

**FOREWORD**

This investigation was carried out by the Department of Electrophysiology, The New York Eye and Ear Infirmary, and was initiated by Captain L. R. Loper, of the Vision Section, Protection Branch, Life Support Systems Laboratory, 6570th Aerospace Medical Research Laboratories, under Project No. 6301, "Aerospace Systems Personnel Protection," Task No. 630103, "Vision Enhancement and Protection."

Primary responsibility was assumed by Jerry Hart Jacobson, M. D., Director of the Department of Electrophysiology. Miss Blossom Cooper, M. S., Physicist, Assistant Administrator, was concerned with the physical equipment and problems of irradiance, dose, and image size. Harold Najac, M. D., supervised and conducted the bulk of the actual experimental exposures.

Animal experiments reported herein were conducted according to the "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

# *Contrails*

ABSTRACT

The retinas of pigmented, grey chinchilla rabbits were exposed to the visible, and, to the visible and near infrared parts of the spectrum to determine the retinal burn threshold.

The study included the variation of four primary parameters; the rate of delivery of energy, the retinal image size, the exposure time, and the spectral characteristics of the source.

Analysis of the data indicated the following: for a given irradiance, the dose necessary to produce a threshold burn increased with the size of the retinal image, for equal total irradiance a higher dose was necessary when the near infrared was included in the spectrum than when the visible alone was present, and for a given retinal image, the threshold dose is determined as a function of the irradiance.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

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Chief, Life Support Systems Laboratory

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## I N T R O D U C T I O N

The objective of this project was to study the effect on retinal function produced by repeated exposure to thermal energy at levels below the retinal burn threshold. This study, which is intended to be the first phase of a multi-phase investigation, was designed primarily to establish a technique for delivering known quantities of thermal energy to in vivo eyes, to determine the burn threshold for light of different spectral characteristics, and to develop as far as possible a mathematical treatment for energy transport in the retina.

Three major problems were attacked during the past year.

1. Devising a suitable source of energy, including calibration of output, control of exposure time, image size, and spectral characteristics.
2. Perfecting a technique for implanting thermocouples within the eye to measure thermal energy transport along the retina.
3. Determination of threshold dose as a function of irradiance, time, image size, and spectral characteristics.

I. SOURCE OF ENERGY

The instrument chosen for delivering known amounts of thermal energy was a light coagulator of the Meyer-Schwickerath type manufactured by Carl Zeiss, Inc. (Fig. 1).

A. Spectral Distribution

According to Geeraets et al,<sup>1</sup> the Osram lamp Model (XB02001) employed in the Zeiss coagulator provides a spectral distribution closely approximating that of a nuclear flash. The thermal energy emitted by a nuclear weapon detonated within the earth's atmosphere depends upon a number of factors, but we generally assumed that the spectral distribution from a black body at 5800° K gives a reasonable approximation to this radiation. A comparison of the radiation from a black body at this temperature and the Osram lamp, suitably normalized, shows that the two are reasonably alike over the spectral range from 350 to 1500 millimicrons.

To comply with the spectral requirements of the contract and to confine the energy to two bands, namely 380-750 millimicrons and 380-1350 millimicrons, an ultraviolet cutoff filter of silica glass GG-13, 2 mm thick, plus an infrared cutoff filter of phosphate glass, KG3, 1.5 mm thick, or a water cell of 1 cm inside diameter were used in a specially constructed filter box.

The use of these filters reduced the total energy of the Xenon lamp by the factors shown in Table I.

TABLE I.  
REDUCTION OF TOTAL BEAM ENERGY BY FILTERS

| <u>Filters</u>                                      | <u>% Reduction</u> |
|---|--------------------|
| Ultraviolet GG-13 (2 mm)                            | 14                 |
| Ultraviolet GG-13 (2 mm) and Water (1 cm)           | 33                 |
| Ultraviolet GG-13 (2 mm) and Infrared KG-3 (1.5 mm) | 69                 |

Transmission curves of these filters were recorded on a Beckman DK-2 spectrophotometer at the New York Naval Shipyard Material Laboratory and are shown in Table II.

Tests under specific heating conditions were conducted to determine any alteration in transmission characteristics of these filters at the time of, or following irradiation. No significant changes were noted for any of the filters.

## B. Optical System

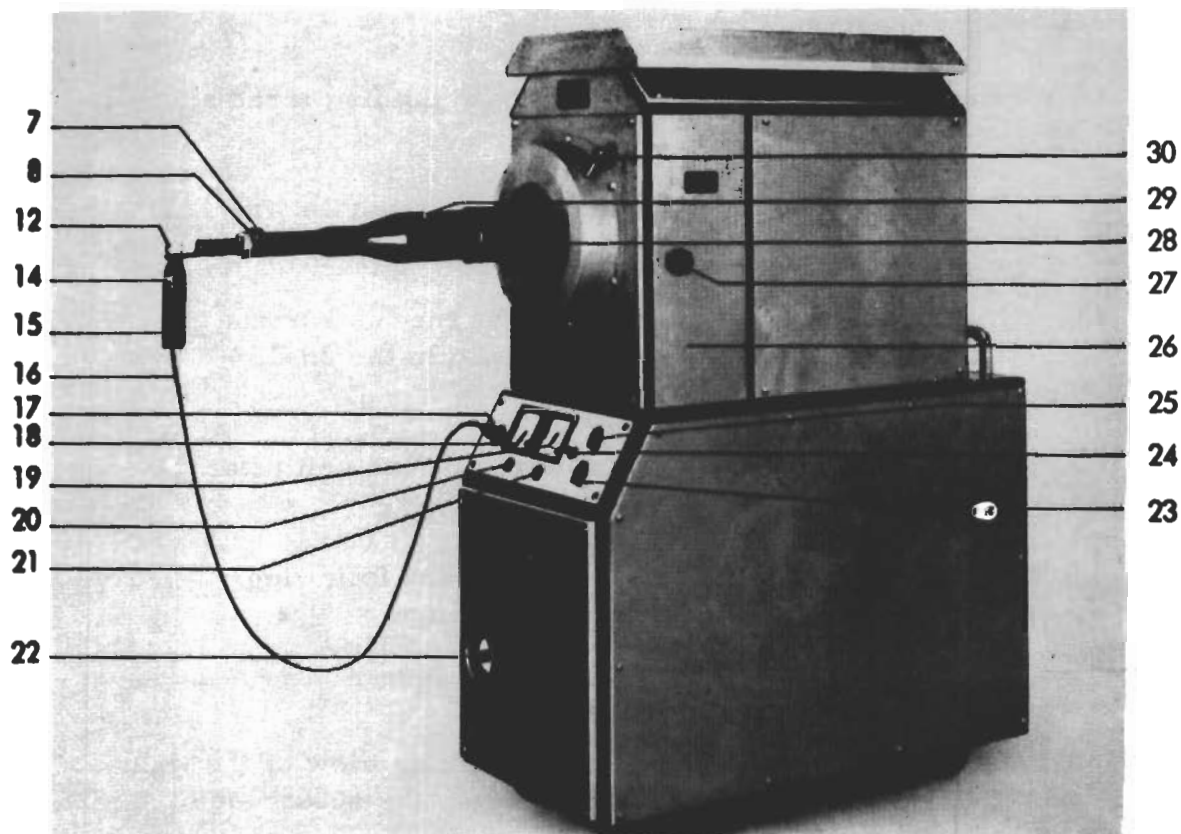
The luminous plasma of the Xenon high pressure lamp Model (XB02001) is reflected back to the lamp by means of a concave mirror in order to increase the luminous intensity and to help homogenize the field of light. A perforated diaphragm and a condenser lens, located in the main housing, are placed in the path of the beam.

An optical tube extending from the coagulator housing interposes successively in the beam path an iris diaphragm, filter disc, image field diaphragm, objective lens and an ophthalmoscope mirror. The image of the luminous plasma of the lamp formed by the condenser lens is situated at the principal focus of an objective lens of 85 mm focal length. The light emerging from this objective lens is therefore collimated. This parallel beam is then reflected by the ophthalmoscope mirror and focussed at a point on the retina by the refractive media of the eye of the experimental animal. (Fig. 2.)

TABLE II.  
TRANSMISSION OF FILTERS

| <u>Wave Length</u><br><u>(m<math>\mu</math>)</u> | <u>Filter</u><br><u>GG13 (2mm)</u> | <u>Filter</u><br><u>H<sub>2</sub>O (1 cm)</u> | <u>Filter</u><br><u>KG3 (1.5mm)</u> |
|--|------------------------------------|---|-------------------------------------|
| 350  | .30                                | .87   | .81                                 |
| 400  | .71                                | .89   | .83                                 |
| 450  | .87                                | .90   | .82                                 |
| 500  | .88                                | .91   | .84                                 |
| 550  | .89                                | .91   | .83                                 |
| 600  | .89                                | .91   | .81                                 |
| 650  | .89                                | .91   | .75                                 |
| 700  | .89                                | .90   | .69                                 |
| 750  | .89                                | .87   | .40                                 |
| 800  | .89                                | .86   | .24                                 |
| 850  | .89                                | .85   | .10                                 |
| 900  | .89                                | .82   | .03                                 |
| 950  | .89                                | .70   | .0                                  |
| 1000   | .89                                | .62*  | .0                                  |
| 1050   | .89                                | .70*  | .0                                  |
| 1100   | .89                                | .72*  | .0                                  |
| 1150   | .89                                | .40*  | .0                                  |
| 1200   | .89                                | .26*  | .0                                  |
| 1250   | .89                                | .26*  | .0                                  |
| 1300   | .89                                | .24   | .0                                  |
| 1350   | .89                                | .05*  | .0                                  |
| 1400   | .89                                | .0  | .0                                  |

\* Energy average over a 50 m $\mu$  band width



- |                          |  |
|--------------------------|--|
| 7. Filter disc           | 21. Switch-ON                          |
| 8. Image field diaphragm | 22. Protective switch                  |
| 12. Mirror               | 23. Multi-stage switch for normal load |
| 14. Release knob         | 24. Selector switch                    |
| 15. Handle               | 25. Multi-stage switch for overload    |
| 16. Cable                | 26. Door                               |
| 17. Cable connection     | 27. Door-handle                        |
| 18. Ammeter              | 28. Optical beam director              |
| 19. Voltmeter            | 29. Lever for iris diaphragm           |
| 20. Switch-OFF           | 30. Locking lever                      |

Figure 1. ZEISS LIGHT COAGULATOR AS DELIVERED

## C. Modification of System

The instrument as delivered failed to meet our requirements in the following respects:

The light source did not provide a uniform irradiance over the entire field.

The maximum retinal image size obtainable was 1.2 mm. Our needs ranged from 0.1 to 5.0 mm in diameter.

No timing device was available in the instrument to allow control of exposure time within the 25-150 millisecond range required.

Insufficient energy was delivered by the unit after filtration.

In order to remedy these inadequacies the following modifications were made to the instrument.

### 1. Modification To Achieve Uniform Irradiance

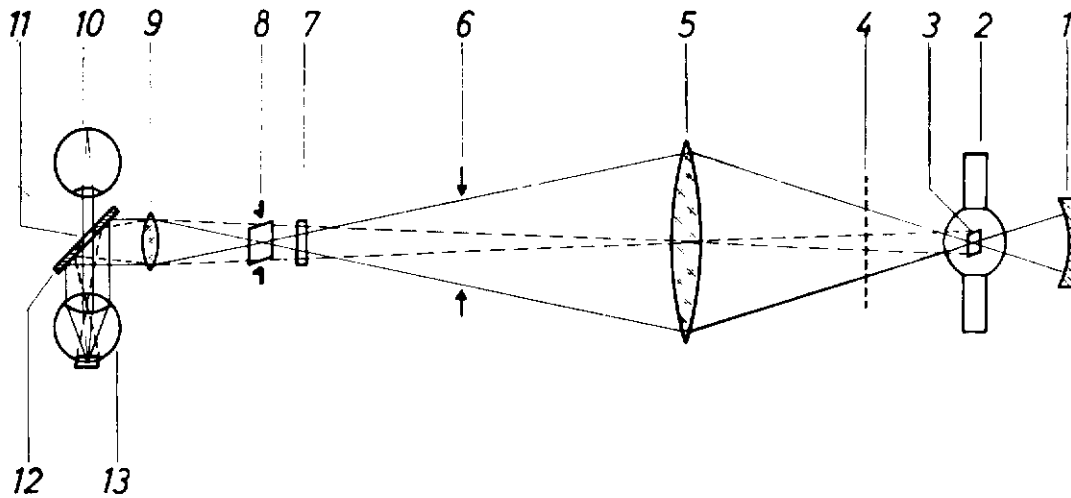
To obtain uniform irradiance a Maxwellian view of the light source was chosen. This was accomplished by the substitution of a two-lens objective system for the standard single lens objective. (Fig. 3.) This new lens system forms a real image of the light source at the plane of the rabbit iris in the experimental situation.

A new housing incorporating this objective system as well as other elements of the optical and shutter systems was designed and fabricated to specification.

### 2. Modification To Achieve Adequate Retinal Image Size

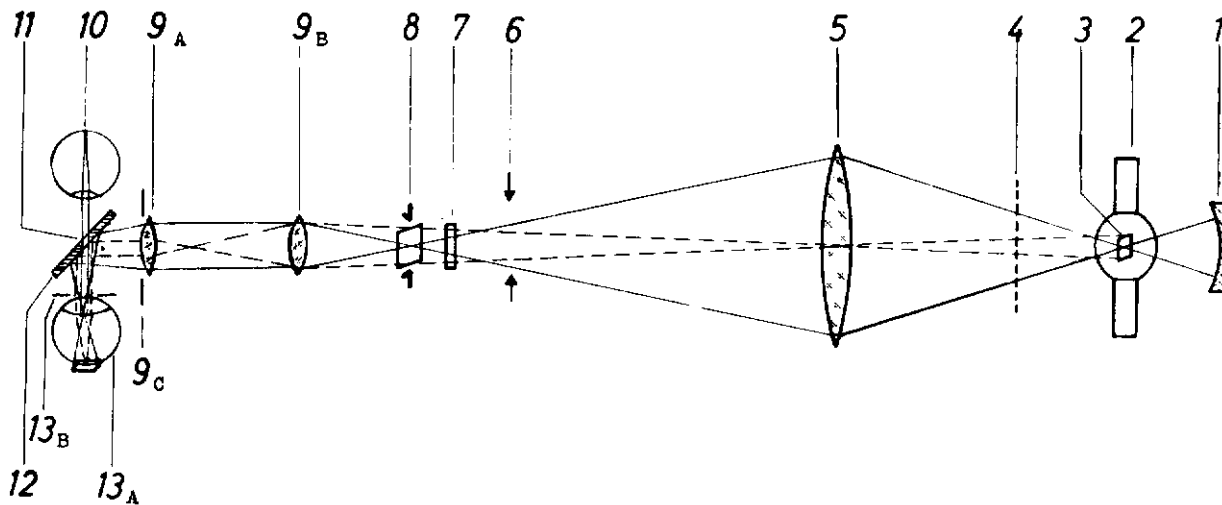
In order to form a 5 mm diameter image on the retina of a rabbit eye, the lens system of which has a focal length of approximately 10 mm, the ratio of the beam diameter of the light emerging from the objective lens to the focal length of this lens must be the same as the ratio of the diameter of the image on the rabbit retina to the focal length of the rabbit eye optical system, i. e., 1:2.

# Contrails



- |                          |                          |                      |
|--------------------------|--------------------------|----------------------|
| 1. CONCAVE MIRROR        | 6. IRIS DIAPHRAGM        | 10. EYE OF PHYSICIAN |
| 2. XENON LAMP            | 7. FILTER DISC           | 11. MIRROR APERTURES |
| 3. LUMINOUS PLASMA       | 8. IMAGE FIELD DIAPHRAGM | 12. EYE MIRROR       |
| 4. PERFORATION DIAPHRAGM | 9. OBJECTIVE             | 13. EYE OF PATIENT   |
| 5. CONDENSER             |                          |                      |

Figure 2. SCHEMATIC OF ORIGINAL OPTICAL SYSTEM



- |                          |   |  |
|--------------------------|---|--|
| 1. CONCAVE MIRROR        | 6. IRIS DIAPHRAGM.                          | 10. EYE OF PHYSICIAN                     |
| 2. XENON LAMP            | 7. FILTERS                                  | 11. MIRROR APERTURES                     |
| 3. LUMINOUS PLASMA       | 8. IMAGE FIELD                              | 12. EYE MIRROR                           |
| 4. PERFORATION DIAPHRAGM | 9. A & B; OBJECTIVE<br>C, LIMITING APERTURE | 13. A, EYE OF RABBIT<br>B, 6mm. APERTURE |
| 5. CONDENSER             |   |  |

Figure 3. SCHEMATIC OF NEW OPTICAL SYSTEM

# Contrails

Limiting apertures of 15.5, 6.7, 3.0, 2.0 and 1.0 mm were placed on the second objective lens (focal length 43 mm) to vary the size of the images on the retina. Measurements were made of the image diameters on the retinas of enucleated eyes using fine pointed calipers. Neutral density filters were used to reduce the glare and thus sharpen the observed edge. In another series of measurements the image was scanned through a pinhole by a silicon cell attached to a sensitive galvanometer. Anterior-posterior measurements of the eyes were also determined. Table III shows the retinal image diameters obtained for the various size rabbit eyes using the several limiting apertures on the objective lens. Calculations based on hypothetical rabbit lens systems of 10 and 11 mm focal lengths, assuming focusing on the retina, provide the theoretical image sizes shown in Table IV.

