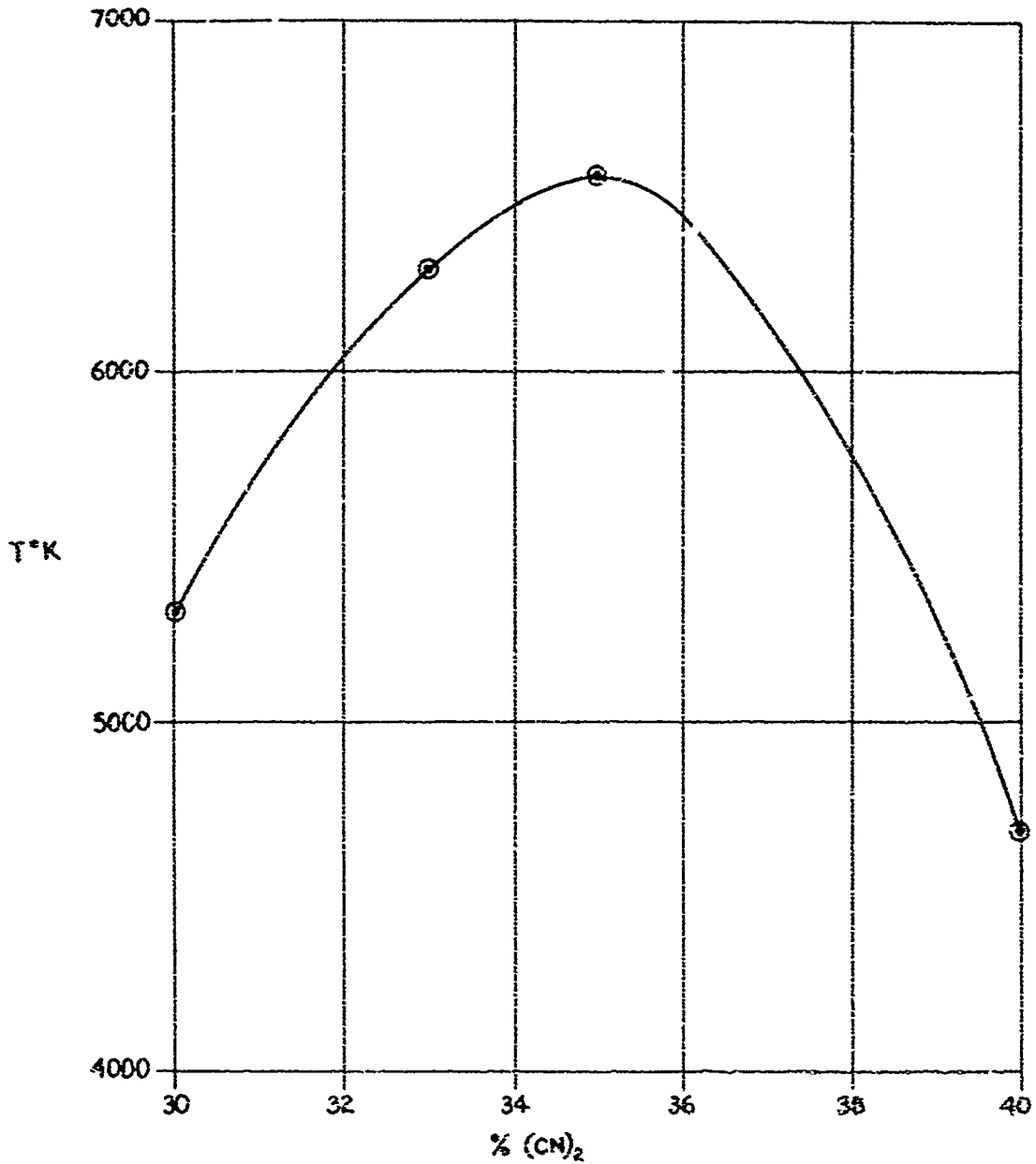


FIGURE 36  
METAL CAVITY DETONATION CELL - TEMP. VS % (CN)<sub>2</sub>, (CN)<sub>2</sub> + NO SYSTEM

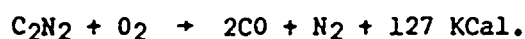
35% cyanogen-65% nitric oxide mixture. The temperature obtained by using this system is in the same range as that of the cyanogen-oxygen system and the small increase of perhaps 100° did not warrant further investigation of this system.

#### E. TEMPERATURE FOR XENON FLASH LAMP TYPE FX-100

It was of interest to determine the temperature produced by a Xenon flash lamp Type FX-100 using a bank of capacitors of 71 MFD varying the voltage from 600 to 2500 V. A plot of the results is shown in Fig. 37 where voltage is plotted vs. temperature and energy, in joules, plotted vs. temperature. As can be seen, temperatures in excess of 10,000° were produced using this type flash lamp. This data is included in this report for comparative purposes with the chemical systems used.

#### F. EFFECT OF INITIAL PRESSURE OF TEMPERATURE PRODUCED BY A FLAME OR DETONATION

The effect of initial pressure on the temperature produced by a flame or detonation. Consider first the cyanogen-oxygen reaction:



The temperature reached by the above flame at 1 Atm. pressure is 4830°K and at 10 Atm. 5050°K. This is not an appreciable increase in temperature (4800° to 5000°K) for the pressure rise. The method of calculation of flame temperature is as follows:

Consider the combustion products  $2 \text{CO} + \text{N}_2$  and raise their temperature until all the reaction heats ( $\Delta H_f$ ) is expended-

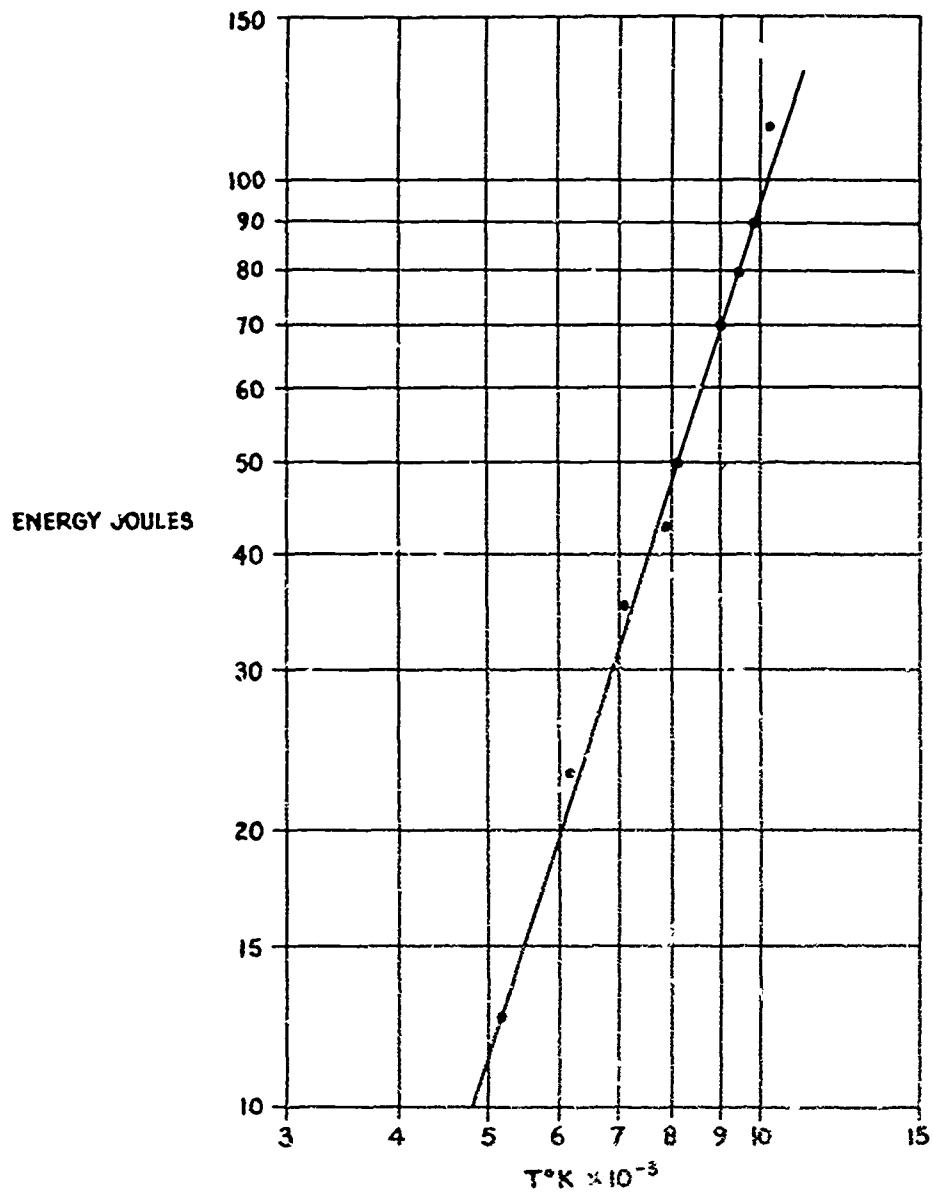


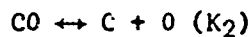
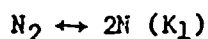
FIGURE 37  
FX-100 XENON FLASH LAMP TEMPERATURE VS ENERGY INPUT

$$\Delta H_f = [C_p(N_2) + 2 C_p(CO)] \Delta T$$

$$\Delta T = T_f - 298^\circ K \quad T_f = \text{flame temperature}$$

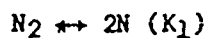
Solve for  $\Delta T$  and then for  $T_f$

