FINAL SUMMARY REPORT
PART 2
LIGHT SOURCE EVALUATION

June 1970

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1. INTRODUCTION

The objective of this investigation of pyrotechnic light sources was confined primarily to the evaluation of output illumination levels, the factors controlling them and comparisons with the existing criteria for optical incapacitation, since these considerations determine the suitability of such a system to a variety of possible weapon applications.

The effort was directed primarily at comparisons of existing threshold energies for incapacitation and damage, pyrotechnic output energies, and the fabrication of test devices with controlled parameters, followed by estimation of their output energies by means of appropriate instrumentation. The approach permitted a comparison with existing data on energy levels corresponding to optical incapacitation and damage. This comparison was used to obtain first order estimates of the effective ranges at which these pyrotechnic illumination devices would either incapacitate or permanently damage exposed personnel.

The four pyrotechnic light mixtures shown in Table I were evaluated during this investigation. In the following sections there are presented the methods and techniques employed, results obtained, and the conclusions regarding the feasibility of this approach.

TABLE I. COMPOSITION OF EXPERIMENTAL MIXTURES

Composition Designation	A	B	C	D
Ingredients	%	%	%	%
Al	40	70	25	50
$KClO_3$	30	20	30	40
$Ba(NO_3)_2$	30	10	10	--
$Ca(Si)_2$	--	--	--	10
Mg	--	--	35	--

2. DESCRIPTION OF EXPERIMENTAL PHOTOFLASH DEVICES

A brief description of the charges was included in the Final Summary Report - Part I. Two basic photoflash cartridges were employed. Design drawings of these cartridges are presented in Figures 1 and 2. The performance of each of the four selected pyrotechnic mixtures was evaluated in each cartridge design. The specifications of each of the mixtures were previously described (see Reference 1).

2.1 PHOTOFLASH CARTRIDGE, TYPE S

The outer diameter of the Type S photoflash cartridge is 2.7 in. and the length is 6.6 in. The outer shell is made of aluminum. A scale drawing of the cartridge is shown in Figure 1. A linear charge of DuPont PETN primacord, .22 in. diameter and 5.25 in. long, was surrounded by the photoflash mix. This central bursting charge was used to break the casing, and to ignite and disperse the pyrotechnic mixture.

2.2 PHOTOFLASH CARTRIDGE, TYPE SDE

This cartridge was identical to the type S with the exception that DuPont Deta sheet explosive was wrapped around the exterior cylindrical wall of the Type S cartridge. These sheets were cut, as shown in Figure 1, to permit the complete coverage of the outer wall. The purpose of this design was to compact the photoflash mixture first before it was disseminated, in an attempt to improve the light output (i.e., as discussed in the last progress report, the rate of burning and light output should increase with the degree of charge compaction). The ignition train was designed so that the Deta sheet would be detonated before the central bursting charge.

2.3 PHOTOFLASH SHELL, TYPE SS

The Type SS shotgun shell has an O.D. of 0.853 and a length of 3.20 in. It is also made of aluminum. Except for dimensions, this photoflash shell design is similar to the 2.7 in. photoflash cartridge (see Figure 2).

2.4 PHOTOFLASH SHELL, TYPE SSDE

This shell is identical to the Type SS, with the exception that Dupont Deta sheet is wrapped around the cylindrical body in a similar manner as the SDE.

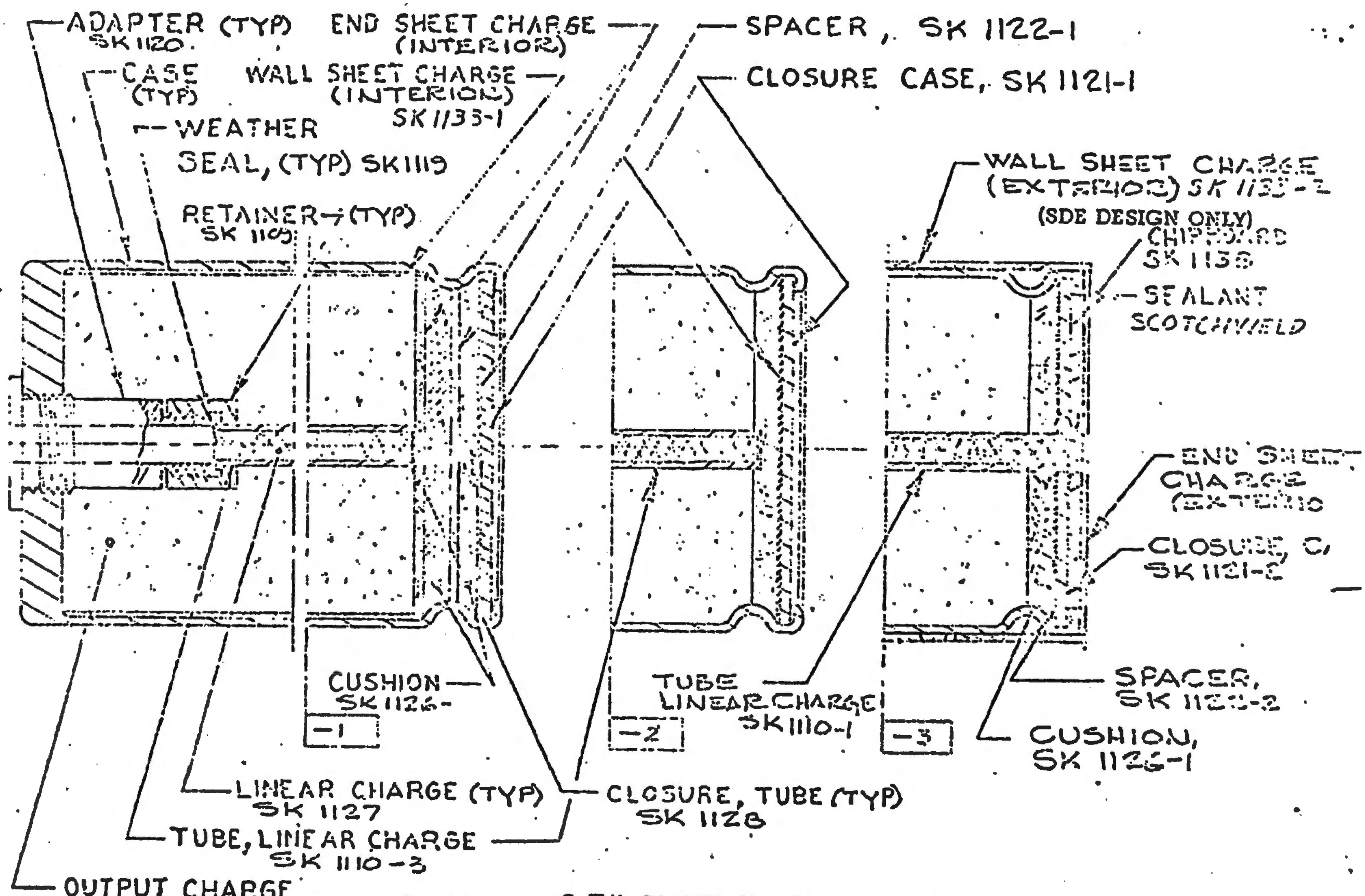

FIGURE 1. 2.7" PHOTOFLASH CARTRIDGE
SCALE 1/1

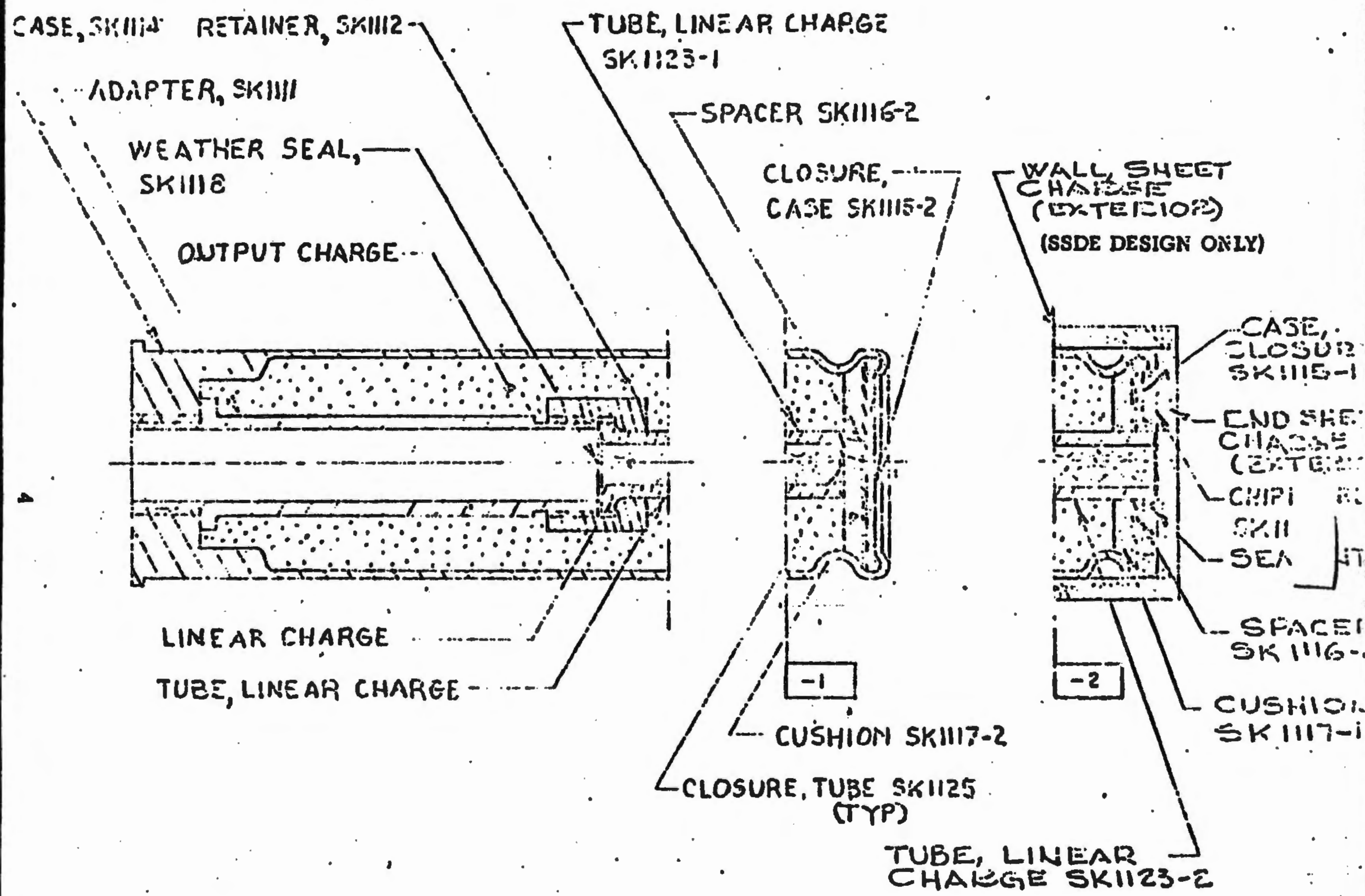

FIGURE 2. 0.83" PHOTOFLASH CARTRIDGE
SCALE 2/1

3. DESCRIPTION OF EXPERIMENTS

The experimental techniques employed and the specific experiments performed are outlined in this section.