Possible explanations for the range of image diameters observed compared to those calculated include variation in the focal lengths of rabbit eyes and the fact that rabbits become myopic in captivity.<sup>2</sup>

Experimentally determined image diameters for limiting apertures of 2 and 3 mm appear much larger than the theoretical values. If retinal irradiances are calculated on the basis of theoretical beam diameters rather than actual ones, gross errors may result, since irradiance varies inversely as the square of the diameter.



TABLE III.  
RETINAL IMAGE DIAMETER MEASUREMENTS  
OBTAINED FOR VARYING ANTERIOR-POSTERIOR  
EYE DIAMETERS

| <u>Anterior-Posterior</u><br><u>Diameter of</u><br><u>Eye (mm)</u> | <u>Limiting Aperture (mm)</u> |            |            |            |
|--|-------------------------------|------------|------------|------------|
|  | <u>15.5</u>                   | <u>6.7</u> | <u>3.0</u> | <u>2.0</u> |
|  | <u>Image Diameter (mm)</u>    |            |            |            |
| 17.9   | 4.4                           |            |            |            |
| 17.6   | 4.3                           |            |            |            |
| 17.6   | 4.2                           |            |            |            |
| 17.5   | 4.1                           |            |            |            |
| 17.5   | 4.0                           |            |            |            |
| 17.5   | 4.0                           |            |            |            |
| 17.5   |                               |            | 0.9        |            |
| 17.3   | 4.0                           |            |            |            |
| 17.3   | 3.9                           |            | 1.0        |            |
| 17.0   | 4.0                           |            |            |            |
| 17.0   | 4.0                           |            |            |            |
| 17.0   |                               | 2.0        |            |            |
| 16.9   | 3.9                           | 2.0        |            |            |
| 16.8   | 3.7                           | 1.9        |            |            |
| 16.7   |                               |            |            | 0.75       |
| 16.5   | 3.9                           | 2.0        |            |            |
| 16.4   | 3.8                           | 1.7        | 1.0        |            |
| 16.4   | 3.6                           | 1.9        | 1.3        |            |
| 16.4   | 3.8                           | 1.9        |            |            |
| 16.2   | 3.8                           |            |            |            |
| 16.1   | 3.7                           | 1.9        | 1.2        |            |
| 16.1   | 3.5                           |            | 0.8        |            |
| 16.1   | 3.7                           | 1.6        | 1.1        |            |
| 16.1   | 3.7                           |            |            |            |
| 16.0   | 3.5                           | 2.1        |            |            |
| 15.2   | 3.4                           |            |            |            |

TABLE IV.  
RETINAL IMAGE SIZES FOR DIFFERENT LIMITING APERTURES

| Limiting Apertures | Calculated For 10 mm System | Calculated For 11 mm System | Measured Diameters |
|--------------------|-----------------------------|-----------------------------|--------------------|
| mm                 | mm                          | mm                          | mm                 |
| 15.5               | 3.61                        | 3.96                        | 3.4 - 4.4          |
| 6.7                | 1.56                        | 1.71                        | 1.6 - 2.1          |
| 3.0                | 0.70                        | 0.77                        | 0.8 - 1.25         |
| 2.0                | 0.46                        | 0.51                        | 0.55- 0.80         |

### 3. Modification To Provide Control of Exposure Time

The desired exposure times range from 25-150 milliseconds. The perforated diaphragm of the light coagulator which is normally used as a shutter will not give reproducible results with the required degree of accuracy. Therefore, an additional shutter from a Hasselblad Reflex Camera 500C was modified to conform to our requirements. This shutter was altered mechanically and electrical controls were added. The new optical tube was constructed in such a manner as to accommodate the shutter physically, while its placement in no way limits the optical beam. This shutter allows focussing of the light source on the rabbit retina at reduced intensity in its "hold open" position.

### 4. Modification To Obtain Adequate Irradiance

The increase of image size on the retina and the addition of filtration caused a decrease of irradiance to such a great extent that it became necessary, after considering various possibilities, to increase the light intensity at its source. The existing electrical system could not be altered so a new circuit was designed to couple with the present one. Precautions had to be taken because the Zeiss equipment and Osram Xenon lamp could not tolerate the rise in current-voltage conditions required to obtain the increase in intensity, for more than a short period of time. The altered coagulator is pictured in Fig. 4.

A circuit was designed to increase the output by pulsing the Xenon lamp for the desired period of time. A maximum pulse duration of 150 milliseconds was required. Longer periods are available with this system, but care must be exercised to prevent damage to the lamp.

# Contrails

The light coagulator was designed for operation on three-phase current, 380 volts, 60 cycles, in a star circuit. The three phases of the main power supply are safeguarded by 20 ampere delay-action fuses. The cabinet is grounded through the neutral conductor.

The standard electrical circuit of the Zeiss coagulator consists of a rectifier, an automatic igniting mechanism for the high pressure lamp and a switch for removing the perforated diaphragm. A two-position selector switch allows a choice of two primary intensities, the "normal" or "overload" condition. Each of these positions, in turn, has four power taps, obtained by means of a separate selector switch, to provide a subdivision of the intensities.

In normal use, when the exposure button is depressed, the perforated diaphragm is pivoted out of the beam path. If the selector switch is set for overload, additional current passes through the lamp only while the button is depressed. With the addition of the Hasselblad shutter it became necessary to move the perforated diaphragm within a very short time and make the exposure; otherwise the experimental animal would receive an additional untimed dose of energy. Therefore, an additional timer circuit (Fig. 5) was added between the Hasselblad shutter and the perforated diaphragm to signal the removal of the perforated diaphragm from the beam path. The circuitry is so arranged that after the shutter is cocked, upon depressing the exposure button on the ophthalmoscope, the following sequence of events takes place:

1. A solenoid actuates the shutter mechanism.
2. Shutter closes, closing a contact which causes the perforated diaphragm to move out of the beam path, simultaneously starting a timing cycle.
3. Shutter opens for the preset time and then closes.
4. Time cycle ends and the perforated diaphragm moves back into the beam path.

This sequence, from the time the push button is depressed to the end of the time cycle, is adjustable through a timer installed in the specially designed circuit and takes less than one second. (see schematic, Fig. 5). Protection from the heat of the Xenon source is afforded to the shutter blades and equipment through interlock systems.

# *Contrails*

The coagulator is turned on by means of a switch, bringing main power to the unit. Upon depressing the ignition button, a surge voltage (kilovolts) ignites the lamp and the voltage across the lamp then drops to about 24 volts at 45 amps (that of the first normal load position).

Typical values for current, voltage and output of the lamp in the various stages originally available are shown in Table V.



Figure 4. ZEISS LIGHT COAGULATOR MODIFIED FOR PULSING

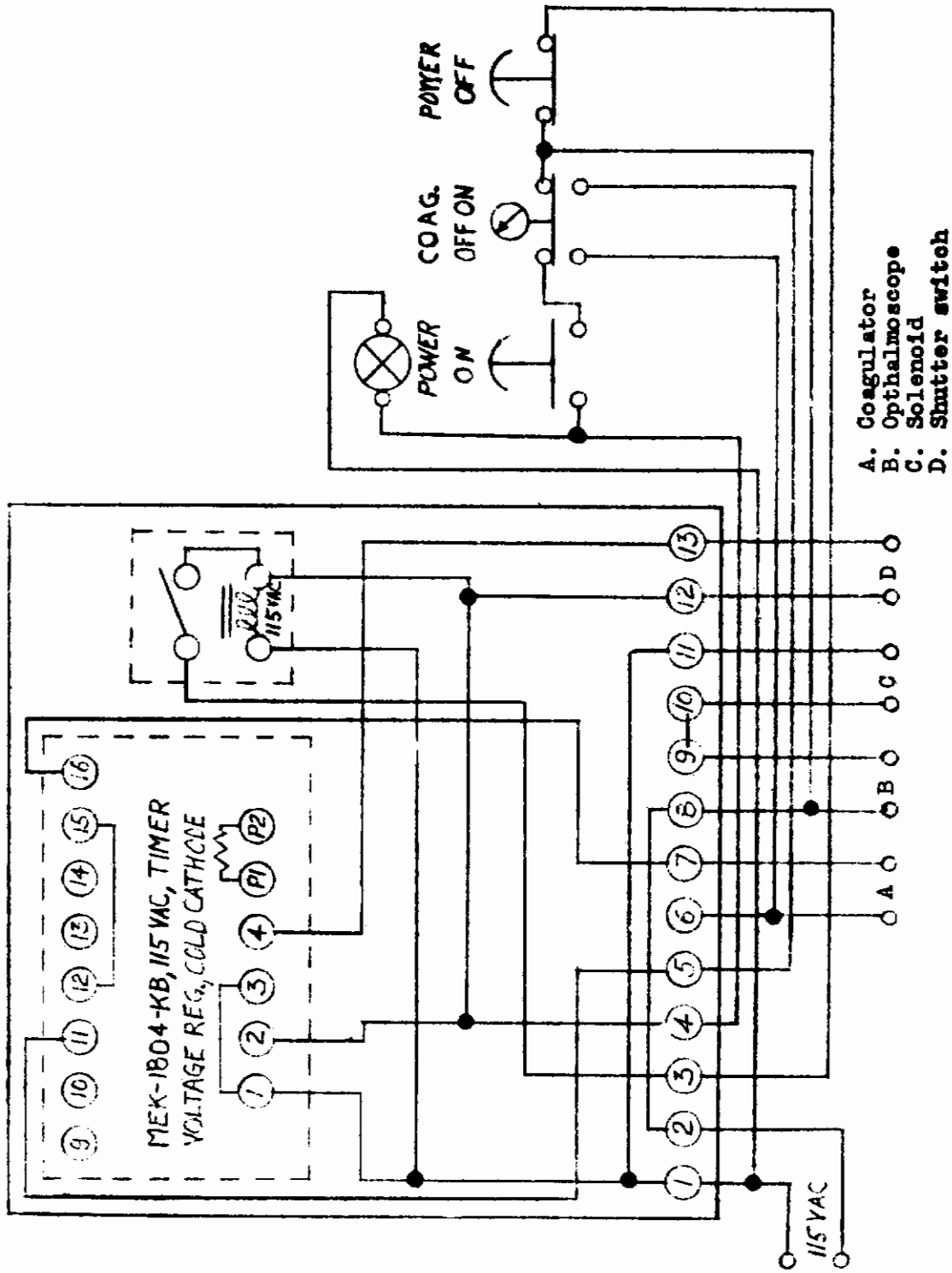


Figure 5. SCHEMATIC OF ELECTRICAL CIRCUIT FOR SYNCHRONIZING PERFORATED DIAPHRAGM SHUTTER AND PULSING SYSTEMS

**TABLE V.**  
**CURRENT-VOLTAGE CHARACTERISTICS IN ORIGINAL**  
**COAGULATOR**

|                   | <u>SETTINGS</u> |          |          |          |                 |          |          |          |
|-------------------|-----------------|----------|----------|----------|-----------------|----------|----------|----------|
|                   | <u>NORMAL</u>   |          |          |          | <u>OVERLOAD</u> |          |          |          |
|                   | <u>1</u>        | <u>2</u> | <u>3</u> | <u>4</u> | <u>1</u>        | <u>2</u> | <u>3</u> | <u>4</u> |
| CURRENT (AMPERES) | 56              | 68       | 80       | 88       | 83              | 99       | 113      | 128      |
| VOLTAGE (VOLTS)   | 28              | 30       | 31       | 32       | 32              | 34       | 35       | 37       |
| OUTPUT (KVA)      | 1.6             | 2.0      | 2.4      | 2.8      | 2.7             | 3.4      | 3.9      | 4.7      |

In parallel with the Zeiss circuit is the new pulsing circuit (Figs. 6 and 7). The source of electrical power is derived from Willard heavy duty 12 volt marine batteries. Five batteries are used for a maximum of 60 volts; 2 volt steps are available for small changes in lamp brightness. Originally, two silicon controlled rectifiers (Westinghouse Trinistors #809 - C - 150V) were in the circuit, one in series with the lamp, the other in parallel. The series Trinistor, when properly gated, permitted the passage of current through the Xenon lamp, while the parallel Trinistor, when gated, acted as a short circuit across the lamp to extinguish it.

Since a Trinistor cannot be turned off by means of the gate signal once it is conducting, the circuit was opened by blowing a calibrated Bussman "Superlag" renewable fuse. Difficulties with the parallel Trinistor when the ignition circuit was operated caused us to eliminate it entirely from the circuit.