The  $T_f$  obtained is the maximum temperature that would be possible for the reaction. However, the  $T_f$  is not obtained experimentally due to dissociation of the combustion products as follows:



$K$  = the equilibrium constant of the reaction

Consider -



$$K_1 = \frac{(\rho N)^2}{\rho N_2} \quad \text{or} \quad K_1 = \frac{(2X)^2}{(1-X)} \cdot \left(\frac{P}{\Sigma n_j}\right)^{\Delta n}$$

where  $P$  = Total pressure

$\rho$  = Partial pressure of a particular product

$X$  = Moles of  $N$

$\Sigma n_j$  = Total number of moles or products

(entire reaction)

$\Delta n$  = change in the number of moles

(products) - (reactants) ie

$$2N - N_2, \quad 2-1 = 1 = \Delta n$$

for dissociation reaction only

Note that in above reaction  $K_1$  is directly proportional to  $P$ , the initial pressure. However, at  $4830^\circ K$ ,  $N_2$  is only 3% dissociated to  $N$ , and, therefore,



a large increase in initial pressure - say 1 to 10 - will not mean much of an increase in the flame temperature. Although dissociation reactions absorb a great deal of heat from the reaction heat, in the  $C_2N_2 + O_2$  case only about 3% of this reaction heat is "lost" to dissociation. The temperature of other reactions, particularly those involving fluorine and like compounds, show a great dependence on initial pressure. For example, two reactions:

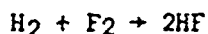
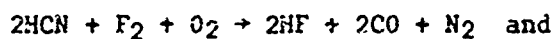


Table XI below compares the pressure dependence of the flame temperature to that of cyanogen.

TABLE XI

<u>Pressure</u> <u>Atm.</u>	<u><math>C_2N_2 + O_2 \rightarrow</math></u> <u><math>2CO + N_2</math></u>	<u><math>2HCN + F_2 + O_2 \rightarrow</math></u> <u><math>2HF + 2CO + N_2</math></u>	<u><math>H_2 + F_2 \rightarrow</math></u> <u><math>2HF</math></u>
1	4848°K	3950°K	4000°K
10	5016°K	4400°K	4400°K
100	5119°K	4890°K	5100°K

In the case of detonation of the above mixtures, the pressure-temperature equilibrium is even more pronounced, since high pressures (20 to 500 Atm.) occur in the shock fronts.

## V. DETONATION VELOCITY MEASUREMENTS

### A. EXPERIMENTAL VELOCITY MEASUREMENTS ON CYANOGEN-OXYGEN SYSTEMS

It was of interest to determine the detonation velocity of cyanogen-oxygen and cyanogen-oxygen-argon mixture. In order to determine first, if the spark initiated detonations were reaching full detonation velocity and second, what effect the addition of argon to the mixture had on the detonation velocity.

Four methods were used to determine detonation velocity:

1. Drum camera velocity measurements done at Picatinny Arsenal's facilities
2. 4' x 1" O.D. Lucite tubes and 2' x 1" O.D. Lucite tubes
3. 1/8" windows inside
4. A special slit fixture shown in Fig. 16

In method 2 the tubes were taped at 10 Cm. intervals with black electrical tape leaving a slit of approximately 1/16". Approximately 6' from the tube a 931A photomultiplier detector was set up and this measured the detonation wave giving pulses as the detonation traveled down the tube past the slits. In method 3 the set-up was very similar in that a photomultiplier tube detector was set up some 2' from the windows and measured the light pulses as the wave passed the windows. Again in method 4 the same procedure was used and the photomultiplier detector was placed some 2' from the slit fixture and the pulses measured. The pulses were photographed on a 535 oscilloscope with a calibrated sweep and thus the time intervals between the pulses could be measured accurately and thus the detonation

velocity calculated from the distance between the slits and windows divided by the time between the pulses. Table XII gives the velocity measurements made with both the cyanogen-oxygen and the cyanogen-oxygen-argon mixtures by the several methods used.

As can be seen from Table XII, the velocity measurements for 52% cyanogen-48% oxygen by four different methods show very good agreement. The velocity can be taken to be on the average of 2700 meters per second. Using a 41.6% cyanogen, 38.4% oxygen and 20% argon, the velocity is lower than in the system without the argon, having an average of 2500 m/s. This is an expected result since the argon in this case merely acts as a diluent. In the case of the metal cavity where the detonation was measured over only a 6' length, the velocity was 2710 m/s. This reflects the ignition delay which occurs with the argon mixture and shows that there is a long period of the order of 300 microseconds where only a flame is produced, increasing the pressure of the system before detonation occurs. This is more fully explained in Section IV. The table also shows the detonation velocity of the 34% cyanogen, 66% nitrogen system to be 2610 m/s. All these values given are in good agreement with theoretical calculations.

#### B. THEORETICAL DETONATION PARAMETERS

Figure 38 shows the theoretical detonation parameters of the gaseous cyanogen-gaseous oxygen system. It shows the maximum theoretical temperature to be 6200°K at 50% C<sub>2</sub>N<sub>2</sub> and developing 57 Atm. pressure with an initial pressure of 1 Atm. Theoretical values are in good agreement with the experimental results of these investigations.

Table XIII lists the detonation parameter of several C<sub>2</sub>N<sub>2</sub> liquid and solid systems.

TABLE XII

DETONATION VELOCITY MEASUREMENTS

OF THE (CN)<sub>2</sub> + O<sub>2</sub> AND (CN)<sub>2</sub> + O<sub>2</sub> + Ar SYSTEMS

<u>SYSTEM</u>	<u>FIXTURE</u>	<u>DETECTOR</u>	<u>INITIAL PRESSURE ATM.</u>	<u>IGNITION</u>	<u>VELOCITY m/sec.</u>	<u>NO. OF RUNS</u>
52% C <sub>2</sub> N <sub>2</sub> + 48% O <sub>2</sub>	1" OD x 4' Lucite Tube	931A	2	Spark	2667	3
	Metal Cavity 3 windows	931A	3	Spark	2645	6
	1" OD x 2' Lucite Tube	Drum Camera	3	Spark	2761	2
41.6% C <sub>2</sub> N <sub>4</sub> + 38.4% O <sub>2</sub> + 20% Ar	Slit	931A	3	Spark	2690	7
	1" OD x 4' Lucite Tube	931A	3	Spark	2470 Decays	6
			3.75	Spark	2535 Decays	8
	Metal Cavity 3 windows	931A	3.75	Spark	2710	6
34% C <sub>2</sub> N <sub>2</sub> + 66% N <sub>0</sub>	1" OD x 2' Lucite Tube	Drum Camera	3.75	Spark	2523	1
	Metal Cavity 3 windows	931A	3	Spark	2670	3