3.1 EXPERIMENTAL ARRANGEMENT

The intensity of the light output as a function of time was measured and recorded using a silicon photodiode (United Detector Technology Inc., PIN-10) and a Tektronix 535 oscilloscope with a Polaroid film attachment. The PIN-10 photodiode has a half-value response between 3600 and 10500 Å. The photodiode, PIN-10, was protected from fragments generated from the explosive dissemination by a metal shield. The light from the flash was indirectly focused onto the PIN-10 sensor using a mirror.

A Corning 1-56 filter was placed in front of the PIN-10. This filter has transmission characteristics similar to the eye response. It has a near gaussian transmission curve between 3600 and 7000 Å with a peak transmission at 5200 A. The ultraviolet is cut-off at 3600 A and less than 10% of the I-R radiation (i.e., between 1 and 4.5 microns) can be transmitted through this filter. Depending on the expected output of each test device, neutral density filters were also used so that the PIN-10 would operate within its linear response regime (i.e., so that light intensity versus output voltage would remain linear).

The output signal from the sensor was fed into a Tektronix 535 oscilloscope with a 50 ohm termination. The signals were permanently recorded using a Polaroid camera attachment. The oscilloscope and event were triggered using a 5 KV firing panel.

The events were also monitored photographically. A speed graphic single exposure camera and a Beckman & Whitley Dynafax motion picture camera were used with Polaroid filters. The Dynafax camera was operated at a framing rate of 3000 frames per second. Both cameras were protected from the blast. The Dynafax camera was located behind a barricade and received the light from the photoflash via a front surface mirror. The speed graphic camera was located behind thick glass.

3.2 DETECTOR CALIBRATION

The PIN-10 photodetector was calibrated using a National Bureau of Standards certified light source. The response of the detector was measured as a function of distance away from the standard source using the following equation

$$I = K \cdot F \cdot V \cdot D^2 \qquad (1)$$

where

I is the intensity of the light source in candle-power,

K is the calibration factor, 2640 foot-candles per 38.07 millivolts response,

F is the factor which compensates for the transmission of the neutral density filters,

V is the output signal, volts, generated by the photo-detector, and

D is the optical distance between the PIN-10 photo-detector and the light source.

The spectral response characteristics of the photodetector are shown in Figure 3. The relative spectral sensitivity of the PIN-10 with the Corning 1-56 filter was calculated. These results are presented in Figure 4.

The optical distance between the light sources and the photo-detector was 23.5 feet in each experiment. The intensity of the source expressed in candle-power was calculated using Eq. (1). The values of candle-power estimated can be interpreted directly in terms of the luminous flux traveling through a normal plane which intersects the light path 1 foot away from the source (i.e., the density of luminous flux incident on a normal surface one foot away from a 1 candle-power source is 1 lumen/ft^2).

3.3 EXPERIMENTAL ERRORS

An experiment was performed to determine the amount of light received by the photo-detectors via wall reflection. A General Electric No. 22 photoflash bulb was placed 23.5 ft. away from the photo-detector in a similar manner as were the photoflash pyrotechnic test devices. Black paper was placed directly in front of the flash bulb to prevent direct light transmission to the photo-detector. When compared with a control test in which the light barrier was not used, it was calculated that less than 5% of the light received by the photo-detector was due to light reflections from the walls of the test chamber. As a precaution, in subsequent tests, all light colored objects were removed from the test chamber before each experiment. The walls of the chamber were washed down after each test, also, to remove any debris which might increase the light reflection.

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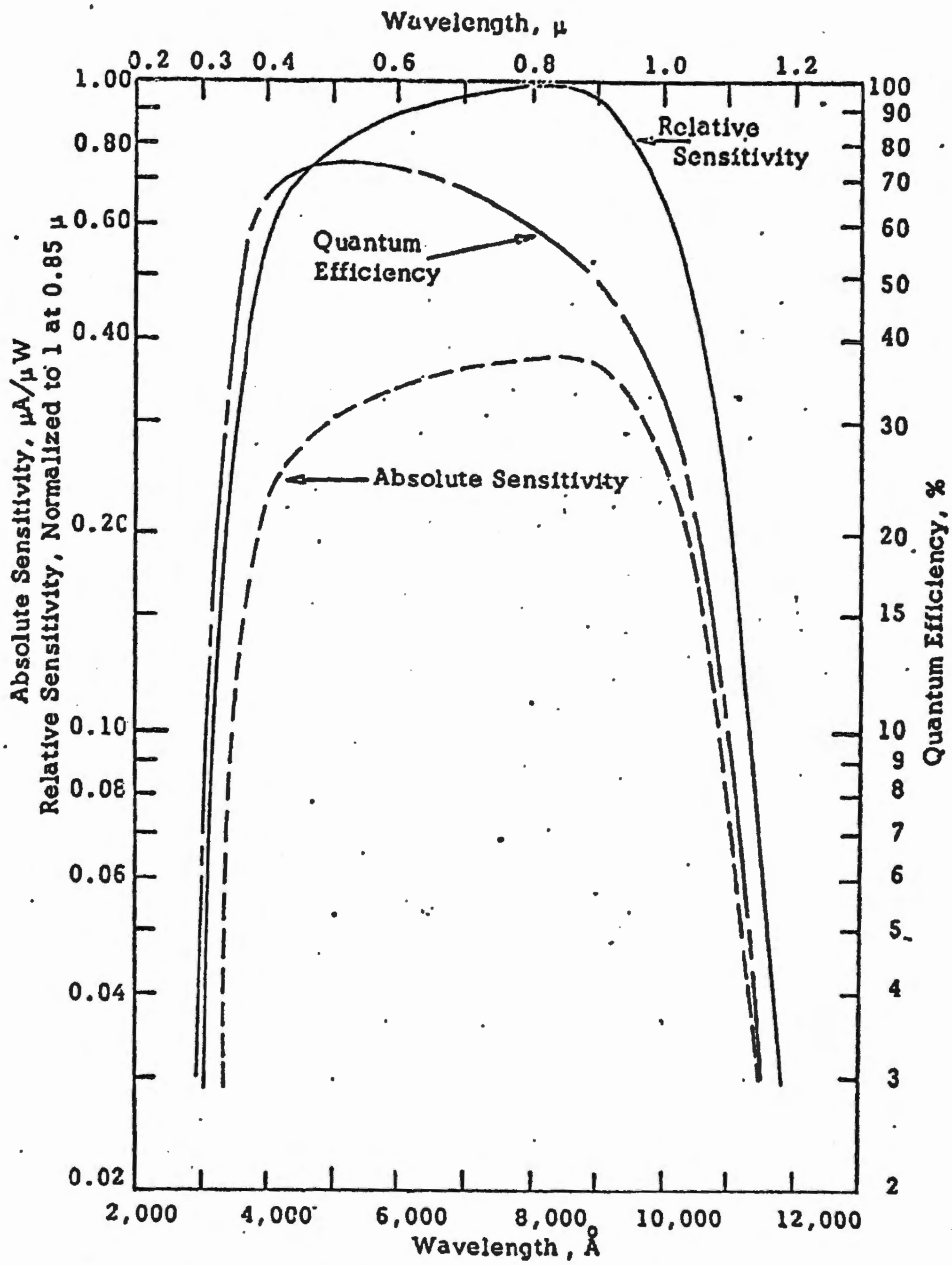

Figure 3. Spectral Characteristics of the United Technology PIN-10 Photodiode

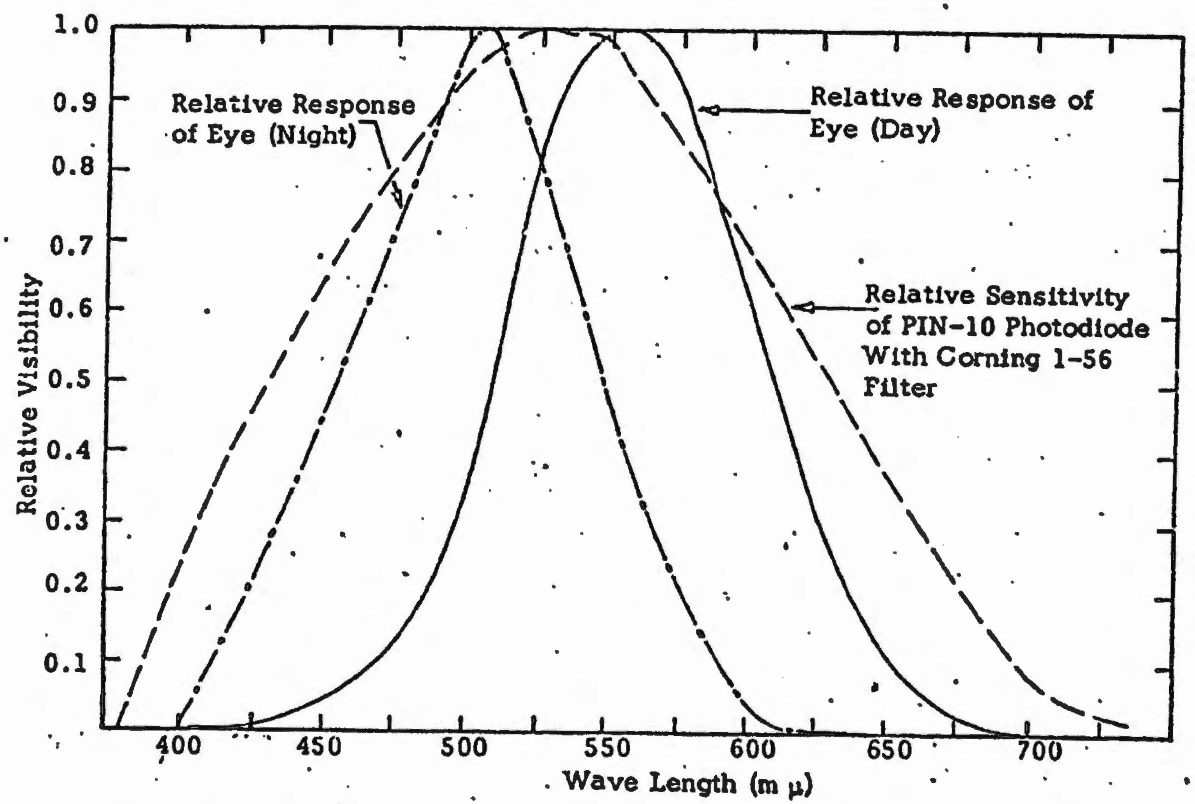

Figure 4. Comparison of Eye and Photodetector Sensitivity Curve.