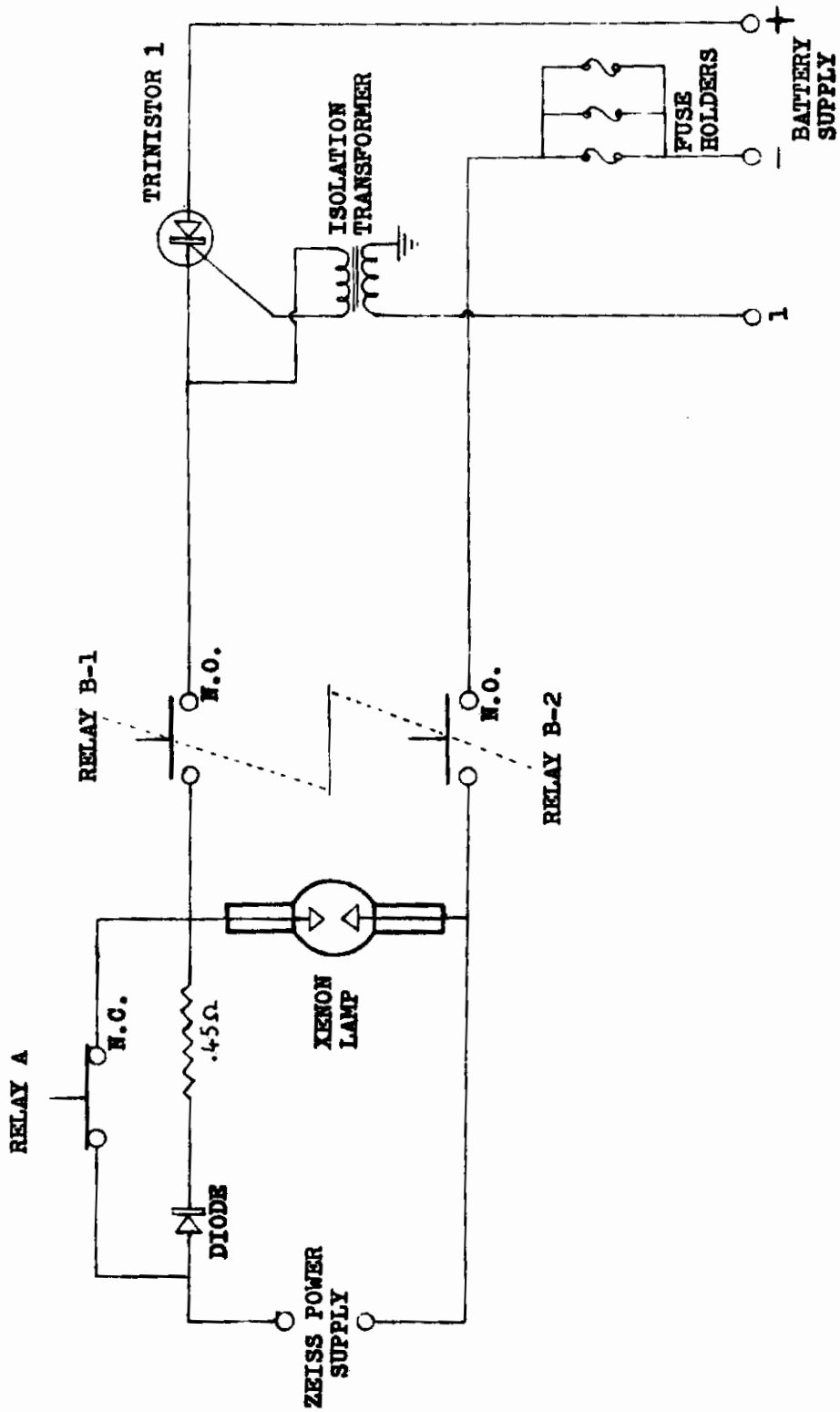


Figure 6. SCHEMATIC OF NEW PULSING CIRCUIT



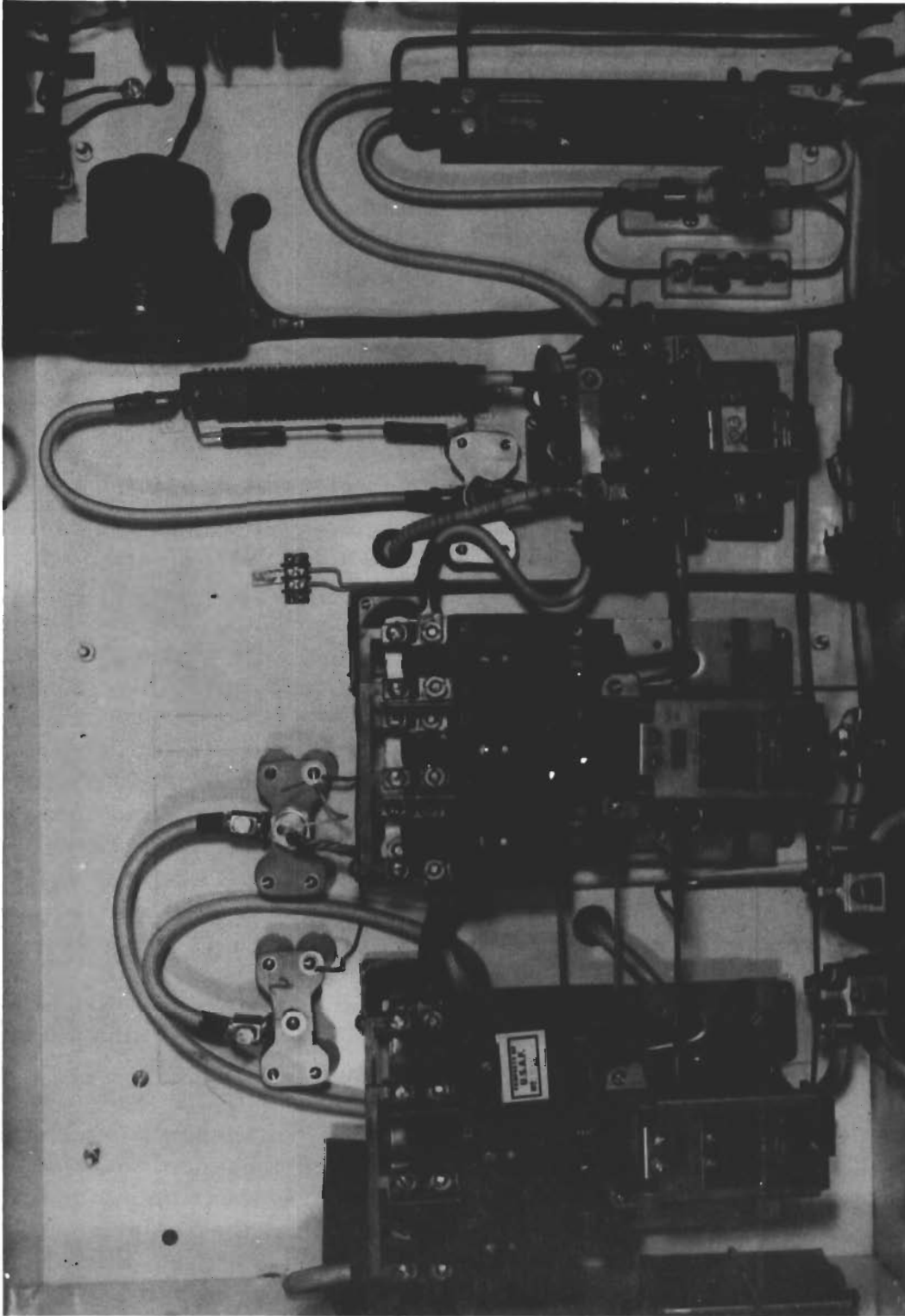


Figure 7. PHOTOGRAPH SHOWING PART OF PULSING CIRCUIT

# Contrails

The controlled rectifier is a three terminal silicon semi-conductor whose characteristics are similar to those of a thyatron, as the device will block voltage in the forward direction below a critical breakover voltage. However, by exceeding the critical breakover voltage or by applying a proper gate-to-cathode signal (approximately 50 ma at 1.5 volts) the device will switch in about 3 micro-seconds to a conducting state. The Trinistor was mounted on bakelite for both support and electrical insulation.

The gate signal and fuse systems used in this manner prevent too long a pulse from being applied to the Xenon lamp and give a pulse of specified and reproducible duration. The gate signal was delivered by a Tektronix pulse generator type 161 operated in conjunction with a Tektronix type 160A power supply and type 162 wave form generator. Recording of the pulse duration was accomplished by directing light reflected from the cornea of the rabbit onto a silicon cell connected to the recorder.

As shown in the schematic diagram, Relay A is a Square D, CO 3-220 VAC magnetic contactor used in the circuit to effect normal operating procedure. It was specially altered to have 4 normally closed contacts and two normally open contacts. The four contacts are used in parallel to increase the current carrying capacity of the relay. The two normally open contacts of the CO-3 are in series with the coils of two Square D EO-220VAC magnetic contactors placed in the pulsing circuit. (Relay B-1 and B-2). As a protective measure, the coil of a Potter and Brumfield PS 11 D 24 DC relay was connected in the coagulator circuit so that when the voltage across the lamp drops (causing the ignition circuit to start firing with approximately 15 KV) the 24V relay opens. It also became necessary to place another Potter and Brumfield 220 VAC, normally closed relay, across the CO-3 in the pulsing circuit. When the coil of this relay is energized it opens the Zeiss ignition circuit, preventing the latter from firing until the pulsing circuit is open.

In general, the purpose of the CO-3 and the Potter and Brumfield relays is to prevent pulsing of the Xenon lamp at improper times and to prevent damage to either the circuit or the Xenon lamp.

Average currents for the several applied voltages, as determined by the blowing of calibrated Bussman fuses, are presented in Table VI. A plot of irradiance vs. current indicates a more linear relationship than a plot of irradiance vs. power, indicating that the resistance of the lamp changes with variation in applied battery voltage. Since the lamp is a non-linear device, one cannot use applied battery voltage when computing power dissipation, but must use the actual lamp drop.

TABLE VI.  
CURRENT VS. APPLIED BATTERY VOLTAGE IN  
PULSING CIRCUIT

| <u>VOLTAGE</u><br><u>VOLTS</u> | <u>CURRENT</u><br><u>AMPS</u> |
|--------------------------------|-------------------------------|
| 32                             | 88                            |
| 34                             | 100                           |
| 36                             | 117                           |
| 38                             | 130                           |
| 40                             | 160                           |
| 42                             | 195                           |
| 44                             | 220                           |
| 46                             | 240                           |
| 48                             | 265                           |
| 50                             | 290                           |
| 52                             | 325                           |
| 54                             | 345                           |
| 56                             | 352                           |
| 58                             | 380                           |
| 60                             | 400                           |

# Contrails

To pulse the lamp, the procedure is as follows: the lamp is ignited as for normal operation, the push button labeled ON is depressed causing relay A to open (a holding circuit keeps it open) and permitting the current to pass through the 0.45 ohm limiting resistor and diode. The function of the diode is to prevent current from the storage battery from flowing in the Zeiss circuit during pulsed operation. Upon depressing the push button labeled RUN relays B-1 and B-2 close (a holding circuit once again acting to keep the circuit closed). The lamp is now ready to be pulsed; this is accomplished by applying the proper gate signal.

The electrical synchronous contact built into the shutter mechanism actuates the pulsing circuit by sending a signal to the waveform generator, which in turn delivers a signal to the gate of the series Trinistor.

## II. RECORDING SYSTEM

To monitor exposure times, measure retinal temperatures as a function of time with thermocouples, and calibrate the irradiance provided by the coagulator, a Honeywell type 906 Visicorder has been used. This is a direct recording oscillograph which utilizes high sensitivity subminiature plug-in galvanometers. These Heiland Galvanometers are specially designed to prevent "drift" of the galvanometer light spot as a result of changes in temperatures, vibration, shock or other disturbing conditions.

The Heiland recording chart is a treated photosensitive paper which develops its image when exposed to fluorescent lamps or other ultraviolet sources, requiring no darkroom developing.

Six galvanometers with sensitivities ranging from .24 mv/in to 10.1 mv/in were obtained with the recorder. Timing marks are placed on the chart by feeding a 60-cycle signal to one of the galvanometers.

As mentioned earlier, the exposure time was recorded by means of a silicon cell which intercepted reflected light from the cornea of the rabbit, and read on the Visocorder charts, using a calibrated Bausch and Lomb magnifying system.

Charts were read with an accuracy of  $\pm 0.5\%$ , and the overall error in exposure time may be specified as  $\pm 1\%$  for long exposures and  $\pm 2\%$  for short exposures.

## II. CALORIMETRY

The measurements of irradiance on the rabbit retinas were first made with two types of calorimeters: a blackened copper button calorimeter and a black body cavity calorimeter. Experiments conducted during the second quarter precluded further use of the black body cavity type because of large radiation losses from the calorimeter wall. For the purpose of verifying the results obtained with the Naval Material Laboratory button calorimeter, an Eppley Laboratory thermopile was employed.

### A. Retinal Measurements

The Eppley Laboratory thermopile was placed at various positions behind an eye-simulator lens and the irradiance determined. Calculations were then made to determine the energy in the rabbit retinal plane. Three eye-simulator lenses having focal lengths of 0.97, 1.2, and 10.3 cm were used.

Measurements were also made using the Naval Material Laboratory button calorimeter in several positions behind the eye simulator lens. In addition, new apertures, 0.305, 0.216, 0.050 and 0.035 cm in diameter were made and substituted for the original one of 0.547 cm, to permit placing the calorimeter in the retinal plane of the eye simulator lens and still have the aperture completely filled.

All measurements were taken with a constant 8 mm diameter artificial pupil in front of the lens.

Recently, a more sensitive calorimeter having smaller mass was acquired from the Naval Material Laboratory (NML) and used in place of the original calorimeter. Once again additional apertures were made so that the calorimeter could be placed in the retinal plane of the simulator lens.

### B. Corneal Measurements

The NML button calorimeter was placed in the same position as the exposed rabbits and the irradiance was determined. An inherent problem of the corneal irradiance method for the determination of retinal

irradiance lies in the accuracy of specifying image sizes on the retina and for this the actual measurements on enucleated eyes were performed. (Table IV.)

## C. Measurements on Enucleated Eyes

Retinal irradiance determination methods using a lens simulator necessitate assumption of a fixed focal length and retinal distance for all rabbits. This assumption is not valid, of course, if extreme accuracy is to be obtained. In an attempt to eliminate this difficulty a second technique for determining retinal irradiance was developed. This technique involved placing a light guide directly behind the retina of the enucleated eye and measuring the irradiance directly.

The light guide consists of bundles of unoriented glass fibers sheathed in plastic tubing. The ends are potted with epoxy resin, then ground and polished. Plastic sleeves are shrunk on the tips to serve as end fittings. Owing to cladding, packing and reflection losses, the guides accept approximately 70% of the light incident upon the input end. This reduction of energy was of no concern in the present instance since the light pipe was calibrated with a 1.2 cm focal length lens (similar optics to that of the rabbit eye) against a NML button calorimeter. The light guide, 0.48 mm in diameter was supplied by American Optical Co. (See Figs. 8 and 9.)

A difficulty inherent in this method was that of removing the layer of pigmented epithelium without collapsing the eye. Although a relatively clear area was chosen, there was a strong possibility that some variation in retinal irradiance, determined by light guide measurements, was due to this phenomenon rather than the difference in focal length and image sizes resulting from a particular rabbit optical system. For the calculation of threshold data, the most representative values of retinal irradiance were used, since initially the individual calibrations were made with the eye and retina intact. A technique was eventually developed for determining retinal irradiance, without pigment absorption, whereby a puncture was made in the retina and the light pipe inserted. Thus, a correction factor for absorption by the retinal pigmented layer was determined and applied to the retinal irradiance formerly determined with the enucleated eye intact.