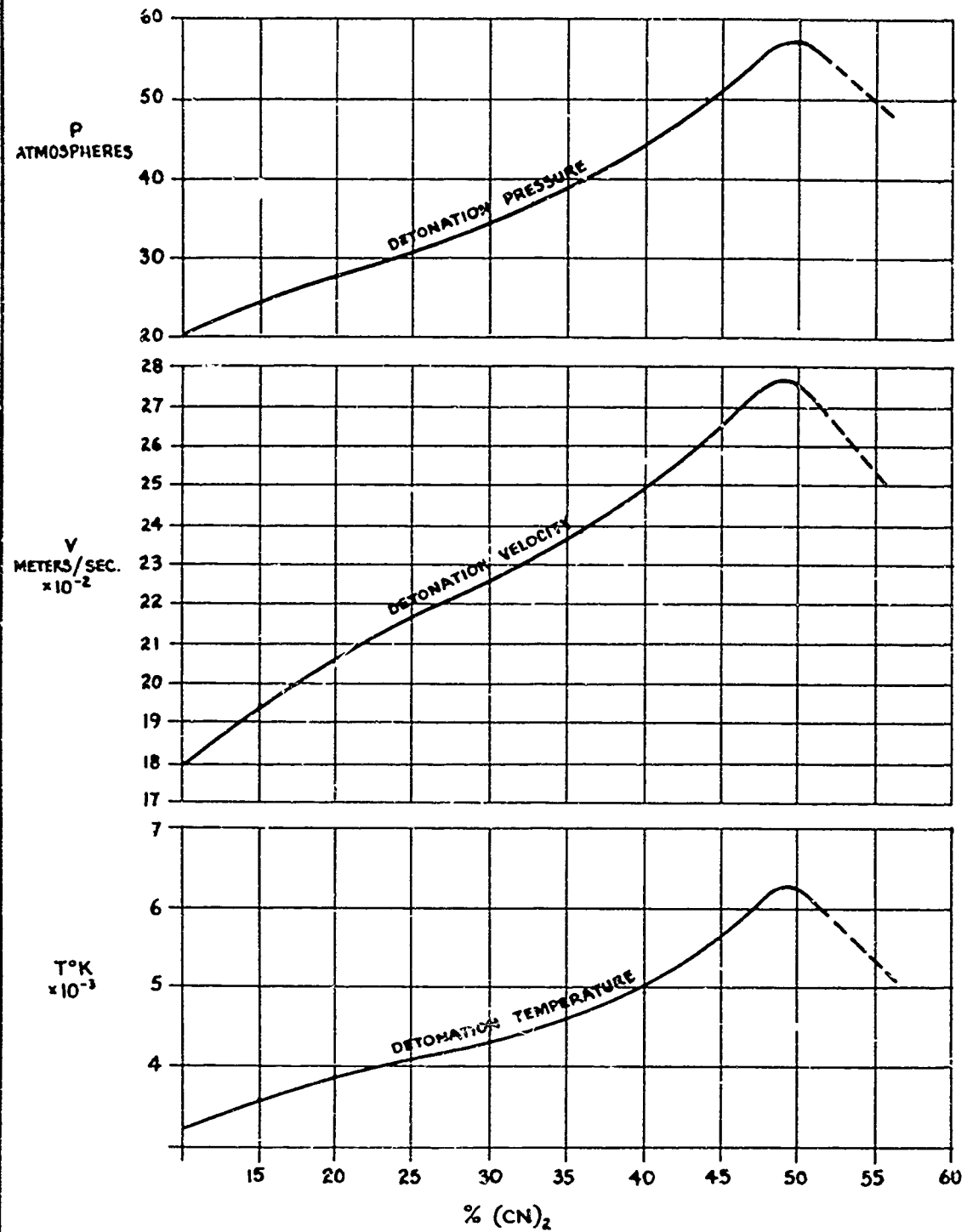


FIGURE 38  
THEORETICAL DETONATION PARAMETERS,  $(CN)_2 + O_2$  SYSTEM

TABLE XIII  
DETONATION PARAMETERS OF SEVERAL CYANOGEN SYSTEMS

<u>System</u>	<u>Detonation Velocity m/sec</u>	<u>Detonation Pressure Atm x 10<sup>-3</sup></u>	<u>Detonation Temp. °K</u>	<u>Loading Density g/cc</u>
C <sub>2</sub> N <sub>2</sub> (Solid) + O <sub>2</sub> (Liq)	5650	94.84	5560	1.01
C <sub>2</sub> N <sub>2</sub> (Solid) + 2O <sub>2</sub> (Liq)	6580	130	8460	1.05
C <sub>2</sub> N <sub>2</sub> (Solid) + 4/3 O <sub>3</sub> (Liq)	7440	190	9740	1.22
2 C <sub>2</sub> N <sub>2</sub> (Liq) + N <sub>2</sub> O <sub>4</sub> (Liq)	8950	108	5760	1.07
2 C <sub>2</sub> N <sub>2</sub> (Liq) + 3/4 N <sub>2</sub> O <sub>4</sub> (Liq)	8650	105	5490	1.05

It should be noted that extremely high temperatures are produced by the C<sub>2</sub>N<sub>2</sub> - ozone system. The liquid C<sub>2</sub>N<sub>2</sub> - N<sub>2</sub>O<sub>4</sub> system produces a theoretical temperature of 5760°K based on Temple calculations which should be repeated for more accuracy.

## VI. SPECTRAL MEASUREMENTS

Emission spectra of the cyanogen-oxygen and cyanogen-oxygen argon systems were made using the metal cavity fixture coupled to a Bausch and Lomb 1.5 meter spectrograph. Four spectra were taken, two on each system. These spectra showed no appreciable difference between the two systems and no argon lines could be identified. For the most part the spectra showed a continuum with the following band heads of carbon identifiable:

5636A	4729
5587	4382.5
5162	4365.5

The implication from these experiments is that there is no appreciable difference between the two systems and that the argon does not contribute to any extent in the emission and merely acts as a diluent.

Emission spectra of a FX-100 Xenon flash tube was taken. Comparison of the spectrogram with that of the cyanogen-oxygen system showed a similar continuum; however, strong line spectra was also present, as would be expected. Although the spectral emissions of the two sources were not exactly similar, it was felt that the use of Xenon flash lamp for a calibration and correlation purposes would be permissible.

## VII. PROBE MEASUREMENTS ON PUMPING FIXTURES UTILIZING CYANOGEN-OXYGEN SYSTEMS

In order to determine the probability of pumping a neodymium or ruby laser with a particular pumping fixture configuration, it was decided to use small probes of the type described in Section II - C. These probes utilized a Philco type L4413 photodiode coupled with appropriate filters. These probes were placed inside the Lucite tubes which held the lasers in the lasing experiments described in the next section. The calibration of the probes was made by threshold lasing a ruby laser in a unit containing 4 Xenon flash tubes. When the threshold lase was obtained, the laser was removed and the probe put in its place. The same energy was then applied to the 4 flash tubes and an oscillograph trace of the probe output was made. This was then repeated for several higher energy level inputs to the flash tubes. From this data the energy output of the chemical systems could then be correlated. This correlation assumed that the spectral emission from both the Xenon flash tubes and the cyanogen-oxygen system were essentially the same, which is discussed in Section VI. Typical traces of the probe output are shown in Fig. 39. In the initial studies, several types of probes were tried. The first one used only an infrared filter, which proved to be unsatisfactory. Second, generation probes utilized Corning filters of the blue and blue-green type. The results from these probes were better than from the infrared types but were not quite reproducible and, therefore, could not be reliably used in comparison studies. Table XIV lists the experiments performed with the two probes described above. The table lists 4 pumping fixtures on which experiments were carried out. These included the coaxial type,



