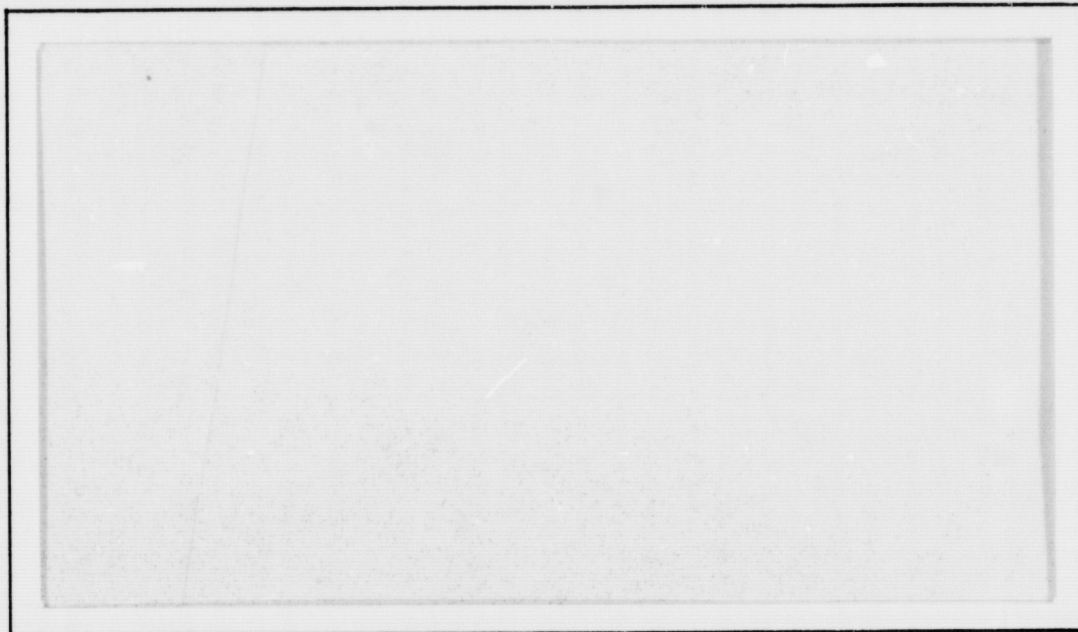


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PRINCETON, NEW JERSEY

FACILITY FORM 602

N 69-11880

(ACCESSION NUMBER)

(THRU)

44

(PAGES)

(CODE)

CR-98131

(NASA CR OR TMX OR AD NUMBER)

14

(CATEGORY)



POST IGNITION HYDROGEN
DETECTION SYSTEM

Contract NAS8-20857

Phase II

System operation; detail design;
breadboard characteristics; design
of prototypes.

Prepared by: D. B. Byron

Approved by: R. J. Levine

Report R-568-31

31st, May 1968

NASSAU INSTRUMENTS, INC.
26 - 206 Center
Princeton, New Jersey
609-924-9608

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SUMMARY

This report describes the work performed under Phase II of NASA contract NAS8-20857. This Phase requires the design and testing of a breadboard device to demonstrate feasibility to detect micro-explosions of hydrogen in air.

A design study is contained in the Phase I report of this contract. (Report R-1167-30). Subsequent work has proved the practicability of the proposed system and a breadboard has been built to demonstrate its successful operation.

I. SYSTEM OPERATION.

The explosion detector is designed to respond to the UV radiation from a hydrogen/air explosion, dominant at 3100 Å (Figure 1), in the presence of solar radiation, which contains radiation at the same wavelength in amounts depending on altitude and time. (Figure 2).

It should be noted that the method of detection employed prohibits the device being used to detect the presence of a constant hydrogen flame, since constant UV radiation will not create an output signal. However as an explosion detector, the device will indicate an explosion within about 15 milliseconds of ignition. Since the UV radiation from a hydrogen/oxygen flame will probably not be entirely constant this device would see the onset of such a flame and most probably would respond to variations in the flame's level.

The detector employs two photomultiplier tubes to monitor radiation in the bands 3100 ± 75 Å and 3400 ± 150 Å. Their output signals are compared and maintained equal by a feedback loop regulating the power supply of one photomultiplier tube. A time delay in the feedback permits a rapidly changing input in the signal channel only to cause a temporary imbalance corresponding to an explosion. Input optics permit a wide angle of view to be monitored and the response to an explosion can be fed to computing equipment to define the magnitude and position of the explosion.

II. DETAIL DESIGN

A. Electronics

Figure 3 shows the electronic part of the detection system consisting of two photomultiplier tubes whose outputs are compared. A filter on PMT A restricts its radiant input to the explosion wavelength at $3100 \pm 75 \text{ \AA}$ while PMT B is filtered to look at an adjacent wavelength not contained by the explosion radiation. i.e. PMT B is looking at a typical band of ambient radiation only. (In the breadboard, PMT B looks at $3400 \pm 170 \text{ \AA}$) The difference in outputs is magnified and used to regulate the output voltage of power supply B, such that the photomultiplier outputs are maintained equal.

The significant property of an explosion which is exploited in this detection system is that the radiation increases rapidly within the band under surveillance. Figure 4 demonstrates the build-up resulting from various hydrogen/air mixtures. Thus the effect of a time constant (C1 in Fig.3) delaying the response of the power supply B permits the A channel signal to exceed that of the B channel by a significant amount while the feedback loop is catching up. This situation can only arise while photomultiplier A responds to a rapidly increasing radiation which the B channel cannot see -- corresponding to a hydrogen explosion.

Any out-of-balance signal resulting from the two photomultipliers is simultaneously passed through a differentiating circuit and what is effectively a level detector. Operational amplifier AT 3 is connected such that its output will become

negative to switch Q1 only when both a minimum level and rate of increase of signal exist. The magnitude is set to correspond with the threshold level specified in the contract (4.2×10^{-9} watts/cm²) and the rate is selected as the lowest which can be expected from mixtures containing up to 70% hydrogen at the threshold level (see Figure 4) (i.e. 4.38×10^{-10} Watts/cm²/msec, 100 cm from the explosion in the band $3100 \text{ \AA} \pm 100 \text{ \AA}$).

Thus the detector will give an output across R22 only when the radiation input has sufficient magnitude and rate of increase. These minimum levels can be adjusted by varying the magnitudes of R16 and $e_{\text{ref.2}}$ respectively.

B. Optics.

In order that the electronic detection system may be incorporated in a useful instrument it is necessary to monitor as wide an area as possible. Since the responses of an interference filter and a photomultiplier are functions of the angle of incidence of radiation, input optics are needed to present a uniform image at the photocathode. In addition an optical system enables a single radiation input to the detector.

Figure 5 (SK 368-1) is a schematic of the breadboard optical assembly. Input radiation passes through a stop and an objective lens to a beamsplitter. The transmitted ray continues through a condenser and $3100 \text{ \AA}$ filter to the signal channel (PMT A) while the reflected ray is turned through 90° and passes through a $3340 \text{ \AA}$ filter to the ambient channel (PMT B). The beam-splitter transmits about four times as much radiation as it reflects and this is partially compensated

by the transmission of the filters -- the signal channel having a narrower bandwidth and lower peak transmission than the ambient channel.

The use of an input stop to the optical system permits the emergent cone of rays to be incident on the focal plane with the center ray nearly normal and independent of field angle. This is necessary since the filter spectral response and photomultiplier sensitivity are both functions of angle of incidence.

C. Computation.

The specification requires that the "sensing system provide an output which is capable of being analyzed to determine the location of the ignition source".

Since the radiation received by a photodetector is proportional to the intensity of radiation and inversely proportional to the square of its distance from the source of radiation, four detectors are required to determine the magnitude and position co-ordinates of an explosion. Figure 6 (SK168-4) shows detectors 1, 2, 3 and 4 located at $(0,0,0)$, $(a,0,0)$, $(b,c,0)$ and (f,e,d) . Point P represents a micro-explosion.

The intensity of light I at a distance from the source is K/r^2 , where K depends only on the magnitude of the light source. Thus the following equations can be set up for the signal received at each detector:

$$r_1^2 = x^2 + y^2 + z^2 = K/I_1$$

$$r_2^2 = (a - x)^2 + y^2 + z^2 = K/I_2$$

$$r_3^2 = (b - x)^2 + (c - y)^2 + z^2 = K/I_3$$

$$r_4^2 = (f - x)^2 + (e - y)^2 + (z + d)^2 = K/I_4$$

Thus we have four equations describing a ninth degree system which can be solved for the four unknowns x, y, z and K and an explicit solution can be found for any set of conditions. Appendix 1 contains a procedure for solving these equations. This assumes that $d \neq 0$, which requires only that the fourth sensor is not in the same plane as the other three.

In practice it is expected that the sensor outputs will be fed to some external computing equipment capable of performing the calculations.

D. Package.

No attempt has been made to minimise the size of the breadboard detector. The optical components and photomultipliers are mounted on a plate roughly 12" square and stand about 3" high. Plate 1 shows a general view of the assembly and Figure 7 shows how the optical components are mounted within the input housing. Radiation enters the detector through an input stop (not shown in Fig. 7) mounted in the objective lens cell. The electronics are mounted separately on a board and the two high voltage power supplies for the photomultipliers (Kepco ABC 1500 M) are free-standing. (See Plate 2).

The breadboard detector operates from a standard 110 volt 60 c/s supply, which is rectified to give a ± 15 volt supply to the operational amplifiers.

Appendix 2 lists the major components of the breadboard detector.

III. CHARACTERISTICS OF BREADBOARD DETECTOR

A. Test set-up.

Tests are performed with the optical parts of the detector inside a light-tight box six feet long and of two foot square section. (See Plates 3 and 4). Ambient and explosion radiation sources are simulated by deuterium lamps, which have a continuous spectrum within the UV. A narrow-band filter is used in conjunction with the lamp simulating the explosion to restrict its output to that of a hydrogen explosion at 3100 Å.

A dividing wall across the box separates the explosion radiation source from the detector and supports an iris and shutter arrangement which permits a controlled magnitude and rate of increase of radiation to reach the detector.

The ambient radiation source is placed in the same compartment as the detector and reflected from the dividing wall and a front surface mirror into the input stop.

B. Calibration of Breadboard Detector

To date, calibration of the detector is approximate but the system has shown sufficient sensitivity to very low radiation levels to permit considerable overestimates to have been made. (i.e. The signal channel is operating at nearly 600 volts in the breadboard, with the possibility of increase to 1000 volts if required.

A Pen-Ray Mercury Vapour lamp was used as the radiation source and the manufacturer's data on the radiant intensity in each

of its spectral lines has been taken as correct. Thus it is possible to estimate the irradiance at a known distance from the source in each of the spectral lines which would pass through the filter in the signal channel ($3110 \text{ \AA} \pm 75 \text{ \AA}$). In addition, the signal photomultiplier voltage was adjusted to give 0.1 uA at the threshold level ($4.2 \times 10^{-9} \text{ watts/cm}^2$) so that the photomultiplier would be most stable. (High anode currents lead to less stable operation). Figures 8A and 8B show the resulting calibration curves.

C. Response to simulated explosion.

By employing a shutter with a known "rise time" (i.e. the time taken to move from the fully closed to the fully open positions) at different aperture settings, it is possible to vary the rate of increase of radiation entering the detector. If the anode current in the signal channel is set with the aperture open at the selected stop number, then the rate of increase of radiation when the shutter is fired equals the radiation level corresponding to the selected current divided by the time for the shutter to open. The response to the simulated explosion is monitored at R22 (See Fig. 3) on an oscilloscope and Plate 5 illustrates a typical response.

Figure 9 demonstrates the linear detector response to explosions of different sizes with and without the presence of ambient radiation. It will be noticed that large explosions are not included on this graph, but initially attention has been directed towards the threshold levels, which are less easy to detect. The response to the full range of explosion levels will be measured in the near future using higher

radiation inputs, but no problems are anticipated. In addition, it should be pointed out that the internal capacitance of the ambient channel power supply was more than enough to delay its response. Further tests will be performed with power supplies with a much higher slewing rate to optimize the time constant of the feedback loop.

D. Response to real explosion.

For repetitive testing it is more convenient to use the lamp and shutter arrangement described above, but it is felt that the device should be tested with a real explosion to confirm its effectiveness. Consequently the device shown in Plate 6 has been built for this purpose.

A small chamber is contained within the cylinder when the piston is fully closed. A coiled nichrome ignition wire is supported in this chamber by a sealed Conax housing and fluids can pass in and out through a plastic hose and clamp arrangement. The chamber is filled with an explosive mixture of hydrogen and air as follows: The piston is closed and the chamber filled completely with water; hydrogen is made by electrolysis of water and fills the chamber by displacement; air is drawn into the chamber by withdrawing the piston a known distance. An explosion is caused by passing a current through the ignition wire.

Radiation given out by an explosion passes through a quartz window at the end of the cylinder. Plate 7 illustrates a typical response of the signal channel photomultiplier to a real explosion seen through the input optics. The anode current was measured as a voltage by passing it through a one megohm resistor to ground. The scope trace indicates an explosion lasting about 5 milliseconds with a peak radiation

equivalent to 0.25 uA. The rise time is about $2\frac{1}{2}$ milliseconds at an average rate of .050 uA/msec.

Plate 8 shows the response of the detector to a real explosion, measured at the output of the subtracting amplifier. The upper trace in this plate can be ignored since it is a datum pulse triggered internally by the scope; the lower trace corresponds to the explosion. It has a peak of .11 volts and a rise time of about one millisecond.

Since the threshold level has been set at 0.1 uA in the signal channel photomultiplier (see Section 3B - Calibration) these scope traces show that the explosions we are making are of the same order as the threshold level. In addition the rise rate of increase of radiation is only a little more than the minimum selected.

E. Response to off-normal radiation.

Since a micro-explosion can be considered to be a point source of radiation, the energy received at the photocathode can be expected to display a $\cos^3\theta$ relationship, where θ is the field angle (i.e. the angle between the normal to the receiving surface and the beam.).

The breadboard optical system was tested by using a board with holes drilled around concentric circles at $22\frac{1}{2}^\circ$ intervals. The detector input was aligned with the center hole and a light shone from behind each hole in turn; corresponding measurements of the signal channel anode current were made. Figure 10 shows that the response to off-normal signals in two directions at right angles is subject to marked attenuation. In addition the detector field of view was limited to a field angle of $\pm 28^\circ$.

It is proposed to supply each of the Phase III prototype detectors with a calibration of the response to off-normal radiation in preference to the alternative of employing a variable density filter in an attempt at compensation -- an attempt which at best is unlikely to be entirely successful.