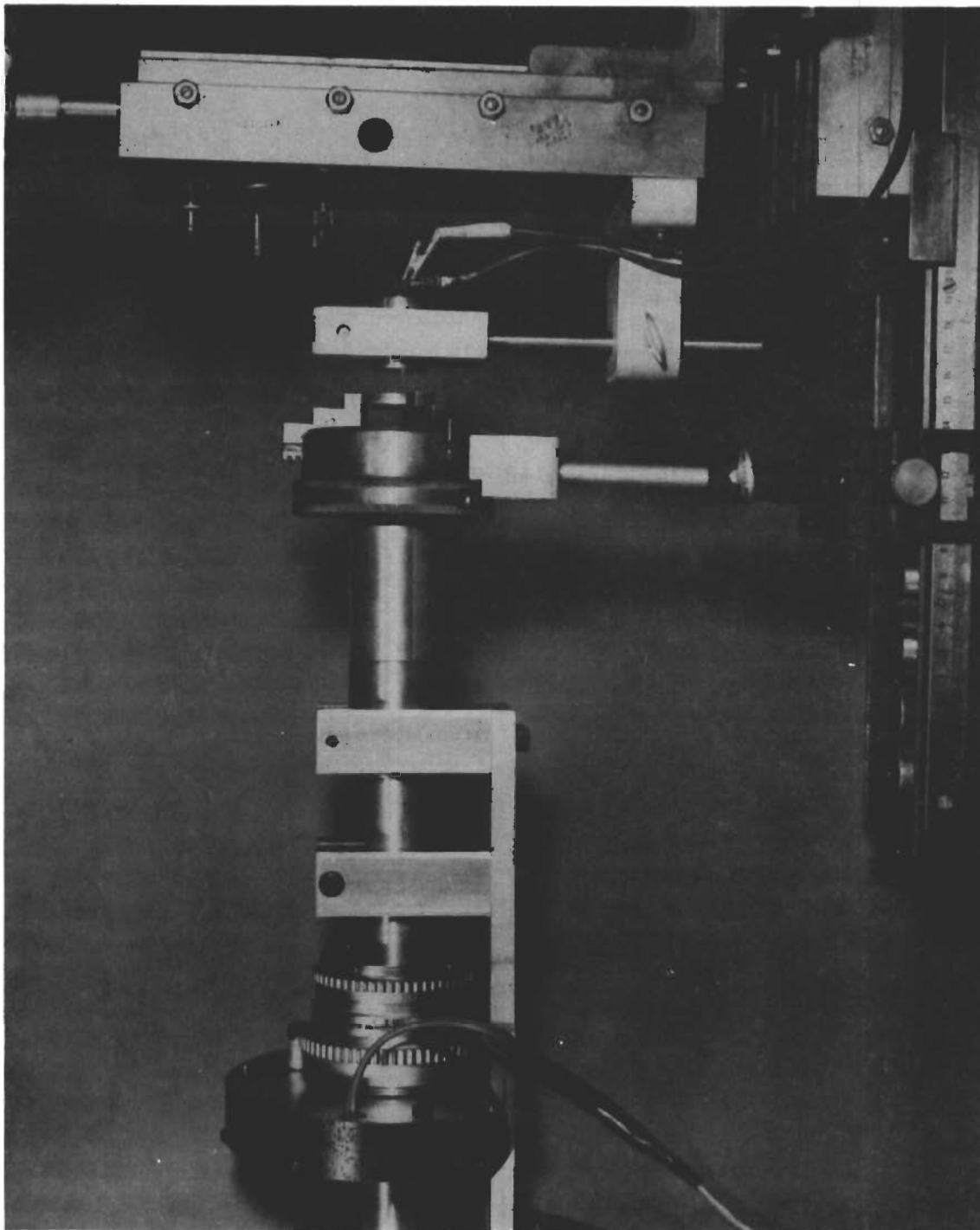


Figure 8. CALIBRATION WITH THE NML BUTTON CALORIMETER



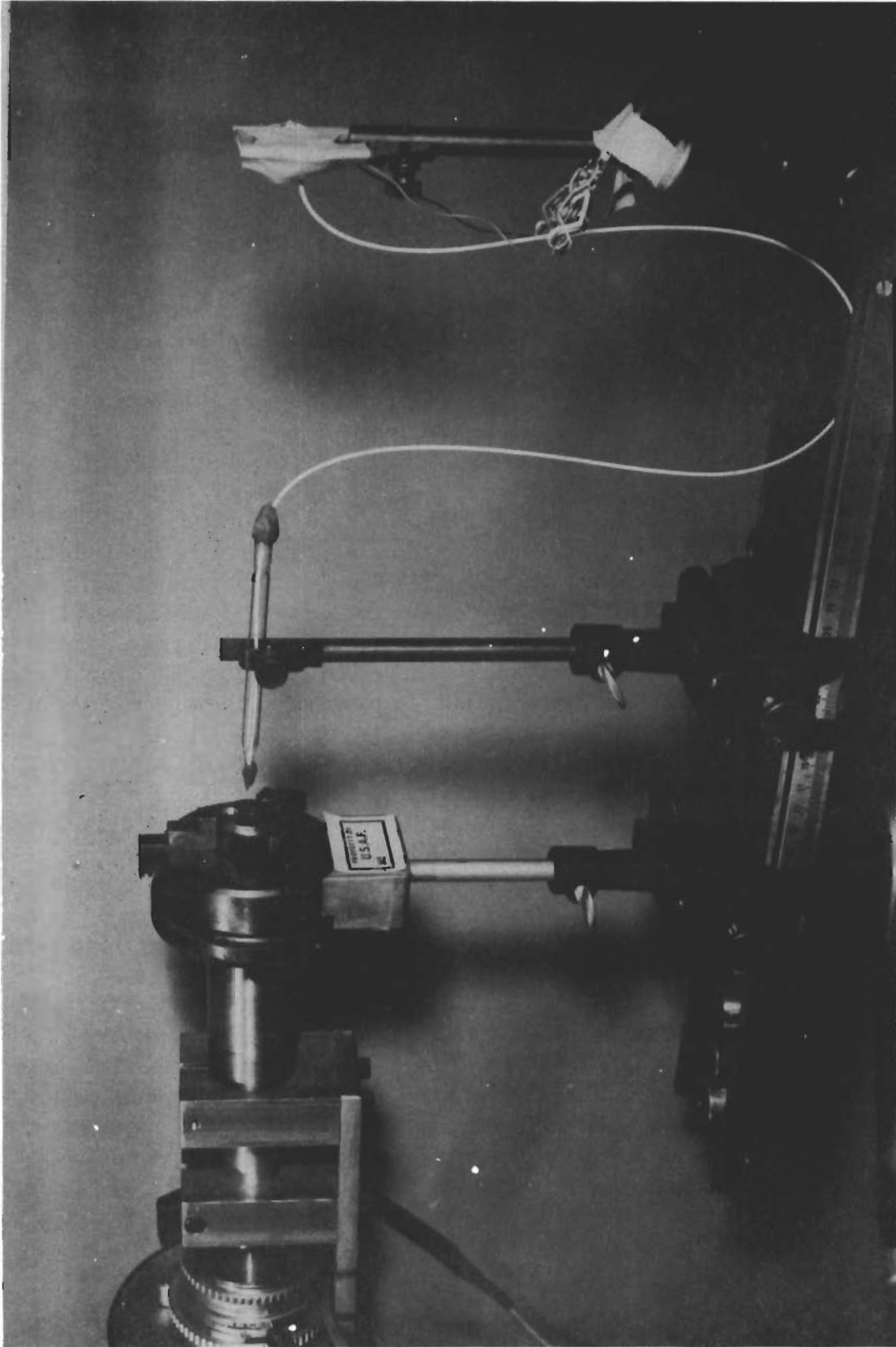


Figure 9. CALIBRATION OF LIGHT GUIDE

#### IV. IRRADIATION OF RABBIT EYE

##### A. Thermocouple Placement for Heat Conduction Measurements

Chinchilla grey rabbits weighing from 4.5 to 6.0 pounds were used. Animals were selected with retinas neither too dark nor too light, and having finely dispersed pigment.

To determine the effect of conduction on the thermodynamics of retinal burn production, thermocouples were placed within the rabbits eyes. These consisted of 38 B & S (0.01 cm in diameter) gauge copper-constantin wire made by copper plating constantin wire along half its length. One or more thermocouples were placed in the coats of the eye, anterior or posterior to the pigmented epithelium.

General anesthesia was obtained using nembutal sodium (25 mg/kg body weight), injected into the marginal ear vein. Pupils were maximally dilated with atropine (1%) neo-syneprine (10%), and cyclogyl (1%), instilled in the conjunctival sac. Tetracaine (0.5%) was used to produce the topical anesthesia. A retrobulbar injection of 1% novocaine completed the anesthesia, and produced an exophthalmos, desirable for the circumstances. It also prevented the nystagmoid motion frequently observed with barbiturates.

Complete peritomy was followed by resection of the rectus muscles. A suture ligature was placed on the proximal and distal end of the severed muscle, the former for hemostasis, the latter for traction. The globe could thus be rotated upward for 45°, exposing a large portion of the posterior pole. The remaining conjunctiva, with Tenon's capsule, was dissected free. Special care was taken to avoid the vortex veins.

Under direct visualization of the fundus with the binocular indirect ophthalmoscope, the site of implantation of the thermocouple was chosen. The thermocouple, in accordance with the specification, was placed in an area free of myelinated nerve fibers and tapetum lucidum. Dye was used to mark the sclera. The globe was placed in a plastic (Teflon) holder for fixation purpose. Two scratch incisions, 2 mm apart and 1 mm long, were made in the sclera, down to the lamina fusca. A 34 gauge needle was inserted in the thickness of the choroid emerging through the second incision. This procedure was carried out under direct ophthalmoscope control. The thermocouple (constantin end) was threaded into the lumen of the needle, and pulled to

the other end of the needle, bringing the junction into approximately the desired position. The needle was now withdrawn, the thermocouple visualized by the ophthalmoscope and adjusted to final position. The wire was then anchored to the sclera with two 7-0 black silk sutures. After the desired number of thermocouples were successfully placed, the plastic holder was removed. The animal was then ready to be exposed.

A burn was placed over one thermocouple. Simultaneously an EMF was recorded from it and every other thermocouple, situated at known distances from the burn. Assuming all the thermocouples were placed in the same plane, the different readings were evaluated as a function of the direct recording from the burned site, the energy delivered and the distance between thermocouples and the burned site.

## B. Threshold Burn Technique

In the study of threshold burns, the rabbits were anesthetized as for surgery. The animal, lying on its side, was positioned in front of the coagulator (Fig. 10, the cornea being 21 mm from the center of the mirror of the ophthalmoscope. An 8 mm apertured diaphragm was placed approximately 1 mm above the corneal surface to prevent any variation in the pupillary size. The beam of light was directed on the retina. The cornea was kept moist during the procedure. If corneal cloudiness occurred the animal was discarded. The indirect binocular ophthalmoscope was used to evaluate the burn. All the burns were evaluated by the same observer to minimize the individual variations.

## C. Irradiance Determination Using Rabbit Eyes

After burns were produced, the eye was enucleated from the anesthetized or freshly sacrificed rabbit. The sclera was trimmed of adherent tissue and the eye placed in a specially designed Teflon holder.

The globe was held before a source of light and the burned areas identified with the unaided eye. An area close to the burns and having similar pigment distribution was cleared of sclera and most of the choroid. The resultant "window" was roughly circular, 2 to 2.5 mm in diameter. When viewed through the cornea with strong background light, the area has a ground-glass appearance, devoid of blood-filled vessels and detectable patches of pigment.

The globe was kept moist (5% Glucose in 0.45% Saline) during the above procedure, and care was taken not to abrade the corneal epithelium. The globe was loosely wrapped in a fluff of cotton-wool, which was then soaked with the glucose/saline solution, to prevent dehydration of the sclera. The cornea was kept moist and clear by the periodic application of the glucose/saline solution throughout the calibration procedure.

The eye, in a holder, was placed in the path of the coagulator beam, the corneal surface being 42 mm from the last objective lens. The Xenon lamp electrodes were focussed on the cornea. By rotating the globe, the coagulator grid pattern was centered on the window, the incident beam falling on the corneal apex. A light guide was centered on the grid pattern, its surface in direct contact with the remaining layers of the window. (Fig. 11)

The 8.0 millimeter aperture was placed before the cornea as when burning.

Standard exposures were made with the various filter systems and beam sizes, followed by exposures duplicating the conditions which had been used in an attempt to produce burns in that eye.

As the number of successive exposures increased, changes in the eye occurred, resulting in progressive decrease in light transmission through the ocular media. The observed changes were:

1. Clouding of aqueous humor.
2. White precipitate deposited on anterior surface of the lens.
3. Dense coagulation of retina overlying the light-pipe site.
4. Slight clouding of vitreous humor.

To correct for any decrease in light transmission, standard exposures were repeated throughout the calibration procedures, and correction factors determined.

#### D. Measurement of Size of Burn

The eye was carefully dissected and a drawing depicting the various burns was made. The following were noted:

# Contrails

1. Gross appearance of burn site.
  - a) Intensity and distribution of pigment at site and of the surrounding area.
  - b) Relative position to nerve head and modulated nerve fibers.
2. Gross appearance of burns.
  - a) Intensity of retinal coagulation.
  - b) Size (Direct measurement with calipers).
  - c) Depth of coagulation. (Choroidal coagulation, hemorrhage, scleral burn.)
  - d) Spatial relationship of one burn to another.



Figure 10. IRRADIATION OF RABBIT

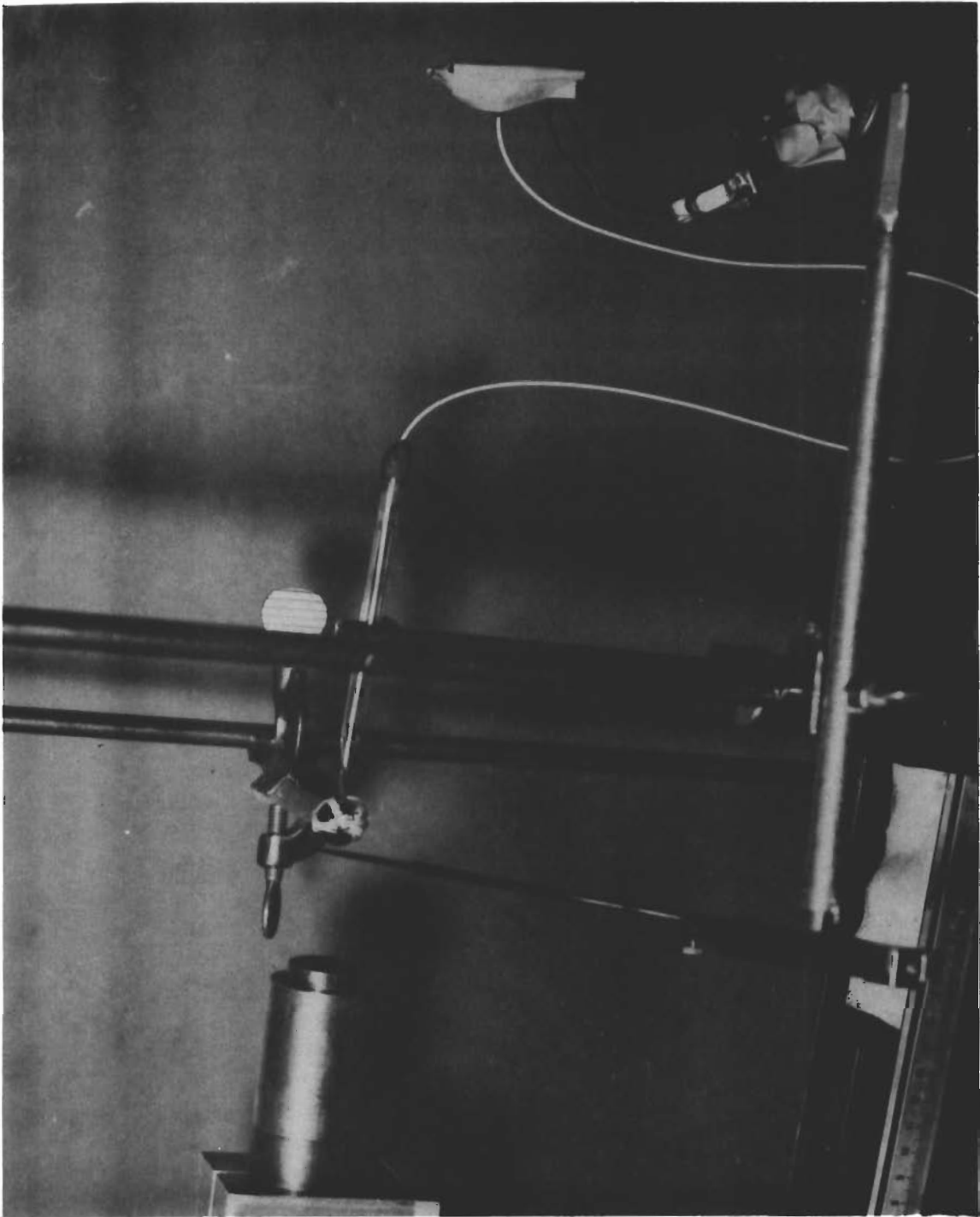


Figure 11. CALIBRATION OF ENUCLEATED RABBIT EYE

V. DISCUSSION OF THRESHOLD BURNS

A. General Factors

All burns were made in the posterior pole of the globe in an area of the retina situated below the optic disc and free of myelinated nerve fibers. As much as possible, the beam was kept perpendicular to the surface of the cornea to prevent aberrations, which might be produced by an obliquely oriented beam.

Burns were produced and characterized as a function of time of exposure, irradiance, image size, and spectral characteristics of the incident energy. Because we were interested in determining the dose that produces a lesion in a relatively short time, lesions were observed 30 seconds, 3 minutes and 5 minutes after the burn and evaluated as shown in Table VII. Burns not intense enough to show erythema after 5 minutes could not be detected and were therefore recorded as 0. However, we did not use the criterion of no burn since in reality a burn might have been produced but not discovered during our period of observation.

Several burns were made in one eye when the retinal image was 2 mm or less; only 2 burns were placed when the size was 3 mm or larger. Inasmuch as the study was undertaken to evaluate the rate of heat dissipation in the retina by the vascular system of the choroid as well as threshold burn, care was taken to avoid impairment of the choroidal blood flow by intense burns. Experience had shown us that multiple small burns did not produce marked impairment of circulation of the retina and choroid. On many occasions following production of large superficial burns, vascular spasm was observed; however, vasodilation and edema usually followed.

For a given dose, the degree of pigmentation of the site may be considered as one of the major factors in producing the burn. However, a subthreshold or threshold burn shows greater dependency upon this than does a more intense burn (because of a certain degree of saturation.)

In spite of careful selection of animals, a range of density of pigmentation was evident on the exposed retinas; although care was exercised as to placement of burns, the above factor contributed to the variations of dose necessary to produce a threshold burn.



Tables VIII, IX, and X present the theoretical energy absorbed by a medium pigmented rabbit retina given the spectral distribution of the Xenon lamp, transmission of the filters and transmission of the ocular media. Assuming the same total energy (irradiance) after filtration, the retina absorbs approximately 53% of the energy when just the visible energy is present, 40% of the energy when the visible and near infrared are present, and 36% of the energy when there is no filtration.

The final data presented in Table XI-XXVI are based on 265 rabbit eyes and 395 exposures.

TABLE VII.  
DESCRIPTION OF BURNS

- 1) 0 Burn - No lesion observed after 5 minutes.
- 2) E Burn - No coagulation of retinal layer but change in appearance of area - reddish color of the area comparable to an erythema.
- 3) T Burn - Same as an E burn but with a small amount of coagulation in the center of the lesion.
- 4) + Burn - Slight coagulation of the retinal layers, with choroidal vessels seen underneath. The burn is not well delineated.
- 5) 1+ Burn - Moderate coagulation of the retinal layers, no choroidal vessels obscured. The burn is well delineated, with a halo of edema.
- 6) 2+ Burn - Dense, white coagulation of the retinal layers, no choroidal vessels seen, presence of hemorrhage or vitreous burns.
- 7) 3+ Burn - Explosion of the retina.

TABLE VIII.  
SPECTRAL DISTRIBUTION OF ENERGY ABSORBED BY PIGMENTED EPITHELIUM  
(NO FILTRATION)

| Wave Length<br>mu | Emission<br>of Xenon<br>Lamp | Normalized<br>Total<br>Energy | Ocular<br>Trans-<br>mission | Energy Falling<br>on Pigmented<br>Epithelium | Relative Absorption<br>of Pigmented<br>Epithelium | Energy Absorbed<br>by Pigmented<br>Epithelium |
|-------------------|------------------------------|-------------------------------|-----------------------------|--|---|---|
| 350               | .25                          | .035                          | .00                         | .000   | .57   | .000  |
| 400               | .37                          | .051                          | .40                         | .020   | .50   | .010  |
| 450               | .49*                         | .068                          | .82                         | .056   | .70   | .039  |
| 500               | .43                          | .060                          | .90                         | .054   | .73   | .039  |
| 550               | .41                          | .057                          | .92                         | .052   | .71   | .037  |
| 600               | .38                          | .053                          | .93                         | .050   | .67   | .034  |
| 650               | .37*                         | .051                          | .93                         | .047   | .60   | .028  |
| 700               | .37                          | .051                          | .94                         | .048   | .52   | .025  |
| 750               | .37                          | .051                          | .93                         | .047   | .45   | .021  |
| 800               | .70*                         | .097                          | .92                         | .089   | .43   | .038  |
| 850               | .70*                         | .097                          | .92                         | .089   | .36   | .032  |
| 900               | .75*                         | .104                          | .89                         | .093   | .31   | .029  |
| 950               | .60                          | .083                          | .87                         | .072   | .28   | .020  |
| 1000              | .33                          | .046                          | .58                         | .027   | .20   | .005  |
| 1050              | .16                          | .022                          | .67                         | .015   | .20   | .003  |
| 1100              | .15                          | .021                          | .82                         | .017   | .17   | .003  |
| 1150              | .10*                         | .014                          | .78                         | .011   | .19   | .002  |
| 1200              | .10                          | .014                          | .22                         | .003   | .15   | .000  |
| 1250              | .07                          | .010                          | .18                         | .002   | .13   | .000  |
| 1300              | .05                          | .007                          | .23                         | .002   | .12   | .000  |
| 1350              | .04                          | .005                          | .16                         | .001   | .18   | .000  |
| 1400              | .03                          | .004                          | .02                         | .000   | .43   | .000  |

\* Average over 50 mu band width.