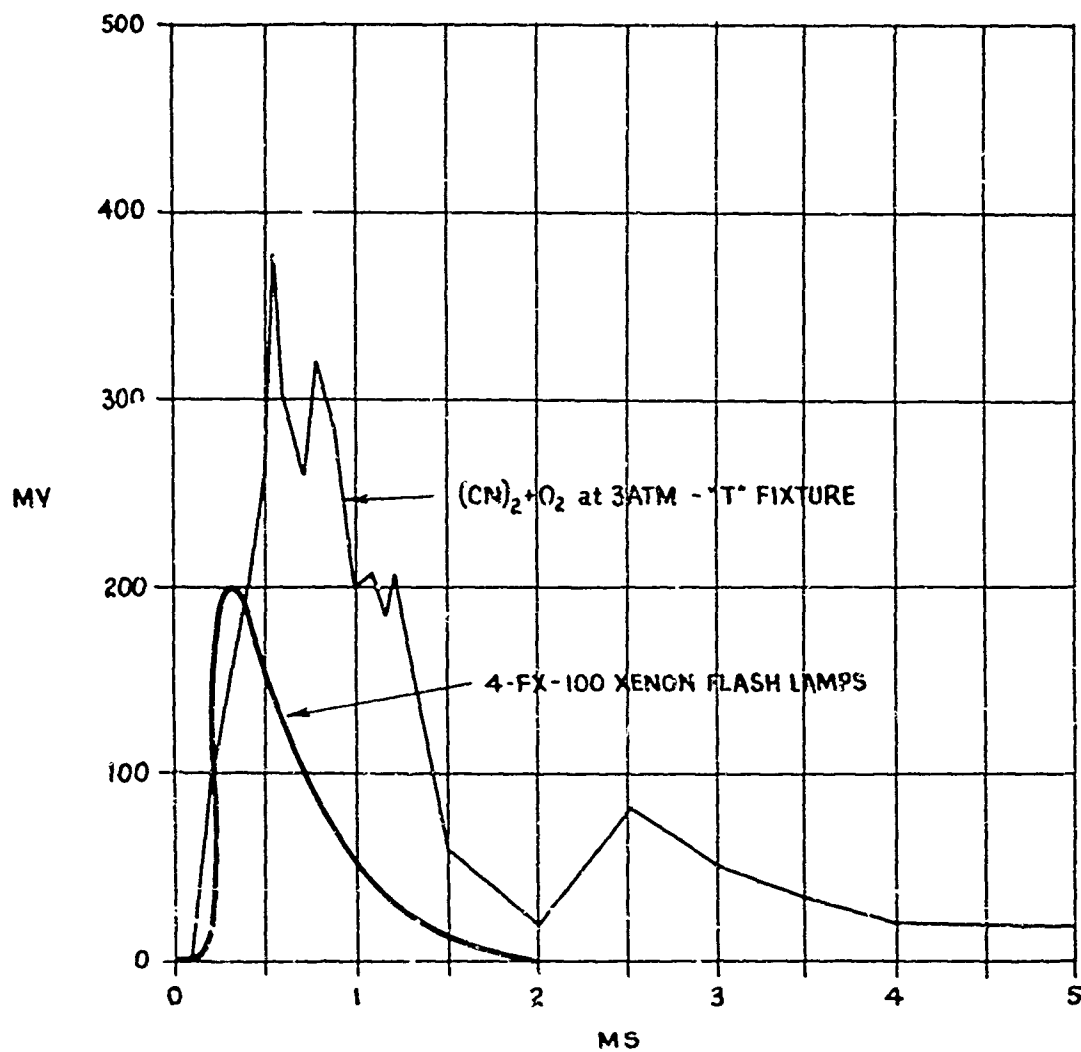


FIGURE 39  
TYPICAL TRACES, PROBE OUTPUT, XENON FLASH TUBE  
AND PUMPING FIXTURE

TABLE XIV

PROBE EXPERIMENTAL DATA

FIX.	NO.	PROBE		MIX C <sub>2</sub> N <sub>3</sub> :O <sub>2</sub> %	P ATM	PEAK MV	PULSE WIDTH MS	VIEW	THRESHOLD LASE		REMARKS
		TYPE	ATTN						MV	RUBY	
Coax.	1	1R	10 <sup>6</sup>	52:48	3	300	0.5	W	120		
Coax.	1	1R	10 <sup>6</sup>	52:48	3	200	1+	W	120		Al. foil
Coax.	3	1R	10 <sup>6</sup>	52:48	3	520	0.7+	W	193		
Coax.	3	1R	10 <sup>6</sup>	34:66@	3	500	0.4	W	193		@C <sub>2</sub> N <sub>2</sub> :NO
Coax.	3	1R	10 <sup>6</sup>	34:66@	3	500	1	W	193		
Coax.	3	1R	10 <sup>6</sup>	52:48	3	540	1.2	W	193		
MP-1	9	1R	10 <sup>6</sup>	52:48	3	250	0.35	W	120		
MP-2	9	1R	10 <sup>6</sup>	52:48	3	250	1.5	W	120		
MP-2	3	1R	10 <sup>6</sup>	52:48	3	480	3.0+	W	193		20% Ar
MP-2	3	1R	10 <sup>6</sup>	52:48	3	380	2.0	W	193		5% He
MP-2	3	1R	10 <sup>6</sup>	52:48	3	550	9.0+	W	193		
MP-2	3	1R	10 <sup>6</sup>	52:48	3	530	9.0+	W	193		
MP-2	3	1R	10 <sup>6</sup>	52:48	3	520	6.5	W	193		20% Ar
T	2	Blue	10 <sup>6</sup>	52:48	3	130 to 170	2.0	F	104		

TABLE XIV (continued)

## PROBE EXPERIMENTAL DATA

FIX. NO.	PROBE TYPE	ATTN	MIX C <sub>2</sub> N <sub>3</sub> &O <sub>2</sub> %	P ATM	PEAK MV	PULSE WIDTH MS	VIEW	THRESHOLD LASE MV - RUBY	REMARKS
T 3	Blue	10 <sup>6</sup>	52:48	3	145 to 270	1.2	F	100	
T 50	B-G	10 <sup>6</sup>	52:48	3	140+	1.0	F	110	
T 50	B-G	10 <sup>6</sup>	52:48	3	400	0.8	F	110	
T 58	B-G	10 <sup>6</sup>	52:48	4	400 sat.	1.3	F	185	
T a51	B-G	10 <sup>6</sup>	52:48	3	300	1	B	200	
T b54	B-G	10 <sup>5</sup>	52:48	3	300	1	F	70	
T b54	B-G	10 <sup>5</sup>	52:48	3	350	1	F	70	
T b54	B-G	10 <sup>5</sup>	52:48	3	350	1.5	E	70	
T b54	B-G	10 <sup>5</sup>	52:48	3	400	0.5	B	70	

Fixtures: Coax. = coaxial fixture

MP-1 = multipass fixture with liners

MP-2 = multipass fixture without liners

T = tee fixture

Ignition: All runs used spark ignition, Type AC-MS spark plug, 0.1 mfd at 5000 volts

View: F = Front facing, looking at spark plug

B = Back facing, looking at opposite wall from spark plug

W = At wall

Probes: 1R = Corning type 1-69

Blue = Corning blue type

B-G = Corning blue-green type

Number refer to wave length (millimicron) of interference filter

multipass, and the "T" fixtures. As noted above, the results showed very high outputs with regard to the threshold lase energy required for ruby laser. As can be seen in the next section, these results were, in effect, erroneous in that ruby lasing was not achieved using the above fixtures.

In order to resolve the problems encountered with the initial probe types, two new probes were developed. These probes used the same photodiode but were coupled with interference filters transmitting in the absorption bands of the ruby laser. The absorption spectra of ruby and neodymium crystals is shown in Figs. 40 and 41. One probe used a 565 m $\mu$  interference filter and the other a 431 m $\mu$  interference filter. These probes were calibrated for both energy and temperature. The energy measurements were made using the previously described Xenon flash tube system. The temperature calibration was based on the AG-1 flash bulbs. The results obtained using the "T" fixture with these new probes is given in Table XV. Figures 42 and 43 show the measured temperature vs. mixture ratios of cyanogen-oxygen-helium respectively. Figures 44 and 45 show the energy output for the above systems measured in the same fixture using the new interference type probes.

The same probe system was used on the implosion fixture and these results are listed in Table XVI. Upon reviewing the data generated using both the "T" and implosion fixture, it was determined that the implosion fixture had the best chances of pumping a ruby laser.

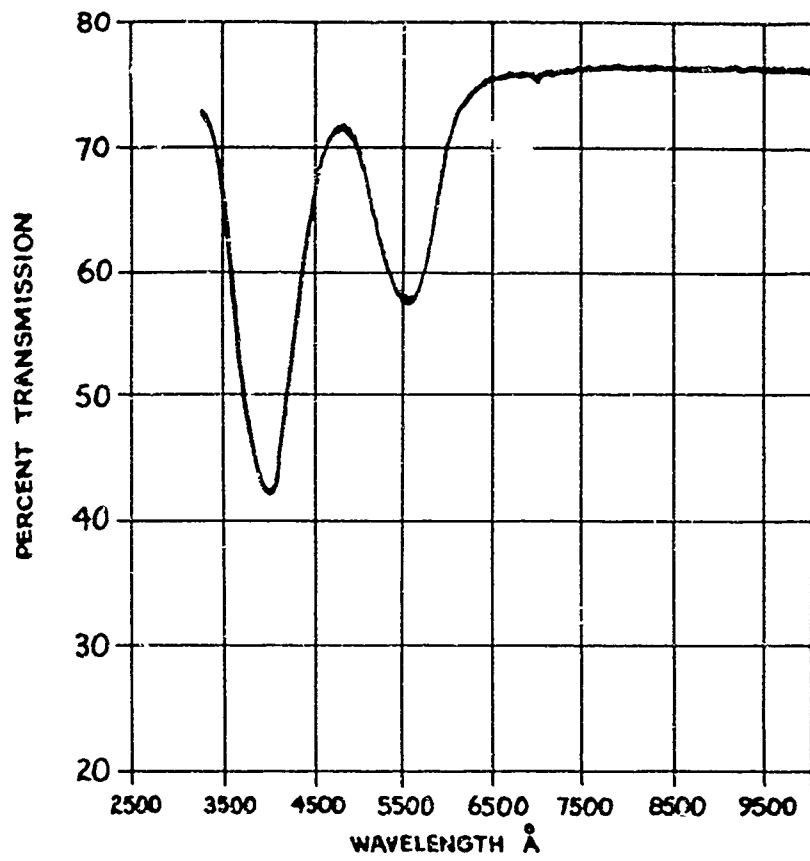


FIGURE 40  
ABSORPTION SPECTRA OF A RUBY CRYSTAL

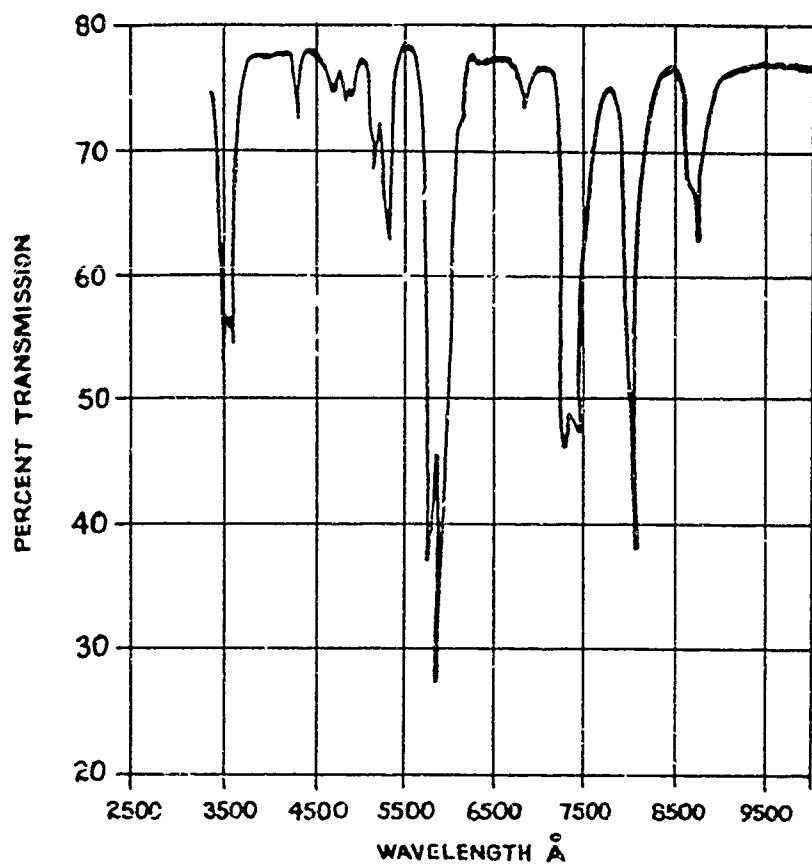


FIGURE 41  
ABSORPTION SPECTRA OF A NEODYMIUM CRYSTAL

TABLE XV

## PROBE EXPERIMENTAL DATA "T" FIXTURE

Probe No.	Mixture C <sub>2</sub> N <sub>2</sub> /O <sub>2</sub> /Inert	Atm. Press.	mv Ave. (Peak)	Ave. Energy Joules	R Ave.	T Ave.	R Peak	T Peak
6-565	52/48/0	3	25	100				
6-565	52/48/0	3	32.5	128				
13-565	52/48/0	3	43	75				
6-565	52/48/0	3	30	120				
51-431	52/48/0	3	31	74				
6-565	52/48/15 Ar	1.15	20	80				
51-431	52/48/15 Ar	1.15	31.5	75				
6-565	52/48/0	3	10	40				
51-431	52/48/0	3	12	29				
6-565	52/48/0	3	6	24				
51-431	52/48/0	3	11	26				
6-565	52/48/15 Ar	1.15	20	80			Spike to 60 mv (240J)	
51-431	52/48/15 Ar	1.15	10	24			Spike to 45 mv (108J)	
22a-431	52/48/0	3	40	54				
56-565	52/48/0	3	90	122				
229-431	52/48/0	3	38	51				

Facing away from spark probe broke

TABLE XV (continued)

## PROBE EXPERIMENTAL DATA "T" FIXTURE

Probe No.	Mixture C <sub>2</sub> N <sub>2</sub> /O <sub>2</sub> /Inert	Atm. Press.	mv Ave. (Peak)	Ave. Energy Joules	R Ave.	T Ave.	R Peak	T Peak
56-565	52/48/0	3	70	95				
22a-431	52/48/0	3	30	41				
56-565	52/48/0	3	erratic	-	Probe no good			
22a-565	52/48/0	3	30	41				
23a-431	52/48/0	3	100	240				
22-565	52/48/0	3	30(60)	90	4.85	5660	9.7	6680
24-431	52/48/0	3	25(70)	23	1.68	4500	4.7	5210
22-565	52/48/0	3	25(50)	75	4.05	5440	2.1	6400
24-431	52/48/0	3	40(84)	36	2.66	4800	5.6	5260
22-565	52/48/0	3	30(47)	90	4.85	5660	7.6	6320
24-431	52/48/0	3	40(92)	36	2.66	4800	6.1	5410
23-565	52/48/20 Ar	2.4	Erratic (160 est)	-	Probe no good		10.0	6720
25-431	52/48/20 Ar	2.4	40(100 est)	154	2.85	4850	7.2	5480
26-565	52/48/20 Ar	2.4	40(80 est)	72	3.35	5240	6.7	6130
25-431	52/48/20 Ar	2.4	No signal					
25-565	52/48/20 He	2.4	60(100)	116	5.4	5800	7.7	6300
23-431	52/48/20 He	2.4	No signal					



TABLE XV (continued)

## PROBE EXPERIMENTAL DATA "T" FIXTURE

Probe No.	Mixture C <sub>2</sub> N <sub>2</sub> /O <sub>2</sub> /Inert	Atm. Press.	mv Ave. (Peak)	Ave. Energy Joules	R Ave.	T Ave.	R Peak	T Peak
25-565	52/48/20 He	2.4	60(102)	116	5.4	5800	7.8	6330
23-431	52/48/20 He	2.4	50(100)	123	2.8	4830	5.55	5350
25-565	52/48/20 He	3.0	80(130)	140	6.15	6000	10.0	6750
23-431	52/48/20 He	3.0	60(90+)	135	3.35	4960	5.0	5260
26-565	54/46	3.0	30(70)	95	2.7	5060	6.3	6000
23-431	54/46	3.0	20(30)	90	5.0	5260	7.5	5640
26-565	56/44	3.0	22(54)	88	2.0	4780	4.9	5660
23-431	56/44	3.0	12(20)	78	3.0	4880	5.0	5260
26-565	52/48	3.0	40(88)	108	3.6	5320	8.0	6360
23-431	52/48	3.0	20(32)	90	5.0	5260	8.0	5690
26-565	50/50	3.0	40(85)	108	3.6	5320	7.7	6320
23-431	50/50	3.0	24(35)	93	6.0	5410	8.8	5800
26-565	48/52	3.0	20(48)	85	1.8	4660	4.3	5500
23-431	48/52	3.0	17(22)	86	4.3	5140	5.5	5340
26-565	52/48/5 He	3.0	38(90)	105	3.5	5290	8.2	6400
23-431	52/48/5 He	3.0	20(38)	90	5.0	5260	9.5	5870

TABLE XV (continued)  
PROBE EXPERIMENTAL DATA "T" FIXTURE

<u>Probe No.</u>	<u>Mixture C<sub>2</sub>N<sub>2</sub>/O<sub>2</sub>/Inert</u>	<u>Atm. Press.</u>	<u>mv Ave. (Peak)</u>	<u>Ave. Energy Joules</u>	<u>R Ave.</u>	<u>T Ave.</u>	<u>R Peak</u>	<u>T Peak</u>
26-565	52/48/10 He	3.0	44(104)	112	4.0	5440	9.5	6660
23-431	52/48/10 He	3.0	20(38)	90	5.0	5260	9.5	5870
26-565	52/48/15 He	3.0	24(80)	90	2.2	4860?	7.3	6230?
23-431	52/48/15 He	3.0	18(30)	88	4.5	5170	7.5	5630

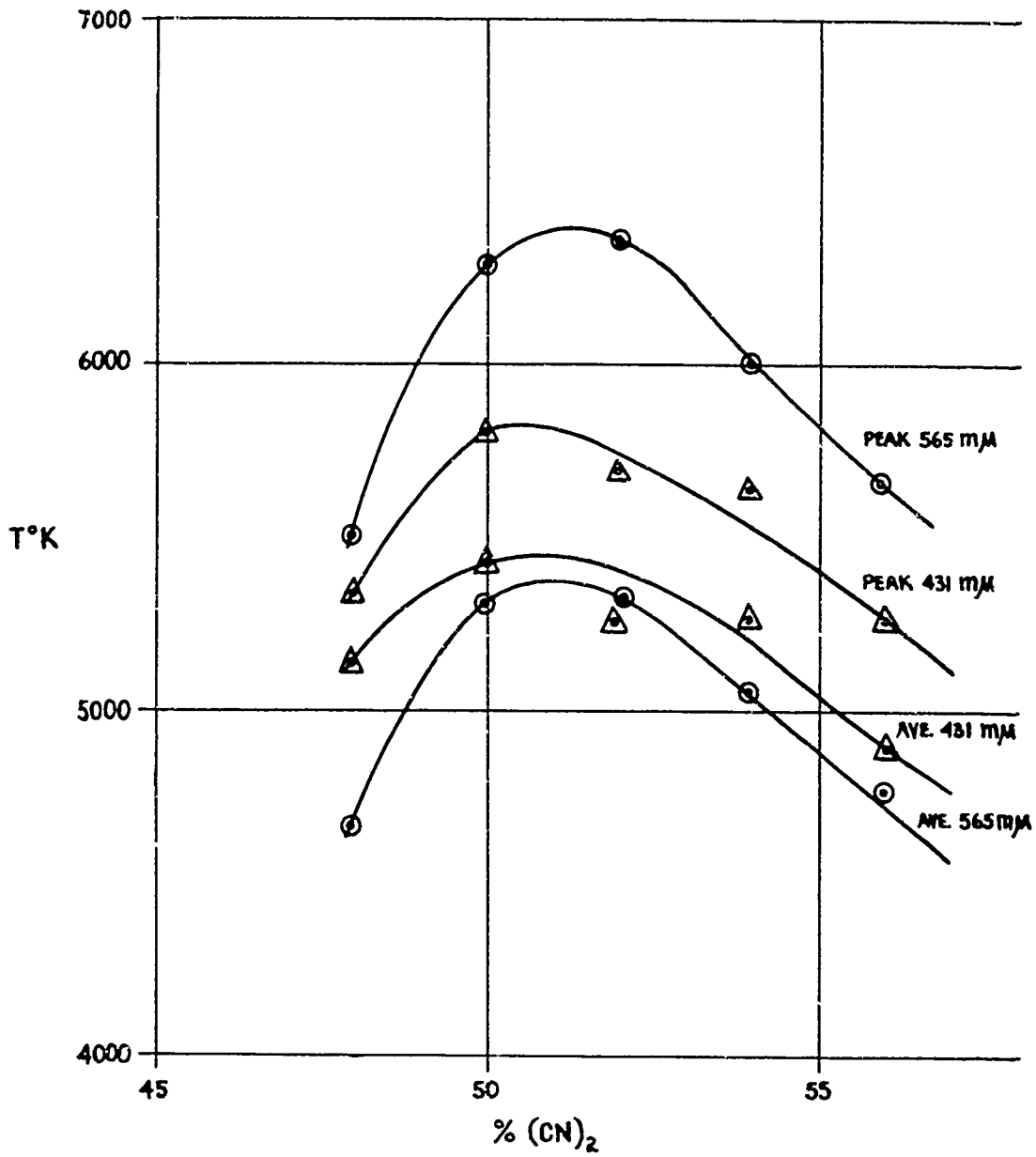


FIGURE 42  
"T" FIXTURE, TEMP. VS % (CN)<sub>2</sub>, (CN)<sub>2</sub> + O<sub>2</sub> SYSTEM