F. Response Time.

The minimum rate of increase of explosion radiation to which the detector will respond has been selected as that which occurs at the threshold level and corresponds to that of a 15% hydrogen in air mixture. These levels are reached within 15 milliseconds of initiation of the explosion (see Fig. 4) and in reality it is felt that a micro-explosion will more probably be very close to a stoichiometric mixture; thus achieving the threshold rate in much less than fifteen milliseconds after ignition.

The response time of a typical photomultiplier is of the order of 10^{-7} or 10^{-8} seconds. These figures are accepted from the manufacturers' data since they are several orders of magnitude less than those which would be critical in the system.

Thus the overall system response time between the appearance of the threshold signal and the indicated output will be almost immediate and considerably less than 100 milliseconds. In addition, the detector will give an output in much less than 100 milliseconds from the moment of initiation of the micro-explosion -- a figure of around 15 milliseconds being anticipated as a maximum.

IV. DESIGN OF PROTOTYPES.

The prototype detectors will be contained in a single package connected by a cable consisting of three low voltage unshielded wires. (+28 volts, ground and signal). Since our investigations show that solid state photo-detectors are only marginally sensitive for this application, photomultipliers will also be employed in the prototype instruments. End-on, ruggedized photomultipliers will probably be used for reasons of availability and uniformity of cathode response and these suggest an overall package size of approximately 3" x 5" x 12" (see Fig.11); the radiation input stop being situated in one of the ends. Appendix 3 describes an E.M.I. 1" diameter end-on photomultiplier, which will be suitable when it is potted along with its dynode resistors and magnetic shield. Other similar tubes are commercially available from EMR and Amperex.

Compact high voltage power supplies operating from a 0 to +15 volt input are also standard commercial units. A Venus Scientific model K15U is to be tested shortly and is expected to be incorporated in the prototype. Appendix 4 describes this power supply which is contained in a package 1" dia. x 2 1/4" long. Other similar power supplies are available from EMR and MIL Associates.

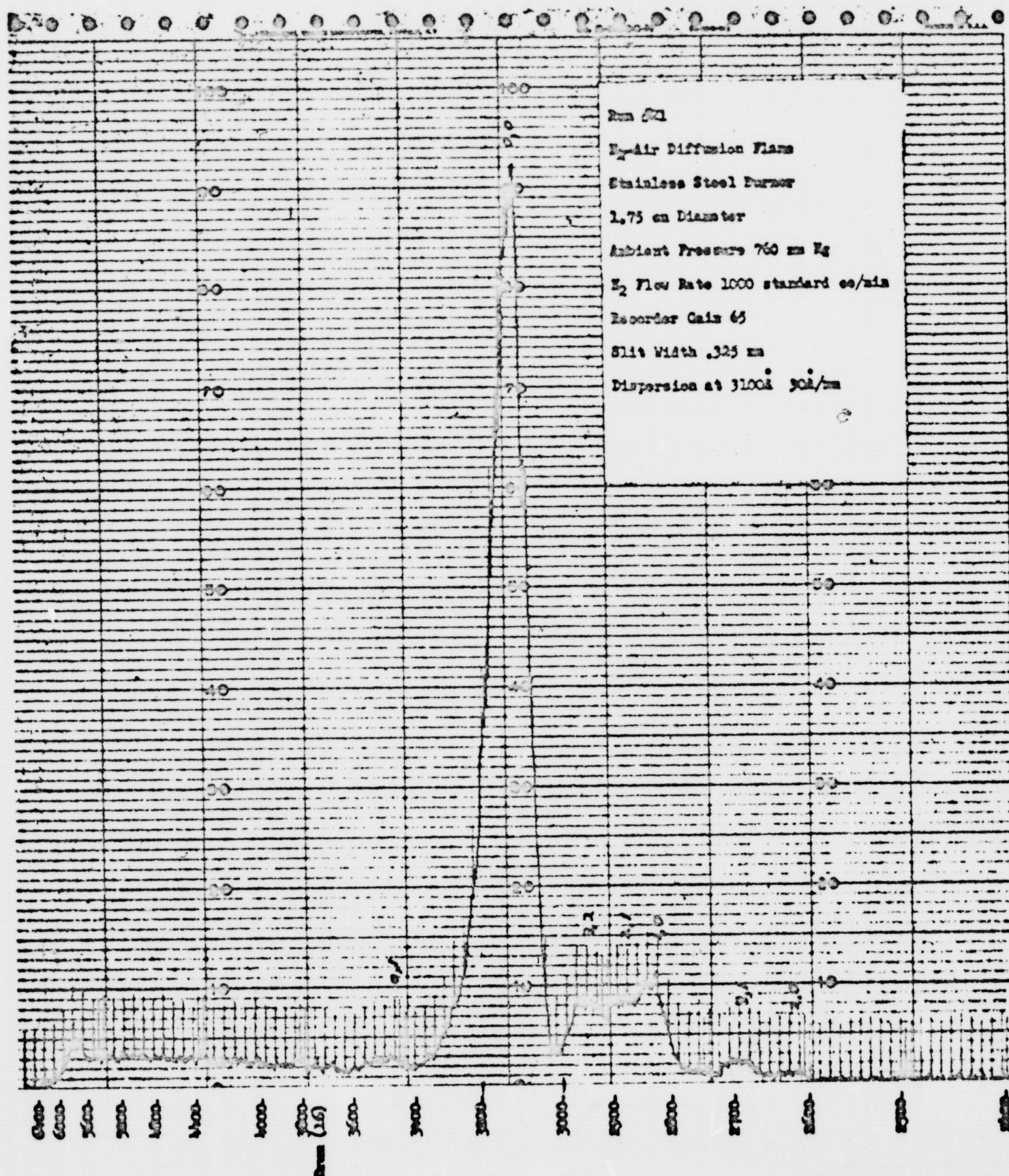
It is anticipated that the input optics will contain components similar to those of the breadboard but current study is aimed at optimizing the instrument package size, field angle and unit cost. The addition of a front surface mirror in the ambient light path permits the two photomultipliers to be situated alongside each other as shown in Figure 11.

ILLUSTRATIONS

- Fig. 1: UV-visible spectrum of hydrogen-air diffusion flame at 760 mm Hg.
- Fig. 2: Ambient solar radiation at sea level and in space.
- Fig. 3: Electronic schematic - micro-explosion detector.
- Fig. 4: UV radiation from hydrogen-air explosion vs. time.
- Fig. 5: Optical breadboard layout.
- Fig. 6: Geometry of photosensors to detect an explosion.
- Fig. 7: Plan view of optical component assembly.
- Fig. 8A&B: Calibration of signal channel with optical input.
- Fig. 9: Detector response to simulated hydrogen-air explosion.
- Fig. 10: Response of detector to off-normal radiation.
- Fig. 11: Schematic hydrogen explosion detector.

PLATES

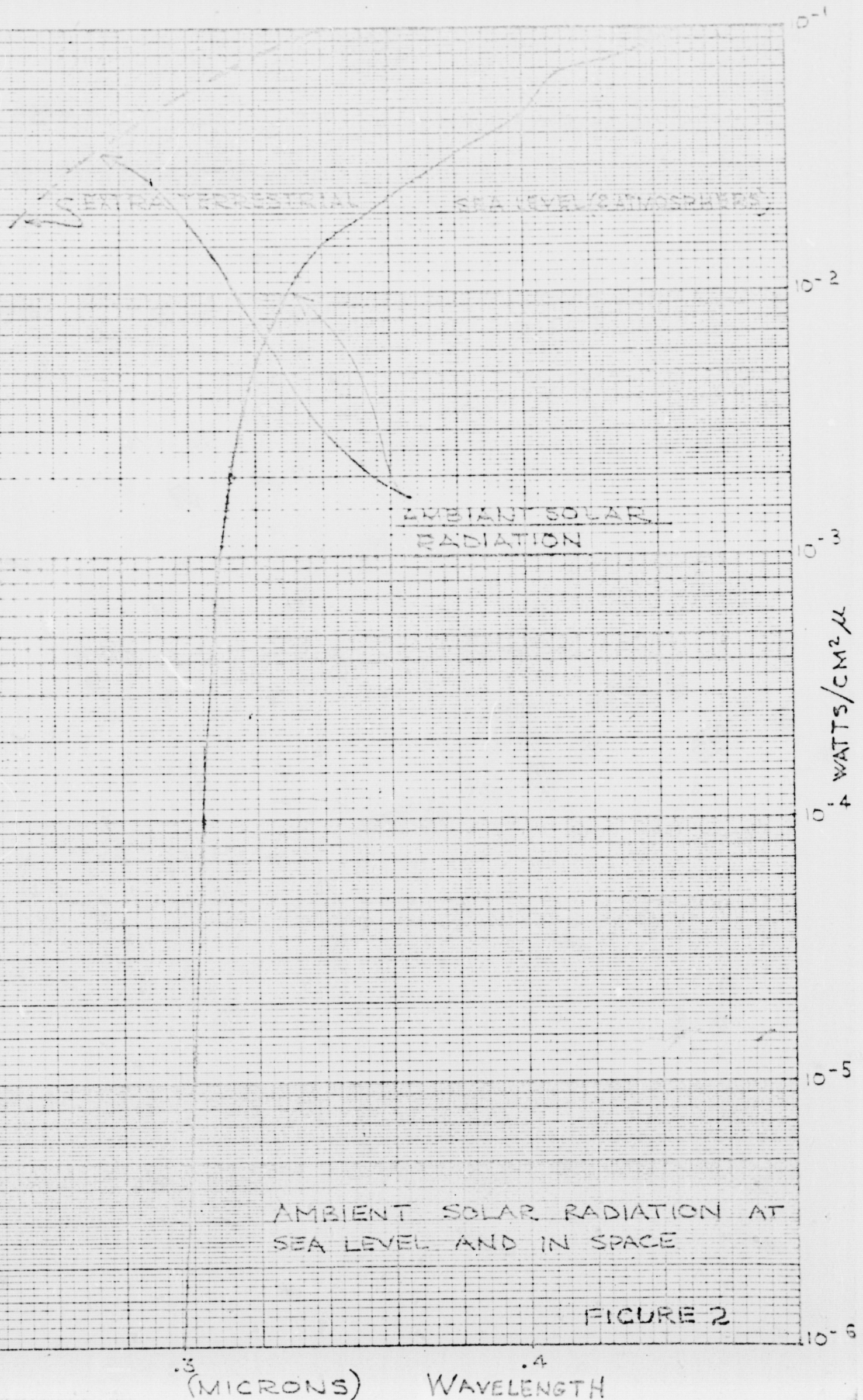
- Plate 1: Explosion detector optical assembly.
- Plate 2: Explosion detector electronics.
- Plate 3: Test set-up - elevation.
- Plate 4: Test set-up - plan view.
- Plate 5: Detector response to simulated explosion.
- Plate 6: Device for making small hydrogen-air explosions.
- Plate 7: Response of signal channel photomultiplier to real explosion.
- Plate 8: Response of detector at output of subtracting amplifier to real explosion.



wavelength in angstroms

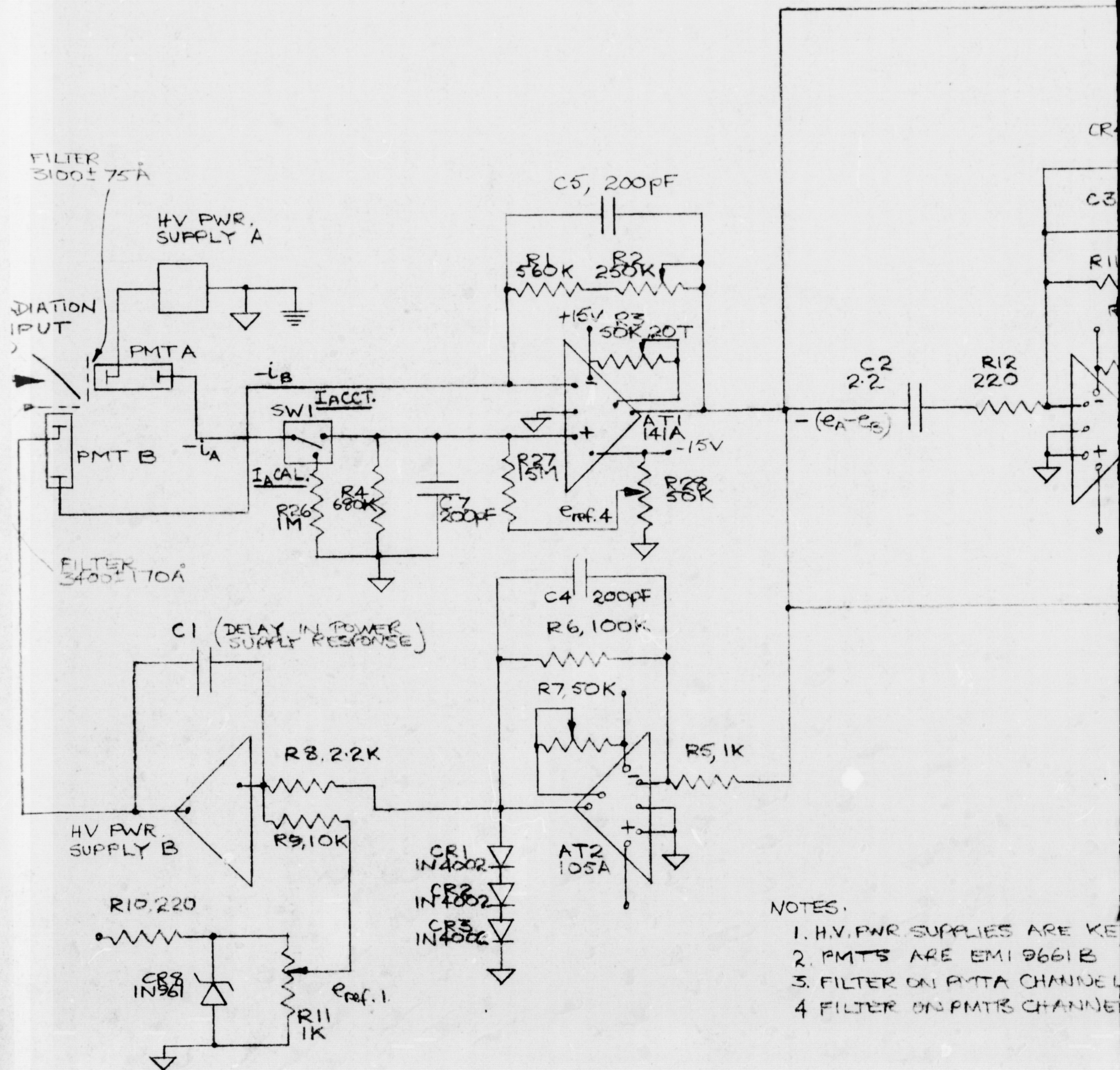
UV-visible spectrum of hydrogen-air diffusion flame at 760 mm Hg. Recorder gain = 65.