4. EXPERIMENTAL RESULTS

The measured outputs versus time for each of the experimental photoflash devices are shown in Figures 5 through 8. These figures were drawn from the oscilloscope traces obtained in each experiment. The results of each photoflash cartridge design were combined so that a ready comparison could be made regarding the relative performance of the light output from each of the four pyrotechnic mixtures. The peak light intensities, the half width of intensity-time and the total integrated area under each curve (i.e., total light output in candle-power-seconds) are reported in Table II. The maximum cloud size generated by each device is also included in this table. The latter data was obtained from the film records taken.

4.1 COMPARISON BETWEEN REPORTED AND MEASURED OUTPUT OF TYPE III MIXTURE

Mixture A has a composition identical to the standard Type III (i.e., mixture A) photoflash mix. This Type III photoflash mixture has previously been used in a variety of standard photoflash cartridges. Light output data was obtained for this mixture,[2] from other sources, and is summarized in Figure 9. The peak intensities and integrated candle-power-seconds total output are plotted as a function of charge size in pounds. Approximations of best-fit curves were drawn through each set of data as shown. The arrow on the abscissa represents the charge weight of the pyrotechnic mixtures in the Type S cartridge, 1.4 lbs.

The predicted peak intensity and total output for this charge are, respectively, 2.3×10^8 c. p. and 4.4×10^6 c.p.s. The experimental values obtained during the tests on this program were $1.?6 \times 10^8$ c.p. and 2.0×10^6 c.p.s. (see Table II). These data are considered to be in reasonable agreement and provide an additional check on the accuracy of the measuring techniques and the charge preparations.

4.2 COMPARISON BETWEEN CHARGES

Based on the peak intensity data, the overall performance of the Type A mixtures in the various shells was the best. In order of decreasing performance it was found that

$$A > C > B > D$$

The peak intensity of the output however is not the only criterion that should be used in evaluating the performance of a mixture for this application. The duration of the light pulse is of equal importance. From