TABLE IX.  
SPECTRAL DISTRIBUTION OF ENERGY ABSORBED BY PIGMENTED EPITHELIUM  
(ULTRAVIOLET AND WATER FILTERS)

| Wave Length<br>mu | Emission<br>of Xenon<br>Lamp | Transmission of<br>GG13+H <sub>2</sub> O<br>Filters | Energy of<br>Xenon +<br>GG13+H <sub>2</sub> O<br>Filters | Normalized<br>Total<br>Energy | Ocular<br>Trans-<br>mission | Energy<br>Falling on<br>Pigmented<br>Epithelium | Relative<br>Absorption<br>of Pigmented<br>Epithelium | Energy<br>Absorbed<br>by Pigmente<br>Epithelium |
|-------------------|------------------------------|---|--|-------------------------------|-----------------------------|---|--|---|
| 350               | .25                          | .26   | .06  | .001                          | .00                         | .000  | .57  |   |
| 400               | .37                          | .63   | .23  | .050                          | .40                         | .020  | .50  | .010  |
| 450               | .49*                         | .78   | .38  | .078                          | .82                         | .064  | .70  | .045  |
| 500               | .43                          | .80   | .34  | .071                          | .90                         | .064  | .73  | .047  |
| 550               | .41                          | .80   | .33  | .071                          | .92                         | .065  | .71  | .046  |
| 600               | .38                          | .80   | .30  | .065                          | .93                         | .060  | .67  | .040  |
| 650               | .37*                         | .80   | .30  | .060                          | .93                         | .056  | .60  | .034  |
| 700               | .37                          | .79   | .29  | .063                          | .94                         | .059  | .52  | .031  |
| 750               | .37                          | .78   | .29  | .063                          | .93                         | .059  | .45  | .027  |
| 800               | .70*                         | .76   | .53  | .060                          | .92                         | .055  | .43  | .024  |
| 850               | .70*                         | .76   | .53  | .099                          | .92                         | .091  | .36  | .033  |
| 900               | .75*                         | .73   | .55  | .119                          | .89                         | .106  | .31  | .033  |
| 950               | .60                          | .62   | .37  | .080                          | .87                         | .070  | .28  | .020  |
| 1000              | .33                          | .55   | .18  | .039                          | .58                         | .023  | .20  | .005  |
| 1050              | .16                          | .62   | .10  | .022                          | .67                         | .015  | .20  | .003  |
| 1100              | .15*                         | .64   | .10  | .022                          | .82                         | .018  | .17  | .003  |
| 1150              | .10*                         | .36   | .04  | .006                          | .78                         | .005  | .19  | .001  |
| 1200              | .10                          | .23   | .02  | .004                          | .22                         | .001  | .15  | .000  |
| 1250              | .07                          | .23   | .02  | .004                          | .18                         | .001  | .13  | .000  |
| 1300              | .05                          | .21   | .01  | .002                          | .23                         | .000  | .12  | .000  |
| 1350              | .04                          | .04   | .00  | .000                          | .16                         | .000  | .18  | .000  |
| 1400              | .03                          | .00   | .00  | .000                          | .82                         | .000  | .43  | .000  |

\* Averaged over 50 mu band width.

*Contrails*

TABLE X.  
SPECTRAL DISTRIBUTION OF ENERGY ABSORBED BY PIGMENTED EPITHELIUM  
(ULTRAVIOLET AND INFRARED FILTERS)

| Wave Length<br>mu | Emission<br>of Xenon<br>Lamp | Transmission of<br>GG13+KG3<br>Filters | Energy of<br>Xenon †<br>GG13+KG3<br>Filters | Normalized<br>Total<br>Energy | Ocular<br>Trans-<br>mission | Relative<br>Absorption<br>of Pigmented<br>Epithelium | Energy<br>Falling on<br>Pigmented<br>Epithelium | Energy<br>Absorbed<br>by Pigmented<br>Epithelium |
|-------------------|------------------------------|--|---|-------------------------------|-----------------------------|--|---|--|
| 350               | .25*                         | .24                                    | .06   | .03                           | .00                         | .57  | .000  | .000   |
| 400               | .37                          | .59                                    | .22   | .09                           | .40                         | .50  | .036  | .018   |
| 450               | .49*                         | .71                                    | .35   | .15                           | .82                         | .70  | .123  | .086   |
| 500               | .43                          | .74                                    | .32   | .14                           | .90                         | .73  | .126  | .092   |
| 550               | .41                          | .74                                    | .30   | .13                           | .92                         | .71  | .120  | .085   |
| 600               | .38                          | .72                                    | .27   | .12                           | .93                         | .67  | .112  | .075   |
| 650               | .37*                         | .67                                    | .25   | .11                           | .93                         | .60  | .102  | .061   |
| 700               | .37                          | .61                                    | .23   | .10                           | .94                         | .52  | .094  | .049   |
| 750               | .37                          | .36                                    | .13   | .06                           | .93                         | .45  | .056  | .025   |
| 800               | .70*                         | .21                                    | .15   | .06                           | .92                         | .43  | .055  | .024   |
| 850               | .70*                         | .09                                    | .06   | .03                           | .92                         | .36  | .028  | .010   |
| 900               | .75*                         | .03                                    | .02   | .01                           | .89                         | .31  | .009  | .003   |
| 950               | .60                          | .00                                    | .00   | .00                           | .87                         | .28  | .000  | .000   |

\* Averaged over 50 mu band width.

B. Discussion of E Burn

The threshold burn as seen ophthalmoscopically represents the minimum irreversible lesion which could be discovered by the observer at the time of the experiment. It is important to consider the time since many lesions not apparent immediately after exposure did become manifest a few hours or days afterwards.

The E burn has been chosen to represent the threshold lesion for the following reasons:

- 1) The minimum lesion is the one that the observer could discover with the indirect ophthalmoscope with some degree of consistency.
- 2) The damage produced is irreversible as proven by pathological study of the lesion.
- 3) There is no evidence at the time of injury of any coagulation of the involved tissue, allowing for a better evaluation of the lesion.

We are certain that the E burn does not represent the actual minimum assault capable of producing damage to the tissue but in view of the limitation in the observation it represents the best lesion compatible with the nature of the experiments.

All burns when examined after 5 minutes showed a halo of edema the extent of which was dependent upon the depth of the burn. The sequence of events for an E burn, for example, would be an erythema in the center about the size of the image, followed by a halo of edema occurring after about 5 minutes. The burn progresses steadily until the burned area shows actual coagulated tissue elevated by sub-retinal fluid, with edema extending on all sides. (See pathology slide, Fig. 12).

In general, the shape of the lesions was round with the denser coagulated damage in the center. An obliquely oriented beam usually resulted in an oval shaped larger burn for the same beam size.

C. Beam Size, Burn Size and Irradiance

The small burns were found to be very difficult to evaluate. Poor contrast between the threshold burn of 1 mm and smaller, and the surrounding normal tissue represents the main handicap. The use of a green filter when observing the retina facilitated the determination of the extent of coagulation, but simple edema or congestion could not

# *Contrails*

be easily discerned. Furthermore, this technique did not allow for any judgement relative to the depth of the lesion.

Observation during the production of the burns and analysis of the data indicate that, for a given retinal image diameter, the size of the burn varies with the irradiance and the intensity of the burn; in other words, for low irradiance, the very dense burns were larger than the superficial ones. The difference in burn size was not noticeable for high irradiances.



Figure 12. Threshold Burn - approximate beam size 2 mm.  
O. S. - Enucleation performed 30 minutes after the (E) burn.  
There is a subclinical coagulation site which shows a flat detachment of the retina and minimal retinal edema in the ganglion and nerve fiber layers.



## VI. DISCUSSION OF RESULTS

Tables XI through XVIII show the irradiance, exposure time, dose, and type of burn for each of the individual exposures. Tables XIX through XXIV show the Burn-No Burn Analysis of the data. Having essentially obtained a sigmoid response, we have analyzed the data by inspection to determine a threshold dose in each case; the results are presented in Table XXV and XXVI. For the most part, this procedure does not yield the RD<sub>50</sub> dose but rather something between this and what is essentially an RD<sub>100</sub> dose. Low irradiance for the 0.7 mm image precluded analysis in a similar manner; the original data are presented in Tables XVII and XVIII.

While the data are insufficient in some details, one can deduce the following observations.

1. The dose required to produce a specific burn increases with the degree of burn, although this appears less evident for the 1 mm burn owing to the difficulty in evaluating the burn itself. For the moderately short exposure times employed in the present investigation, it seems reasonable to expect such a general reciprocity. At very low irradiances, not much greater than those normally encountered in one's environment, this reciprocity clearly breaks down, and at extremely high irradiances one would expect to find saturation effects; but in the range of irradiances considered here evidently the expected relationship does hold.

2. In all cases for a given irradiance a greater dose was required to produce the same thermal lesion when the spectral distribution included both the visible and near infrared. This, too, is to be expected because of the greater absorption of the retinal layers in the visible region compared to the near infrared. (Tables VIII. - X.)

3. For a given irradiance, the threshold dose increases with retinal image size. This appears to contradict the conclusions of Ham et al.,<sup>3</sup> who found the threshold dose to decrease with increasing size of retinal image. It should be noted, however, that Ham's studies covered a different range of retinal image size than did the present investigation, which opens the possibility that a transition occurs in the region where the two studies overlap; namely, at retinal images of the order of 1 mm diameter. Ham's data ranged from 1.1 mm to 0.18 mm, while the present study covered the range of retinal images from 0.7 mm to about 4 mm. In the region common to both investigations, i. e. , at about 1 mm, we are in agreement with Ham on the threshold dose,

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which is of the order of  $1-2 \text{ cal/cm}^2$ . Assuming that both sets of measurements are correct it follows that the threshold dose for a given irradiance reaches a minimum for a retinal image diameter of about 1 mm.

We observe the same failure of reciprocity as does Ham when, for a given retinal image, the threshold dose is determined as a function of the irradiance. Here we find, with Ham, that it increases with decreasing irradiance, although the departure from reciprocity is not as marked with large retinal images as with the very small image sizes employed by Ham.

Ham accounts for the departure from reciprocity on the grounds of increased efficiency of conduction to the surrounding tissues as the size of the image decreases; i. e., if the cooling is largely due to conduction along the retina, one can see that with decreasing image size the ratio of circumference to area increases and hence the cooling effect is enhanced. It is difficult to reconcile our observations with such a cooling effect, first because our dependence on image size is in the opposite direction, and secondly because the thermal lesions observed appear to be sharply defined and of the same size or smaller than the retinal image in each case, even for the severe burns, provided the irradiance is high. Strangely enough, at low irradiance and large doses the lesion is generally larger than the image. It should be noted that this condition implies relatively long exposure times. If there were appreciable conduction along the retina one would expect to find the damaged area somewhat less sharply outlined. Furthermore, in our thermocouple measurements we found very little temperature rise (less than  $0.1^\circ \text{C}$ ) at distances of the order of 1-2 mm from the central image (where the temperature rise was roughly  $20^\circ \text{C}$ ).

Nor does the convective transport of heat by the choroidal blood supply appear to account for appreciable cooling of the image for, as pointed out by Vos <sup>4</sup>; the blood transport is too small in the short exposure times used in Ham's (and in the present) investigation to play a significant role. It may be, as suggested by Ham, that the vitreous humor plays a role in the dissipation of energy, particularly at very high irradiances and small retinal images.

It will be useful at this point to consider the "steam production" theory proposed by Vos to account for Ham's results. Briefly, this theory seeks to account for the observed lesions by assuming that a threshold lesion is produced when a steam explosion takes place which is sufficient to give a marked disruption of the retinal tissue. Calculations based upon this theory seem to agree quite well with Ham's results except at his largest image size, 1.1 mm, where the computed temperatures

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rise is not great enough to reach the boiling point of water. If this is correct it may be significant that the steam production theory breaks down just in that region of retinal image size where a transition occurs between Ham's data and ours in the dependence of threshold doses upon irradiance.

This would suggest two possible mechanism for retinal damage; steam production for small retinal images and perhaps a coagulation of retinal albumins in the larger images. The latter finds additional support in our thermocouple measurements, which, while not very extensive, show temperature rises in the center of a 2 mm image to be in the range of 20-30° C. This, added to the normal body temperature, results in a total temperature of about 60° C, which clearly is not in the region of steam production but is in the range of albumin coagulation.

In conclusion, it would seem that while the evidence is not fully conclusive, there may be a dual picture needed to account fully for retinal burn damage. Knowing what steps must be taken to pinpoint the investigation should now make it possible to complete this picture.

TABLE XI  
EXPOSURES - ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN     |        |        |
|---|--------------|------------------------------|----------|--------|--------|
|   |              |                              | 1/2 Min. | 3 Min. | 5 Min. |
| 55.0                                    | .016         | 0.88                         | 0        | 0      | E      |
| 55.0                                    | .020         | 1.10                         | 0        | 0      | E      |
| 51.5                                    | .030         | 1.55                         | 0        | 0      | E      |
| 55.0                                    | .025         | 1.38                         | 0        | E      | E      |
| 42.5                                    | .028         | 1.19                         | 0        | E      | E      |
| 42.5                                    | .043         | 1.93                         | 0        | E      | E      |
| 13.6                                    | .243         | 3.30                         | 0        | E      | E      |
| 7.8                                     | .259         | 2.02                         | 0        | E      | E      |
| 55.0                                    | .016         | 0.88                         | E        | E      | E      |
| 55.0                                    | .018         | 0.99                         | E        | E      | E      |
| 55.0                                    | .025         | 1.38                         | E        | E      | E      |
| 51.5                                    | .059         | 3.04                         | E        | E      | E      |
| 42.5                                    | .041         | 1.74                         | E        | E      | E      |
| 42.5                                    | .043         | 1.83                         | E        | E      | E      |
| 38.0                                    | .053         | 2.01                         | E        | E      | E      |
| 34.5                                    | .046         | 1.59                         | E        | E      | E      |
| 38.0                                    | .059         | 2.24                         | E        | E      | E      |
| 42.5                                    | .043         | 1.83                         | E        | E      | E      |
| 42.5                                    | .052         | 2.21                         | E        | T      | T      |
| 34.5                                    | .078         | 2.69                         | E        | T      | T      |
| 16.8                                    | .173         | 2.91                         | E        | T      | T      |
| 55.0                                    | .040         | 2.20                         | T        | T      | T      |
| 52.3                                    | .065         | 3.40                         | T        | T      | T      |
| 48.0                                    | .033         | 1.59                         | T        | T      | T      |
| 48.0                                    | .035         | 1.68                         | T        | T      | T      |
| 44.6                                    | .038         | 1.69                         | T        | T      | T      |
| 38.0                                    | .071         | 2.70                         | T        | T      | T      |