FIGURE 1



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Foldout FRAME 1



NOTES.

1. H.V. PWR. SUPPLIES ARE KE
2. PMTS ARE EMI 9661 B
3. FILTER ON PMT A CHANNEL
4. FILTER ON PMT B CHANNEL

"REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR."

REVISIONS

SYM	DESCRIPTION	DATE	APPROVED
A	1/P TO AT1 MODIFIED; R_{13} MOVED; COMP. AROUND AT3 CHANGED; C4, C5, C6, R22, R23, CR5 ADDED.	5:29:68	
B	R25 REMOVED, C7 ADDED.	6:11:68	

FOLDOUT FRAME 2

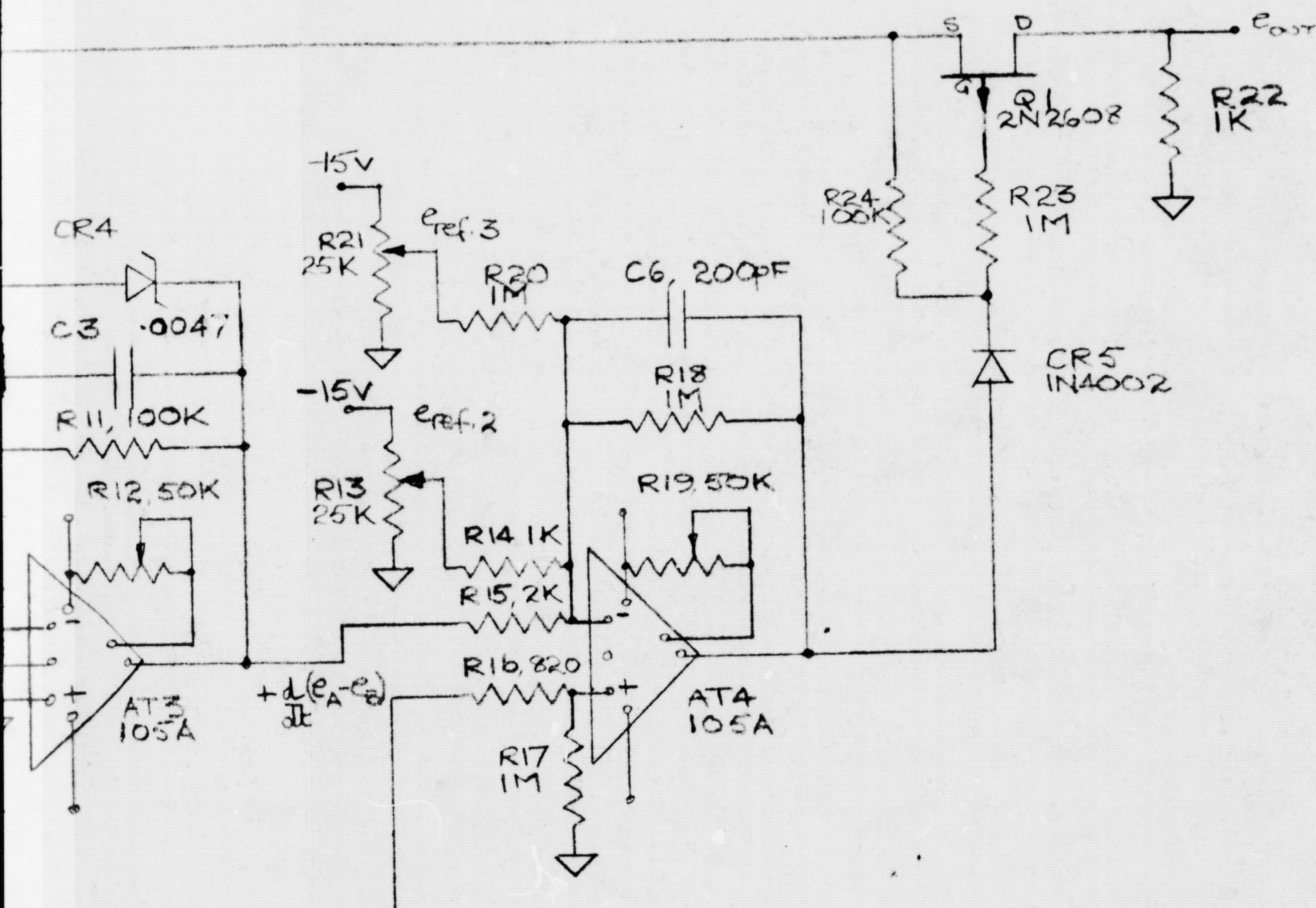


FIGURE 3

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SCALE:
DATE: 5:7:68

APPROVED BY:

DRAWN BY DBB
REVISED 5:29:68

SCHEMATIC-MICRO EXPLOSION DETECTOR

DRAWING NUMBER
SK 568-7 B

KEPCO ABC 1500M
SIB
CHANNEL 3110 Å ± 75
CHANNEL 3400 Å ± 170

NASSAU INSTRUMENTS, INC.
 26 206 CENTER, HIGHWAY 206
 PRINCETON, NEW JERSEY 08540
 (609) 924-9608

HYDROGEN-AIR EXPLOSIONS
 UV RADIATION FROM
 SOURCE VS. TIME

IRRADIANCE
 MWATTS/CM²
 (2200-4000Å)

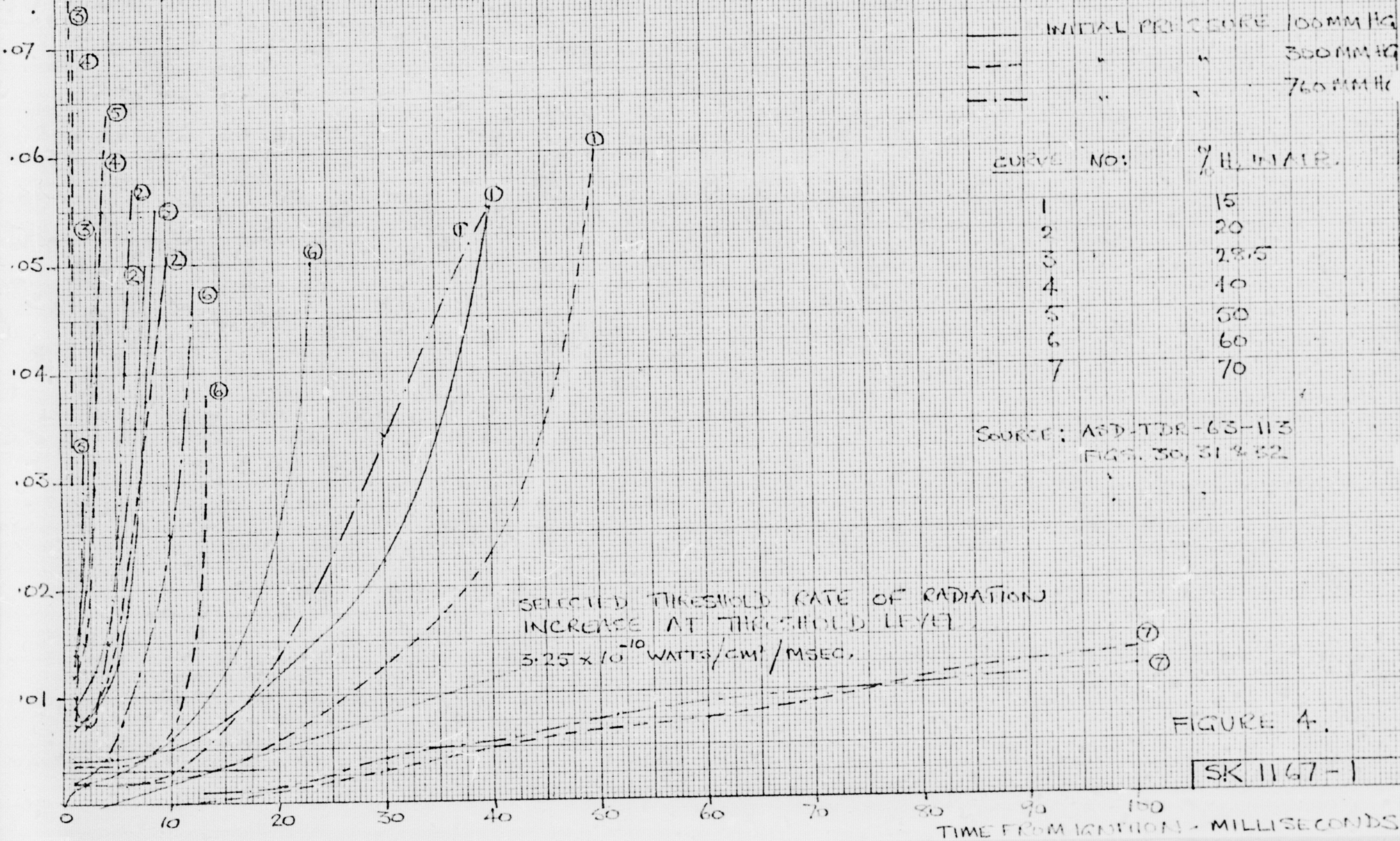


FIGURE 4.

SK 1167-1

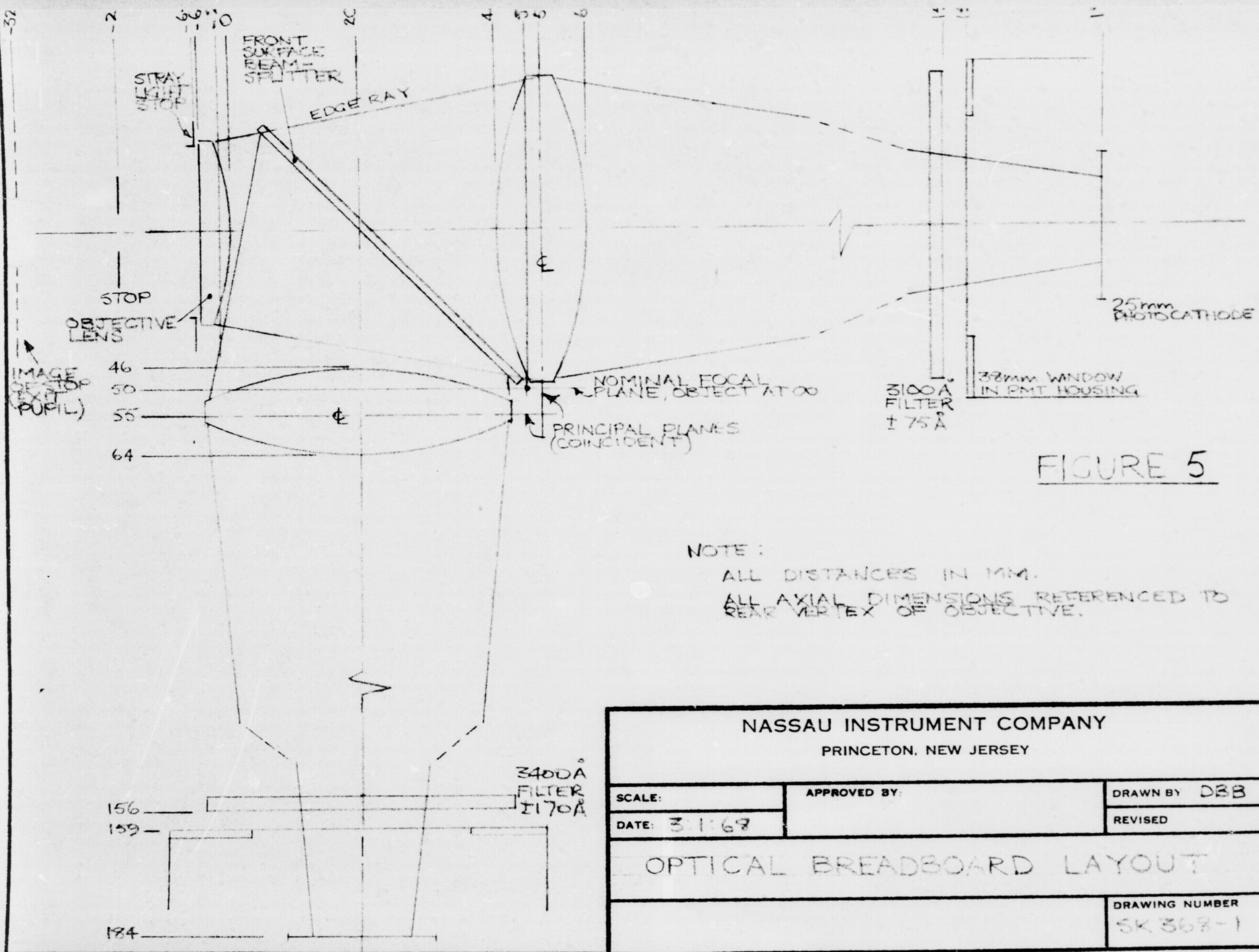


FIGURE 5

NOTE:
ALL DISTANCES IN MM.
ALL AXIAL DIMENSIONS REFERENCED TO
REAR VERTEX OF OBJECTIVE.