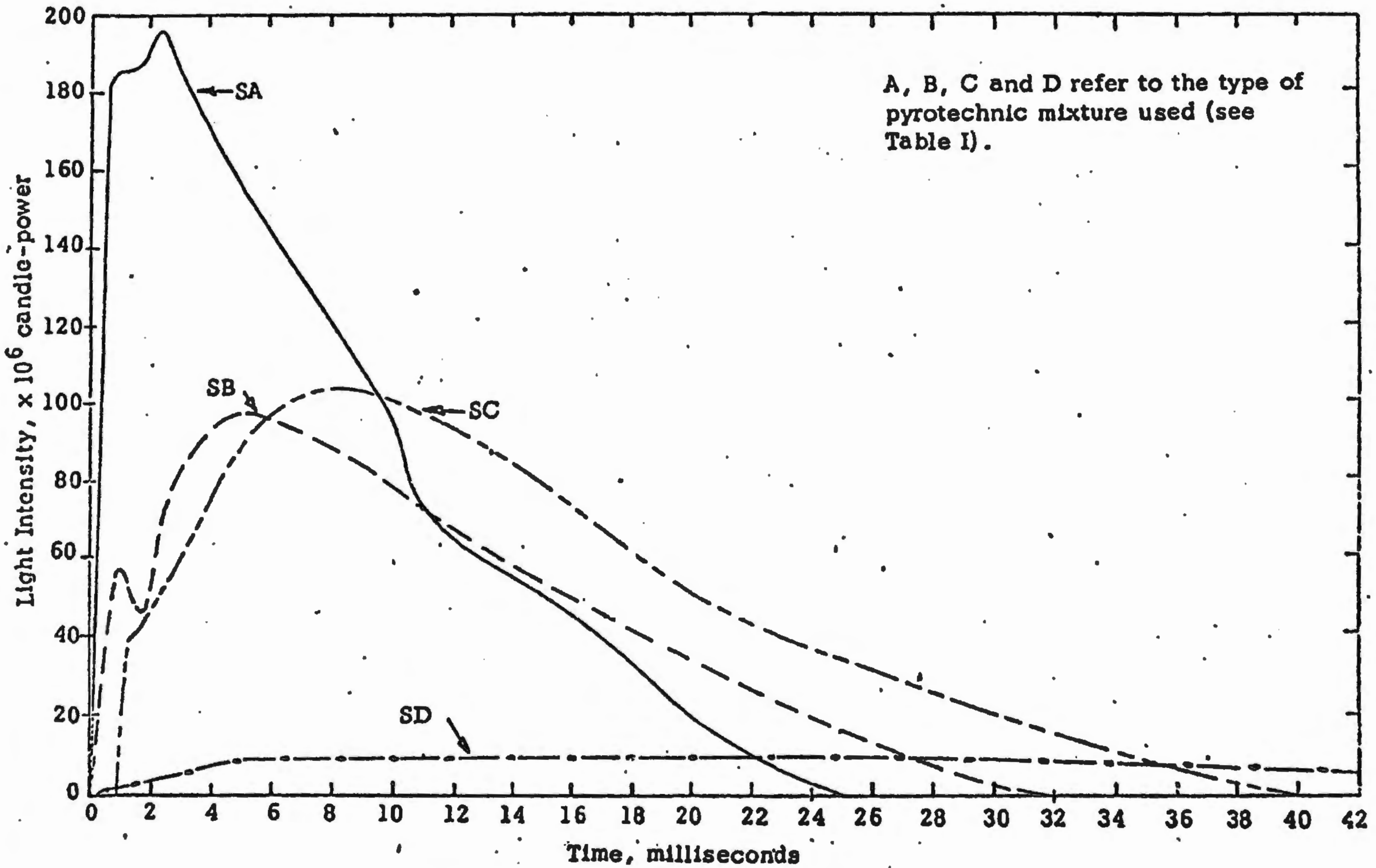

Figure 5. Light Output From Series S Photoflash Units

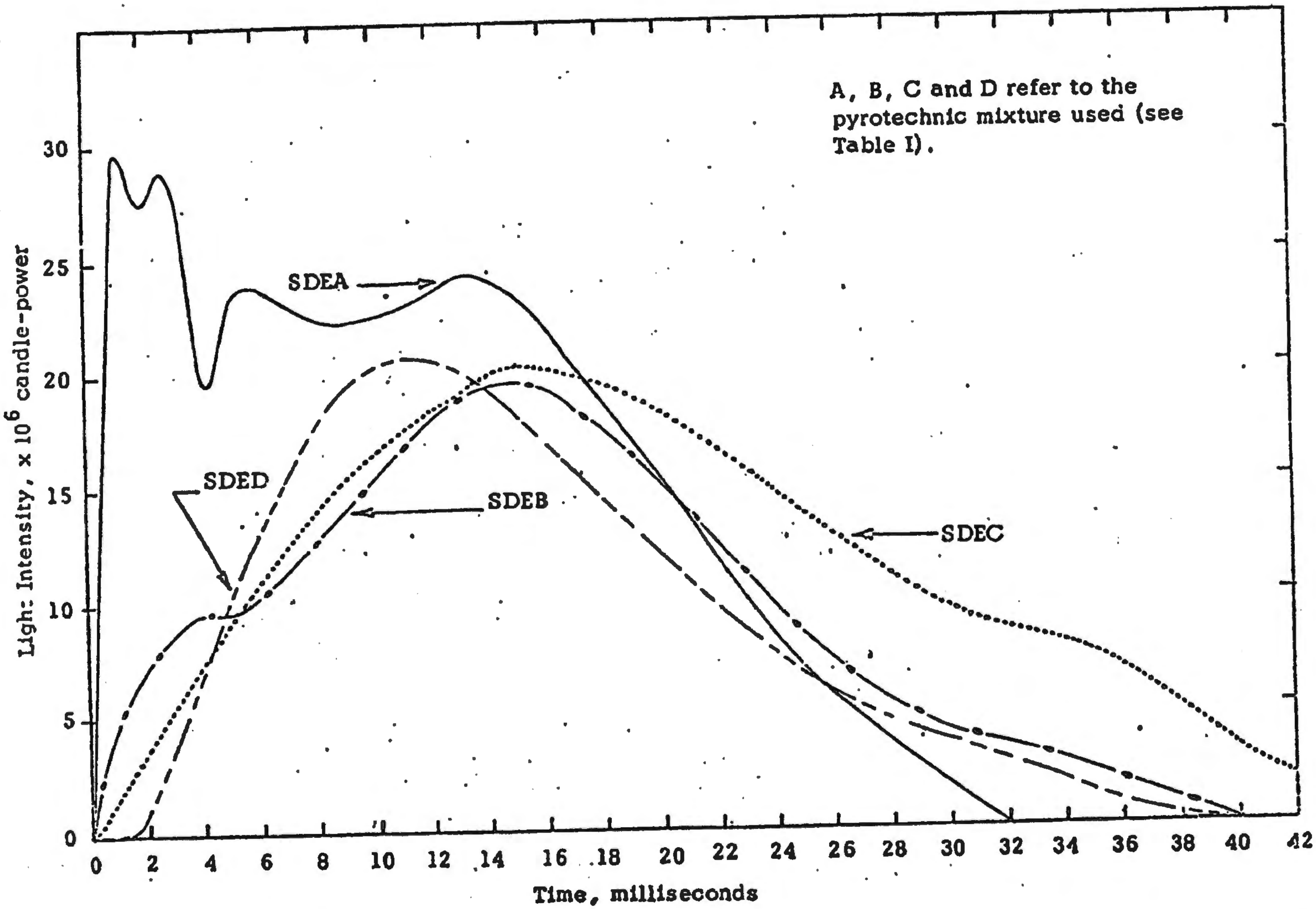

Figure 5 Light Output From Series SDE Photoflash Units

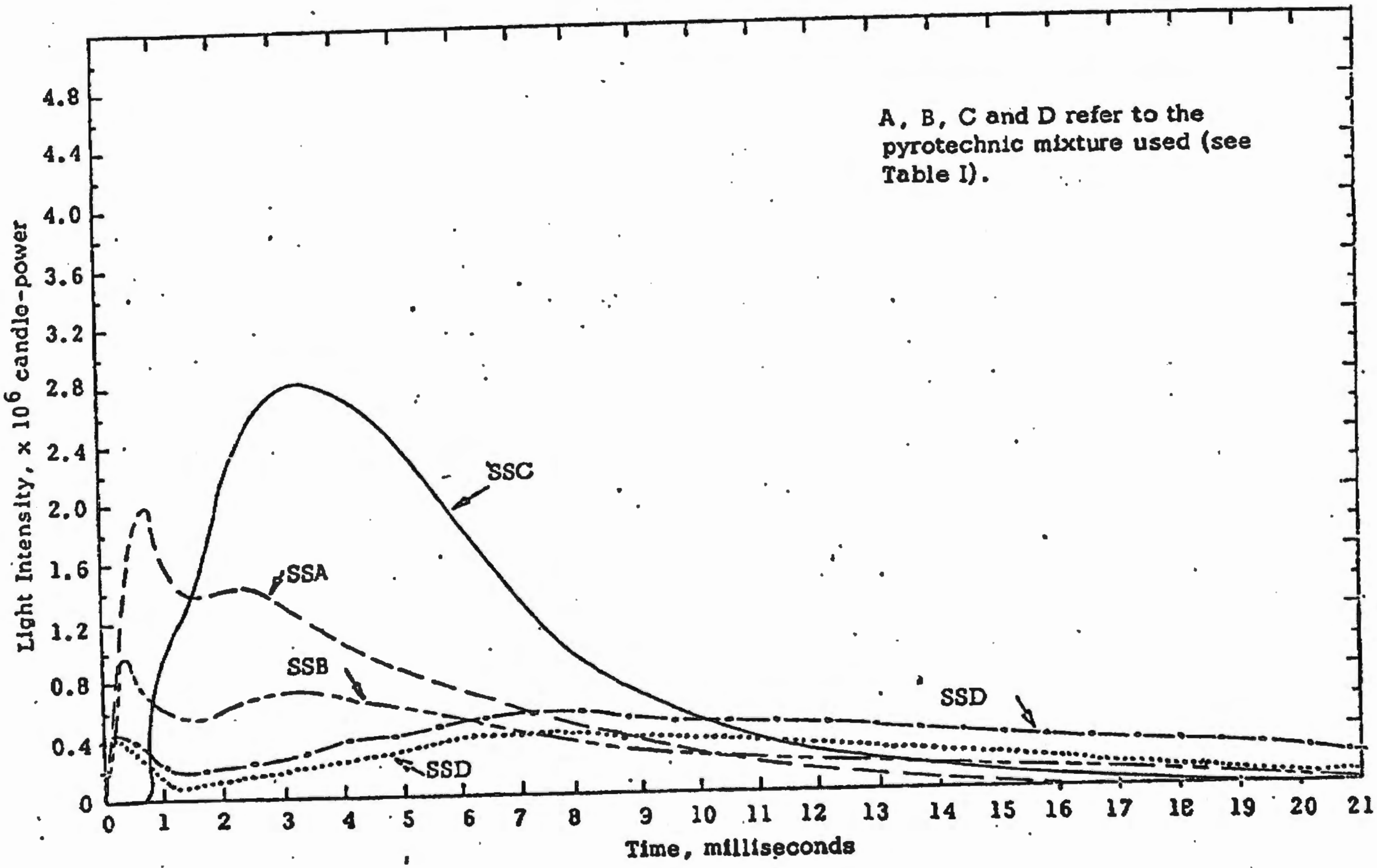

Figure 7. Light Output From Series SS Photoflash Units

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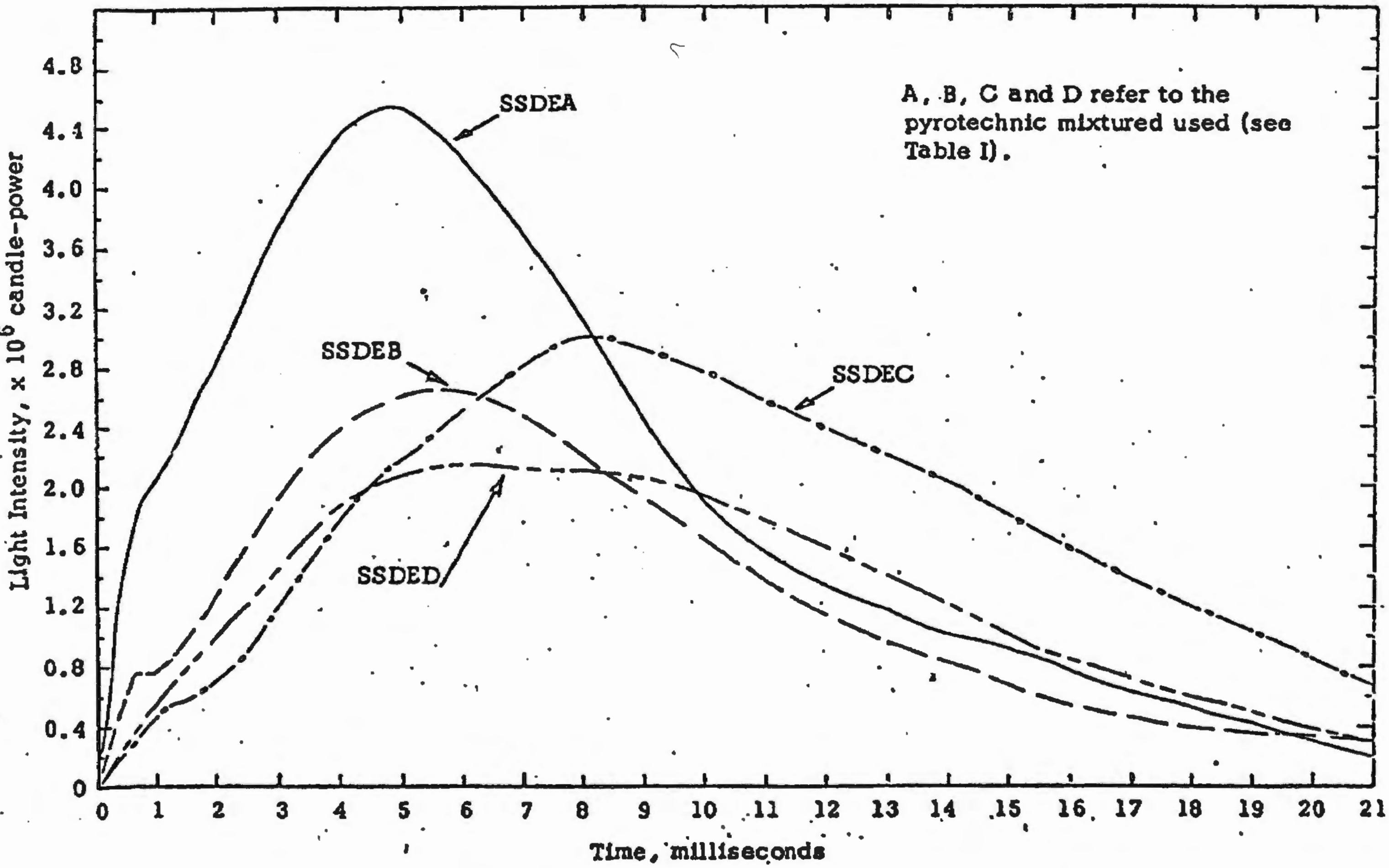

Figure 8. Light Output From Series SSDE Photoflash Units

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TABLE II. SUMMARY OF TEST RESULTS

Sample* Type	Peak Candle-Power (10^6 cp)	Half-Width Duration (msec)	Total Output (10^3 cps)	Peak Cloud Size (ft.)
SA	195.7	9.8	2010	7.4
SB	97.8	15.5	1579	7.5
SC	103.6	17.8	2021	7.1
SD	9.5	40.4	371	3.5
SDEA	29.8	20.7	526	7.0
SDEB	19.5	20.1	375	7.0
SDEC	20.3	18.3	493	7.3
SDED	20.5	16.4	354	4.3
SSA	1.99	4.0	10.3	---
SSB	0.99	6.0	7.8	1.8
SSC	2.81	5.4	17.1	2.4
SSD	0.57	20.0	8.8	1.5
SSDEA	5.59	8.3	52.9	2.8
SSDEB	2.64	9.1	29.0	3.5
SSDEC	3.02	12.7	40.2	3.2
SSDED	2.14	13.0	28.6	2.7

*S and SDE refer to the type of photoflash cartridge used. A, B, C and D refer to the pyrotechnic mixture used (see Table I).

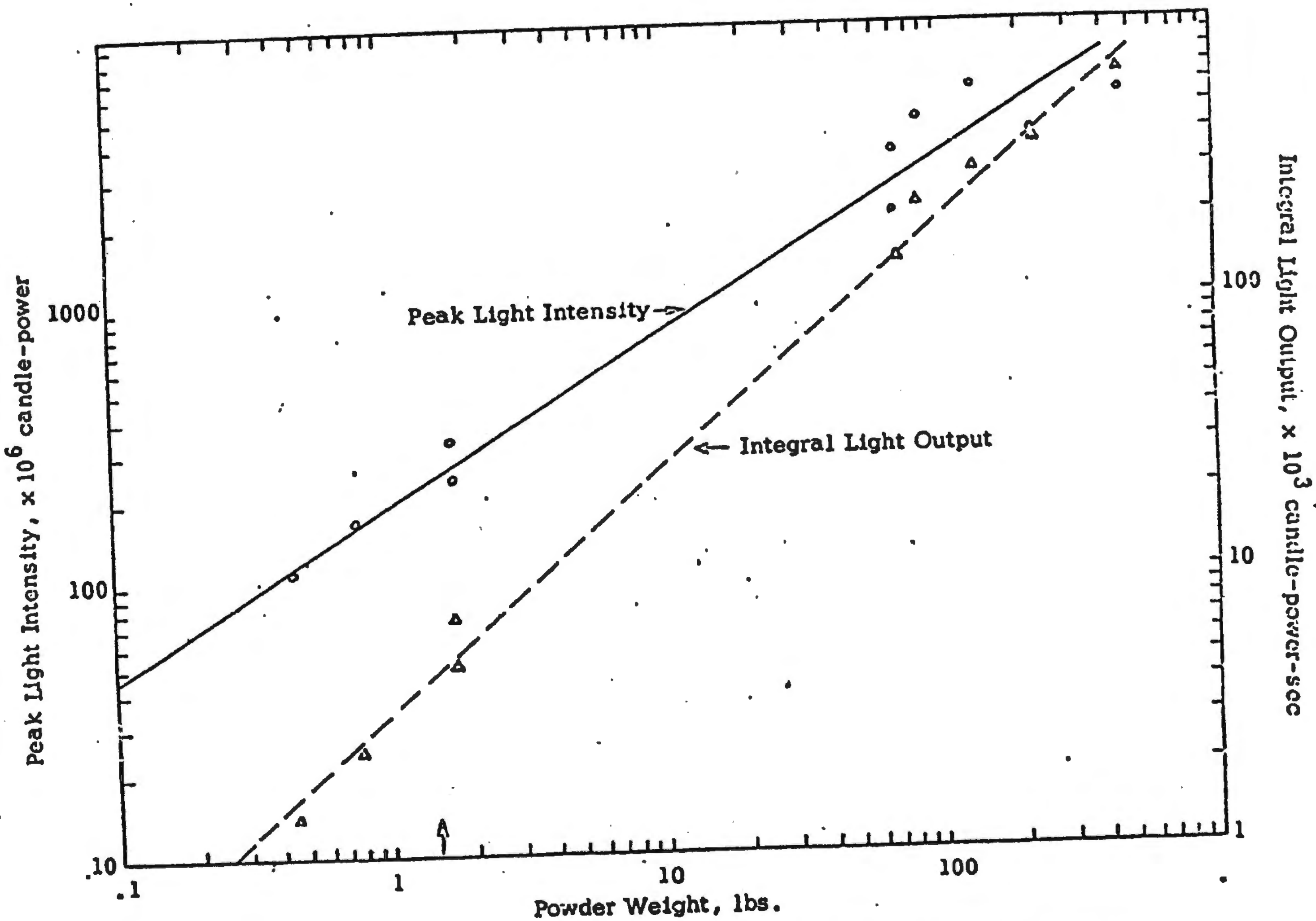


Figure 9. Peak Intensities Produced by Type III Photoflash Mixtures as a Function of Charge Weight[2].

the plots of intensity versus time it was shown that the light pulses from the "C" mixture were in most cases of longer duration. Based on the total integrated light output the "C" and "A" mixtures were equally effective.

i.e., $C \approx A > B > D$

It could be concluded that of the mixtures studied, the "A" and "C" mixtures provided the most intense and total light output. The "B" and "D" mixtures generated, significantly, less light in the visible spectrum.