TABLE XI. (Cont. )  
EXPOSURES - ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |            |            |
|---|--------------|------------------------------|------------|------------|------------|
|   |              |                              | 1/2 Min.   | 3 Min.     | 5 Min.     |
| 51.5                                    | .051         | 2.62                         | <u>+</u> - | <u>+</u> - | 1-         |
| 51.5                                    | .055         | 2.83                         | <u>+</u> - | <u>+</u> - | <u>+</u> - |
| 48.0                                    | .070         | 3.36                         | <u>+</u> - | 1-         | 1-         |
| 44.6                                    | .074         | 3.30                         | <u>+</u> - |            | <u>+</u>   |
| 52.3                                    | .084         | 4.39                         | <u>+</u> - | 1-         | 1          |
| 51.5                                    | .083         | 4.27                         | <u>+</u> - | <u>+</u> + | <u>+</u> + |
| 42.5                                    | .115         | 4.89                         | <u>+</u> - | <u>+</u> + | <u>+</u> + |
| 38.0                                    | .188         | 7.14                         | <u>+</u> + | <u>+</u> + | <u>+</u> + |
| 48.0                                    | .073         | 3.50                         | <u>+</u>   | 1-         | 1-         |
| 44.5                                    | .105         | 4.69                         | <u>+</u>   | 1-         | 1-         |
| 42.5                                    | .115         | 4.89                         | <u>+</u> - | <u>+</u> - | <u>+</u> - |
| 38.0                                    | .188         | 7.14                         | <u>+</u> - | <u>+</u> - | <u>+</u> + |
| 48.0                                    | .073         | 3.50                         | <u>+</u>   | 1-         | 1-         |
| 44.6                                    | .105         | 4.69                         | <u>+</u>   | 1-         | 1-         |
| 38.0                                    | .185         | 7.03                         | <u>+</u> + | <u>+</u> + | 1          |
| 48.0                                    | .073         | 3.50                         | <u>+</u> + | 1          | 1          |
| 44.6                                    | .125         | 5.57                         | <u>+</u> + | 1          | 1          |
| 44.6                                    | .103         | 4.60                         | <u>+</u> + | 1+         | 1+         |
| 44.6                                    | .130         | 5.80                         | <u>+</u> + | 1+         | 1+         |
| 51.5                                    | .101         | 5.20                         | 1          | 1          | 1          |
| 42.5                                    | .107         | 4.55                         | 1          |            | 1          |

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TABLE XII  
EXPOSURES - ULTRAVIOLET AND INFRARED FILTERS  
AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |            |            |
|---|--------------|------------------------------|------------|------------|------------|
|   |              |                              | 1/2 Min.   | 3 Min.     | 5 Min.     |
| 42.6                                    | .016         | 0.68                         | 0          | 0          | 0          |
| 42.6                                    | .023         | 0.98                         | 0          | 0          | E          |
| 42.6                                    | .023         | 0.98                         | 0          | E          | E          |
| 42.6                                    | .025         | 1.06                         | 0          | E          | E          |
| 38.8                                    | .025         | 0.97                         | 0          | E          | E          |
| 34.8                                    | .018         | 0.63                         | 0          | E          | E          |
| 33.0                                    | .049         | 1.62                         | 0          | E          | E          |
| 28.0                                    | .060         | 1.68                         | 0          | E          | E          |
| 33.0                                    | .050         | 1.65                         | E          | E          | E          |
| 42.6                                    | .044         | 1.87                         | E          | T          | T          |
| 34.1                                    | .039         | 1.33                         | E          | T          | T          |
| 33.0                                    | .043         | 1.42                         | E          | T          | T          |
| 42.6                                    | .048         | 2.04                         | T          | T          | T          |
| 42.6                                    | .048         | 2.04                         | T          | T          | T          |
| 42.6                                    | .036         | 1.54                         | T          | T          | T          |
| 40.1                                    | .048         | 1.93                         | T          | T          | T          |
| 36.9                                    | .080         | 2.95                         | T          | T          | T          |
| 16.2                                    | .080         | 1.30                         | T          | T          | T          |
| 42.6                                    | .044         | 1.87                         | T          | <u>+</u> - | <u>+</u> - |
| 33.0                                    | .066         | 2.82                         | T          | <u>+</u> - | <u>+</u> - |
| 42.6                                    | .062         | 2.64                         | <u>+</u> - | <u>+</u> - | <u>+</u> - |
| 33.0                                    | .131         | 4.32                         | <u>+</u> - | <u>+</u> - | <u>+</u> - |
| 33.0                                    | .130         | 4.29                         | <u>+</u>   | <u>+</u> + | <u>+</u> + |
| 33.0                                    | .213         | 7.03                         | <u>+</u> + | 1          | 1          |

TABLE XIII.  
EXPOSURES - ULTRAVIOLET AND WATER FILTER  
AVERAGE BEAM DIAMETER 2. 0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |            |            |
|---|--------------|------------------------------|------------|------------|------------|
|   |              |                              | 1/2 Min.   | 3 Min.     | 5 Min.     |
| 13.5                                    | .143         | 1.93                         | 0          | -          | E          |
| 44.5                                    | .023         | 1.03                         | 0          | E          | E          |
| 42.1                                    | .021         | 0.88                         | 0          | E          | E          |
| 28.8                                    | .035         | 1.01                         | 0          | E          | E          |
| 23.8                                    | .093         | 2.21                         | 0          | E          | E          |
| 13.5                                    | .160         | 2.16                         | 0          | E          | E          |
| 44.5                                    | .016         | 0.71                         | E          | E          | E          |
| 44.5                                    | .018         | 0.80                         | E          | E          | E          |
| 44.5                                    | .019         | 0.85                         | E          | E          | E          |
| 44.5                                    | .023         | 1.02                         | E          | E          | E          |
| 16.8                                    | .093         | 1.56                         | E          | E          | E          |
| 44.5                                    | .044         | 1.96                         | E          | T          | T          |
| 40.9                                    | .047         | 1.92                         | E          | T          | T          |
| 36.3                                    | .076         | 2.76                         | E          | T          | T          |
| 11.7                                    | .209         | 2.44                         | E          | -          | T          |
| 44.5                                    | .040         | 1.78                         | T          | T          | T          |
| 44.5                                    | .043         | 1.91                         | T          | T          | T          |
| 42.1                                    | .045         | 1.89                         | T          | T          | T          |
| 39.4                                    | .066         | 2.60                         | T          | <u>+</u> - | <u>+</u> - |
| 44.5                                    | .035         | 1.56                         | <u>+</u> - | <u>+</u>   | <u>+</u> + |
| 44.5                                    | .050         | 2.22                         | <u>+</u> - | <u>+</u>   | <u>+</u> - |
| 16.8                                    | .040         | 0.67                         | <u>+</u> - | <u>+</u>   | <u>+</u>   |
| 28.8                                    | .048         | 1.38                         | <u>+</u>   | <u>+</u> + | <u>+</u> + |
| 44.5                                    | .060         | 2.67                         | <u>+</u>   | -1         | -1         |
| 44.5                                    | .062         | 2.76                         | <u>+</u> + | <u>+</u> + | 1          |

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## EXPOSURES - ULTRAVIOLET AND INFRARED FILTERS AVERAGE BEAM DIAMETERS 2. 0 mm

| Irradiance<br>cal/cm. <sup>2</sup> | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |          |          |
|------------------------------------|--------------|------------------------------|------------|----------|----------|
|                                    |              |                              | 1/2 Min.   | 3 Min.   | 5 Min.   |
| 25.9                               | .027         | 0.70                         | 0          | 0        | E        |
| 9.4                                | .116         | 1.09                         | 0          | 0        | E        |
| 6.8                                | .151         | 1.03                         | 0          | 0        | E        |
| 28.3                               | .016         | 0.45                         | 0          | E        | E        |
| 28.3                               | .019         | 0.54                         | 0          | E        | E        |
| 26.7                               | .025         | 0.67                         | 0          | E        | E        |
| 25.9                               | .083         | 2.15                         | 0          | E        | E        |
| 24.7                               | .025         | 0.62                         | 0          | E        | E        |
| 9.4                                | .090         | 0.85                         | 0          | E        | E        |
| 9.4                                | .101         | 0.95                         | 0          | E        | E        |
| 6.8                                | .233         | 1.58                         | 0          | E        | E        |
| 17.6                               | .048         | 0.85                         | E          | E        | E        |
| 14.1                               | .087         | 1.22                         | E          | E        | E        |
| 9.4                                | .100         | 0.94                         | E          | E        | E        |
| 9.4                                | .120         | 1.13                         | E          | E        | E        |
| 9.4                                | .133         | 1.25                         | E          | E        | E        |
| 28.3                               | .039         | 1.10                         | E          | E        | T        |
| 28.3                               | .041         | 1.16                         | E          | E        | T        |
| 25.9                               | .055         | 1.43                         | E          | E        | T        |
| 28.3                               | .043         | 1.22                         | E          | T        | T        |
| 28.3                               | .045         | 1.27                         | T          | T        | T        |
| 26.7                               | .052         | 1.39                         | T          | T        | T        |
| 24.7                               | .069         | 1.70                         | T          | T        | T        |
| 22.5                               | .076         | 1.71                         | T          | T        | T        |
| 9.4                                | .201         | 1.89                         | T          | T        | T        |
| 28.3                               | .035         | 0.99                         | <u>+</u> - | <u>+</u> | <u>+</u> |
| 25.9                               | .051         | 1.32                         | <u>+</u> - | <u>+</u> | <u>+</u> |
| 25.9                               | .051         | 1.32                         | <u>+</u> - | <u>+</u> | <u>+</u> |



TABLE XV.  
EXPOSURES - ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |          |            |
|---|--------------|------------------------------|------------|----------|------------|
|   |              |                              | 1/2 Min.   | 3 Min.   | 5 Min.     |
| 17.6                                    | .038         | 0.67                         | 0          | 0        | E          |
| 10.3                                    | .247         | 2.54                         | 0          | 0        | E          |
| 17.6                                    | .043         | 0.76                         | 0          | E        | E          |
| 17.6                                    | .045         | 0.79                         | 0          | E        | E          |
| 17.6                                    | .050         | 0.88                         | 0          | E        | E          |
| 17.6                                    | .083         | 1.46                         | 0          | E        | E          |
| 17.0                                    | .081         | 1.38                         | 0          | E        | E          |
| 17.0                                    | .088         | 1.49                         | 0          | E        | E          |
| 16.6                                    | .142         | 2.36                         | 0          | E        | E          |
| 12.9                                    | .132         | 1.70                         | 0          | E        | E          |
| 12.9                                    | .210         | 2.71                         | 0          | E        | E          |
| 11.5                                    | .208         | 2.39                         | 0          | E        | E          |
| 11.5                                    | .220         | 2.53                         | 0          | E        | E          |
| 17.6                                    | .078         | 1.37                         | E          | E        | E          |
| 17.6                                    | .092         | 1.62                         | E          | E        | E          |
| 17.6                                    | .079         | 1.39                         | E          | E        | T          |
| 17.6                                    | .083         | 1.46                         | 0          | E        | T          |
| 17.0                                    | .116         | 1.97                         | E          | E        | T          |
| 17.6                                    | .059         | 1.04                         | E          | T        | T          |
| 17.6                                    | .054         | 1.48                         | E          | T        | T          |
| 17.0                                    | .081         | 1.38                         | E          | T        | T          |
| 17.0                                    | .087         | 1.48                         | E          | T        | T          |
| 15.4                                    | .122         | 1.88                         | E          | T        | T          |
| 14.4                                    | .131         | 1.88                         | E          | T        | T          |
| 12.9                                    | .175         | 2.26                         | E          | T        |            |
| 16.6                                    | .118         | 1.96                         | T          | T        | T          |
| 16.4                                    | .171         | 2.80                         | T          | T        | T          |
| 17.6                                    | .188         | 3.31                         | <u>+</u> - | <u>+</u> | <u>+</u> + |

TABLE XVI.  
EXPOSURES - ULTRAVIOLET AND INFRARED FILTERS  
AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN       |            |        |
|---|--------------|------------------------------|------------|------------|--------|
|   |              |                              | 1/2 Min.   | 3 Min.     | 5 Min. |
| 10.7                                    | .084         | 0.90                         | 0          | 0          | E      |
| 8.9                                     | .111         | 0.99                         | 0          | 0          | E      |
| 10.7                                    | .078         | 0.84                         | 0          | E          | E      |
| 10.7                                    | .078         | 0.84                         | 0          | E          | E      |
| 10.7                                    | .092         | 0.98                         | 0          | E          | E      |
| 10.7                                    | .101         | 1.08                         | 0          | E          | E      |
| 10.7                                    | .106         | 1.13                         | 0          | E          | E      |
| 10.7                                    | .108         | 1.16                         | 0          | E          | E      |
| 7.3                                     | .180         | 1.31                         | 0          | E          | E      |
| 10.7                                    | .084         | 0.90                         | E          | E          | E      |
| 10.7                                    | .096         | 1.03                         | E          | E          | E      |
| 10.7                                    | .100         | 1.07                         | E          | E          | E      |
| 10.7                                    | .143         | 1.53                         | E          | E          | E      |
| 10.2                                    | .070         | 0.71                         | E          | E          | E      |
| 10.7                                    | .089         | 0.95                         | E          | E          | T      |
| 10.7                                    | .112         | 1.20                         | E          | E          | T      |
| 7.9                                     | .151         | 1.19                         | E          | E          | T      |
| 10.7                                    | .073         | 0.78                         | E          | T          | T      |
| 10.5                                    | .111         | 1.16                         | 0          | T          | T      |
| 9.7                                     | .163         | 1.58                         | E          | T          | T      |
| 10.5                                    | .083         | 0.87                         | T          | T          | T      |
| 10.5                                    | .089         | 0.94                         | T          | T          | T      |
| 10.2                                    | .137         | 1.40                         | T          | T          | T      |
| 10.7                                    | .231         | 2.47                         | <u>+</u> - | <u>+</u> - | +1     |
| 10.7                                    | .219         | 2.34                         | <u>+</u>   | 1-         | 1-     |
| 10.0                                    | .218         | 2.18                         | <u>+</u>   | 1          | 1      |
| 10.0                                    | .211         | 2.11                         | <u>+</u> - | <u>+</u>   | 1      |

TABLE XVII.  
EXPOSURES - ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 0.7 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN     |        |            |
|---|--------------|------------------------------|----------|--------|------------|
|   |              |                              | 1/2 Min. | 3 Min. | 5 Min.     |
| 8.4                                     | .269         | 1.72                         | 0        | 0      | E          |
| 8.5                                     | .452         | 3.85                         | 0        | 0      | E          |
| 7.3                                     | .370         | 2.70                         | 0        | E      | E          |
| 7.3                                     | .335         | 2.45                         | 0        | E      | E          |
| 6.0                                     | .396         | 2.38                         | 0        | E      | T          |
| 6.0                                     | .348         | 2.08                         | 0        | E      | T          |
| 7.3                                     | .393         | 2.87                         | E        | E      | T          |
| 8.5                                     | .384         | 3.26                         | E        | E      | T          |
| 8.5                                     | .445         | 3.78                         | E        | E      | T          |
| 6.4                                     | .648         | 4.15                         | T        | T      | <u>±</u> - |

TABLE XVIII.  
EXPOSURES - ULTRAVIOLET AND INFRARED FILTERS  
AVERAGE BEAM DIAMETERS 0.7 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | BURN     |          |          |
|---|--------------|------------------------------|----------|----------|----------|
|   |              |                              | 1/2 Min. | 3 Min.   | 5 Min.   |
| 5.3                                     | .441         | 2.33                         | 0        | 0        | E        |
| 5.1                                     | .466         | 2.38                         | 0        | 0        | E        |
| 5.1                                     | .430         | 2.19                         | 0        | 0        | E        |
| 4.8                                     | .530         | 2.54                         | 0        | 0        | E        |
| 5.3                                     | .393         | 2.08                         | 0        | E        | E        |
| 5.3                                     | .410         | 2.17                         | 0        | E        | E        |
| 4.2                                     | .436         | 1.83                         | 0        | E        | E        |
| 4.2                                     | .921         | 3.85                         | T        | <u>†</u> | <u>†</u> |

TABLE XIX.  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND WATER FILTERS  
 AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |      |
|--|--------------------------|-----------------------|-------------------------------|------|
| 55.0                                     | .014*                    |                       | 0.77                          |      |
|  | .014*                    |                       | 0.77                          |      |
|  | .014*                    |                       | 0.77                          |      |
|  | .016*                    |                       | 0.88                          |      |
|  | .016*                    |                       | 0.88                          |      |
|  | .018*                    |                       | 0.99                          |      |
|  | .019*                    |                       | 1.04                          |      |
|  | .019                     |                       | 1.04                          |      |
|  | .020                     |                       | 1.10                          |      |
|  | .020                     |                       | 1.10                          |      |
|  | .020                     |                       | 1.10                          |      |
|  | .025*                    |                       | 1.37                          |      |
|  |                          |                       | .038                          | 2.09 |
|  |                          |                       | .040                          | 2.20 |
|  |                          |                       | .040                          | 2.20 |
| 52.3                                     |                          | .043                  | 2.36                          |      |
|  |                          | .045                  | 2.47                          |      |
|  |                          | .058                  | 3.19                          |      |
|  |                          | .065                  | 3.39                          |      |
|  |                          | .084                  | 4.39                          |      |
| 51.5                                     | .030                     |                       | 1.54                          |      |
|  |                          | .051                  | 2.62                          |      |
|  |                          | .055                  | 2.83                          |      |
|  |                          | .083                  | 4.27                          |      |
|  |                          | .101                  | 5.20                          |      |