NASSAU INSTRUMENT COMPANY
PRINCETON, NEW JERSEY

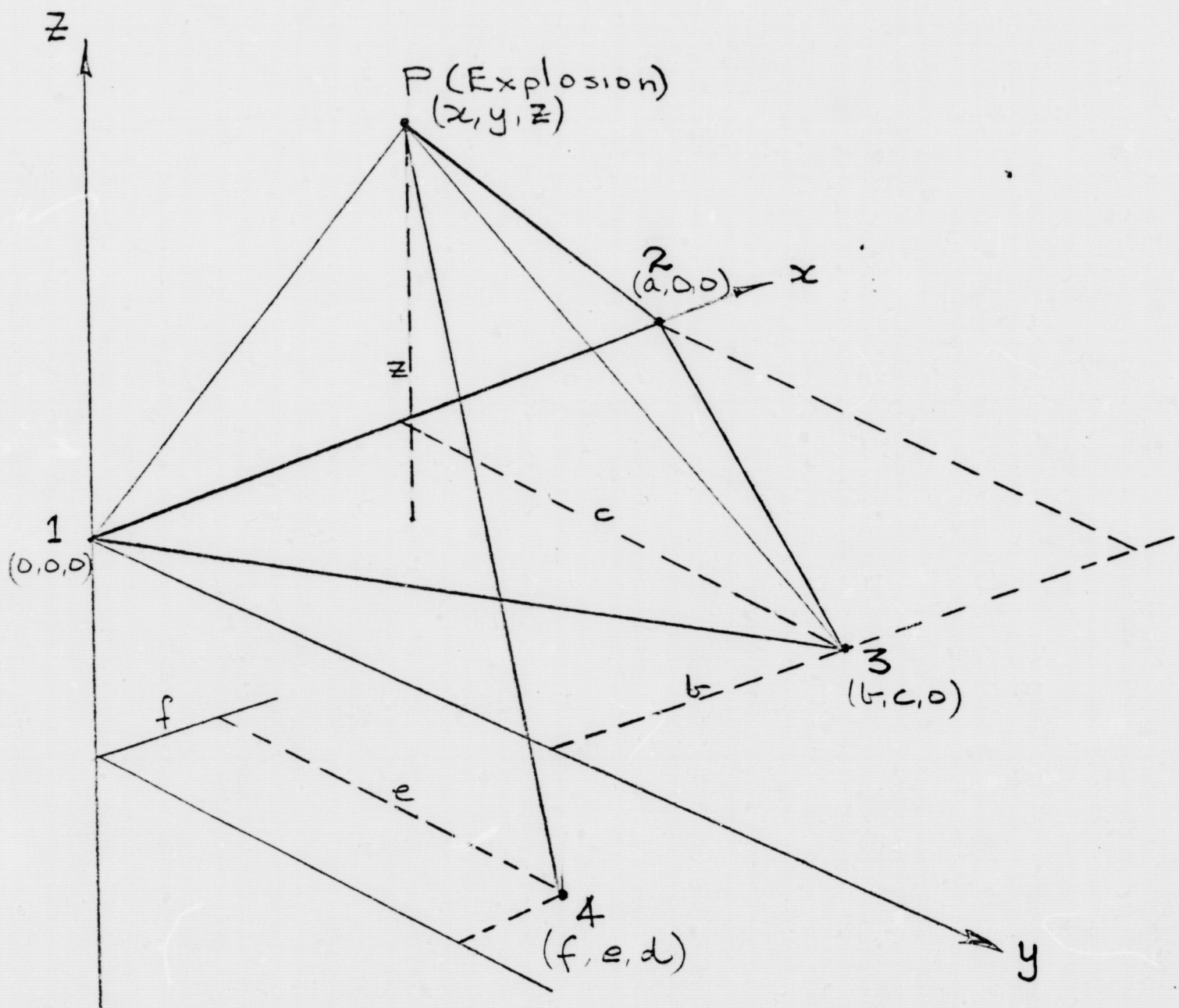
SCALE:
DATE: 3-1-68

APPROVED BY:

DRAWN BY DBB
REVISED

OPTICAL BREADBOARD LAYOUT

DRAWING NUMBER
SK 368-1



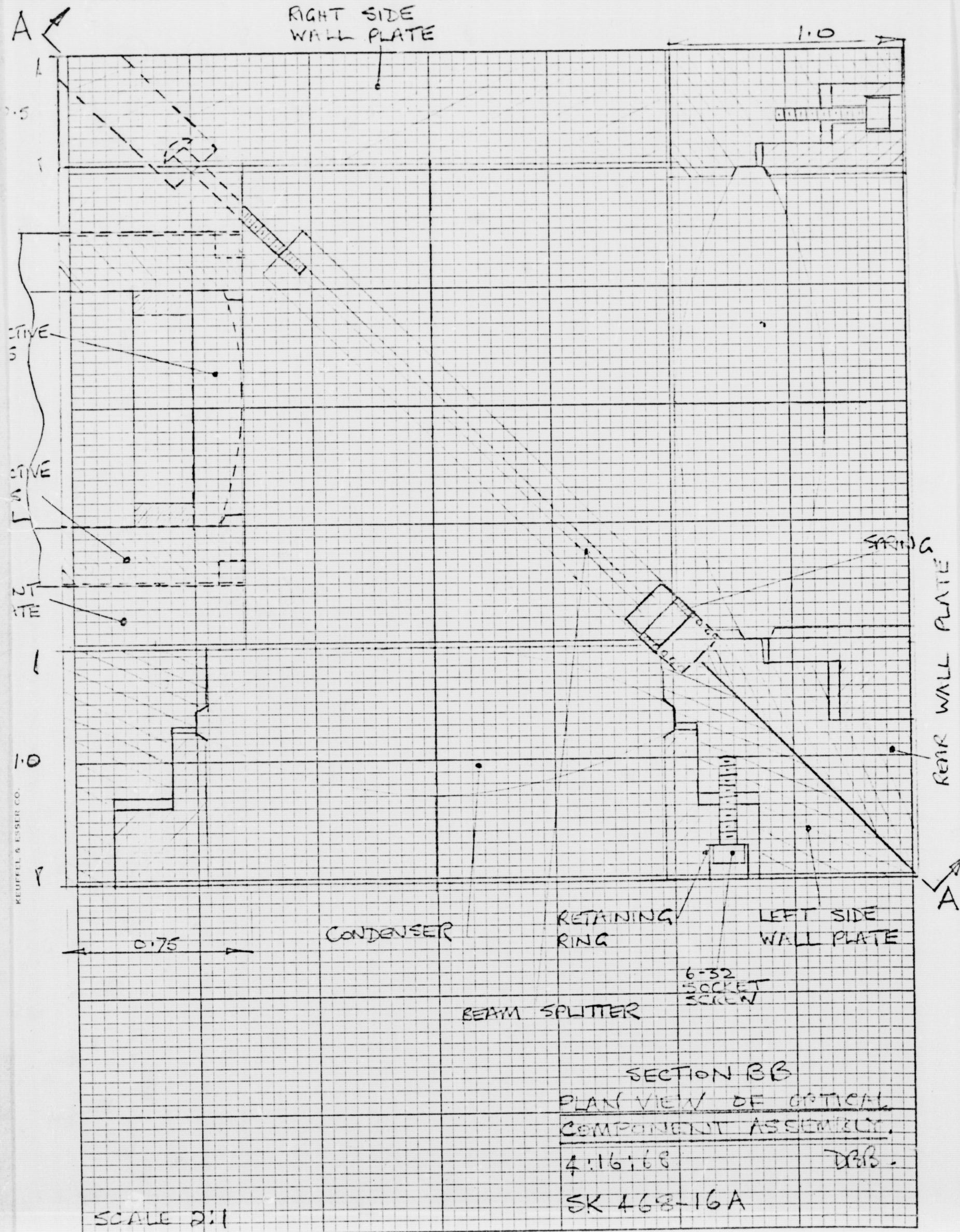
Sensors 1, 2 & 3 are in plane xy
 Sensor 4 is below plane xy

FIGURE 6

NASSAU INSTRUMENTS, INC.

GEOMETRY OF PHOTSENSORS
 TO DETECT EXPLOSION AT P.

SK 168-4
 DBB.



Squares to the Inch

SIGNAL
CURRENT
 I_A

READINGS OF I_A TAKEN
WITH PMT H.V. PWR. SUPPLY = 593 VOLTS.

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

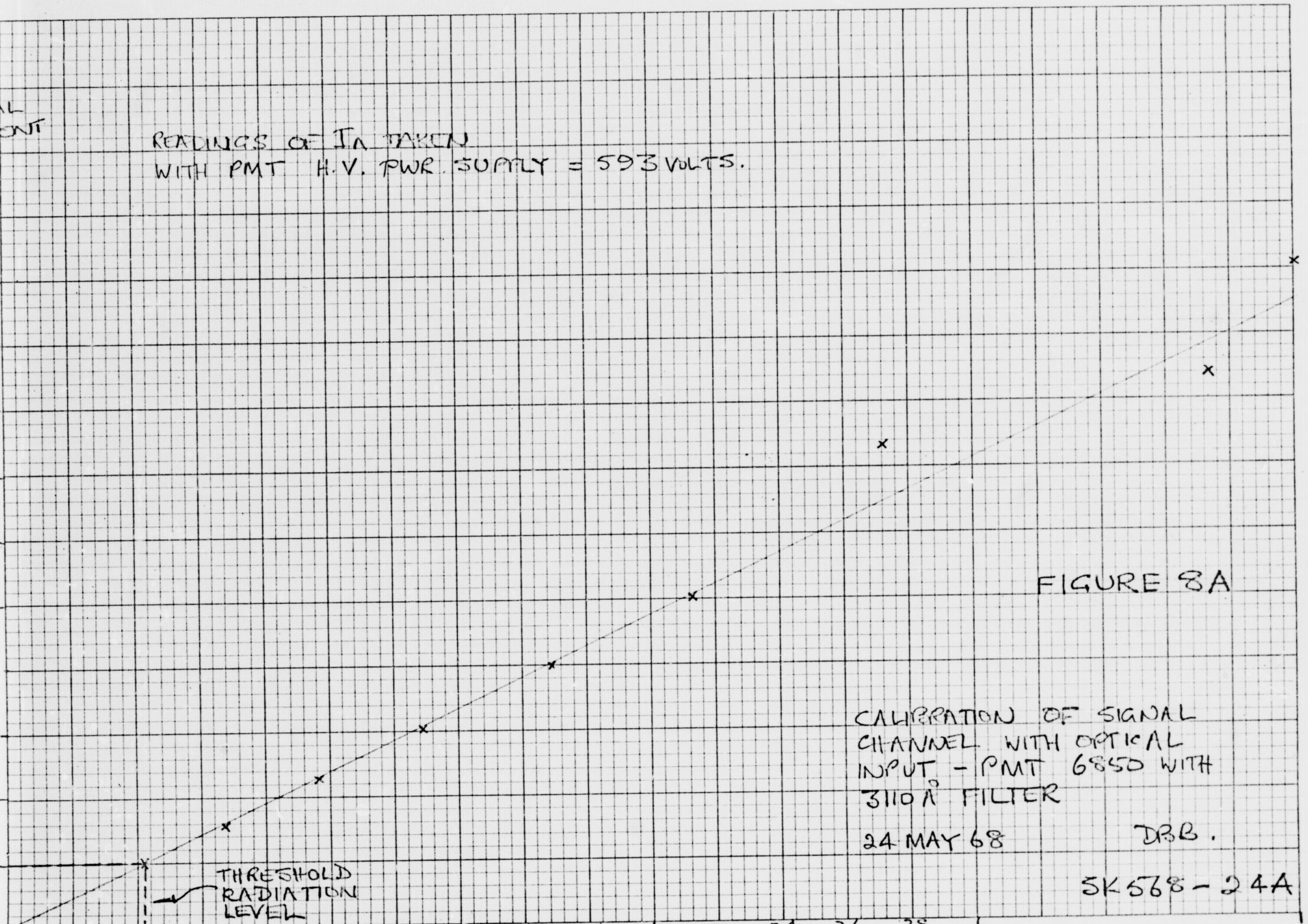


FIGURE 8A

CALIBRATION OF SIGNAL
CHANNEL WITH OPTICAL
INPUT - PMT 6850 WITH
3110 Å FILTER

24 MAY 68

DRB.

5K568-24A

INTENSITY OF RADIATION AT INPUT STOP. $\times 10^{-9}$ WATTS/CM²

SIGNAL
CURRENT
IA

READINGS OF IA TAKEN
WITH PMT. H.V. POWER SUPPLY = 593 VOLTS.

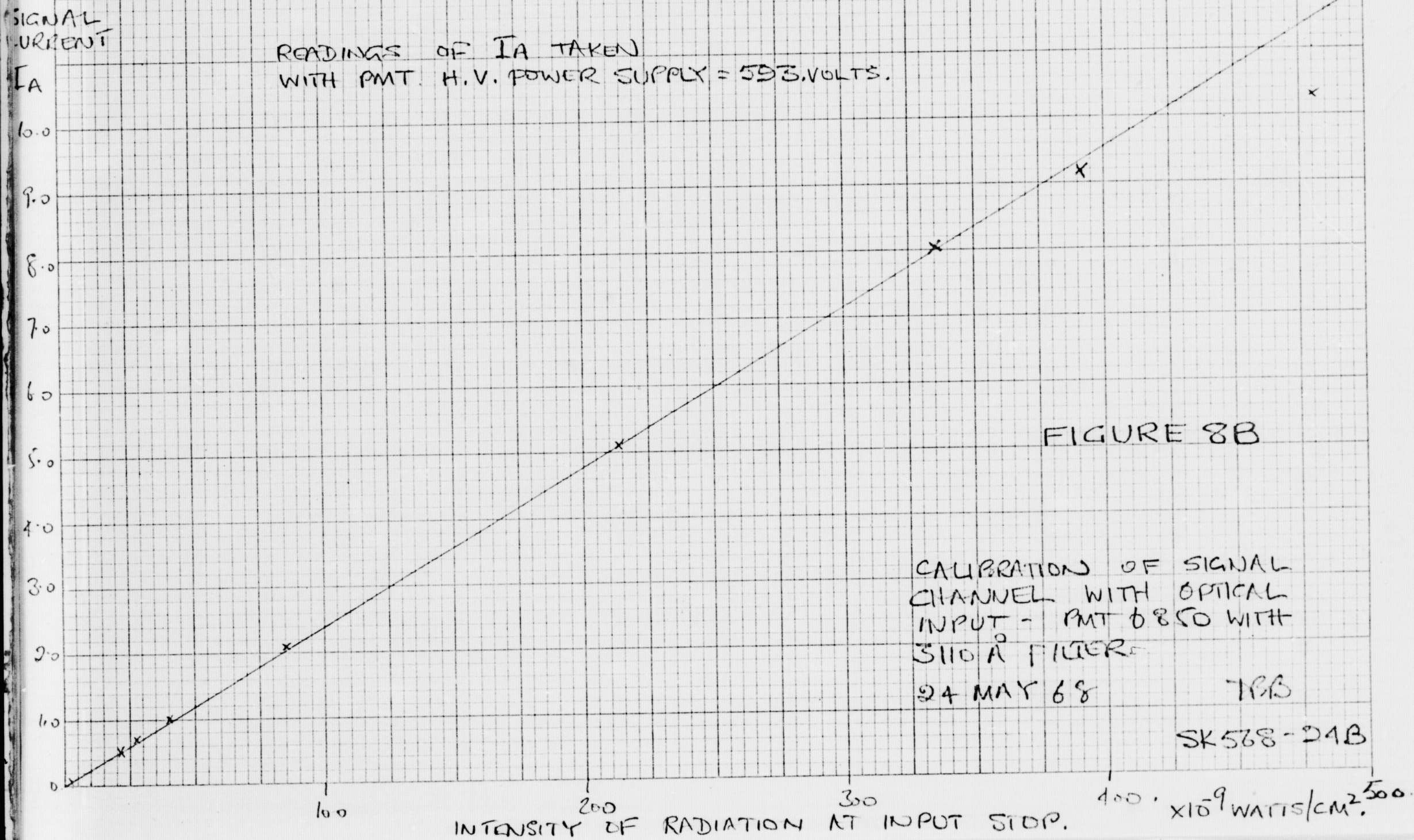


FIGURE 8B

CALIBRATION OF SIGNAL
CHANNEL WITH OPTICAL
INPUT - PMT 0850 WITH
3110 Å FILTER

24 MAY 68

TGB

SK568-24B

DETECTOR RESPONSE TO SIMULATED HYDROGEN/AIR EXPLOSION

OUTPUT
VOLTAGE
E_g (mV)

-200

-150

x WITHOUT AMBIENT

o WITH AMBIENT 12x
THRESHOLD LEVEL IN
BAND 300175A.