5. DISCUSSION OF POTENTIAL FLASH BLINDNESS EFFECTS

Several important questions had to be answered before these data could be interpreted in terms of potential flash blindness effects:

1. What is the level of flash luminosity that will produce permanent eye injury?

2. What is the level of flash luminosity that will produce transient flash blindness?

3. If the measure of the transient flash blindness is expressed in terms of functional requirements calling for viewing and resolution of specific objects, how does the luminosity of the objects to be viewed by the observer affect recovery time from non-injurious flash blindness?

5.1 PERMANENT EYE DAMAGE

It has been reported that the threshold energy level for permanent eye damage is between 0.2 and 1.6 cals/cm^2.[3-6]

Zaret[3] expresses the requirements for permanent eye injury in terms of the fraction of the photopigments which are bleached by the light flash. This bleaching process involves the photochemical transformation of 11-monocis retinene to trans-retinene. The 11-monocis retinene complexes with the opsin enzymes to form the active photosensitive pigments. Upon light excitation the 11-monocis olefin is transformed to the more chemically stable trans isomer via an electronically or vibrationally excited state.[7-9] The trans-retinene, a yellow pigment, which is formed is not compatible with the opsin enzyme and, thus, does not form a photosensitive pigment. Recovery of the bleached pigment is dependent upon a chemical transformation back to the 11-monocis isomer catalysed by retinene isomerizase.

The concentration of visual pigment only begins to be significantly affected by light intensities of the order of 10^5 troland-seconds* and decreases rapidly with further increase in intensity. The concentration of bleached pigment as a function of light intensity can be expressed as follows[3]

*The troland is the unit of retinal illumination. It is equal to the product of the luminance of the object viewed in candles/(meter)^2 and the area of the pupil in mm^2.

$$C_b/C_o = 1 - \exp(-\alpha\gamma I t) \qquad (2)$$

where

- C_b is the concentration bleached at exposure It,
- C_o is the original pigment concentration,
- It is the retinal total irradiance in troland-seconds, and
- $\alpha\gamma$ is the photosensitivity expressed in $(\text{td-sec})^{-1}$

In the case of the human pigments the value of $\alpha\gamma$ is approximately 10^{-7} $(\text{td-sec})^{-1}$. Zaret estimates that as the fraction of pigment bleaching approaches unity permanent retinal damage occurs. Within the time frame of the flashes which were produced in the experiments reported here, the threshold damage irradiances are approximately 0.4 cals/cm^2 (4×10^9 td-sec) and 1.6 cals/cm^2 (1.6×10^{10} td-sec)[10-12] for exposures of 1 and 100 msec, respectively. According to Brown,[4] these irradiance levels must be delivered at flux levels of at least 0.7 cals/cm^2-sec or the rate of heat dissipation in the eye tissue will be sufficient to prevent an elevation of temperature to the degree where thermal burn will occur.

At 5550 angstroms the wavelength of maximum sensitivity to the eye, one watt of radiant energy corresponds to 672.1 lumens. Assuming that all of the light emitted from the pyrotechnic flash devices tested during the program is at this wavelength, the light intensities required to affect thermal damage to the retina would be 1.75 and 6.99×10^4 lumen-sec/ft^2 for exposures of 1 and 100 msec, respectively. The above estimates take into account the fact that the light received at the cornea is intensified when it arrives at the retina (i.e., the image size is reduced): Ham[6] noted that an irradiance received at the cornea of a rabbit eye is intensified by a factor of 60 times when it reaches the retina.

With respect to the experiments performed in this investigation, these values are considered to be low. Assuming that the light emitted from the flash units have the same spectral characteristics as the sensor, than the luminous efficiency of the light output is only 28 percent that of 5550 angstrom light. The threshold light exposures would then be 6.26×10^4 and 2.48×10^5 lumen-sec/ft^2 for exposures between 1 and 100 msec, respectively.

Based on the luminous intensity data, shown in Table II, it can be seen that the small photoflash charges (i.e., the SS and SSDE series) are not capable of delivering damaging light flashes. The larger charges (i.e., the S and SDE series) can produce permanent eye damage. Further discussions regarding the possibility of permanent eye injury are presented elsewhere in this report (see Section 5.3.2).

5.2 RECOVERY TIME TO LIGHT FLASHES

Before one can estimate the recovery period after light exposure it is important that the important recovery measurement conditions be defined. Clearly, the intensity of the light which the observer is exposed to will determine recovery time. An additional consideration is the illuminance of the object which the observer needs to detect after exposure for functional reasons.

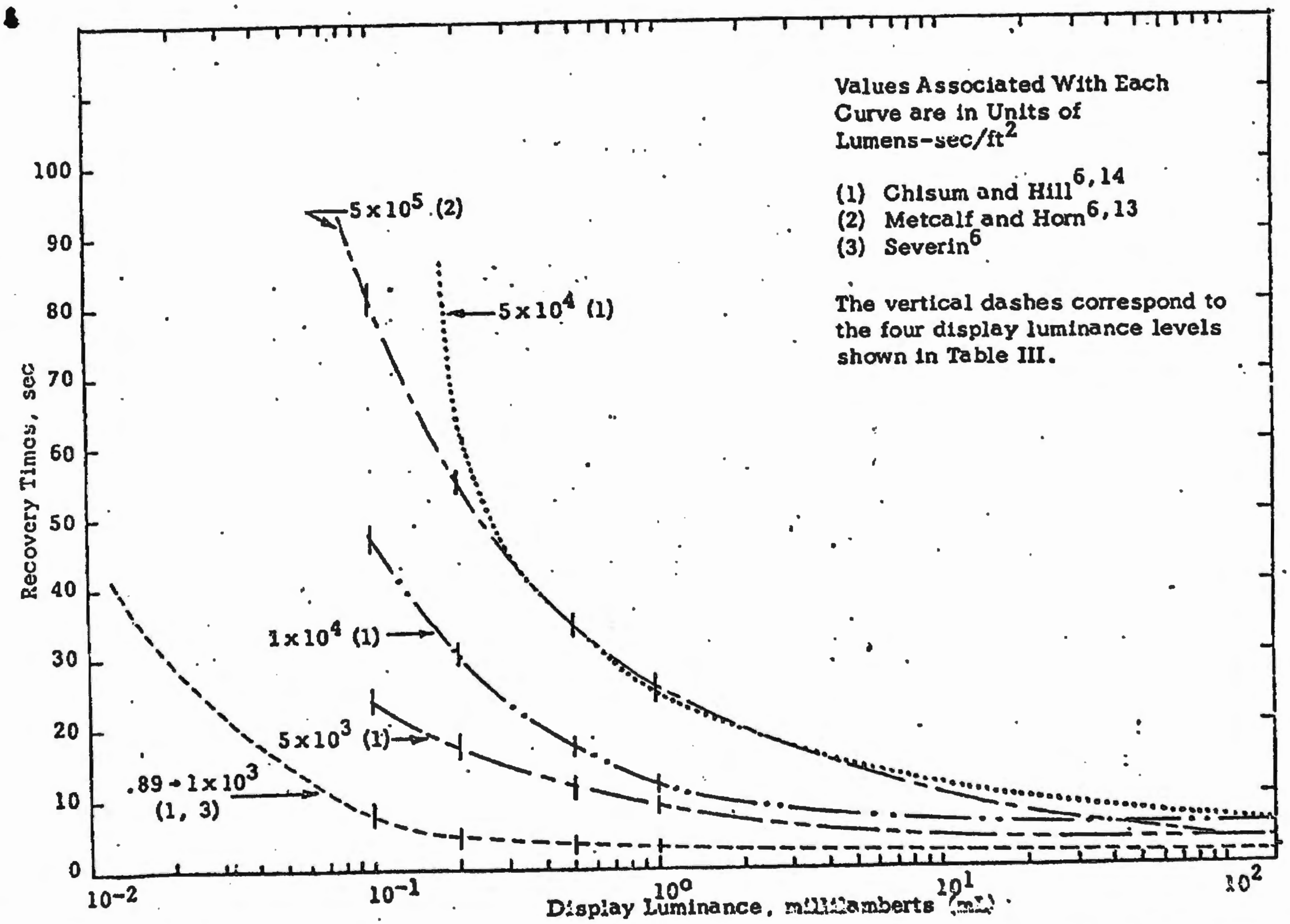
A review of the literature was made in order to define the dependence of recovery on the two factors noted above. The results of this search and the subsequent analyses are shown in Figure 10.

5.2.1 Review of Flash Blindness Experiments

Metcalf and Horn[6,13] conducted flash blindness experiments using the high intensity flashes from a carbon arc. The experiment was designed to determine the effect of light exposures likely to be encountered during nuclear operations. Each of the four subjects had their pupils dilated prior to exposure. A 6mm artificial pupil was used in order to maintain constant pupil size. The subjects were exposed for 100 msec to illumination ranging from 70 to 12,000 lumens per square foot. Following this exposure, the subjects were required to detect the flashing of a 17 minute visual angle circular patch. The luminance of the test patch was varied between .07 and 71 foot-Lamberts. A summary of a complete set of this data at a flash luminosity of 5×10^5 lumen-sec/ft^2 is shown in Figure 10.