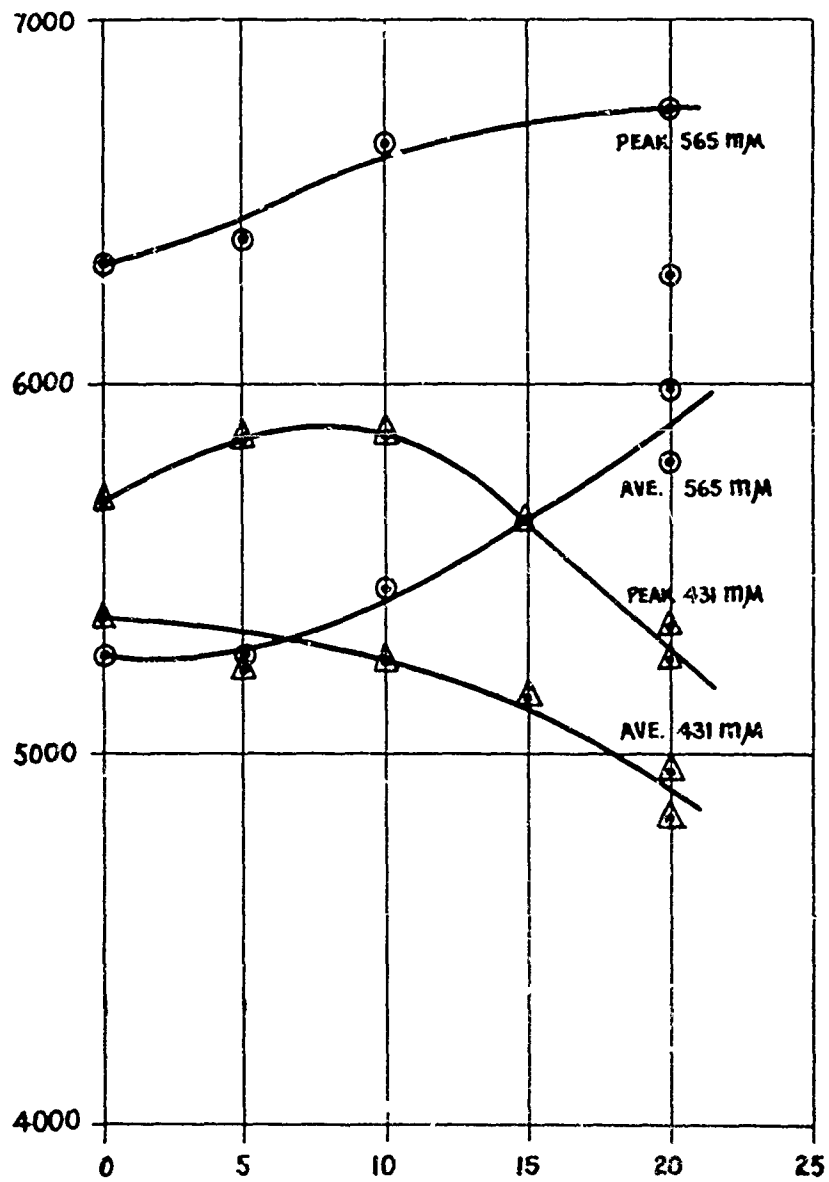


FIGURE 43  
"T" FIXTURE, TEMP. VS % He,  $(CN)_2 + O_2 + He$  SYSTEM

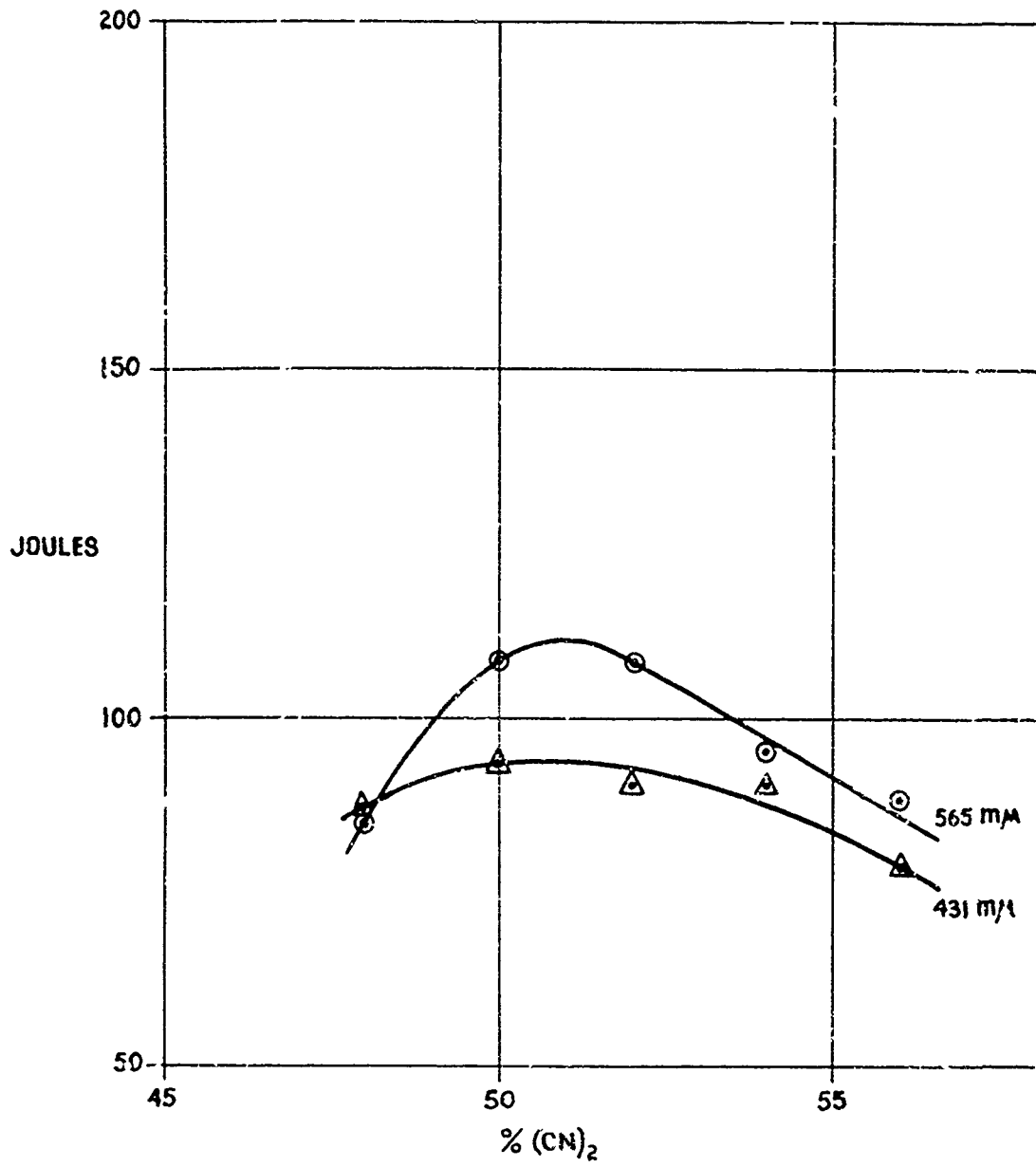


FIGURE 44  
"T" FIXTURE, ENERGY VS %  $(CN)_2$ ,  $(CN)_2 + O_2$  SYSTEM

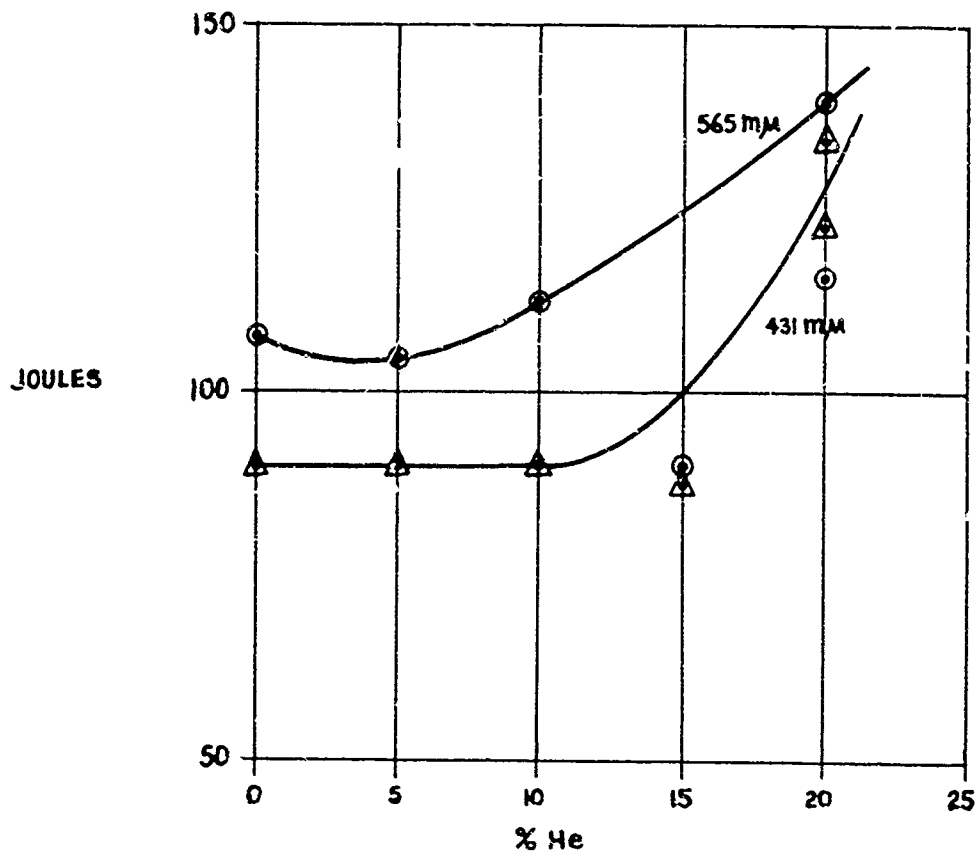


FIGURE 45  
T MIXTURE, ENERGY VS % He, (CN)<sub>2</sub> + C<sub>2</sub> + He SYSTEM