SK668-4

THRESHOLD
LEVEL

ANODE CURRENT IN
SIGNAL CHANNEL

0

-0.1

-0.2

-0.3

-0.4

-0.5 mA

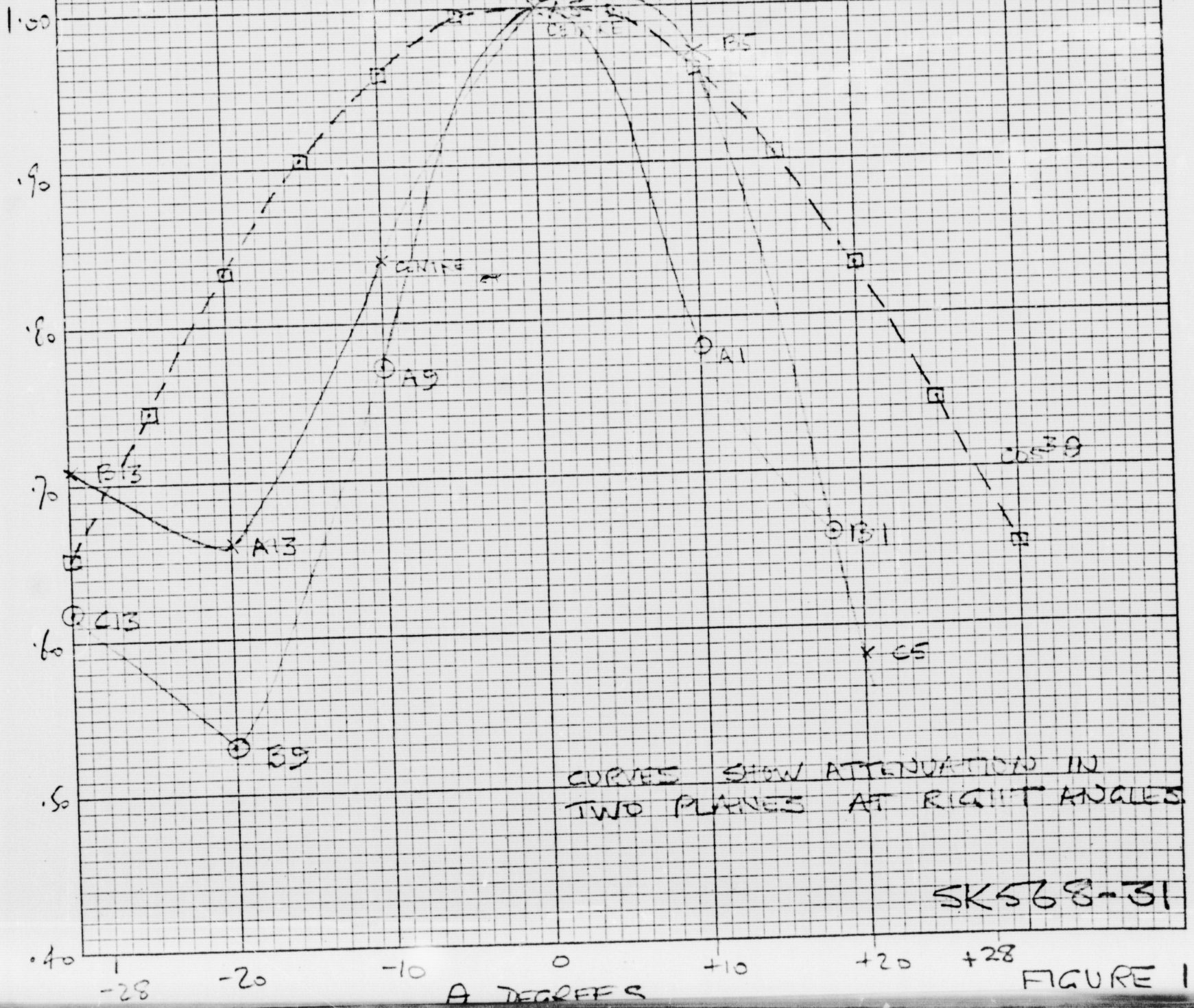
FIGURE 9

RESPONSE OF DETECTOR TO OFF-NORMAL RADIATION

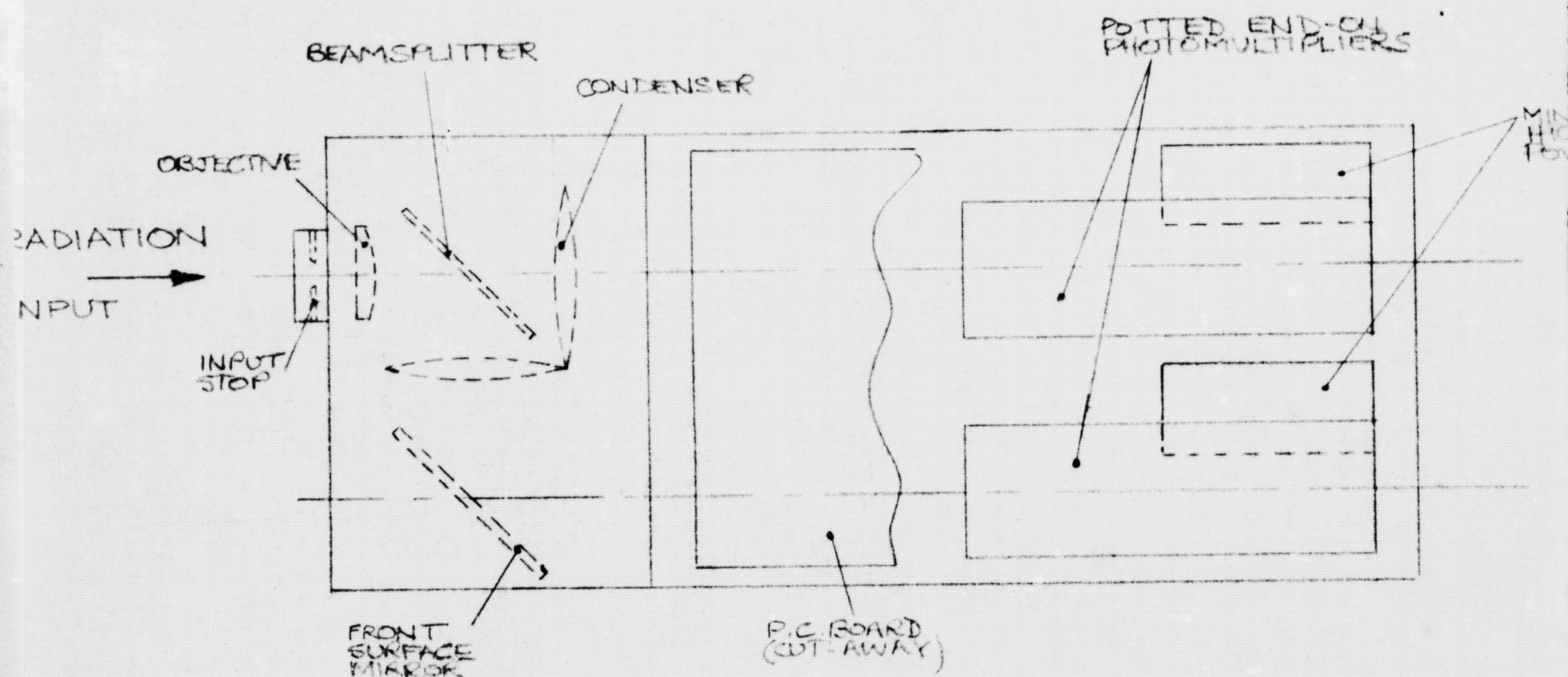
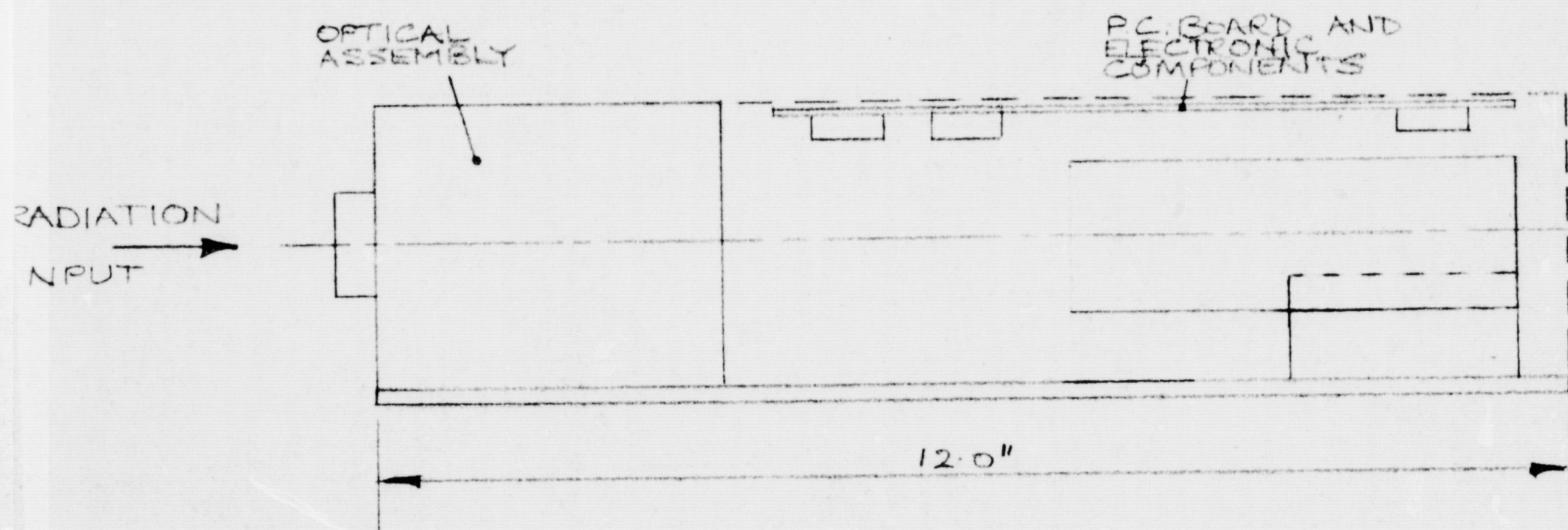
5/31/68

JEG

NORMALISED
RESPONSE

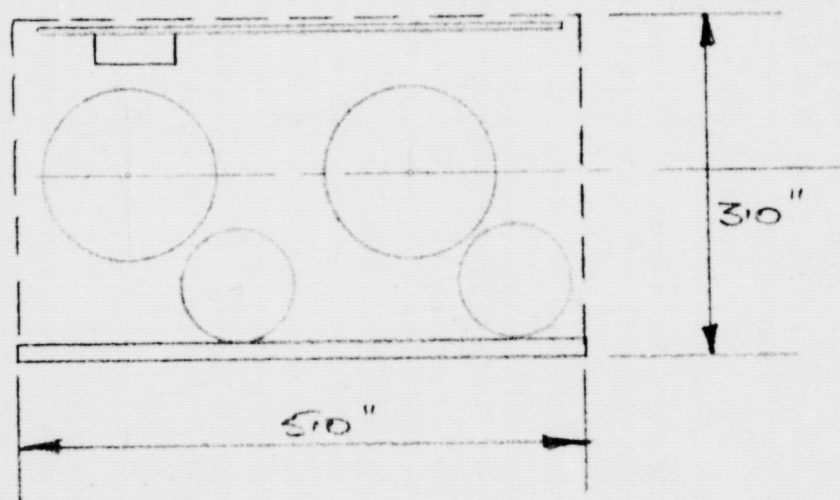


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Foldout FRAME

REVISIONS			
SYM	DESCRIPTION	DATE	APPROVED



MINIATURE
HIGH VOLTAGE
TOWER SUPPLIES

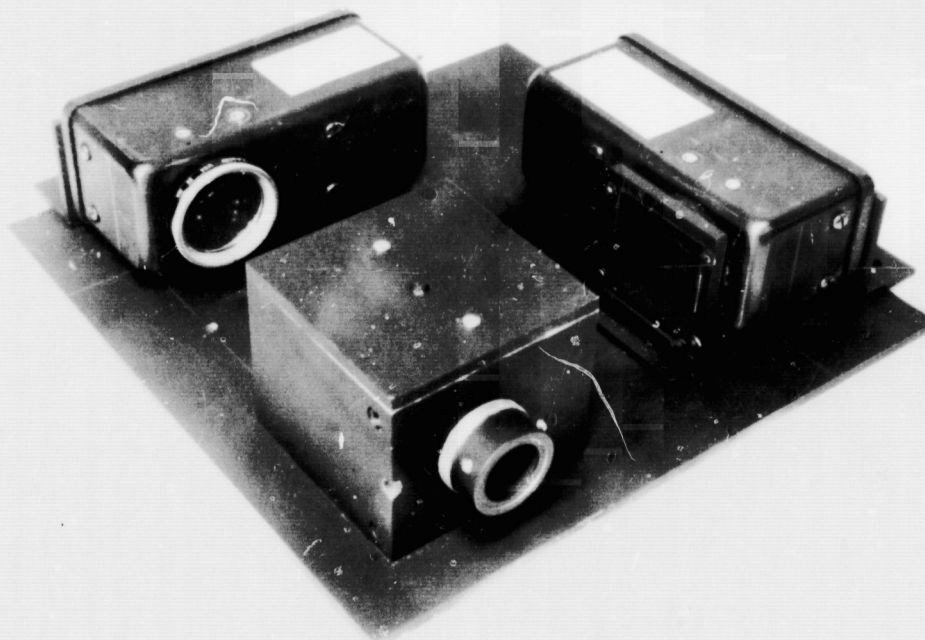
FIGURE 11

Foldout FRAME 2

NASSAU INSTRUMENT COMPANY PRINCETON, NEW JERSEY		
SCALE: 1" = 2"	APPROVED BY	DRAWN BY DBB
DATE: 6-11-68		REVISED
SCHEMATIC HYDROGEN EXPLOSION DETECTOR		
		DRAWING NUMBER SK 668-11