The time required to recover visual sensitivity following exposure to high intensity, short duration adapting flashes also has been investigated by Chisum and Hill.[8,14] Adapting flashes of 33 to 165 μsec and 9.8 msec in duration with luminances from 1×10^4 to 5×10^8 lumens/ft^2 were used. Visual sensitivity was determined by the resolution of gratings requiring acuities* of 0.13 and 0.33 at display luminances between approximately .004 to 200 millilamberts. The 0.33 acuity level requires the function of cones while the 0.13 acuity level can be resolved by rod vision. The light pulses used by Chisum and Hill which best represent the flashes

*Acuity is defined as the relative ability of the visual organ to resolve detail. It is usually expressed as the reciprocal of the minimum angular separation in minutes of two lines just resolvable as separate.


Values Associated With Each Curve are in Units of Lumens-sec/ft²
(1) Chisum and Hill 6,14
(2) Metcalf and Horn 6,13
(3) Severin 6
The vertical dashes correspond to the four display luminance levels shown in Table III.
5 x 10⁵ (2)
5 x 10⁴ (1)
1 x 10⁴ (1)
5 x 10³ (1)
.89 → 1 x 10³ (1, 3)
Recovery Times, sec
0
10
20
30
40
50
60
70
80
90
100
10⁻²
10⁻¹
10⁰
10¹
10²
Display Luminance, millilamberts (mL)

from the pyrotechnic devices tested during this program were selected for the comparisons made in Figure 10. Also the data for the acuity level 0.33 was used, since the effects to cone vision are the most critical to this study. It should be noted that recovery from rod saturation is a much faster process than recovery from cone saturation. The latter also requires more energy for saturation.[3]

It was observed that the recovery times for the light illuminations of 5×10^5 lumens-sec/ft^2, reported by Metcalf and Horn, and 5×10^4 lumens-sec/ft^2, reported by Chisum and Hill were almost identical. This is not too surprising after one reviews the discussions by Brown[4] and Zaret.[3] Namely, both postulate that the relation between the energy of an adapting flash and recovery time for a specific visual task is similar in nature to that shown in Figure 11.

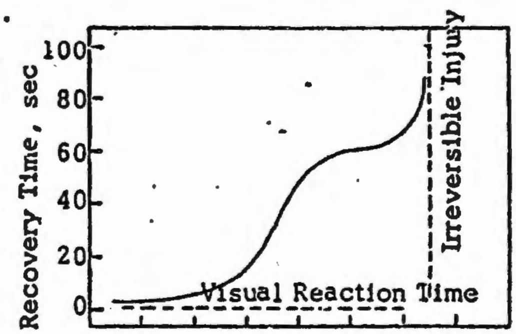


Figure 11. A hypothetical curve illustrating the relation between energy of a blinding flash and time required for detection of information in a visual display. The minimum detection time at low flash energy corresponds to visual reaction time. Detection time approaches infinity as flash energy approaches a value which will cause irreversible injury.

For very low adapting flash energies* there is very little, if any, effect on the visual capability, and recovery time is minimal. As energy is increased, there is an increase in recovery time at an increasing rate. The form of this function depends on the nature of the visual task. As the energy of the adapting flash reaches a level which corresponds to a maximum possible bleaching of the photosensitive pigments of the retina, the rate of increase of recovery time may be expected to decrease. It is postulated as shown in Figure 11 that recovery time may actually assume a constant value over some range of adapting flash energies beyond that at which maximum bleaching occurs.

*Adapting flash energy usually refers to the total energy to which the subject is exposed and from which the subject must recover normal vision.

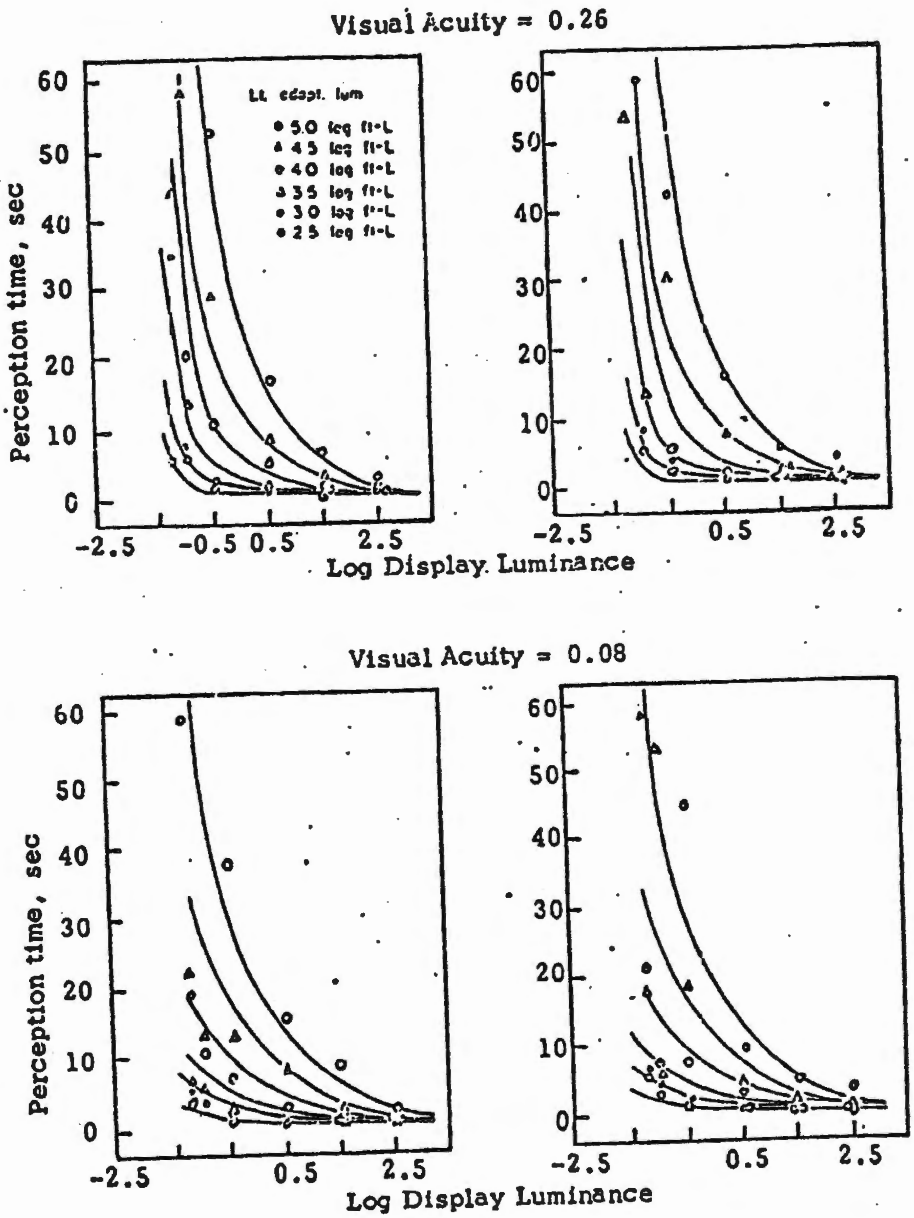


Figure 12. Relations of Perception Time to Log Display Luminance (ft-L) for Each of 6 Adapting Flash Luminances[4]

of the light pulse. Therefore there is an uncertainty in the total exposure duration of each subject to the light. Therefore these data were not used to correlate results obtained in the present study.

5.3 INTERPRETATION OF RESULTS

The measured light intensities and durations were interpreted in terms of possible irreversible and reversible eye effects.

5.3.1 Illumination of Photoflash

The experimentally measured illuminance of each pyrotechnic test device as reported in Table II was estimated as a function of distance from the flash origin using the inverse square law. These estimates are shown in Figures 13 and 14. The expected illuminance which observers would received from exposure to a G.E. No. 50 flash bulb are also shown in these figures. The value for the total output of this flash bulb, 1×10^5 lumen-sec/ft^2, was obtained from General Electric specifications.

5.3.2 Estimated Eye Effects

Some of the iso-illuminance curves shown in Figure 11 were extrapolated to a display illuminance level of 0.1 millilamberts (or 0.093 lumens/ft^2). The recovery time for each of the reported adapting flash energies shown in Figure 11 were estimated for each of four display luminances; 0.1, 0.2, 0.5 and 1.0 millilamberts. These estimates are tabulated in Table III.

TABLE III. ESTIMATED RECOVERY TIMES AS A FUNCTION OF ADAPTING LIGHT ENERGY AND TARGET DISPLAY LUMINANCE

Adapting Flash Energy (lumen-sec/ft^2)	Recovery Time (sec)			
	Target Luminance (millilamberts)			
	0.1	0.2	0.5	1.0
.5 – 5×10^5	82	55	35	26
1×10^4	47	31	18	12
5×10^3	24	17	12	9
.9 – 1×10^3	8	5	4	3