TABLE XVI  
PROBE EXPERIMENTAL DATA IMPLOSION FIXTURE

Implosion Fixture Configuration	Probe	Mixture	Press.	mv Ave.	Peak	Load	Ave. Energy Joules	R Ave.	T Ave.	R Peak	T Peak
4 Spark Plugs	26-565	52/48	3	70	(83)	950	150	6.3	6000	7.5	6260
"	27-431	52/48	3	35	(120)	950	150	5	5300	17.2	6500
"	31-431	52/48	3	40	(50)	470	138	5.7	5400	7.15	5600
"	30-565	52/48	3	60	(84)	470	80	5.0	5700	7.0	6180
"	31-431	52/48	3	30	(49)	470	115	4.3	5160	5.7	5370
1" ring + 8 Spark Plugs	30-565	52/48	3	60	(80)	470	80	5.0	5700	6.7	6100
"	31-431	52/48	3	30	(50)	470	115	4.3	5160	7.0	5550
"	33-565	52/48	3	70	(80)	470	140	7.0	6180	8.0	6360
"	32-431	52/48	3	60	(70)	470	85	7.5	5640	8.8	5800
"	32-431	52/48	3 1/2	70	(90)	470	140	8.8	5800	11.3	6000
"	33-565	52/48	3 1/2	50	(70)	470	100	5.0	5700	7.0	6180
"	32-431	52/48	3 1/2	50	(70)	470	75	6.2	5440	8.8	5800
"	33-565	52/48	3 1/2	60	(80)	470	115	6.0	5940	8.0	6360
"	32-431	52/48	4	60	(80)	470	85	7.5	5640	10.0	5920
"	33-565	52/48	4	65	(80)	470	130	6.5	6050	8.0	6360

TABLE XVI (continued)

PROBE EXPERIMENTAL DATA IMPLSION FIXTURE

<u>Implosion Fixture Configuration</u>	<u>Probe</u>	<u>Mixture</u>	<u>Press.</u>	<u>mv Ave.</u>	<u>Peak Load</u>	<u>Ave. Energy Joules</u>	<u>R Ave.</u>	<u>T Ave.</u>	<u>R Peak</u>	<u>T Peak</u>
1" ring + 8 Spark Plugs	33-565	52/48	3 1/2	60	470	115	6.0	5940		
"	32-431	52/48	3 1/2	45	470	55	5.6	5360		
"	32-431	52/48	3 1/2	60	470	85	7.5	5640		
"	32-431	52/48	3 1/2	60	470	115	6.0	5940		
2" ring + 12 Spark Plugs	32-431	52/48	3	50	470	75	6.2	5440		
"	33-565	52/48	3	80	470	160	8.0	8360		
"	29-565	52/48	3	15	470	100	8.6	6460		
"	32-431	52/48	3	50	470	75	6.2	5440		
"	32-431	52/48	3	40	470	60	5.0	5260		
"	32-431	52/48	3	10	470	85	5.7	5860		



### VIII. LASING EXPERIMENTS UTILIZING CYANOGEN-OXYGEN SYSTEMS

A series of experiments were run using the various pumping fixtures to determine if a lase could be obtained from either a glass neodymium rod or a ruby rod. The probe experiments showed that the implosion fixture had the best chance of pumping ruby; however, the other fixtures were also experimentally tried. Using a glass neodymium doped laser rod of 2" length and approximately 1/4" diameter placed in the center of a Lucite tube which was inserted into the pumping fixture, several experiments were made using cyanogen-oxygen mixtures in order to determine if lasing could be obtained. Table XVII shows the experiments run using the glass neodymium rod and the cyanogen-oxygen system. The threshold energy required for lasing the glass rod was from 30 to 60 joules.

Figure 46 shows a plot of the input energy in joules vs. the output energy in millijoules for the Kodak 4 HM neodymium glass laser rod (1/4" diameter x 2" long) using two FX-100 Xenon flash tubes as the pumping source. The laser was held in a 10 mm OD piece of glass tubing with the flash tubes 180° apart touching the glass tubing. A piece of aluminum foil was wrapped around the flash tubes and glass tubing making the pumping cavity. As can be seen from Fig. 46, the threshold energy required for lasing this rod was 39 joules; that is, below this input energy no lasing was observed on the detectors. In many cases lasing was observed using the cyanogen-oxygen system. The best lasing occurred using the implosion fixture initiated peripherally with 12 spark plugs. The maximum output obtained using the implosion fixture with the 2" ring was 14.5 mj using a 52% cyanogen-48% oxygen mixture.

TABLE XVII

LASING EXPERIMENTS, NEODYMIUM CRYSTAL

Fix.	Laser Type	Laser No.	Threshold Energy Joules	Mixture C <sub>2</sub> N <sub>2</sub> :O <sub>2</sub> %	P Atm	Ignition	Lase	Remarks
Coax.	Glass Nd+	354	33	52:48	3	Spark(2)	No	
Coax.	Glass Nd+	354	33	52:48	3	Spark(2)	Yes	Threshold lase
Coax.	Glass Nd+	354	33	52:48	3	Spark(2)	No	
Coax.	Glass Nd+	354	33	52:48	3	Spark(2)	No	
Coax.	Glass Nd+	354	33	52:48	3	Spark(2)	No	Al. foil liner
Coax.	Glass Nd+	Isomet80J?	?	52:48	3	Spark(2)	No	Laser chipped
Coax.	Glass Nd+	HM-2	33	52:48	3	Spark(2)	Yes	Threshold lase
MP-1	Glass Nd+	354	33	52:48	3	Spark	No	
MP-1	Glass Nd+	354	33	52:48	3	Spark	Yes	Lg. pump pulse
MP-1	Glass Nd+	354	33	52:48	3	Spark	No	
MP-2	Glass Nd+	354	33	52:48	3	Spark	Yes	4 lg.-3 sm. pumps
MP-2	Glass Nd+	354	33	52:48	3	Spark	Yes	1 lg.-2 sm. pumps
MP-3	Glass Nd+	Isomet80J?	?	52:48	3	Spark	No	
T	Glass Nd+	CL1730	56	52:48	3	Spark	Yes	6 lg.-many sm. pulses
T	Glass Nd+	HM-1	30	52:48	3	Spark	No	
T	Glass Nd+	HM-1	30	52:48	3	Spark	No	

TABLE XVII (continued)

LASING EXPERIMENTS, NEODYMIUM CRYSTAL

Fix.	Las- Type	Co.	Threshold Energy Joules	Mixture C <sub>2</sub> N <sub>2</sub> :O <sub>2</sub> %	P Atm	Ignition	Lase	Remarks
T	Glass Nd+	HM-1	30	52:48	3	Spark	No	
T	Glass Nd+	CL1730	56	52:48	3	Spark	Yes	Lase Energy-.047J
T	Glass Nd+	HM-2	33	52:48	3	Spark	No	
T	Glass Nd+	311731A	60	52:48	3	Spark	Yes	5 pump pulses
T	Glass Nd+	CL1731A	60	52:48	3	XM-70	Yes	8 pulses
T	Glass Nd+	CL1730	56	52:48	3	XM-70	Laser damaged end	
T	Glass Nd+	354	33*(140)	52:48	3	XM-70	Yes	Threshold
T	Glass Nd+	354	33*(140)	52:48	3	XM-70	Yes	Threshold
T	Glass Nd+	354	33*(140)	52:48	3	Spark	No	Probe 50 in tube also
T	Glass Nd+	354	33*(140)	52:48	3	Spark	?	Probe 50 in tube also
T	Glass Nd+	354	33*(140)	52:48	4	Spark	No	Probe 58 in tube also
T	Glass Nd+	Kodak 6"#2		52:48	3	Spark	?	Laser rater showed .8J
T	Glass Nd+	Kodak 6"#2		52:48	3	Spark	No	Fluorescence noted
D	Glass Nd+	Kodak HM-1		52:48	3	4 plugs	Yes	
D	Glass Nd+	Kodak HM-1		52:48	3	4 plugs	?	Tube broke-destroyed all
D+2	Glass Nd+	Kodak 3HM		52:48	3	12 plugs	Yes	Strong lase

TABLE XVII (continued)

LASING EXPERIMENTS, NEODYMIUM CRYSTAL

Fix.	Laser		Threshold Energy Joules	Mixture C <sub>2</sub> N <sub>2</sub> :O <sub>2</sub> %	P Atm	Ignition	Lase	Remarks
	Type	No.						
D+2	Glass Nd+	Kodak 3HM		52:48	3	12 plugs	Yes	Strong lase-9 mj output
D+2	Glass Nd+	Kodak 4HM	39	52:48	3	12 plugs	Yes	4.2 mj output
D+2	Glass Nd+	Kodak 4HM	39	52:48	3	12 plugs	Yes	14.5 mj output
D+2	Glass Nd+	Kodak 4 HM	39	52:48	3	12 plugs	Yes	7.5 mj output
D+2	Glass Nd+	Kodak 4HM	39	52:48	3	12 plugs	Yes	3.0 mj output

Legend for Tables XVII and XVIII:

Fixtures:

- Coax. = coaxial fixture
- MP-1 = multipass fixture with liners
- MP-2 = multipass fixture without liners
- MP-3 = multipass fixture with 5" OD x 1 1/4" thick Lucite window
- T = Tee fixture
- D = Implosion fixture
- D+1 = Implosion fixture + 1" spacer
- D+2 = Implosion fixture + 2" spacer

Ignition:

- Spark = Spark plug, type AC-M8 spark plug, 0.1 mfd at 5000 volts
- XM-70 = small detonator

\* Laser threshold energy 140J -- due to laser end plating damage

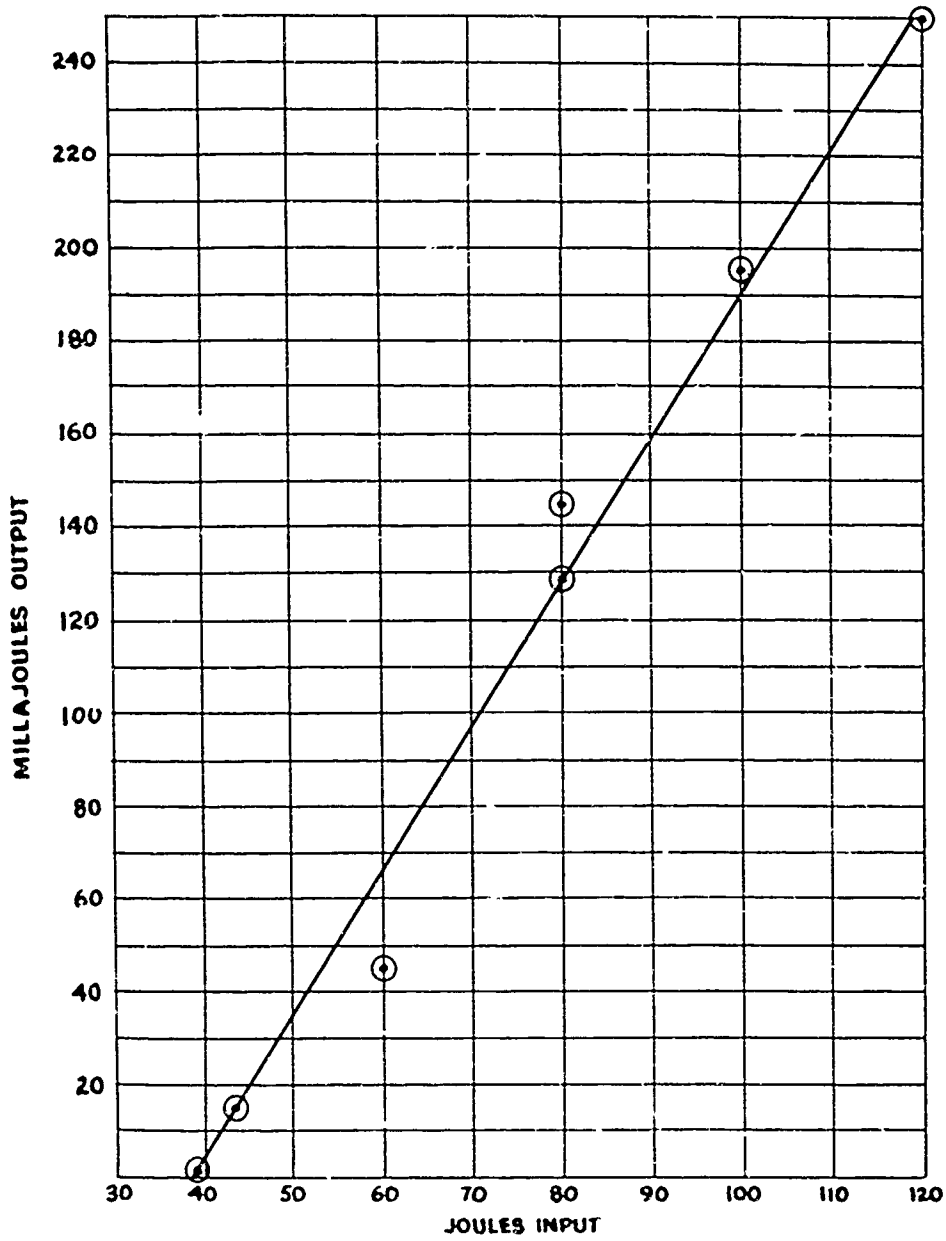


FIGURE 46  
INPUT VS OUTPUT ENERGY OF THE KODAK 4HM Nd<sup>3+</sup> GLASS ROD.  
PUMPING SOURCE: 2-FX-100 XENON FLASH TUBES

Attempts were made to pump a ruby rod which had a threshold lasing energy of approximately 150 joules using multipass, "T", and implosion type fixtures. Successful lasing was achieved using the implosion fixture, as listed in Table XVIII. The implosion fixture with the 2" ring showed the best results and the maximum energy output measured was 3 mj. It should be noted that the lasing pulses obtained using the ruby crystal occurred 1.5 ms after initiation. This period of time is extremely long for lasing pulses to appear after initiation and it has not been determined at this time what the cause of this delay is. However, these experiments show that the cyanogen-oxygen system is capable of pumping a ruby laser. These experiments showed that neodymium doped glass rods can be pumped above threshold using the above system.

TABLE XVIII

## LASING EXPERIMENTS, RUBY CRYSTAL

Fix.	Laser		Threshold Energy Joules	Mixture C <sub>2</sub> N <sub>2</sub> :O <sub>2</sub> %	P Atm	Ignition	Lase	Remarks
	Type	No.						
MP-2	Ruby	Mellor #1	140	52:48	3	Spark	No	
MP-2	Ruby	Mellor #1	140	52:48	3	Spark	No	
MP-2	Ruby	Mellor #1	140	52:48	3	Spark	No	
T	Ruby	Mellor #1	162	52:48	3	Spark	No	
T	Ruby	Mellor #1	162	52:48	3	Spark	No	
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	
D+1	Ruby	Mellor #2		52:48	3	8 plugs	Yes	Threshold lase
D+1	Ruby	Mellor #2		52:48	3	8 plugs	Yes	Spikes noted @ 400-500 μs + 1000-1200 μs from initiation
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	
D+1	Ruby	Valpier.13" dia.		52:48	3	8 plugs	Yes	Threshold @ 600 μs
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	Detection Sys. failure
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	Detection Sys. failure
D+1	Ruby	Mellor #2	52:	52:48	3	8 plugs	No	Detection Sys. failure
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	Detection Sys. failure

TABLE XVIII (continued)

## LASING EXPERIMENTS, RUBY CRYSTAL

Fix.	Laser Type	Laser No.	Threshold Energy Joules	Mixture C <sub>2</sub> N <sub>2</sub> :O <sub>2</sub> %	P Atm	Ignition	Lase	Remarks
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	Detection Sys. failure
D+1	Ruby	Mellor #2		52:48	3	8 plugs	No	Tube broke-sys. destr.
D+2	Ruby	Mellor W-167.03CR		52:48	3	12 plugs	?	1 Philco det. got spikes-other did not
D+2	Ruby	Valpier #1		52:48	3	12 plugs	No	
D+2	Ruby	Mellor Sap. Clad		52:48	3	12 plugs	No	
D+2	Ruby	Valpier.13" dia.		52:48	3	12 plugs	Yes?	Philco det. showed no pulses-931A showed sm. lasing pulses @ 1.5 ms
D+2	Ruby	Valpier.13" dia.		52:48	3	12 plugs	?	3 mj reading on laser rater-bad reading on det.
D+2	Ruby	Mellor Sap. Clad		52:48	3	12 plugs	Yes	Def. lasing @ 1.5 ms after peak



## IX. CONCLUSIONS

The major accomplishment of this program was the pulse pumping of a ruby solid-state laser utilizing as the energizing source a cyanogen-oxygen-gaseous detonation confined in a specially designed pumping fixture. Also a neodymium solid-state laser could be pulse pumped using the same system. The program studies yielded information on the production of high intensity light sources by using fast chemical reactions as well as a better understanding of the mechanisms that produce these high temperatures.

Unclassified  
Security Classification

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<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
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		2b. GROUP
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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Army Army Materiel Command Picatinny Arsenal	
13. ABSTRACT Feldman Research Laboratory Dover, New Jersey 07801 <p>The use of a cyanogen-oxygen gaseous detonation system has been demonstrated successfully to pump both neodymium and ruby solid state lasers. Several types of pumping fixtures have been evaluated and the energy input in terms of radiation temperature have been correlated to mixture ratio, initial pressure, ignition geometry, and vessel geometry. A complete study of the radiation output of the cyanogen-oxygen gaseous detonation system including the effect of inert gas addition (helium, argon and xenon) was undertaken. The radiation temperature of the cyanogen-oxygen detonation using 52% cyanogen with the initial system pressure at 3 atm was 6300°K. The use of inert additives yielded temperatures as high as 8000°K. Emission spectra were taken of the detonation together with detonation velocity measurements.</p>		

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Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Lasers Cyanogen Solid-State Lasers High Temperature Reactions High Brightness Chemical Pyrotechnic Sources Detonation, gas						

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