Signal channel
photomultiplier
with $3100 \pm 75\text{\AA}$
filter

Ambient channel
photomultiplier
with $3400 \pm 170\text{\AA}$
filter



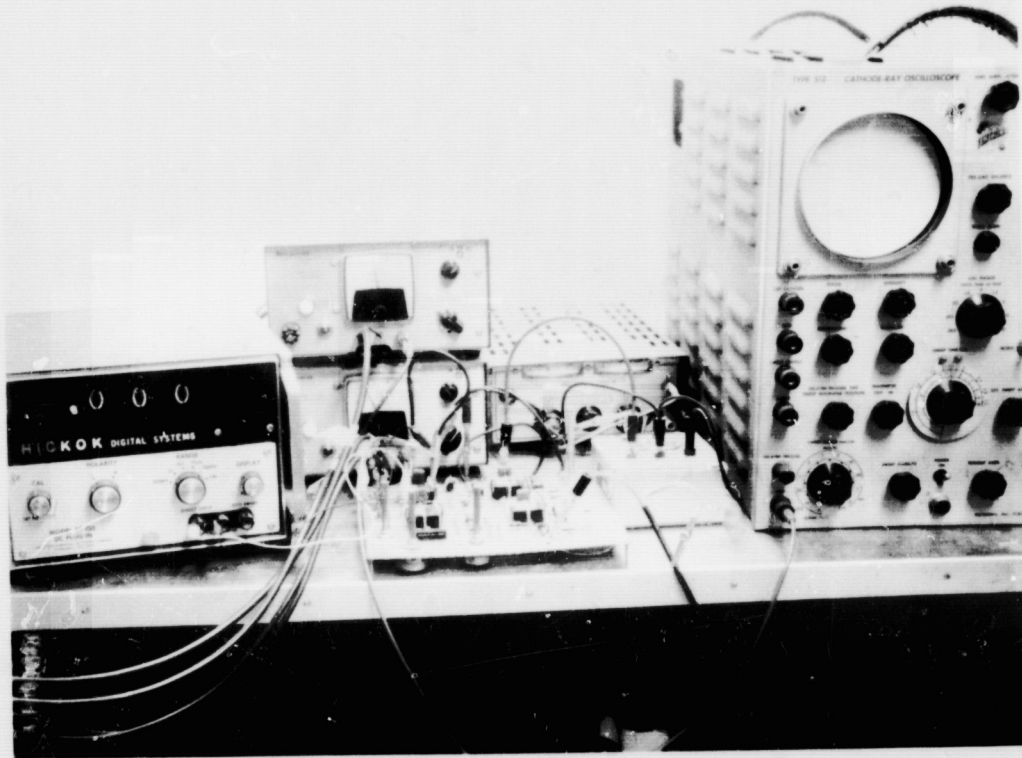
Input
stop

EXPLOSION DETECTOR OPTICAL ASSEMBLY

PLATE 1

2 Kepco high
voltage power
supplies
#ABC1500M

Op.amp. power
supply. Deltron
type HP



Digital
Voltmeter

Breadboard
electronics

EXPLOSION DETECTOR ELECTRONICS

PLATE 2

Dividing
Wall

Shutter

White paper and
mirror reflect
ambient light into
detector input



Wall of
light tight
box

Optical
Assembly

Deuterium lamp
to simulate
ambient light.

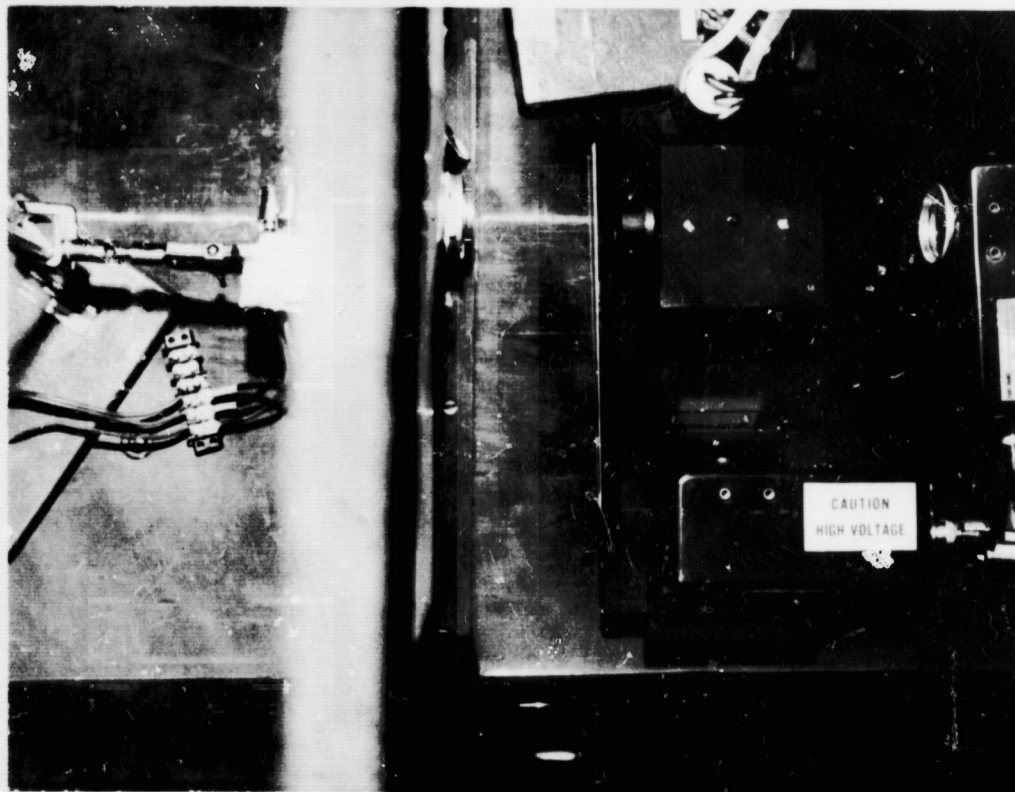
TEST SET-UP - ELEVATION

PLATE 3

Deuterium lamp to
simulate explosion
radiation

Shutter

Deuterium lamp to
simulate
ambient light

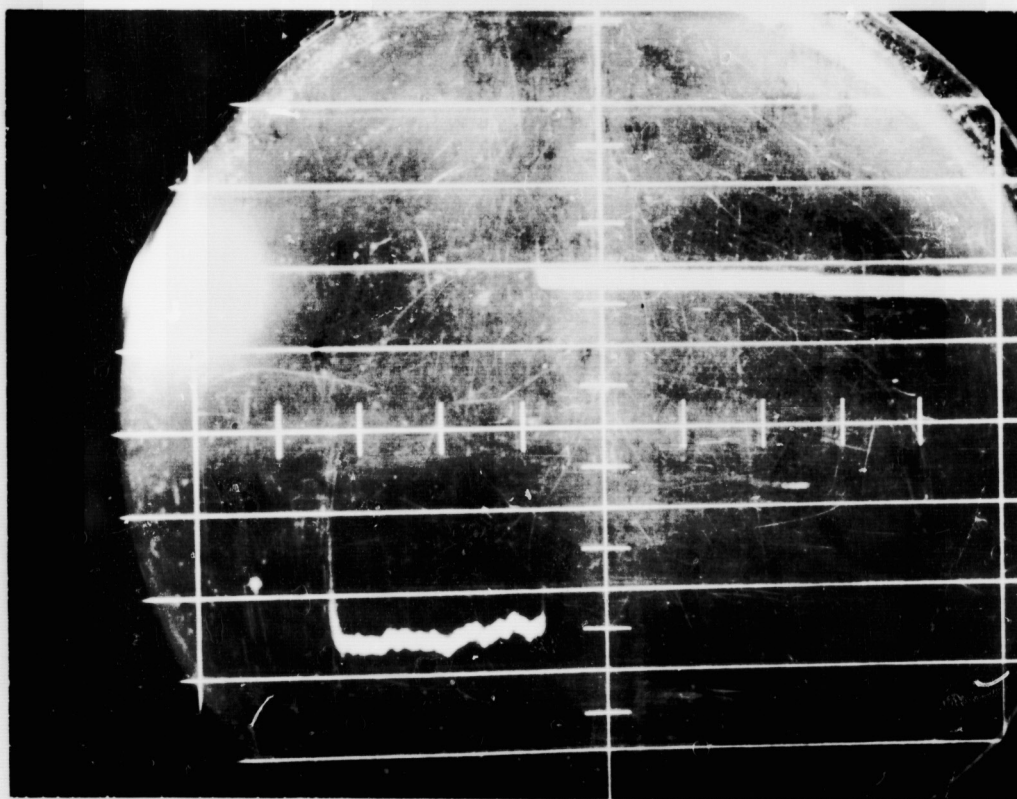


Dividing
Wall

Optical
Assembly

TEST SET-UP - PLAN VIEW

PLATE 4

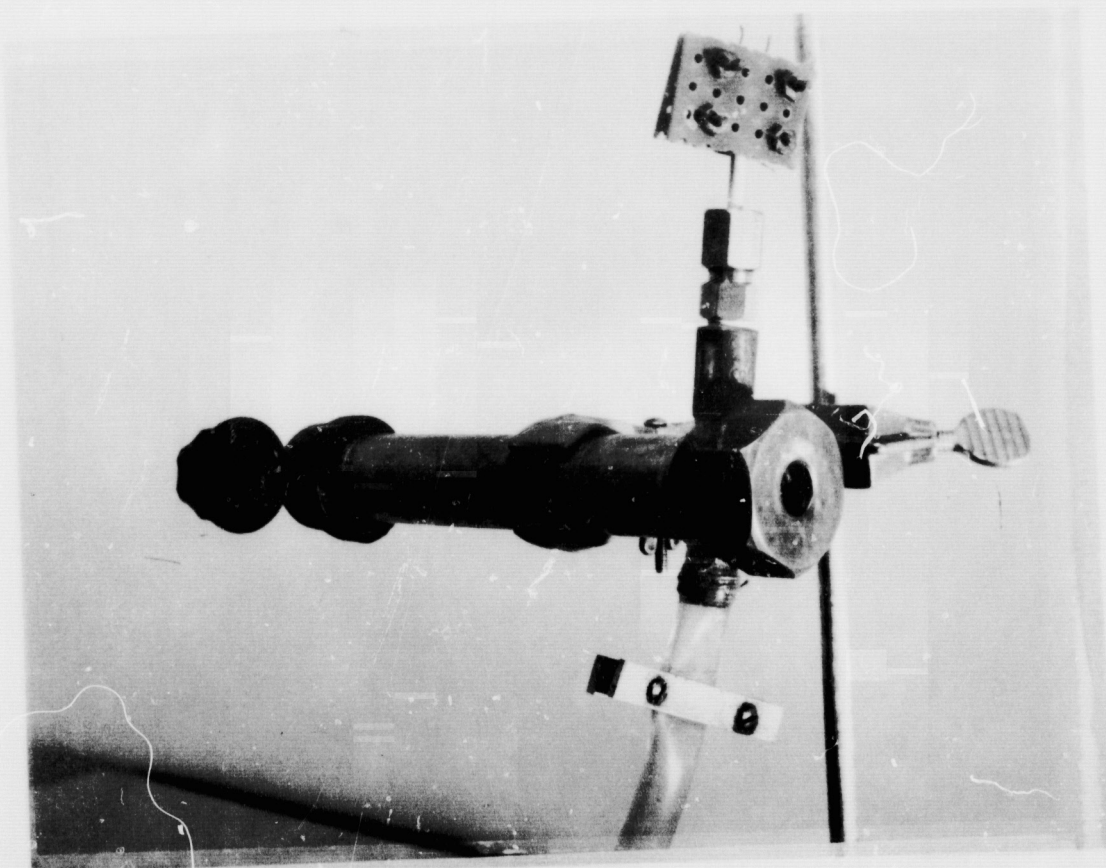


DETECTOR RESPONSE TO SIMULATED
EXPLOSION

PLATE 5

Head of
piston

Ignition
wire ends.