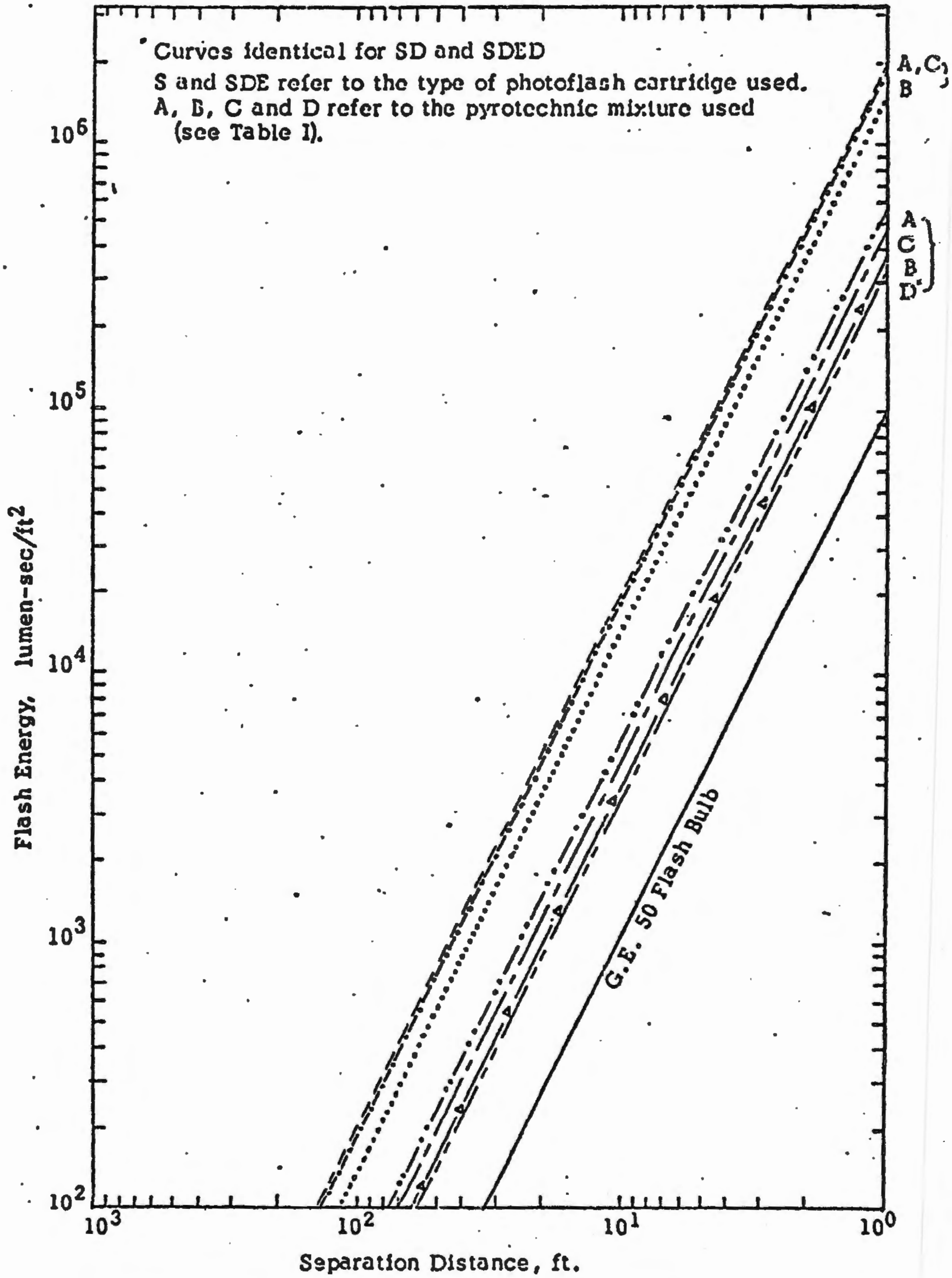


Figure 13. Light Illumination From Type S and SDE Photoflash

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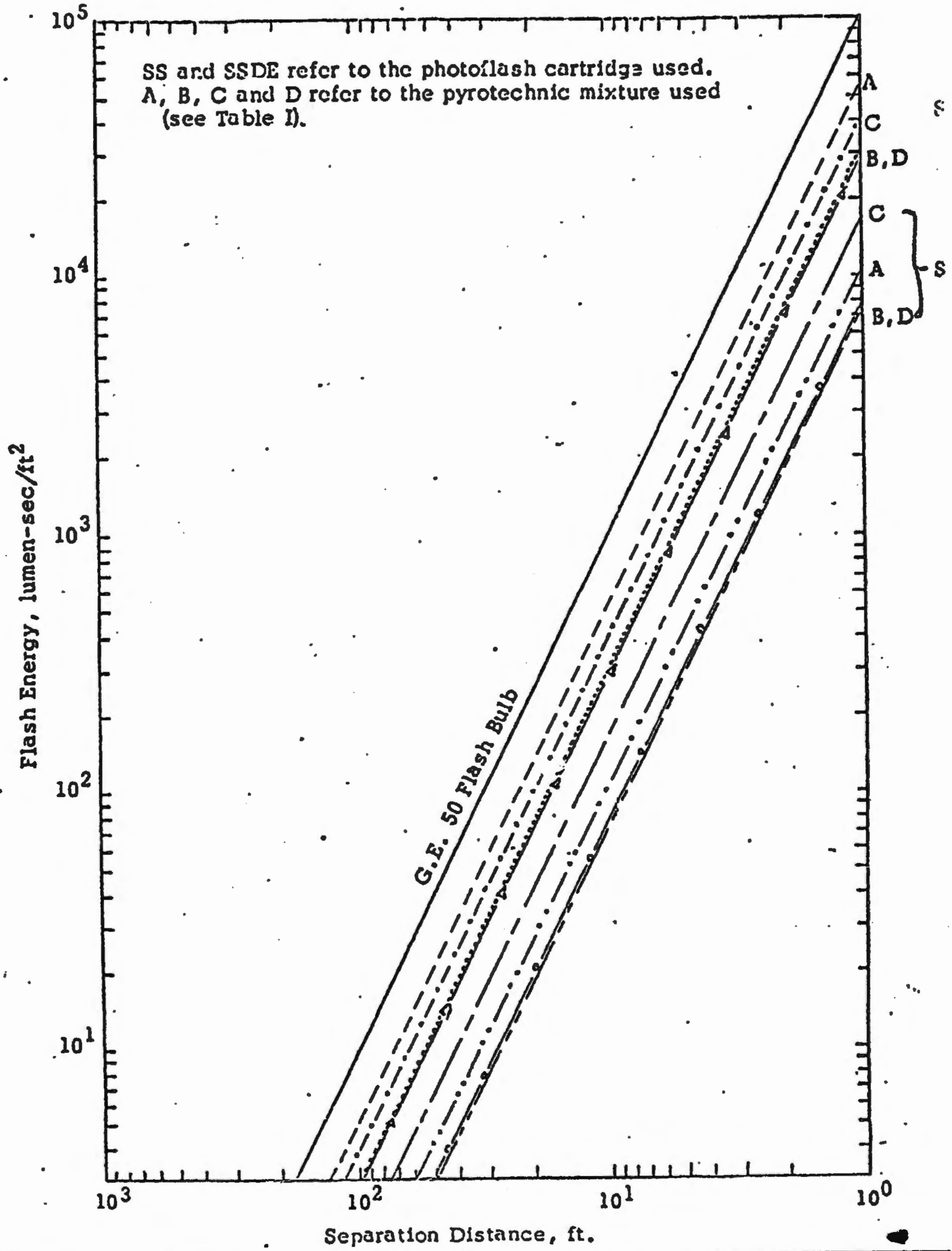


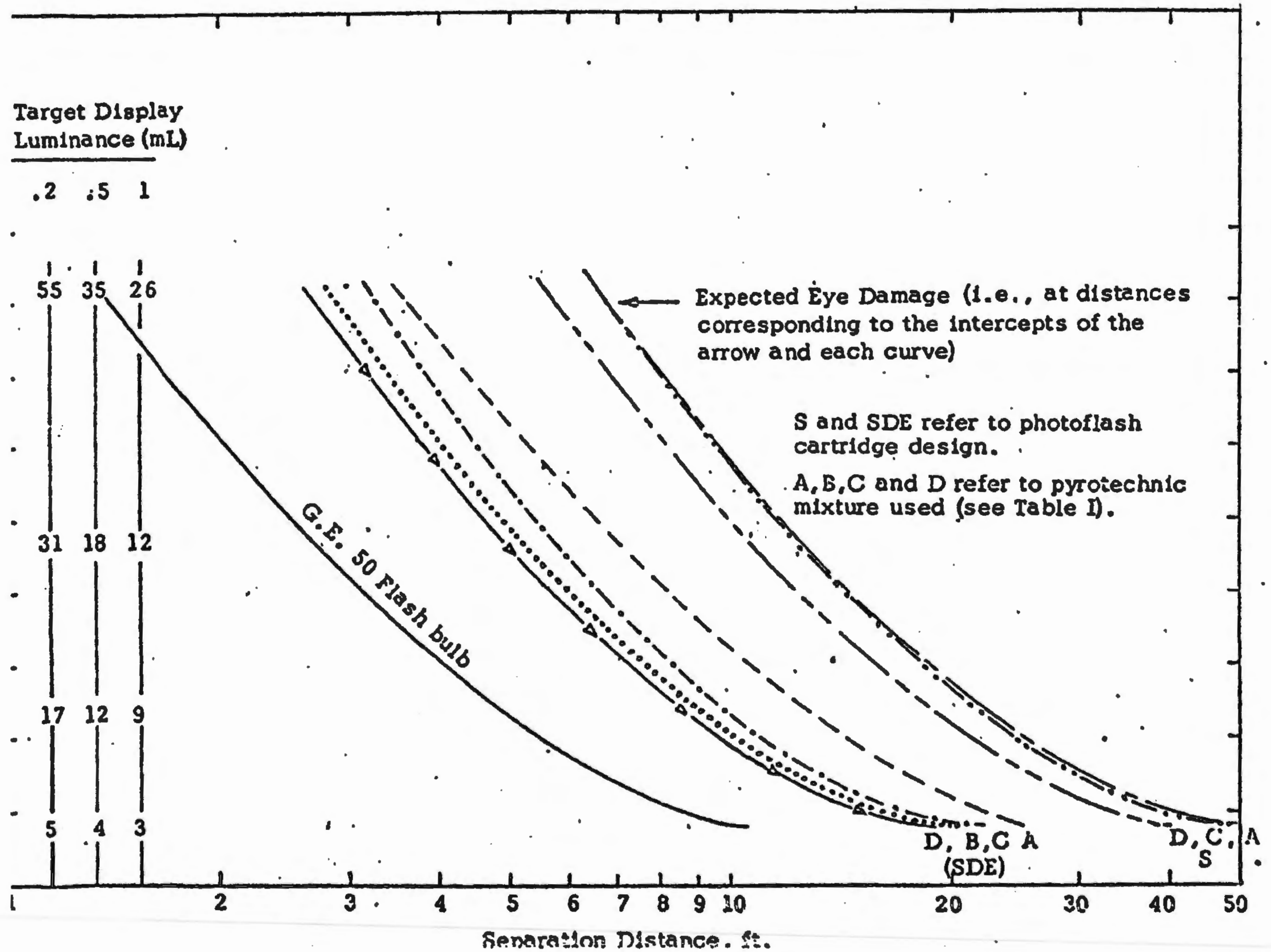
SS and SSDE refer to the photoflash cartridge used.
A, B, C and D refer to the pyrotechnic mixture used (see Table I).
G.E. 50 Flash Bulb
A
C
B, D
C
A
B, D
S
Flash Energy, lumen-sec/ft^2
10^5
10^4
10^3
10^2
10^1
10^3
10^2
10^1
10^0
Separation Distance, ft.

These estimates are also indicated by the vertical dashes crossing each of the curves in Figure 11.