\* E Burn

TABLE XIX. (Cont.)  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND WATER FILTERS  
 AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |
|--|--------------------------|-----------------------|-------------------------------|
| 48.0                                     | .029                     |                       | 1.39                          |
|  | .030                     |                       | 1.44                          |
|  | .033                     | .033                  | 1.58                          |
|  |                          | .034                  | 1.63                          |
|  | .064                     |                       | 3.07                          |
|  |                          | .066                  | 3.17                          |
|  |                          | .070                  | 3.36                          |
|  |                          | .073                  | 3.50                          |
|  |                          | .073                  | 3.50                          |
|  | 44.6                     |                       | .038                          |
|  |                          | .074                  | 3.30                          |
|  |                          | .079                  | 3.52                          |
|  |                          | .081                  | 3.61                          |
|  |                          | .104                  | 4.64                          |
|  |                          | .105                  | 4.68                          |
|  |                          | .114                  | 5.09                          |
|  |                          | .125                  | 5.57                          |
| 42.5                                     | .028*                    |                       | 1.19                          |
|  | .031*                    |                       | 1.32                          |
|  | .040*                    |                       | 1.70                          |
|  | .043*                    |                       | 1.83                          |
|  | .043                     |                       | 1.83                          |
|  |                          | .043                  | 1.83                          |
|  | .049                     |                       | 2.08                          |
|  |                          | .050                  | 2.12                          |
|  |                          | .053                  | 2.25                          |
|  |                          | .053                  | 2.25                          |
|  |                          | .066                  | 2.80                          |
|  |                          | .069                  | 2.93                          |
|  |                          | .108                  | 4.59                          |
|  |                          | .115                  | 4.89                          |
|  |                          | .126                  | 5.36                          |
|  | .126                     | 5.36                  |                               |

TABLE XIX. (Cont.)  
BURN - NO BURN ANALYSIS  
ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |
|--|--------------------------|-----------------------|-------------------------------|
| 38.0                                     | .038                     |                       | 1.44                          |
|  | .059*                    |                       | 2.24                          |
|  | .053*                    |                       | 2.01                          |
|  |                          | .071                  | 2.70                          |
|  |                          | .185                  | 7.03                          |
|  |                          | .188                  | 7.05                          |
| 34.5                                     | .023                     |                       | 0.79                          |
|  |                          | .046                  | 1.59                          |
|  |                          | .078                  | 2.69                          |
| 16.7                                     | .038                     |                       | 0.63                          |
|  | .039                     |                       | 0.65                          |
|  | .039                     |                       | 0.65                          |
|  | .126                     |                       | 2.10                          |
|  | .155                     |                       | 2.59                          |
|  | .166                     |                       | 2.77                          |
|  |                          | 0.173                 | 2.89                          |

# Contrails

TABLE XX.  
BURN - NO BURN ANALYSIS  
ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 2.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |      |
|--|--------------------------|-----------------------|-------------------------------|------|
| 44.5                                     | .016*                    |                       | 0.71                          |      |
|  | .018                     |                       | 0.80                          |      |
|  | .018                     |                       | 0.80                          |      |
|  | .019*                    |                       | 0.85                          |      |
|  | .023*                    |                       | 1.02                          |      |
|  | .023*                    |                       | 1.02                          |      |
|  |                          |                       | .035                          | 1.56 |
|  |                          |                       | .040                          | 1.78 |
|  |                          |                       | .043                          | 1.91 |
|  |                          |                       | .050                          | 2.22 |
|  |                          |                       | .050                          | 2.22 |
|  |                          |                       | .055                          | 2.45 |
|  |                          |                       | .049                          | 2.18 |
|  |                          |                       | .063                          | 2.80 |
|  |                          |                       | .065                          | 2.89 |
|  |                          |                       | .034                          | 3.74 |
|  |                          |                       | .086                          | 3.83 |
|  |                          | .098                  | 4.36                          |      |
| 42.1                                     | .021*                    |                       | 0.83                          |      |
|  |                          | .045                  | 1.89                          |      |
|  | .053*                    |                       | 2.10                          |      |
|  |                          | .053                  | 2.23                          |      |
|  |                          | .053                  | 2.23                          |      |
|  |                          | .055                  | 2.31                          |      |
|  |                          | .065                  | 2.73                          |      |
|  |                          | .070                  | 2.94                          |      |
|  |                          | .075                  | 3.15                          |      |
|  |                          | .078                  | 3.28                          |      |
|  | .091                     | 3.83                  |                               |      |



# Contrails

TABLE XX. (Cont.)  
BURN - NO BURN ANALYSIS  
ULTRAVIOLET AND WATER FILTERS  
AVERAGE BEAM DIAMETER 2.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |
|--|--------------------------|-----------------------|-------------------------------|
| 40.9                                     | .018                     |                       | 0.74                          |
|  |                          | .045                  | 1.84                          |
|  |                          | .047                  | 1.92                          |
|  |                          | .061                  | 2.49                          |
|  |                          | .078                  | 3.19                          |
|  |                          | .080                  | 3.27                          |
|  |                          | .128                  | 5.24                          |
|  |                          | .134                  | 5.49                          |
|  |                          | .138                  | 5.65                          |
| 39.4                                     | .029<br>.030*            |                       | 1.14                          |
|  |                          |                       | 1.18                          |
|  |                          | .051                  | 2.01                          |
|  |                          | .055                  | 2.17                          |
|  |                          | .066                  | 2.60                          |
|  |                          | .083                  | 3.27                          |
|  |                          | .101                  | 3.98                          |
| 36.3                                     |                          | .076                  | 2.76                          |
| 28.8                                     | .035*                    |                       | 1.02                          |
|  |                          | .130*                 | 3.74                          |
| 23.3                                     | .093*                    |                       | 2.21                          |
| 16.8                                     | .093*                    |                       | 1.56                          |
|  |                          | .206                  | 3.46                          |
| 13.5                                     | .143*<br>.160*           |                       | 1.92                          |
|  |                          |                       | 2.16                          |
| 11.7                                     | .070                     |                       | 0.82                          |
|  |                          | .209                  | 2.44                          |
| 12.5                                     | .105<br>.131<br>.169     |                       | 1.31                          |
|  |                          |                       | 1.64                          |
|  |                          |                       | 2.11                          |
|  |                          | .291                  | 3.64                          |
| 9.6                                      | .250                     |                       | 2.40                          |

\* E Burn

TABLE XXI.  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND WATER FILTERS  
 AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |      |
|--|--------------------------|-----------------------|-------------------------------|------|
| 17.6                                     | .033                     |                       | 0.58                          |      |
|  | .036                     |                       | 0.63                          |      |
|  | .039                     |                       | 0.69                          |      |
|  | .039                     |                       | 0.69                          |      |
|  | .043*                    |                       | 0.76                          |      |
|  | .044                     |                       | 0.77                          |      |
|  | .045                     |                       | 0.79                          |      |
|  | .045*                    |                       | 0.79                          |      |
|  | .050*                    |                       | 0.88                          |      |
|  |                          |                       | .059                          | 1.04 |
|  |                          |                       | .079                          | 1.39 |
|  |                          |                       | .079                          | 1.39 |
|  |                          | .083                  |                               | 1.46 |
|  |                          | .083*                 |                               | 1.46 |
|  |                          |                       | .083                          | 1.46 |
|  |                          |                       | .084                          | 1.48 |
|  |                          | .086                  |                               | 1.51 |
|  |                          | .088                  |                               | 1.56 |
|  |                          | .093*                 |                               | 1.64 |
|  |                          |                       | .093                          | 1.64 |
|  |                          |                       | .181                          | 3.18 |
|  |                          |                       | .189                          | 3.32 |
|  |                          | .196                  | 3.45                          |      |
|  |                          | .198                  | 3.48                          |      |
|  |                          | .205                  | 3.61                          |      |
|  |                          | .236                  | 4.15                          |      |
|  |                          | .245                  | 4.31                          |      |
| 17.0                                     |                          | .081                  | 1.38                          |      |
|  |                          | .087                  | 1.48                          |      |
|  | .088*                    | .088*                 | 1.50                          |      |
|  |                          | .116                  | 1.97                          |      |

\* E Burn

TABLE XXI. (Cont)  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND WATER FILTERS  
 AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 16.6                                    | .075                     |                       | 1.25                         |
|   |                          | .119                  | 1.98                         |
|   | .130                     |                       | 2.16                         |
|   | .142                     |                       | 2.36                         |
|   | .155                     |                       | 2.57                         |
| 16.4                                    |                          | .171                  | 2.80                         |
| 13.4                                    |                          | .123                  | 1.90                         |
| 14.4                                    |                          | .131                  | 1.89                         |
| 12.9                                    | .133                     |                       | 1.72                         |
|   |                          | .175                  | 2.26                         |
|   | .210*                    |                       | 2.71                         |
| 11.0                                    | .220                     |                       | 2.84                         |
|   | .130                     |                       | 1.43                         |
|   | .209                     |                       | 2.30                         |
|   | .220                     |                       | 2.42                         |
| 10.3                                    | .043                     |                       | 0.44                         |
|   | .076                     |                       | 0.78                         |
|   | .135                     |                       | 1.39                         |
|   | .201                     |                       | 2.07                         |
|   | .248                     |                       | 2.55                         |

\* E Burn

# Contrails

TABLE XXII.  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND INFRARED FILTERS  
 AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 42.6                                    | .016*                    |                       | 0.68                         |
|   | .019*                    |                       | 0.81                         |
|   | .023*                    |                       | 0.99                         |
|   | .025*                    |                       | 1.06                         |
|   |                          | .036                  | 1.53                         |
|   |                          | .044                  | 1.87                         |
|   |                          | .044                  | 1.87                         |
|   |                          | .048                  | 2.04                         |
|   |                          | .048                  | 2.04                         |
|   |                          | .063                  | 2.68                         |
| 41.4                                    |                          | .060                  | 2.49                         |
|   |                          | .063                  | 2.61                         |
|   |                          | .100                  | 4.14                         |
| 40.1                                    | .020                     |                       | 0.80                         |
|   | .026                     |                       | 1.04                         |
|   | .029                     |                       | 1.16                         |
|   | .031                     |                       | 1.24                         |
|   | .033                     |                       | 1.32                         |
|   |                          | .069                  | 2.77                         |
|   |                          | .073                  | 2.93                         |
|   |                          | .080                  | 3.21                         |
|   |                          | .080                  | 3.21                         |
|   |                          | .080                  | 3.21                         |
|   |                          | .083                  | 3.33                         |
|   |                          | .086                  | 3.45                         |
|   |                          | .091                  | 3.65                         |
|   | .099                     | 3.97                  |                              |
| 34.1                                    | .024                     |                       | 0.82                         |
|   | .038                     |                       | 1.29                         |
|   | .038                     |                       | 1.29                         |
|   |                          | .039                  | 1.33                         |
|   |                          | .085                  | 2.90                         |
|   |                          | .109                  | 3.72                         |
|   | .110                     | 3.75                  |                              |

\* E Burn

# Contrails

TABLE XXII. (Cont )  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND INFRARED FILTERS  
 AVERAGE BEAM DIAMETER 4.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 33.0                                    | .026                     |                       | 0.86                         |
|   | .035                     |                       | 1.15                         |
|   | .040                     |                       | 1.32                         |
|   | .040                     |                       | 1.32                         |
|   | .043*                    |                       | 1.42                         |
|   | .049                     |                       | 1.62                         |
|   | .049                     |                       | 1.62                         |
|   | .050*                    |                       | 1.65                         |
|   |                          | .126                  | 4.16                         |
|   |                          | .126                  | 4.16                         |
|   |                          | .130                  | 4.29                         |
|   |                          | .131                  | 4.32                         |
|   |                          | .131                  | 4.32                         |
|   | 28.0                     | .060*                 |                              |
|   |                          | .153                  | 4.29                         |
| 26.2                                    | .060*                    |                       | 1.57                         |
|   |                          | .060                  | 1.57                         |
|   | .078                     |                       | 2.04                         |
|   |                          | .154                  | 4.03                         |
|   | .214                     | 5.60                  |                              |
| 15.2                                    | .148                     |                       | 2.25                         |
|   |                          | .148                  | 2.25                         |
| 9.2                                     | .038                     |                       | 0.35                         |
|   | .059                     |                       | 0.54                         |
|   | .105*                    |                       | 0.97                         |
|   | .109*                    |                       | 1.00                         |
|   | .111                     |                       | 1.02                         |
|   | .125                     |                       | 1.15                         |
|   | .155                     |                       | 1.42                         |
|   | .170                     |                       | 1.56                         |
|   | .299                     | 2.75                  |                              |
| 5.1                                     | .243*                    |                       | 1.24                         |

\* E Burn

# Contrails

TABLE XXIII.  
BURN - NO BURN ANALYSIS  
ULTRAVIOLET AND INFRARED FILTERS

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 28.3                                    | .016*                    |                       | 0.45                         |
|   | .019*                    |                       | 0.54                         |
|   | .021                     |                       | 0.59                         |
|   |                          | .023                  | 0.65                         |
|   |                          | .039                  | 1.10                         |
|   |                          | .039                  | 1.10                         |
|   |                          | .041                  | 1.16                         |
|   |                          | .043                  | 1.21                         |
|   | .045                     |                       | 1.27                         |
|   |                          | .045                  | 1.27                         |
|   |                          | .065                  | 1.84                         |
|   |                          | .080                  | 2.26                         |
|   |                          | .080                  | 2.26                         |
|   | .086                     | 2.43                  |                              |
|   | .109*                    | 3.09                  |                              |
| 26.7                                    | .025                     |                       | 0.67                         |
|   | .025*                    |                       | 0.67                         |
|   |                          | .050                  | 1.33                         |
|   |                          | .051                  | 1.36                         |
|   |                          | .053                  | 1.41                         |
|   |                          | .056                  | 1.50                         |
|   |                          | .058                  | 1.55                         |
|   |                          | .080                  | 2.14                         |
|   |                          | .085                  | 2.27                         |
|   |                          | .099                  | 2.64                         |
| 25.9                                    | .028*                    |                       | 0.73                         |
|   |                          | .048                  | 1.24                         |
|   |                          | .051                  | 1.32                         |
|   |                          | .066                  | 1.71                         |
|   |                          | .068                  | 1.76                         |
|   |                          | .069                  | 1.79                         |
|   |                          | .073                  | 1.89                         |
|   |                          | .079                  | 2.04                         |
|   |                          | .081                  | 2.10                         |
|   | .083                     |                       | 2.15                         |
|   |                          | .130                  | 3.37                         |
|   | .144                     | 3.73                  |                              |

\* E Burn

TABLE XXIII. (Cont.)  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND INFRARED FILTERS  
 AVERAGE BEAM DIAMETER 2.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 24.9                                    | .025*                    |                       | 0.62                         |
|   | .028                     |                       | 0.70                         |
|   |                          |                       | 0.70                         |
|   |                          | .055                  | 1.37                         |
|   |                          | .069                  | 1.72                         |
|   |                          | .083                  | 2.07                         |
|   |                          | .083                  | 2.07                         |
|   | .094                     | 2.34                  |                              |
| 22.5                                    | .028                     |                       | 0.63                         |
|   |                          | .074                  | 1.66                         |
| 17.6                                    | .048*                    |                       | 0.85                         |
| 14.1                                    | .088*                    |                       | 1.24                         |
| 9.6                                     | .065                     |                       | 0.62                         |
|   | .090*                    |                       | 0.86                         |
|   | .100*                    |                       | 0.96                         |
|   | .116*                    |                       | 1.11                         |
|   | .120*                    |                       | 1.15                         |
|   | .121                     |                       | 1.16                         |
|   | .133*                    |                       | 1.28                         |
|   |                          | .201                  | 1.93                         |
| 7.0                                     | .126                     |                       | 0.88                         |
|   | .148                     |                       | 1.04                         |
|   | .151*                    |                       | 1.06                         |
| 6.3                                     | .319*                    |                       | 2.01                         |

\* E Burn

# Contrails

TABLE XXIV.  
 BURN - NO BURN ANALYSIS  
 ULTRAVIOLET AND INFRARED FILTERS  
 AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm <sup>2</sup> . sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm <sup>2</sup> . |
|--|--------------------------|-----------------------|-------------------------------|
| 10.7                                     | .055                     |                       | 0.59                          |
|  |                          | .073                  | 0.78                          |
|  |                          | .079*                 | 0.85                          |
|  |                          | .079*                 | 0.85                          |
|  |                          | .080                  | 0.86                          |
|  |                          | .083                  | 0.89                          |
|  |                          | .084*                 | 0.90                          |
|  |                          |                       | .089                          |
|  |                          | .093*                 | 1.00                          |
|  |                          | .096*                 | 1.03                          |
|  |                          | .100*                 | 1.07                          |
|  |                          | .101*                 | 1.08                          |
|  |                          | .106*                 | 1.13                          |
|  |                          | .144*                 | 1.54                          |
|  |                          | .164                  | 1.76                          |
|  |                          | .169*                 | 1.81                          |
|  |                          | .173*                 | 1.85                          |
|  |                          |                       | .205                          |
|  |                          |                       | .211                          |
|  |                          |                       | .219                          |
|  |                          | .219                  |                               |
|  |                          | .221                  |                               |
|  |                          | .221                  |                               |
|  |                          | .231                  |                               |
| 10.5                                     |                          | .089                  | 0.94                          |
|  |                          | .111                  | 1.17                          |
| 10.2                                     | .070*                    |                       | 0.71                          |
|  |                          | .138                  | 1.41                          |
| 9.7                                      | .081                     |                       | 0.79                          |
|  |                          | .164                  | 1.59                          |
| 8.9                                      | .111*                    |                       | 0.99                          |

\* E Burn



TABLE XXIV. (Cont.)  
BURN - NO BURN ANALYSIS  
ULTRAVIOLET AND INFRARED FILTERS  
AVERAGE BEAM DIAMETER 1.0 mm

| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time For<br>No Burn sec. | Time For<br>Burn sec. | Dose<br>cal/cm. <sup>2</sup> |
|---|--------------------------|-----------------------|------------------------------|
| 7.8                                     |                          | .151                  | 1.18                         |
| 7.3                                     | .180*                    |                       | 1.31                         |
|   | .193                     |                       | 1.41                         |
|   | .213                     |                       | 1.55                         |
| 2.4                                     | .254                     |                       | 0.61                         |

\* E Burn

TABLE XXV.  
SUMMARY OF RESULTS OF THRESHOLD BURN STUDIES  
ULTRAVIOLET AND WATER FILTERS

| Beam Diameter<br><u>4.0 mm</u>          |              |                              | Beam Diameter<br><u>2.0 mm</u>          |              |                              | Beam Diameter<br><u>1.0 mm</u>          |              |                              |
|---|--------------|------------------------------|---|--------------|------------------------------|---|--------------|------------------------------|
| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> |
| 55.0                                    | .014         | 0.77                         | 44.5                                    | .017         | 0.76                         | 20.0                                    | .046         | 0.92*                        |
| 49.8                                    | .019         | 0.95                         | 42.1                                    | .020         | 0.84                         | 17.6                                    | .054         | 0.95                         |
| 42.5                                    | .028         | 1.19                         | 28.8                                    | .030         | 0.86                         | 12.9                                    | .132         | 1.70                         |
| 36.3                                    | .046         | 1.67                         | 20.0                                    | .064         | 1.28*                        | 11.0                                    | .209         | 2.30                         |
| 20.0                                    | .120         | 2.40*                        | 16.5                                    | .085         | 1.43                         | 10.3                                    | .247         | 2.54                         |
| 16.7                                    | .140         | 2.34                         | 13.5                                    | .143         | 1.92                         |   |              |                              |
| <u>E Burn in 5 Minutes</u>              |              |                              |   |              |                              |   |              |                              |
| 55.0                                    | .026         | 1.43                         | 44.5                                    | .029         | 1.29                         | 20.0                                    | .070         | 1.40*                        |
| 49.8                                    | .033         | 1.64                         | 39.4                                    | .040         | 1.58                         | 17.6                                    | .083         | 1.46                         |
| 42.5                                    | .047         | 2.00                         | 28.8                                    | .082         | 2.36                         | 17.0                                    | .090         | 1.53                         |
| 38.0                                    | .065         | 2.47                         | 20.0                                    | .125         | 2.50*                        | 12.9                                    | .140         | 1.81                         |
| 20.0                                    | .143         | 2.86*                        | 13.5                                    | .185         | 2.50                         | 11.0                                    | .220         | 2.42                         |
| 16.7                                    | .164         | 2.74                         | 11.5                                    | .209         | 2.40                         |   |              |                              |
| <u>T Burn in 5 Minutes</u>              |              |                              |   |              |                              |   |              |                              |

\*Taken from curve

TABLE XXVI.  
SUMMARY OF RESULTS OF THRESHOLD BURN STUDIES  
ULTRAVIOLET AND INFRARED FILTERS

| Beam Diameter<br><u>4.0 mm</u>          |              |                              | Beam Diameter<br><u>2.0 mm</u>          |              |                              | Beam Diameter<br><u>1.0 mm</u>          |              |                              |
|---|--------------|------------------------------|---|--------------|------------------------------|---|--------------|------------------------------|
| Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> | Irradiance<br>cal/cm. <sup>2</sup> sec. | Time<br>sec. | Dose<br>cal/cm. <sup>2</sup> |
| <u>E Burn in 5 Minutes</u>              |              |                              |   |              |                              |   |              |                              |
| 42.6                                    | .016         | 0.68                         | 28.3                                    | .016         | 0.45                         | 20.0                                    | .030         | 0.60*                        |
| 33.0                                    | .030         | 0.99                         | 26.7                                    | .025         | 0.67                         | 10.7                                    | .064         | 0.68                         |
| 28.0                                    | .040         | 1.12                         | 25.9                                    | .028         | 0.73                         | 10.4                                    | .070         | 0.73                         |
| 20.0                                    | .080         | 1.60*                        | 20.0                                    | .040         | 0.80*                        | 8.9                                     | .111         | 0.99                         |
| 5.1                                     | .243         | 1.24                         | 9.6                                     | .110         | 1.06                         | 7.3                                     | .160         | 1.17                         |
|   |              |                              | 7.0                                     | .160         | 1.12                         |   |              |                              |
| <u>T Burn in 5 Minutes</u>              |              |                              |   |              |                              |   |              |                              |
| 42.6                                    | .030         | 1.28                         | 28.3                                    | .039         | 1.10                         | 20.0                                    | .048         | 0.96*                        |
| 40.1                                    | .035         | 1.40                         | 25.9                                    | .048         | 1.24                         | 10.7                                    | .110         | 1.18                         |
| 33.0                                    | .043         | 1.42                         | 20.0                                    | .075         | 1.50*                        | 7.8                                     | .151         | 1.18                         |
| 26.2                                    | .060         | 1.57                         | 9.6                                     | .160         | 1.54                         | 7.3                                     | .180         | 1.31                         |
| 20.0                                    | .095         | 1.90*                        | 6.3                                     | .319         | 2.01                         |   |              |                              |
| 9.2                                     | .235         | 2.16                         |   |              |                              |   |              |                              |

\*Taken from curve

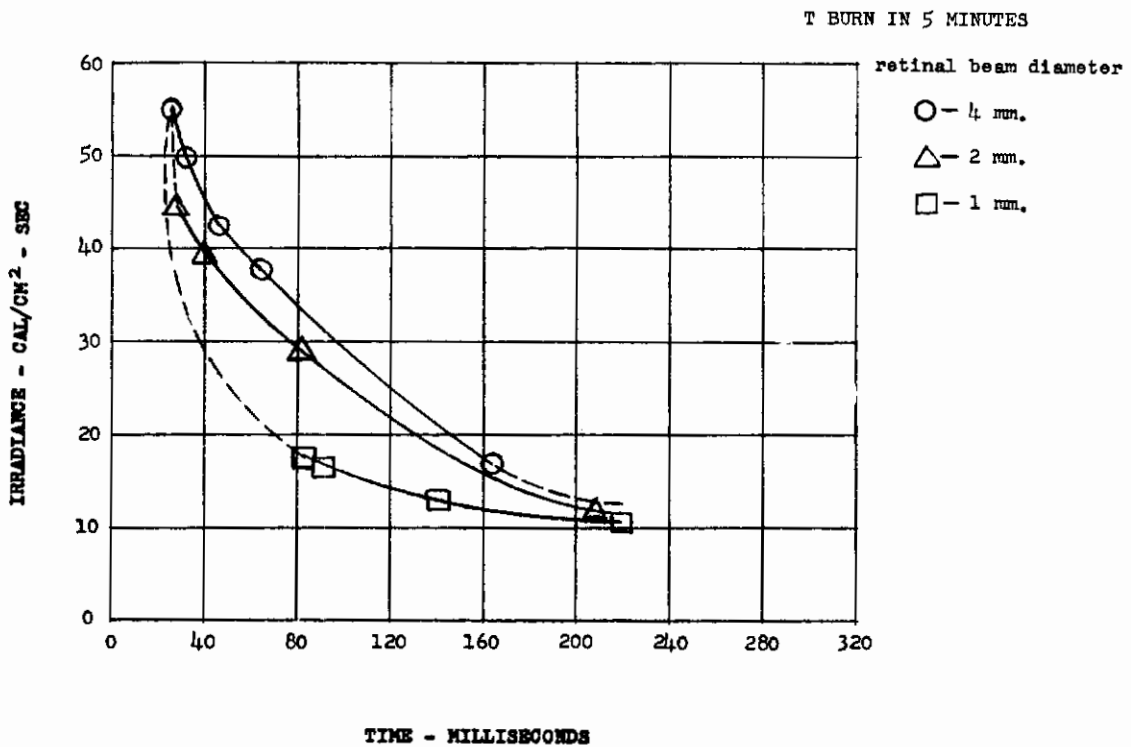
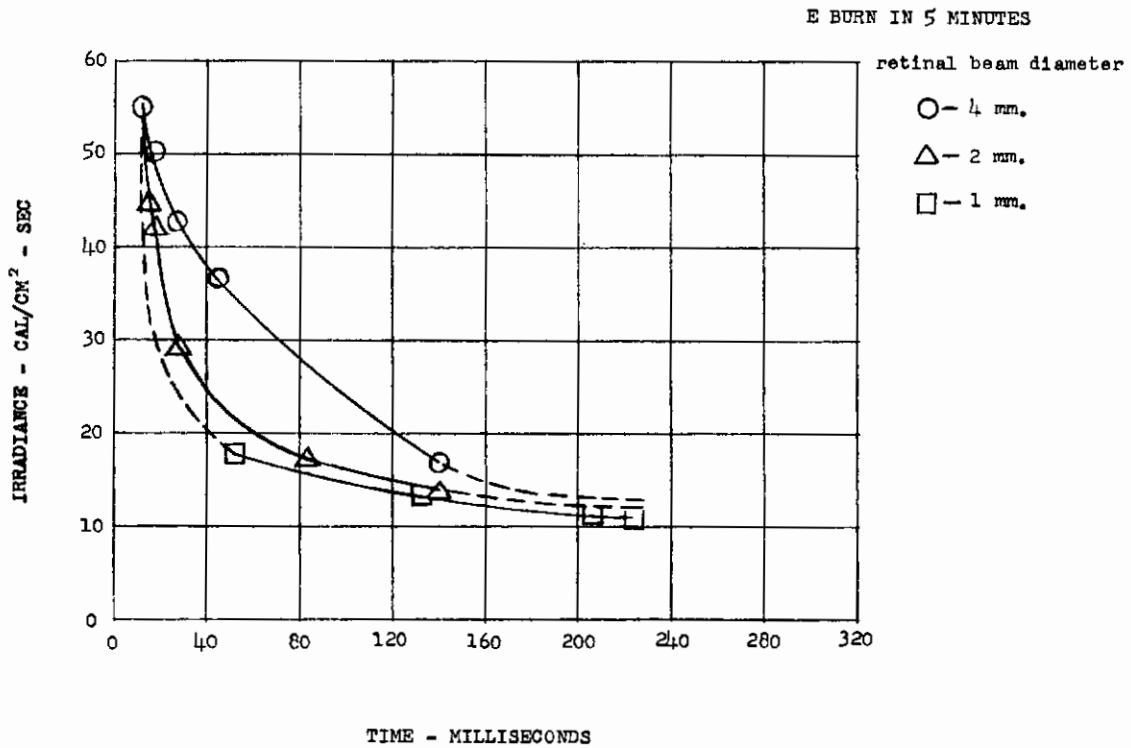


Figure 13. RETINAL IRRADIANCE vs. TIME FOR LESION (ULTRAVIOLET AND WATER FILTERS)

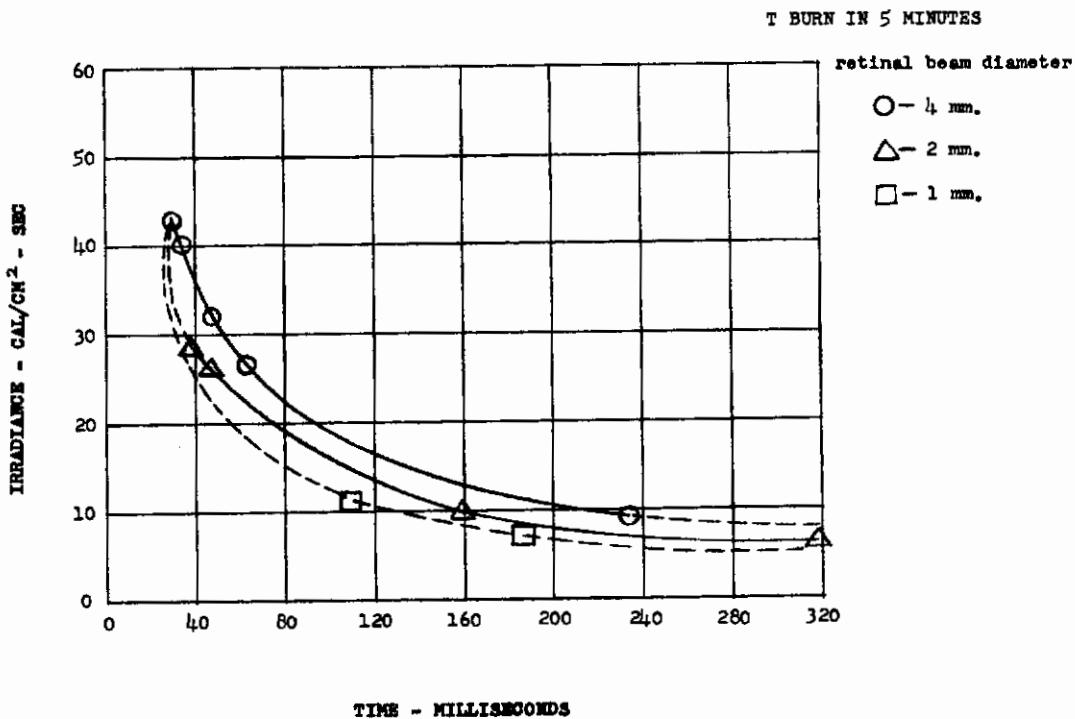
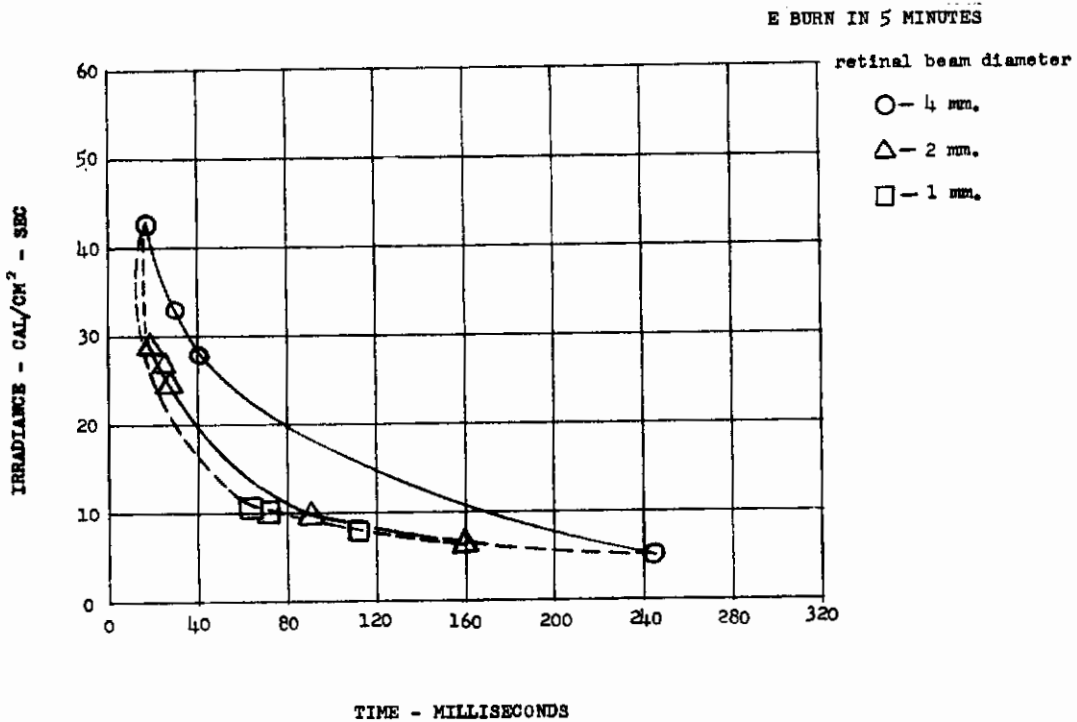


Figure 14. RETINAL IRRADIANCE vs. TIME FOR LESION (ULTRAVIOLET AND INFRARED FILTERS)

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