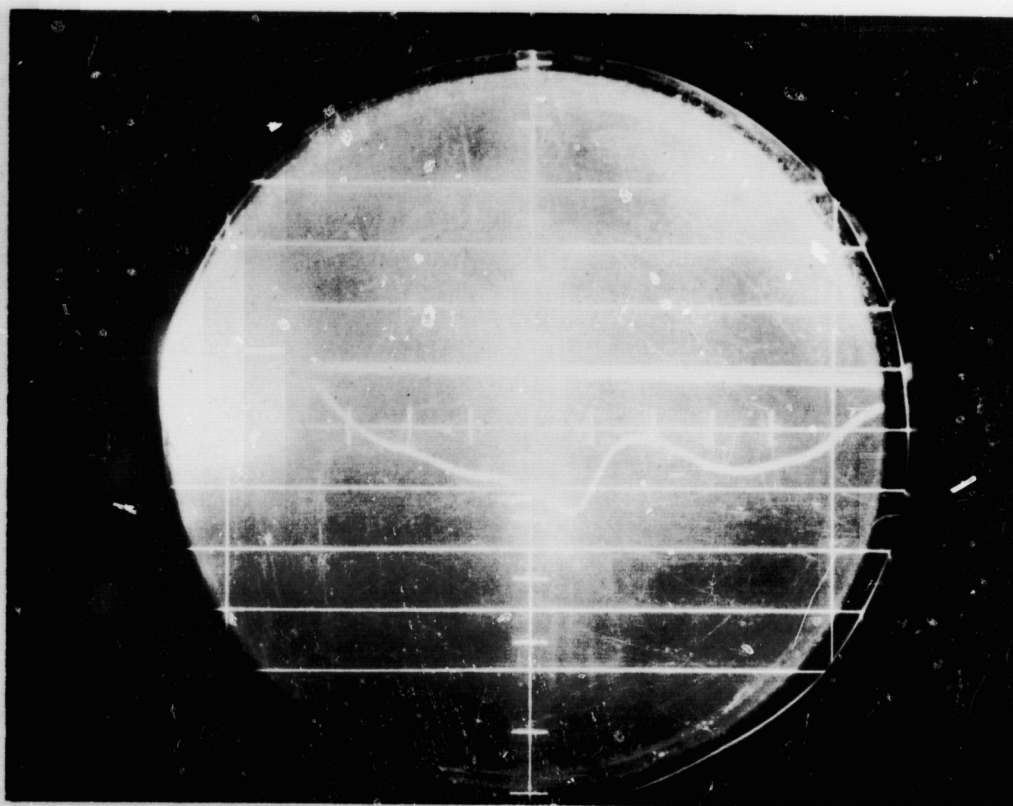
plastic hose
and clamp

quartz
window

DEVICE FOR MAKING SMALL
HYDROGEN/AIR EXPLOSIONS

PLATE 6

10 cm

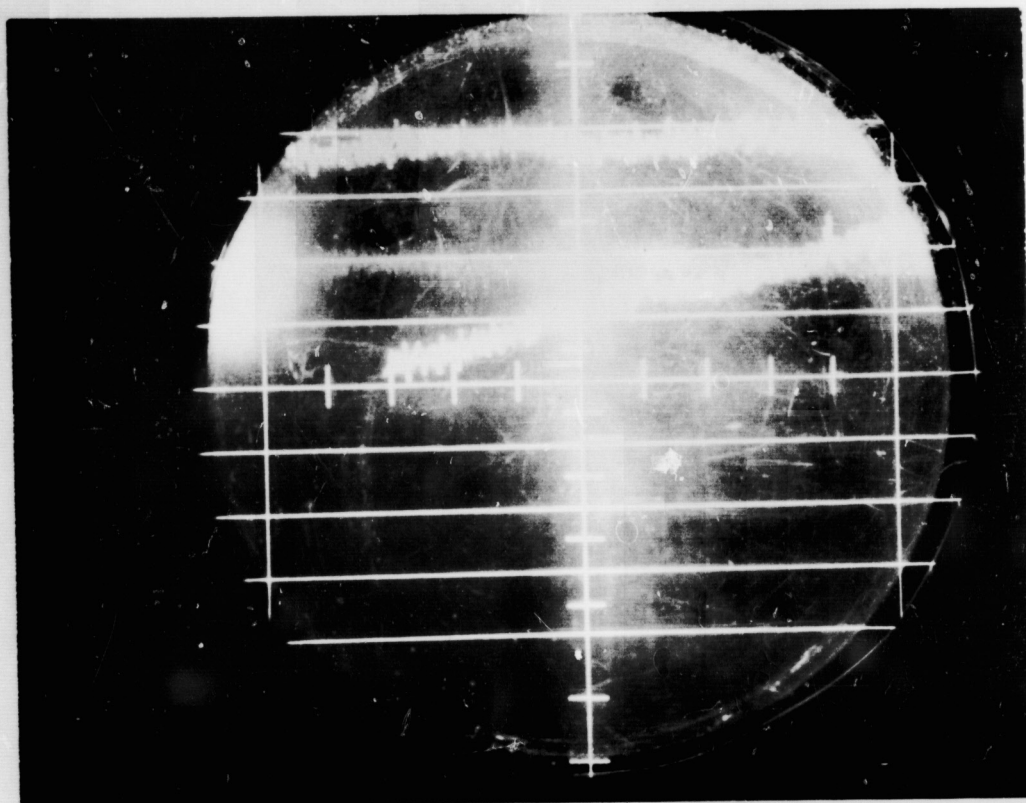


Vert. calibration 4.8 cm $\equiv$ 0.5 volts
Horiz. sweep 0.48 msec/cm

RESPONSE OF SIGNAL CHANNEL
PHOTOMULTIPLIER TO REAL EXPLOSION

PLATE 7

10 cm



Vert. calibration 4.8 cm $\equiv$ 0.15 volts

Horiz. sweep 4.8 msec/cm.

RESPONSE OF DETECTOR TO REAL
EXPLOSION - MONITORED AT OUTPUT
OF SUBTRACTING AMPLIFIER

PLATE 8

APPENDICES

APPENDIX 1: Procedure for solving equations to determine the position and magnitude of a micro-explosion.

APPENDIX II: List of breadboard components.

APPENDIX III: Data sheet on ruggedized photomultiplier.

APPENDIX IV: Data sheet on compact high voltage power supply.

APPENDIX 1.

PROCEDURE FOR SOLVING EQUATIONS TO DETERMINE THE POSITION AND MAGNITUDE OF A MICRO-EXPLOSION

$a, b, c, d, e, f, I_1/I_2, I_1/I_3, I_1/I_4$ are given.

Then: $A = I_1/I_2 - 1$

$$B = I_1/I_3 - 1$$

$$C = I_1/I_4 - 1$$

$$L = A/B$$

$$M = C/A$$

$$\alpha = \frac{L(b^2 + c^2) - a^2}{2bL - 2a}$$

$$\beta = \frac{2cL}{2bL - 2a}$$

$$\gamma = \frac{Ma^2 + f^2 + d^2 + e^2}{2f - 2aM}$$

$$\delta = \frac{e}{f - aM}$$

$$\eta = \frac{d}{f - aM}$$

$$\epsilon = \frac{\alpha - \gamma}{\eta}$$

$$\mu = \frac{\delta - \beta}{\eta}$$

APPENDIX 1 (CONT.)

$$Q = A (\beta^2 + \mu^2 + 1)$$

$$R = a\beta + \alpha\beta A - \mu EA$$

$$S = A (\alpha^2 + \varepsilon^2) + 2a\alpha - a^2$$

If $d \neq 0$:

$$T = R/Q = \frac{A(\alpha\beta - \mu\varepsilon) + a\beta}{A(\beta^2 + \mu^2 + 1)} = \frac{(a\beta + \alpha\beta A)\eta^2 + (\gamma - \alpha)(\delta - \beta)A}{A[(\beta^2 + 1)\eta^2 + (\delta - \beta)^2]}$$

$$U = S/Q = \frac{A(\alpha^2 + \varepsilon^2) + 2a\alpha - a^2}{A(\beta^2 + \mu^2 + 1)} = \frac{(A\alpha^2 + 2a\alpha - a^2)\eta^2 + (\alpha - \gamma)^2 A}{A[(\beta^2 + 1)\eta^2 + (\delta - \beta)^2]}$$

Then $y = T \pm \sqrt{T^2 - U}$

$$x = \alpha - \beta y$$

$$z = \varepsilon + \mu y$$

If $d = 0$, the system becomes degenerate.

For 2-dimensional use, $d = 0$; $\eta = 0$ and $z = 0$

$$y = \frac{\gamma - \alpha}{\delta - \beta}$$

$$x = \alpha - \beta y.$$

APPENDIX 2

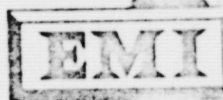
BREADBOARD DETECTOR COMPONENTS

Optical

1. Objective lens 1" dia, 50 mm focal length, plano-convex, fused silica.
2. Beam splitter 2" square, 50% transmission, 10% reflectivity.
3. Condensers (2), 2" dia., 50 mm. focal length, bi-convex, fused silica.
4. Filters, interference, either 2" square or 1 5/8" dia.

Electronic

5. Photomultipliers (2) type EMI9661B, S5 Spectral response, 9 dynodes.
6. PMT power supplies (2), KEPCO ABC 1500M, 0-1500 V. externally programable.



rugged photomultiplier tubes

This series of EMI photomultipliers represent a selection of the most generally useful types which have been modified or redesigned to withstand the severe environmental conditions found in military or space applications. They represent a reasonable compromise between cost and mechanical performance without sacrifice of electrical quality. Properly mounted and encapsulated, they will be suitable for most applications of the type mentioned above. All EMI rugged photomultipliers are constructed entirely from non-ferromagnetic materials. The standard type from which each rugged design is derived is given below.

	Ruggedized	Standard	Quartz/Spectrosil Ruggedized
1 Inch Diameter	9734NB*	9735B	9734QNB
2 Inch Diameter	9647NB	6097B	9647QNB
	9644NB	9514B	9644QNB
3 1/2 Inch Diameter	9711NB	9531B	9711QNB
5 Inch Diameter	9712NB	9530B	9712QNB

Additional useful information may be obtained by reference to the appropriate data sheets for the standard types.

Each type which carries the suffix "N" is designed to withstand the following environmental conditions and to operate successfully after vibration.

VIBRATION SPECIFICATION

Sinusoidal vibration along three axes, once, with the frequency increasing at a sweep rate of 2 octaves/minute.

Frequency CPS	g/ZZ Axis	g/XX & YY Axes	Duration Minutes (Min.)
10-50	2.3	1.0	1.66
50-60	10	2.5	0.1
60-70	14	3.5	0.1
70-80	19	4.25	0.1
80-90	24	6	0.1
90-100	30	7.5	0.1
100-200	40	10	0.5
200-500	10	4	0.66
500-2000	21	4	1.0

* See also 9734B which is of rugged construction but not vibration tested.

Random motion along three axes at 0.07g²/c/s, 11.5g r.m.s. for 4 minutes each.

At the conclusion of the tests, the tube must be mechanically sound, and on electrical retest must meet original measurements $\pm 5\%$.

The above tests are carried out on a percentage of the tubes made in each production batch.

Since experience has dictated that it is unwise to vibrate tubes to be used in the system, because of possible fatigue effects, such tubes are routinely subjected only by the following reduced schedule:

Frequency CPS	g/ZZ Axis	Duration Minutes (Min.)
10-100	2	1.0
100-2000	10	1.0

Every tube, including the designation "N" in its type number, is supplied with a test certificate.

MECHANICAL CHARACTERISTICS

	9644NB	9647NB	9734NB	9711NB	9712NB
Max. Neck Dia.:	—	—	—	54mm	54mm
Max. Envelope Dia.:	51.5mm	51.5mm	30 mm	91mm	130mm
Min. Cathode Dia.:	44 mm	44 mm	23 mm	77mm	111mm
Cathode Type:	"N" types S-11, "QN" types S-13				
Window Material: "N"	Pyrex	Pyrex	Lime Soda	Pyrex	Pyrex
"QN"	Spectrosil	Spectrosil	Spectrosil	Quartz	Quartz
Dynodes:	13 VB	11 VB	9 BG	11 VB	11 VB
All have CsSb secondary emitting surfaces					
Base:	B19A	B19A	B14B	B19A	B19A
All are low loss pressed glass bases furnished with appropriate high quality Teflon socket.					

ELECTRICAL RATINGS

	9644NB	9647NB	9734NB	9711NB	9712NB
Cathode -D1 Max.:	300 V.	300 V.	150 V.	350 V.	500 V.
Cathode to Anode Max.:	2500 V.	2200 V.	1700 V.	2350 V.	2500 V.
(Subject to not exceeding)	5000 A/L	2000 A/L	200 A/L	2000 A/L	2000 A/L
Overall Sensitivity, Rated:	2000 A/L	200 A/L	50 A/L	200 A/L	200 A/L
Max.:	5000 A/L	2000 A/L	200 A/L	2000 A/L	2000 A/L
Max. Anode Current (Mean):	1 mA.	1 mA.	0.5 mA.	1 mA.	1 mA.
Max. Anode Dissipation:	1 W.	1 W.	0.5 W.	1 W.	1 W.
Max. Operating Temperature	All 60 degrees C.				
Min. Operating Temperature	All -80 degree C.				
Max. Tolerable Cathode Current	0.3 uA	0.3 uA	0.1 uA	1 uA	2 uA
Rise Time, nS:	8	7	10	12	16
Time Spread, nS:	16	14	20	32	44
Capacitance, anode to all dynodes:	8 pF.	8 pF.	6 pF.	8 pF.	8 pF.
Dark current noise (equivalent inputs)					
Typical (A peak): lumens watts:	3.8x10 ⁻¹³ 4.5x10 ⁻¹⁶	3.8x10 ⁻¹³ 4.5x10 ⁻¹⁶	1.7x10 ⁻¹⁴ 2.0x10 ⁻¹⁶	6.8x10 ⁻¹³ 1.0x10 ⁻¹⁵	1.0x10 ⁻¹² 1.5x10 ⁻¹⁵
For recommended dynode chains refer to groups indicated page 14	K, L, M	H, I, J	E, F, F"	H, I, J	H, I, J

	Cathode Sensitivity		Overall Sensitivity		Overall Sensitivity		Overall Sensitivity	
	Min.	Typ.	Typ.	Max.	Typ.	Max.	Typ.	Max.
9644NB	50	80	1500	2100	50	500	1700	125
			200 A/L		2000 A/L			
9647NB	50	80	1400	1800	5	50	1950	50
9711NB	50	100	1400	1900	100	250	1800	1000
9712NB	50	90	1500	2000	200	500	1950	2000
			50 A/L		200 A/L			
9734NB	50	70	1100	1350	1	5	1400	4

Note: "QNB" types will have identical characteristics.