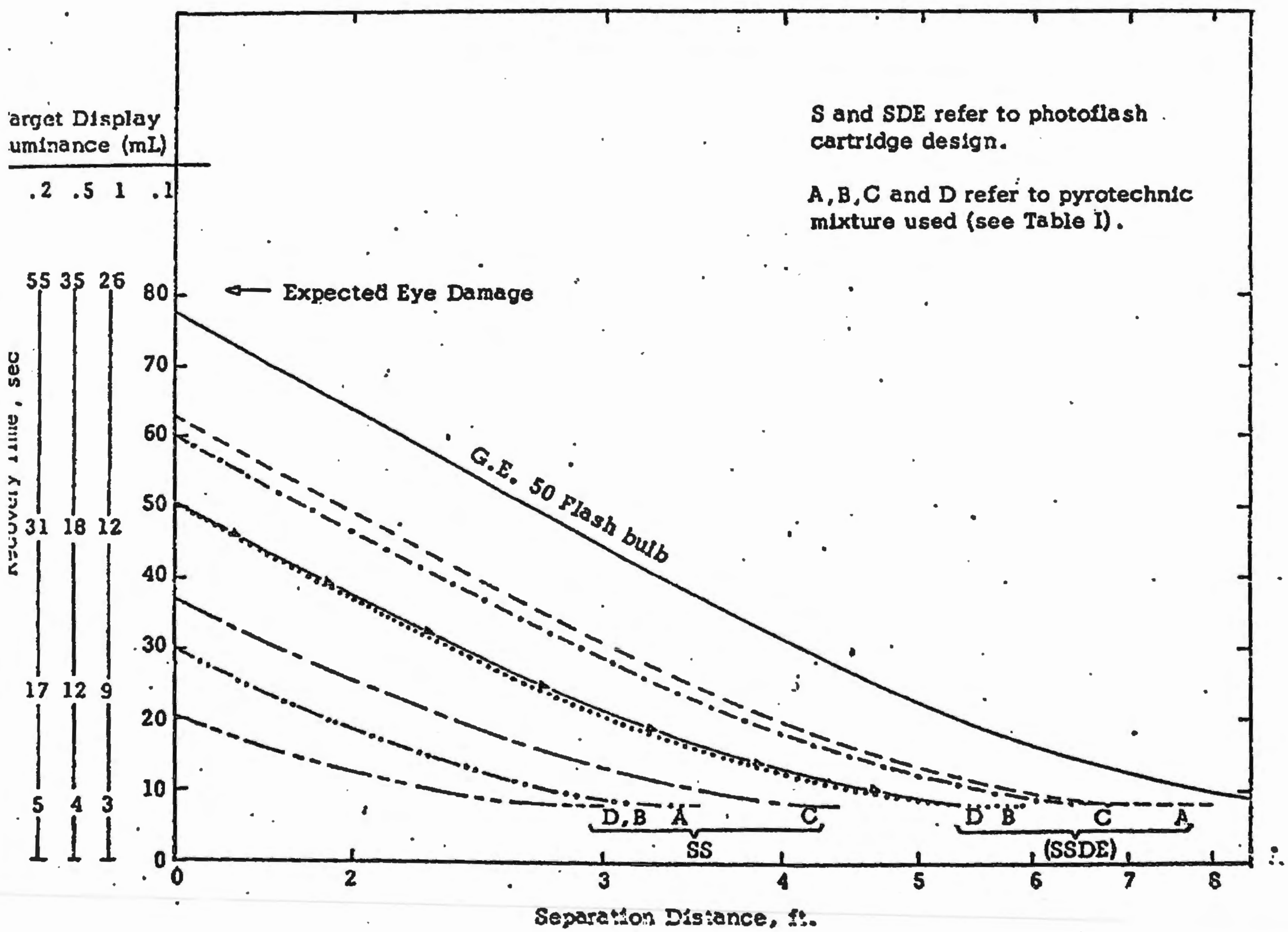
For each pyrotechnic device tested, the recovery times for a subject exposed to the light flash were estimated using the data in Figures 11, 13, and 14 and Table III. These estimates were made as a function of distance away from the flash and the luminance levels of objects which the observer might attempt to detect after exposure. These estimates are reported in Figures 15 and 16.

As expected the large photoflash devices (i.e., the S and SDE series) should be the most effective as far as separation distance is concerned. An observer separated from the flash by 50 feet can be affected if an SA charge is employed. At separation distances less than 7 feet there would be the possibility that irreversible eye damage could be affected using the SA charge. Significant flash blindness effects are expected within this distance range for all of the charges. Recovery times of as long as 60 seconds are predicted for the detection of objects which are very dimly illuminated.

The effects of exposure to a G.E. 50 flash bulb were also predicted. It can be seen that the estimated effects are not as great as for the S and SDE series photoflash units. By further comparison with a recent report by Tiller et al.[16] (ARPA Contract DAAK02-69-C-0338) the estimates made for the G.E. 50 flash bulb appear to be reasonable. Tiller et al. evaluated the effects of exposure to this flash bulb to subjects performing military tasks. The subjects were exposed to a flash at distances between 6 and 19 feet. After exposure the subjects were required to detect ground emplaced mines or detect and fire upon a test target. All of these tests were performed under various night time conditions to which the subjects had adapted before being exposed to the light flash. It was found that the subjects, all trained Marines, were able to resume their assigned task with the same efficiency after an average recovery time of 5 to 20 seconds. No indication of reflected luminances of the objects detected were made. It is felt, however, that the predictions of recovery times for dimly lit displays (viz., 0.1 and 0.2 millilamberts) agree with the results obtained by Tiller et al. Between 6 and 10 feet it is predicted that exposure to the G.E. 50 flash should take approximately 8 to 18 seconds. No predictions beyond 10 feet for the G.E. 50 were made because of lack of data. However there is much indication to suggest that at longer distances (i.e., lower flash energies) the recovery times versus distance decreases at a very small rate.


Target Display
Luminance (mL)
.2 .5 1
55 35 26
31 18 12
17 12 9
5 4 3
G.E. 50 Flash bulb
Expected Eye Damage (i.e., at distances corresponding to the intercepts of the arrow and each curve)
S and SDE refer to photoflash cartridge design.
A, B, C and D refer to pyrotechnic mixture used (see Table I).
D, B, C A
(SDE)
D, C, A
S
1 2 3 4 5 6 7 8 9 10 20 30 40 50
Separation Distance, ft.

The estimated recovery times after exposure to the smaller photo-flash sources are shown in Figure 16. It is not anticipated that eye damage could be affected by these charges even at short separation distances. Again the "A" and "C" mixtures are expected to be the most efficient.



S and SDE refer to photoflash cartridge design.
A,B,C and D refer to pyrotechnic mixture used (see Table I).
'arget Display
uminance (mL)
.2 .5 1 .1
55 35 26
31 18 12
17 12 9
5 4 3
80
70
60
50
40
30
20
10
0
Expected Eye Damage
G.E. 50 Flash bulb
D,B A C
SS
D B C A
(SSDE)
0 2 3 4 5 6 7 8
Separation Distance, ft.

6. CONCLUSIONS

Sixteen pyrotechnic flash mixtures - fragmenting container combinations were tested. It was shown that significant flash blindness effects can be expected to result from the exposure to these flashes, all of which occur within 50 msec. These effects can result by exposure to these charges at distances within a range of 50 feet depending on the pyrotechnic mixture and quantity, container design, and method of initiation.

6.1 CARTRIDGE DESIGN

The series S and SDE charges (i.e., the 2.7 in. photoflash cartridge) produced the most intense light and are expected to be effective at distances as far as 50 feet. The external explosive burster attached to the outside of the "S" cartridge was expected to increase the light intensity by compacting the mix before ignition.. However, for the larger cartridge this does not appear to have been successful. For the smaller 0.83 in. photoflash cartridge the expected trend resulted. The effective compaction by this imploding mechanism probably increases with decreasing cross-sectional area.

6.2 PHOTOFLASH MIXTURE

The type "A" and "C" mixtures in all cases generated the most light output. In some cases the "C" mixture produced light pulses of longer duration as previously anticipated. The "B" and "D" mixtures were not as effective. In fact the performance of the "D" mixture was relatively poor.

6.3 DATA INTERPRETATIONS

In order to estimate the flash blindness effects, correlations between reported data had to be made. The results of the analyses appear to be consistent with expectation, namely that recovery time is dependent not only on the flash energy but also on the luminance of objects which are visually sought during the recovery period. Also the relatively insensitive change of recovery time at flash energies which produce 90 to 100 percent pigment bleach was shown in this analysis.

It is useful to note that the large light sources used in our experiments (i.e., the S and SDE series), produced more intense illumination than the source employed by the Vertex Corporation. Correspondingly, longer incapacitation times are predicted for the S and SDE photoflash units as compared with the G.E. 50 photoflash used in the Vertex studies. In addition, on the basis of our independent experimental data, we could predict the shorter incapacitation times reported by Vertex for their weaker light source.

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APPENDIX I

In order to clarify the question of potential applications of bright light sources, a series of simple scenarios have been developed, which illustrate possible suitable situations.

The use of a detonating pyrotechnic permits the generation of casing fragments as well as intense light, if the material is enclosed in a metal casing. On the other hand, packing the pyrotechnic into a non-metallic (e.g., cardboard) casing, essentially eliminates any significant fragment hazard. These two modes of operation find separate regimes of possible application.

I. PERIMETER DEFENSE

Given a situation in which a village or a group of men wish to provide a very distinct indication of an attempt at perimeter penetration, by the enemy, and in addition wish to either inflict temporary optical incapacitation alone, permanent optical incapacitation alone, or fragment damage in addition to the optical incapacitation, these pyrotechnic light sources can play a useful role.

Thus, cased in metal and triggered by sensors (or trip wires) within the effective fragment range, they provide direct fragment damage capability with a good possibility of severe permanent optical impairment at such relatively short ranges.

Triggered by sensors deployed outside the effective fragment range, the effects would be primarily temporary optical incapacitation and disorientation with a low probability of fragment damage.

In specific situations, calling for no fragmentation effects, such as one in which friendly personnel may inadvertantly trigger the charge, the sensors can be deployed far enough away to assure only temporary optical incapacitation and fragmentation can be completely eliminated with a cardboard casing for the pyrotechnic.

II. VEHICLE PROTECTION AGAINST KIDNAP ATTEMPT

Given the premise that abductors (e.g., of South American diplomatic representatives) do not wish to kill the hostage during the kidnap attempt, a system for providing even 5 - 10 seconds of optical incapacitation in a 360° field around the car in which the hostage is driving, provides an opportunity for escape, while the abductors are optically disoriented. This system would be more effective at night than in the daytime. The light source could be either pyrotechnic or electric discharge. It could be made safe against accidental discharge causing permanent damage to innocent bystanders.

[redacted]

III. TEMPORARY DISRUPTION OF VEHICLE CONVOY BY CAUSING OPTICAL INCAPACITATION OF LEAD DRIVER

The scenario here is relatively simple in that the lead driver can be optically incapacitated as he's rounding a turn, or caused to block the road by his inability to see it for a sufficient time to cause a wreck.

IV. ESCAPE FROM AN ENCLOSURE WITH NO PERMANENT DAMAGE TO OTHERS

In some situations, where the presence of innocent bystanders, e.g. women and children prevents the use of more damaging techniques, the use of temporary optical incapacitation is of potential interest.

V. PRELIMINARY TO INDIVIDUAL CAPTURE

Where a single individual is to be captured alive, the use of optical incapacitation may provide useful assistance. Thus, a bright light source generated near him by impact functioning of a device fired from a shotgun can provide sufficient temporary optical incapacitation to permit other capture techniques to be employed more reliably.

VI. SUMMARY

While these scenarios do not provide a complete list of potential applications, they should be useful in examining the value of a system which combines the capability for fragmentation damage, severe permanent optical incapacitation and transient optical incapacitation with the choice fairly easy to control.

[redacted]

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