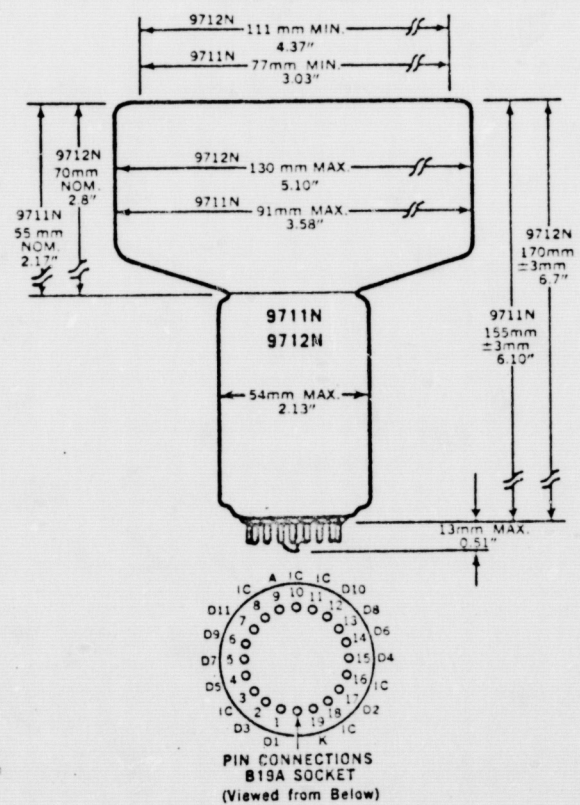
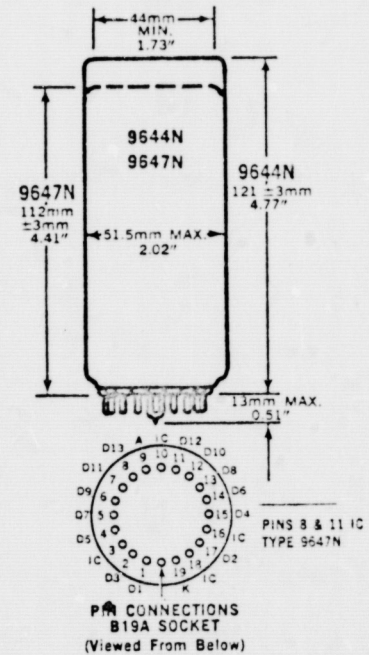
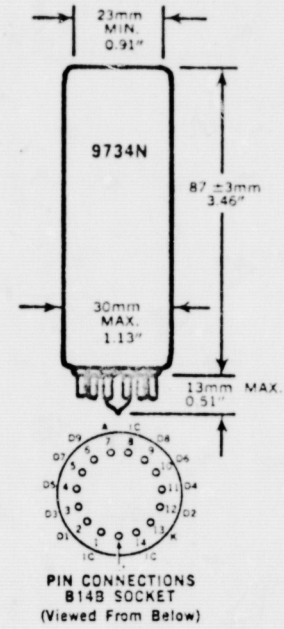
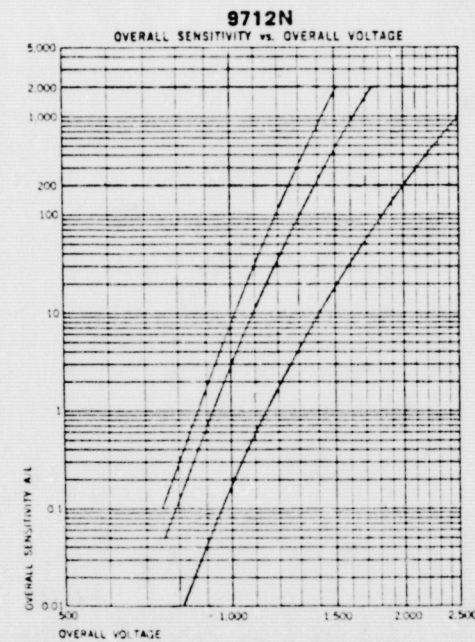
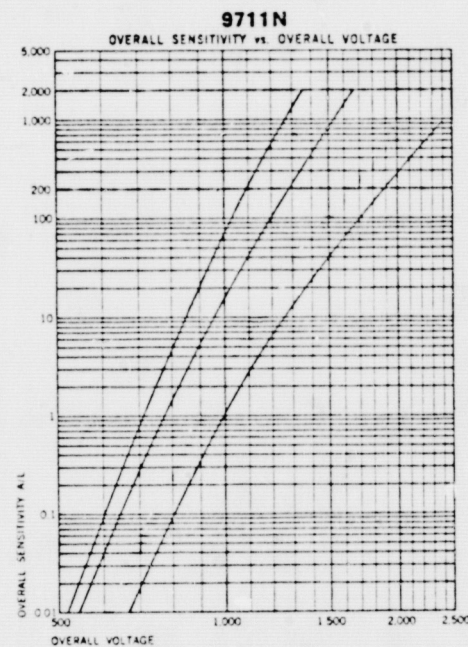
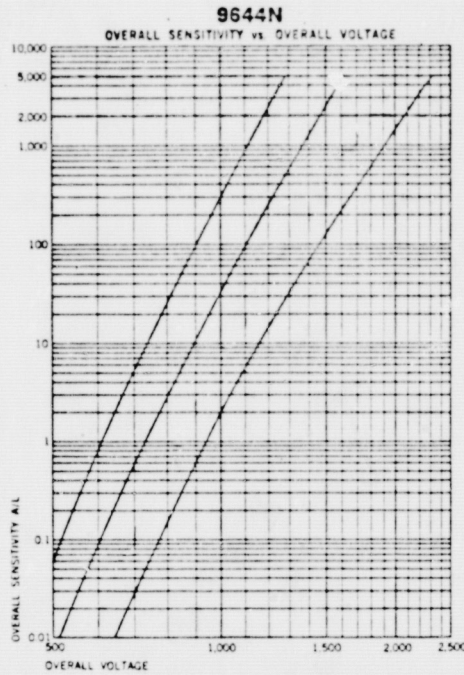
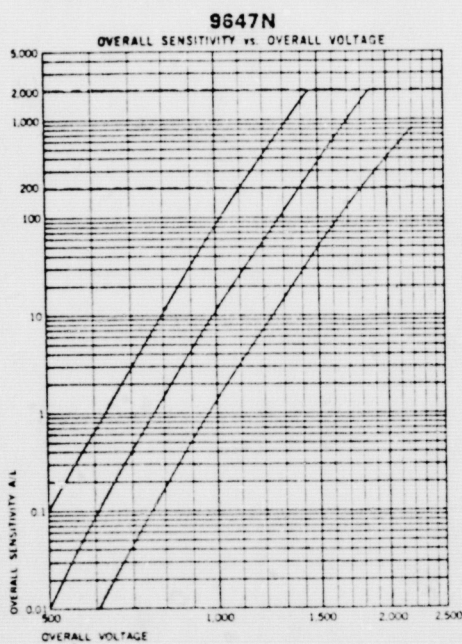
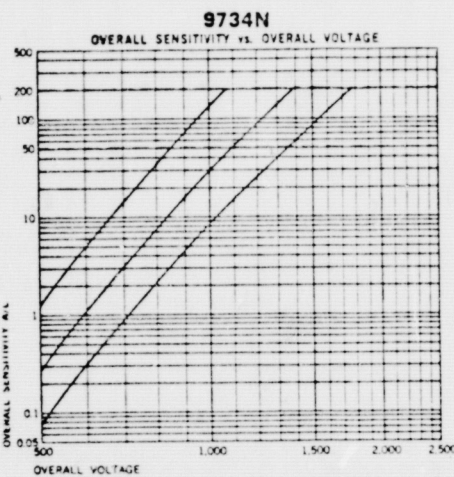
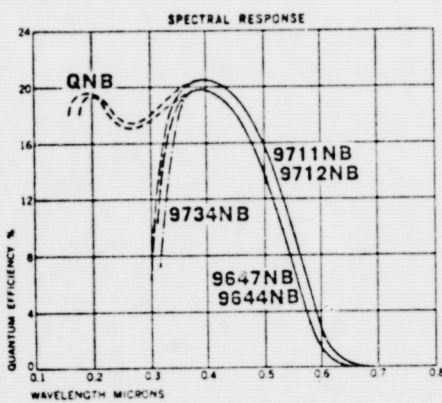
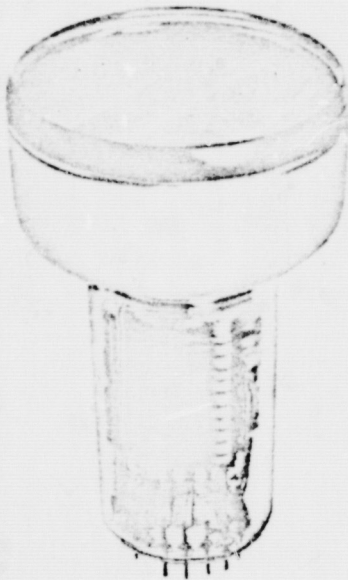
NOTES

- a) Each tube is individually calibrated and test ticket furnished with the tube specifies the cathode sensitivity in $\mu\text{A/L}$, the overall voltage at:

9644NB	2000 A/L	9711NB	200 A/L
9647NB	200 A/L	9712NB	200 A/L
9734NB	50 A/L		
- b) Test data is obtained with a "Standard" dynode chain and cathode -D1 voltage held at:

9644NB	150 V.	9711NB	300 V.
9647NB	150 V.	9712NB	450 V.
9734NB	100 V.		
- c) In general, when setting up experiments or designing for equipment, it is desirable to work at, or below, the ticket voltage of the individual tube.
2. Any material contact with the glass envelope must be held at cathode potential. Failure to do so may result in erratic operation and high dark current.
3. Take great care in clamping tubes, particularly those with quartz (Spectrosil) envelopes. Excess pressure may fracture the glass in which case the warranty is void.
4. Photomultipliers are affected by magnetic fields and mu-metal shields should be used.
5. Window materials, particularly quartz, are permeable to helium. Contact with high pressures of helium should therefore be avoided.

9734NB 9647NB 9644NB 9711NB 9712NB





VENUS SCIENTIFIC INC.

PHOTOMULTIPLIER POWER SUPPLY

MODEL K 15 *Reliable • Efficient • Compact • Versatile*



- 1500 Volts @ 1ma
- Efficiency > 50%
- M.T.B.F. 105,000 Hrs.
- $E_{out} \cong 100 \times E_{in}$
- Ripple < 0.1% Peak-Peak
- Output isolated from Input
- Reverse Polarity Protected
- Short Circuit Protected
- All Silicon Components

The K15 is a high voltage power supply whose versatility makes it a very useful component in a number of applications. The unit is fully encapsulated and shielded in a nickel-plated steel can. The two output high voltage leads are floating and are fully isolated from the two input leads. This permits operation from voltage sources having either plus or minus polarity while still allowing the user to employ the unit as a plus or minus high voltage power supply. In addition, the case is isolated from both input and output and can be grounded by the user at a remote point. The high voltage filter capacitor inside the unit is .006 uf at 3 KV. This keeps the ripple at full load down to 0.1%. Where even less ripple is desired, the addition of .01 uf across the output will reduce this figure to approximately 0.03%.

The K15 is protected against improper polarity voltages applied to its input by a series diode. The presence of this protective diode accounts for the most part for the temperature coefficient of output voltage of $\pm 0.02\%/^{\circ}\text{C}$.

The K15 is 100% tested to guarantee reliable trouble-free operation to the user. The electrical operating characteristics for a typical unit are shown on the graph for input voltages of 3 volts to 15VDC and loads of 10 megs and 1.25 megs. A plot of input current as a function of input and loads is also included. From this plot it can be seen that the operating efficiency of the K15 is better than 50% for a load of 1 ma.

Applications: Photomultipliers . . . Flying spot scanners . . . Image dissectors . . . Ionization chambers . . . Scan converters . . . Geiger tubes . . . Cathode ray tube bias supply . . . Scintillation tubes.

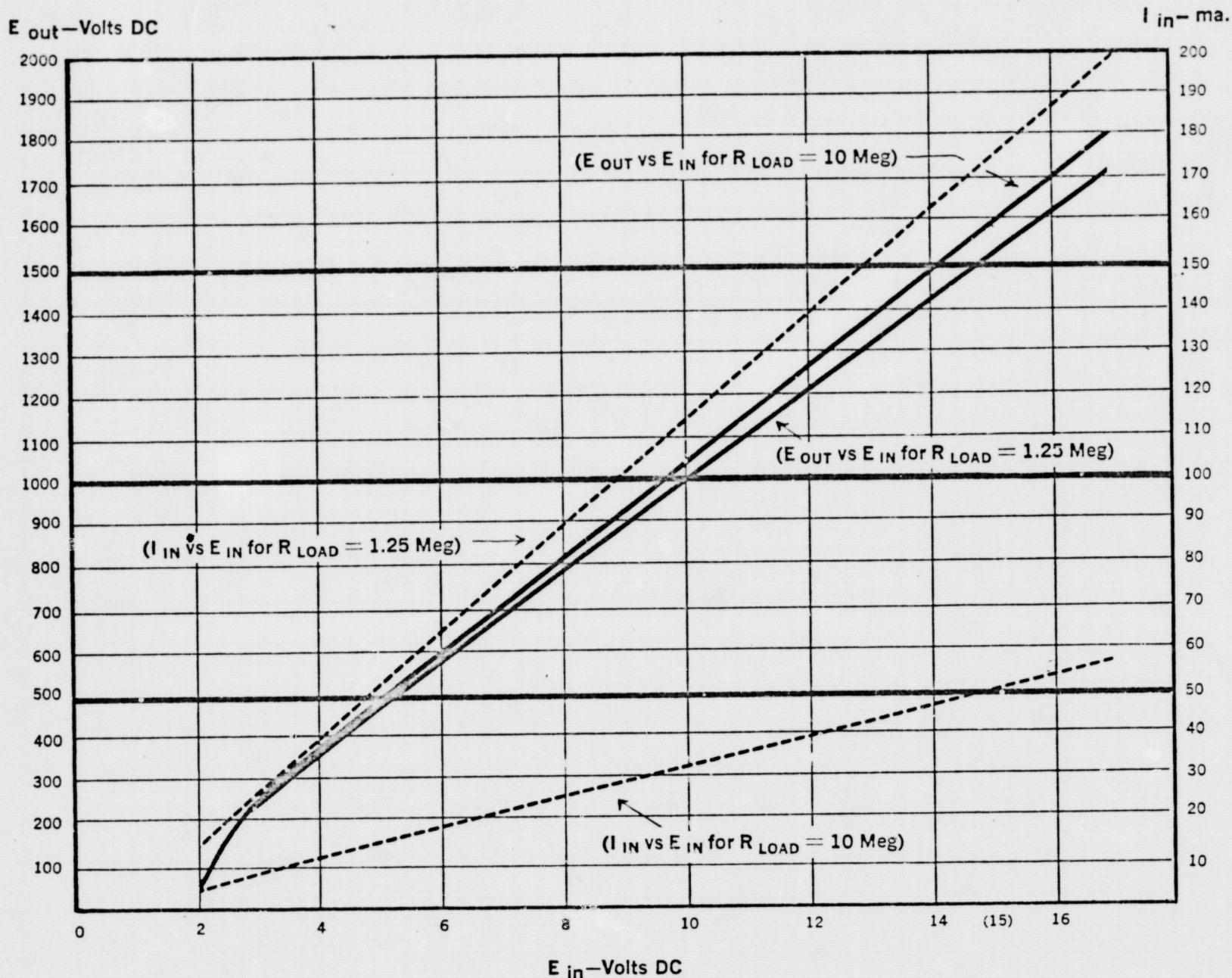
Model K15U: For those users requiring fast response to input voltage changes, the K15 can be supplied without internal capacitors. This will enable the user to arrive at the best compromise between response time and output ripple.

Photo: 2 x Actual Size

MODEL K-15

(Electrical Characteristics)

Temp = $\pm 25^{\circ}\text{C}$
Ripple = 0.1%



PHYSICAL SPECIFICATIONS

Dimensions 1" dia. x $2\frac{1}{4}$ " length
Volume 1.8 cu. in.
Weight 3.5 ounces
Shock 40 g's per MIL-STD-810, Method 516, Procedure IV
Vibration 20 g's per MIL-STD-810, Method 514, Curve E, Figure 514-3
Acceleration MIL-STD-810, Method 513
Thermal Shock -54°C to $+71^{\circ}\text{C}$ per MIL-STD-810, Method 504, Class 2
Finish, Case Bright Nickel Plate
Can cold rolled steel

ELECTRICAL SPECIFICATIONS

E_{out} proportional to E_{in} (see curve above)
Floating Output . . . 2500V insulation strength with respect to input ground
Temperature -55°C to $+71^{\circ}\text{C}$ (operating)
Temperature coefficient is less than .02% / $^{\circ}\text{C}$
Efficiency > 50% @ full load
M.T.B.F. 105,000 Hrs. @ 71°C . (Mil-hdbk. 217-A)
Electrical connections as shown below:

