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NUCLEAR FLASH EYE EFFECTS TECHNICAL REPORT FOR  
MILITARY PLANNERS

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\*This work was supported by the Department of Ophthalmology, Air Force School of Aerospace Medicine, Brooks Air Force Base, Texas and the Medical Division, Defense Atomic Support Agency, Washington, D. C.

## FOREWORD

This report was prepared by personnel of the Life Sciences Division of Technology Incorporated--

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This research was performed for the U. S. Air Force under Task 630103 and under Program Element 6.16.46.01.D, Project 5710, Subtask 03.138, and was partially funded by Defense Atomic Support Agency. Mr. E. O. Richey, SAM, was Contract Monitor during the contractual period. Grateful acknowledgement is made of the assistance provided by Mr. E. O. Richey and Captain J. E. Hamilton of the Ophthalmology Branch.

Other major contributors to the effort were Messrs. R. A. Schmall and A. F. Muller of Technology Incorporated. Acknowledgement is also made of the contribution of Oskar L. Ritter, Ph. D., Office of the Chief Scientist, School of Aerospace Medicine for his atmospheric transmission model which takes into consideration the curvature of the earth.

## ABSTRACT

This report is intended to be used as an aid to military mission planners in determining allowable proximity to a nuclear fireball from the standpoints of permanent retinal injury and the temporary effects of flashblindness. Pertinent physical and physiological phenomena are discussed in moderate detail; the nucleus of the work being a family of curves which indicate acceptable separation distances for the prevention of retinal burns and flashblindness. Detailed instructions for approximating acceptable separation distances using a slide rule are included as an appendix.

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## I. INTRODUCTION

It has been known for many years that damage to the eyes can occur as a result of viewing a very bright light, and that this damage could result in a permanent loss of visual acuity. The early evidence of retinal damage produced in this way was observed in individuals who had viewed a solar eclipse without adequate eye protection <sup>(1)</sup>. The resulting loss in vision was called "eclipse blindness", and even now despite frequent warnings to the public, injuries from viewing eclipses are still reported <sup>(2)</sup>.

The development of nuclear weapons introduced a new and potentially more hazardous source of radiation capable of producing eye injuries. The potential for eye injury was recognized from the beginning since protective goggles were worn at the first atomic bomb test in 1942--and in each test thereafter.

The first experiments dealing with the effects of a nuclear flash on the eyes were conducted by the Air Force School of Aviation Medicine in 1951 during Operation Buster. It appears, however, that this problem was not discussed in the open literature until 1953 when it was pointed out <sup>(3)</sup> that, because of the focusing of energy by the eye, injury could be sustained at extremely long distances--much longer distances than those at which injury could be produced by any other direct effects.

Following Operation Buster came a series of field experiments to study the effects of nuclear detonations on vision. This series of field studies

culminated with an extensive experiment conducted during Operation Dominic and Fishbowl in 1962<sup>(4)</sup>.

Today, there are several sources of radiant energy that are capable of producing retinal damage, and most of these sources possess a much greater capacity for producing damage than does the sun. With the exception of the Q-switched laser--an ultra-high power mode of laser operation that introduces a new spectrum of biological damage<sup>(5, 6)</sup>--the mechanism by which injury to the eye is produced appears to be the same in all cases, viz., the production of regions of elevated temperatures in the retina and adjacent regions as a result of absorption of the incident radiation energy. Since permanent injury appears to be simply a consequence of generating excessive temperatures, no matter whether the source is the sun, a nuclear detonation, a normally operated laser, a pulsed xenon tube, an incandescent plasma, or some other high intensity source, the damage produced will be similar in each case--differing only as a result of variations in the conditions of exposure, differences in the characteristics of the sources, and differences in the subjects themselves.

The significance of chorioretinal burns depends upon a number of factors. Some of these factors are associated with the physical characteristics of the actual lesions--such as size, location, and severity. These factors determine the particular visual function affected and the extent of loss of function. In contrast, other factors involve the consequences of having



suffered a loss of visual function. These factors deal with the importance to the individual of the specific function affected, the extent of the functional loss, the possibility of partial recovery, and the potential for partly overcoming the loss by visual training and/or practice.

## II. GENERAL DISCUSSION

This report was developed for use in determining acceptable proximity to nuclear detonations in so far as eye effects are concerned. Two potential mission hazards are dealt with - retinal burns and flashblindness. Weapon yields from .01 KT to 25 MT at burst and flight altitudes ranging from sea level to 100,000 feet have been considered.

The distances determined using the retinal burn envelopes are the minimum allowable distances from fireball to observer that are considered "safe", i. e., distances at which no permanent damage will be produced before a reflexive blink occurs and protects the eye.

The distances determined using the flashblindness envelopes are also minimum allowable distances, but in this case, they refer to temporary rather than permanent visual impairment. These curves describe the distance at which 10 seconds of flashblindness will be experienced, i. e. distances at which it will take 10 seconds to recover at least 20/120 acuity, sufficient acuity to obtain useful information from flight instruments.

Weapon characteristics, atmospheric transmission, and pertinent aspects of the physiology of vision are discussed cursorily in order to acquaint the reader with the basic concepts involved and to relate retinal exposure to loss of visual function.

To the extent possible, the prediction techniques employed incorporate the results of observations taken during the most recent nuclear tests (4).

### Weapon Characteristics

There are several basic differences between nuclear and conventional high-explosive weapons. A nuclear explosion may be many times more powerful than the largest conventional explosion, a nuclear explosion is accompanied by highly penetrating ionizing radiations, the fission products remaining after a nuclear explosion are radioactive, and a large amount of the nuclear energy is converted to thermal energy (light and heat). This thermal energy is the energy that is responsible for chorioretinal burns and flashblindness.

Figure 1 shows the distribution of energy from a fission weapon in a typical air burst. For detonations in the atmosphere below 100,000 feet the fraction of energy converted to thermal energy lies between 30 and 40 percent (7) and is taken as 33 percent in the calculations described herein.

At lower altitudes, a gaseous fireball is formed and essentially all of the thermal energy is emitted in two pulses (Figure 2) (7). The first

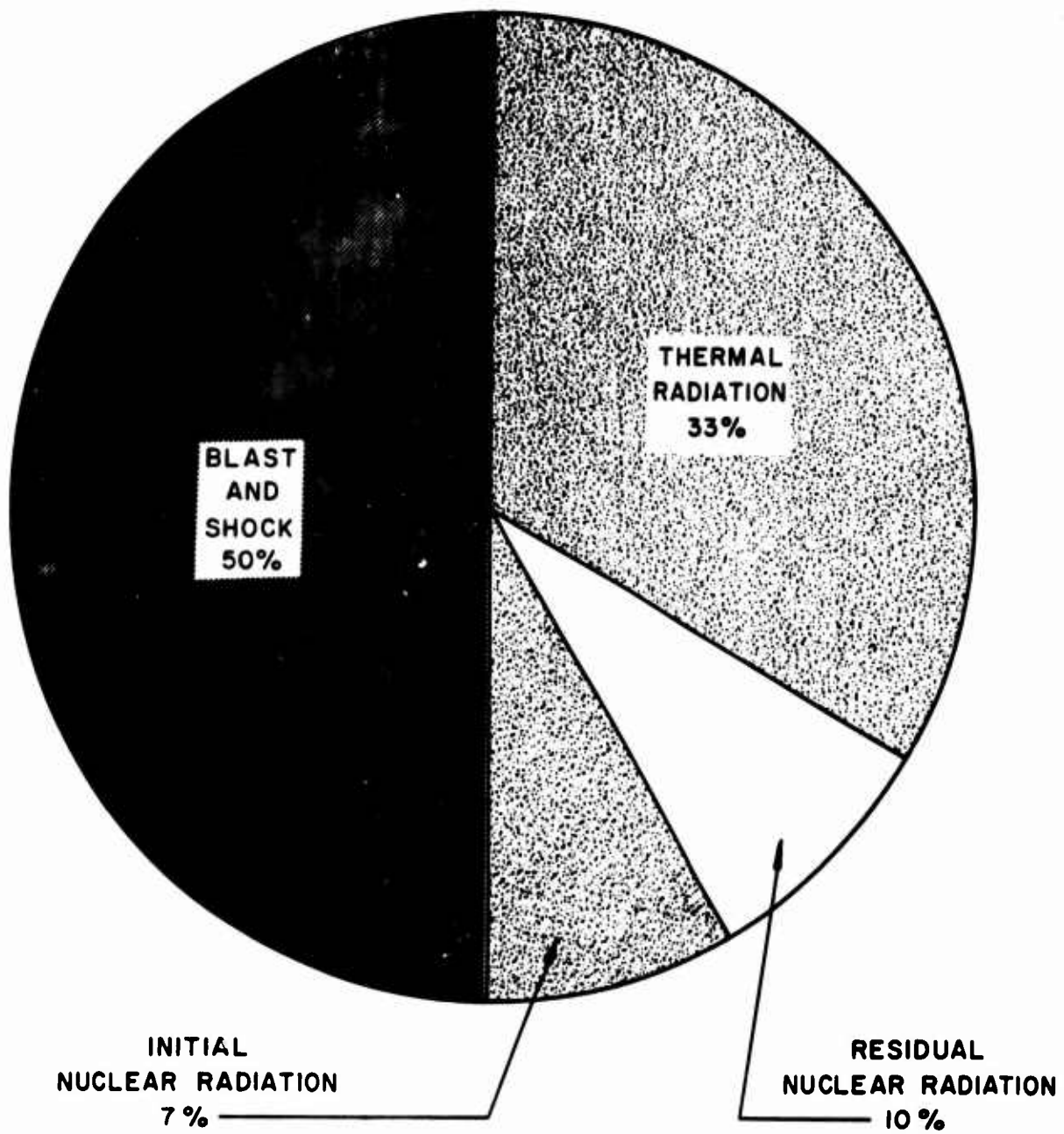


FIGURE 1. Distribution of energy in a typical air burst

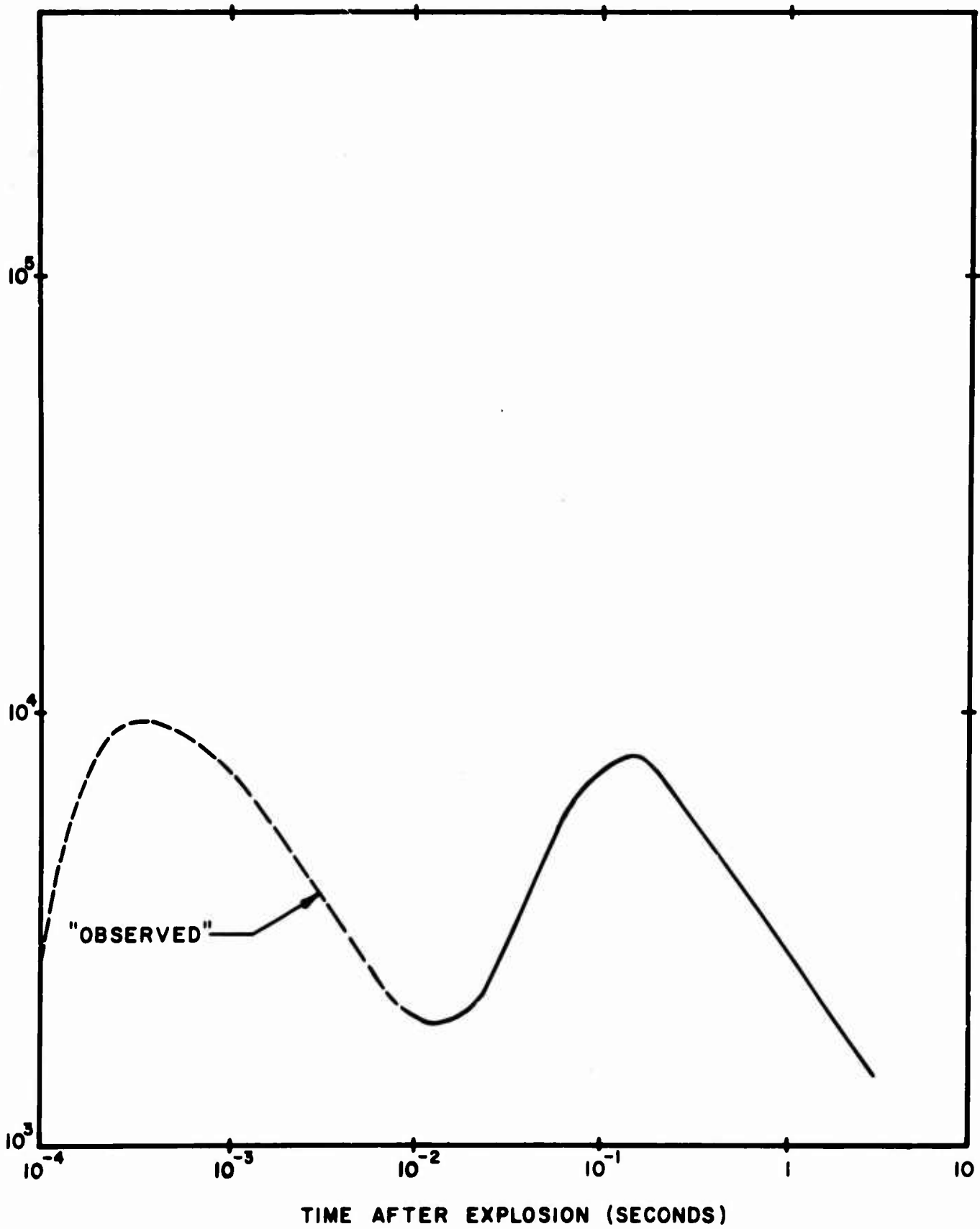


FIGURE 2. Temperature variation in a 20 kiloton air burst

pulse is relatively short and contains approximately one percent of the total energy. The second pulse, which contains the remainder of the energy, is much longer. Although the first pulse contains only one percent of the energy, under certain circumstances it is capable of producing permanent injury to the retina. For detonations at higher altitudes, more of the thermal energy appears in the first pulse. For very high altitude detonations, essentially all of the energy is emitted in a single very short pulse.

The amount of thermal energy arriving at the position of the observer depends upon the weapon design, its size, altitude of the detonation, distance to and altitude of the observer, and characteristics of the intervening atmosphere. Estimation of this energy comprises a large part of the problem of predicting safe separation distances.

#### Atmospheric Transmission

Before reaching the eye, the radiant energy emitted by the fireball is attenuated by the atmosphere through processes of scattering and absorption. Attenuation by the atmosphere is a subject of some complexity due to the variety of phenomena and situations which can be involved. In general, attenuation of radiant energy by the atmosphere depends upon the composition, characteristics, and distribution of the atmosphere in the path between detonation and observer and the energy spectrum of the emitted radiation. The composition, distribution, and characteristics of the atmosphere vary from time to time and place to place and frequently are difficult or impossible

to predict with any accuracy. For the retinal burn problem, it is not necessary to consider all of the phenomena involved, or to account for the full range of situations and variations which can occur. It is sufficient to limit consideration to the unscattered or image forming radiation transmitted through a clear cloudless atmosphere, the situation most favorable to the production of retinal burns, under the assumption that transmission through the atmosphere may be described adequately by the expression:

$$T_{AT} = \exp \left[ -k_A^{\text{eff}} m \right] \cdot \exp \left[ -k_w^{\text{eff}} w \right]$$

where:

$m$  = the mass of air in the path between detonation and observer  
(a function of burst and observer altitudes and horizontal range).

$w$  = the mass of precipitable water vapor in the path between detonation and observer (also a function of burst and observer altitudes and horizontal range).

$k_A^{\text{eff}}$  = effective narrow beam extinction coefficient of dry air.

$k_w^{\text{eff}}$  = effective narrow beam extinction coefficient of water vapor.

The Standard U. S. Atmosphere (1962) is used as a model for air density variation with altitude whereas an exponential decrease with altitude is assumed for water vapor density.

### Interaction of Radiant Energy with the Eye

The effects of thermal radiation on the eyes may be classified as permanent (chorioretinal burns) or temporary (flashblindness). Concentration of thermal energy on the retina by the eye lens system can result in injury to the retina. However, this will normally occur only if the source of energy is in the field of vision so that an image of the source is formed on the retina. Because of the focusing of energy by the eye, the distances at which chorioretinal burns can occur may be much greater than those where thermal radiation produces skin burns. This comes about as follows: the irradiance (energy per unit area per unit time) incident on the eye is inversely proportional to the square of the distance from the fireball. However, the area of the fireball image on the retina is also inversely proportional to the square of the distance from the fireball. As a result, the irradiance at the retina in the image of the fireball is independent of the distance from the fireball--except for the effect introduced by atmospheric attenuation. Fortunately, atmospheric attenuation increases with distance so that distance can provide protection. There are two other factors which enter into the problem in a significant way--one is pupil size and the other is blink time. In order to admit more light, the pupil of the eye normally enlarges at low levels of illumination. Thus, under conditions of low ambient illumination (dusk or night) the pupil will be larger than in daylight and allow more of the thermal energy from the fireball to strike the retina. Average pupil diameters assumed for this work were 6.5 mm (night); 5 mm (behind 2% gold filter), and 2.5 mm (day).

Considering blink time, it is apparent that only radiation received prior to closing the eyes in a reflexive blink can contribute to the production of retinal damage. As a result, the time for a blink to occur can be important. For the predictions made herein, exposure times are taken to be 250 milliseconds for small weapons and 450 milliseconds for larger weapons.

### III. RESULTS OF EXCESSIVE EXPOSURES

#### Chorioretinal Burns

A sketch of the human eye is shown in Figure 3. For purposes of discussion, the eye may be compared to a camera. Light rays received by the eye are refracted by the cornea, lens, and ocular media so that they are focused on the retina producing there an image of the fireball.

#### Mechanism of Production

Heat generated in the retina and adjacent structures will in time diffuse away from the area in which the image is focused and will also be conducted away by the flow of blood in the vascular bed. If the rate of heat diffusion in an area is less than the rate of heat generation in that area, the temperature will increase. If the temperature exceeds the biological tolerances for the area involved, injury to the photo-receptors (rods and cones), to the optical nerve tissue and other structures in the retina and choroid may result--with a subsequent permanent loss of vision. Current research efforts are attempting to define threshold temperatures but relatively little reliable



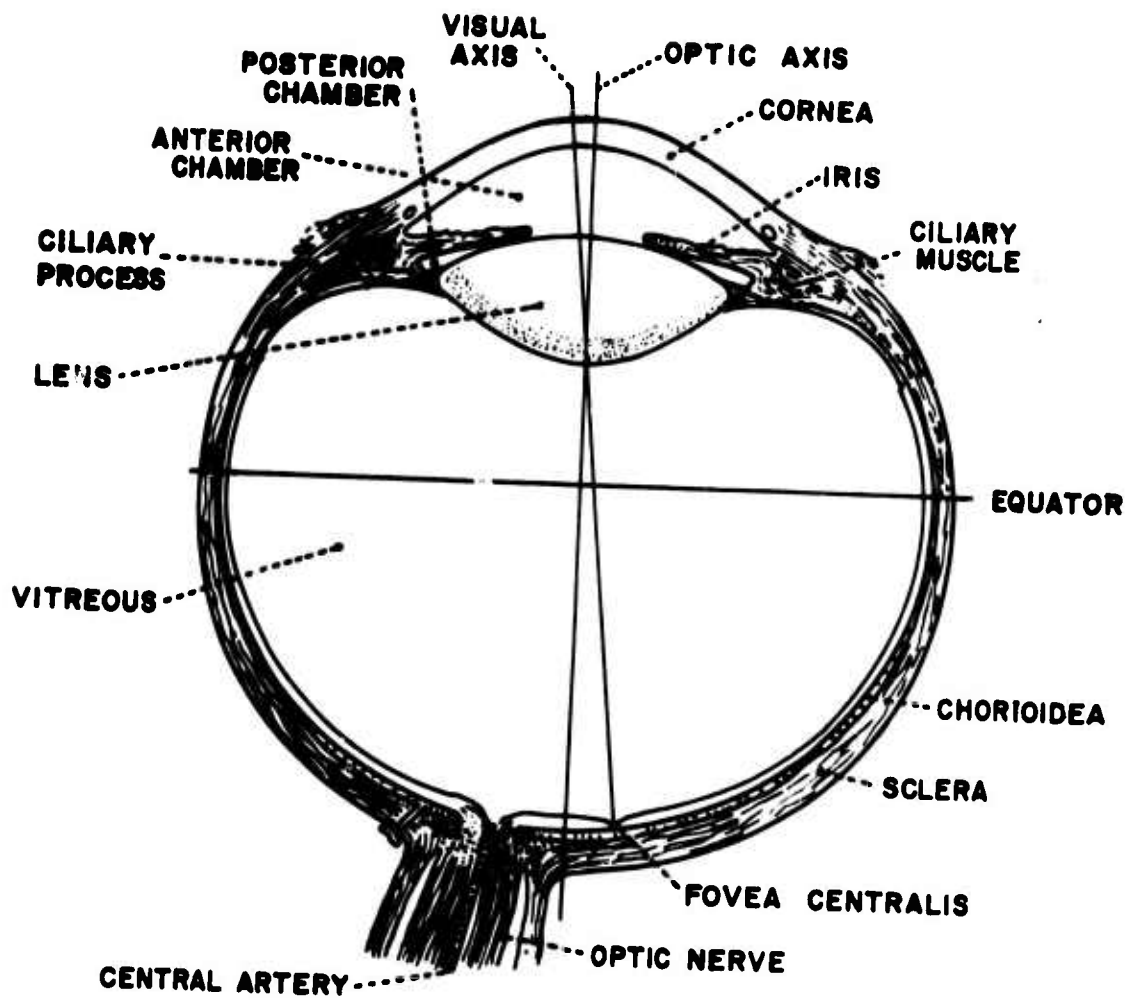


FIGURE 3. Schematic drawing of eye

quantitative information exists at present. Until more knowledge is gained in this area, it will be necessary to continue to base threshold criteria upon visual observations of retinal changes produced in laboratory animals and, with appropriate safety factors, extrapolate these results to humans.

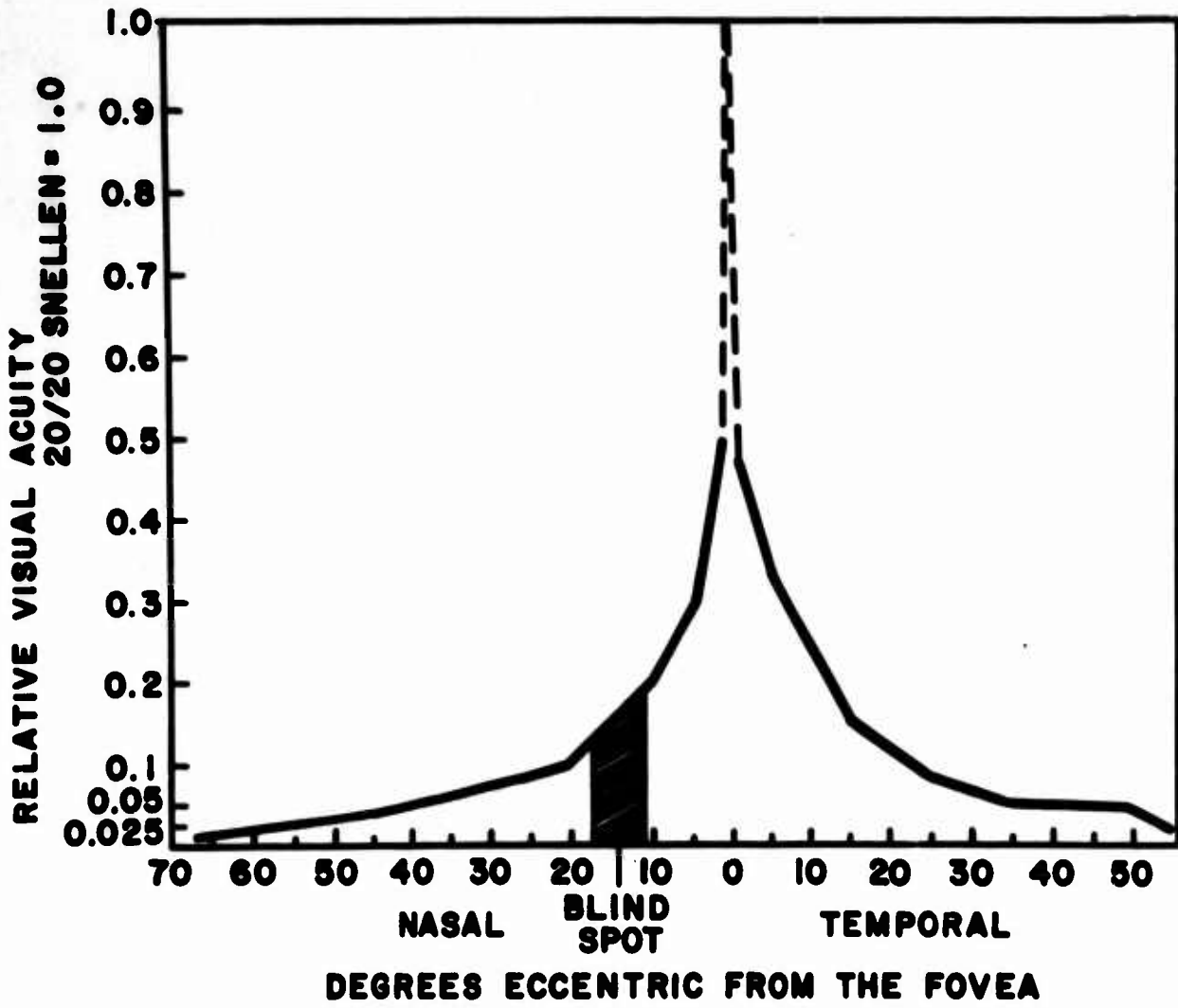
#### Effects on Vision

The degree of visual impairment caused by a retinal burn will be dependent on the size, severity, and location of the burn. The size of the image, which influences the size of a burn, depends on the visual angle subtended by the object--i. e. , the size of the fireball and its distance from the observer. The severity of a burn depends in general upon the amount by which the exposure exceeds the threshold exposure. The function affected will be determined by the location of the burn(s). For example, sustaining a burn in the fovea would be most detrimental to visual acuity and color vision since the fovea is employed for high acuity and color recognition. A burn in the periphery would have less effect on visual acuity, and, barring complications, could result in a scotoma or blind spot that might not be noticed. From Figure 4, it can be estimated that burns exactly centered in each fovea and large enough to include the central 2.5 degree visual field, would reduce visual acuity to about 57 percent of normal (20/35 on the Snellen scale). In theory, if the central 10 degree visual field were destroyed, the

acuity would be 29 percent (20/70). Even if the central 20 degrees of vision were destroyed, an extremely unlikely situation, visual acuity would be reduced to approximately 20 percent, i. e. about 20/100.

A schematic drawing of central field defects and the burns responsible for these defects are shown in Figure 5. The burns numbered 1-6 are shown in the region of the macula as they would appear in size and relation to the optic nerve. Burns having corresponding numbers result from a bilateral view of a single source. Corresponding scotomata are plotted on the field charts. The centrally located 1.8 mm (6 degree) burn would cause a permanent visual impairment of approximately 1/2 to 3/4 of normal if centered on the fovea. Visual acuity would probably be no better than 20/60 even after edema has subsided. Burns located off the fovea should not reduce acuity, but only produce blind spots.

Extra-foveal burns may produce visual defects that are significantly different than foveal burns. Since a lesion of the nerve fiber layer produces a defect which corresponds to the area which is served by the affected fibers and not the area of the lesion, a small heavy burn near the disc could cause an extensive field defect as well as a localized scotoma at the site of the burn. The course of the nerve fibers of the retina are shown schematically in Figure 6. Figure 7



The regional variations of the visual acuity (after Wertheim)

FIGURE 4. Visual acuity as a function of angular distance from the fovea.

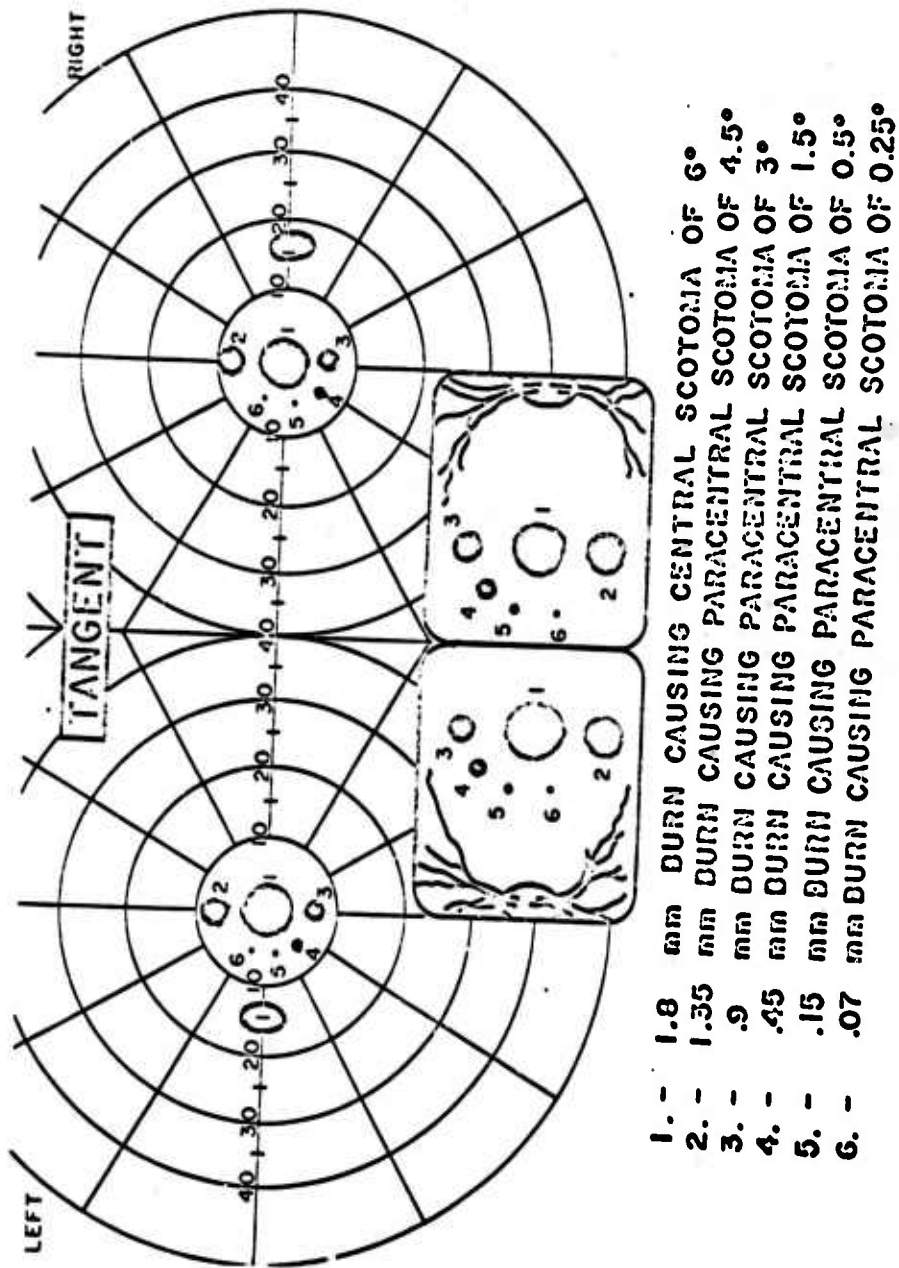


FIGURE 5. Schematic drawings of bilateral burns and resulting visual field defects.

shows field defects produced by damage to nerve fiber bundles.

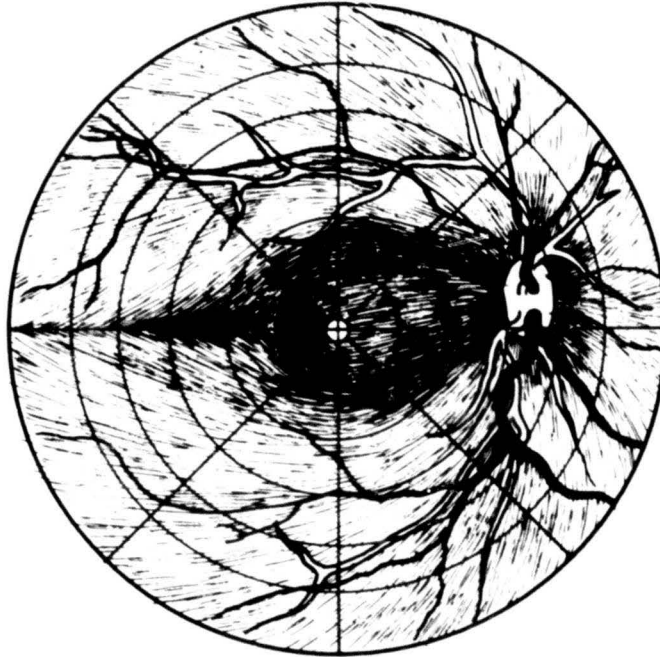
It should be emphasized that the loss of vision resulting from retinal burns although permanent and uncorrectable, will not take the form of total blindness. Burns can result in some impairment of vision in the form of blind "spots", but complete visual incapacitation as a result of retinal burns is extremely unlikely.

### Flashblindness

The temporary decrease in visual sensitivity following exposure to a bright light has been termed flashblindness, and the time required to regain visual function is called recovery time. In considering recovery time, it is necessary to specify the visual task or the particular visual capability desired since the time required to reach a given level of visual performance depends upon the performance level selected.

### Mechanism of Production

Briefly, high-luminance lights produce afterimages of the shape and size of the primary images. The initially perceived brightness of an afterimage is related to the amount of photo-pigment bleached in the area covered by the image, and the decrease in afterimage brightness with time appears to be related to the regeneration of the photo-pigments. An afterimage appears as a bright area in the visual field (or a dark area--depending upon the luminance of the background) and reduces



**THE RADIATING LINES SHOW HOW THE NERVE FIBRES FAN OUT.  
NOTE THAT TEMPORAL TO THE MACULA THE FIBRES MEET IN A  
MEDIAN RAPHE.**

**Semidiagrammatic picture of the Fundus Oculi, right Eye.**

FIGURE 6. Schematic drawing of the nerve fibers

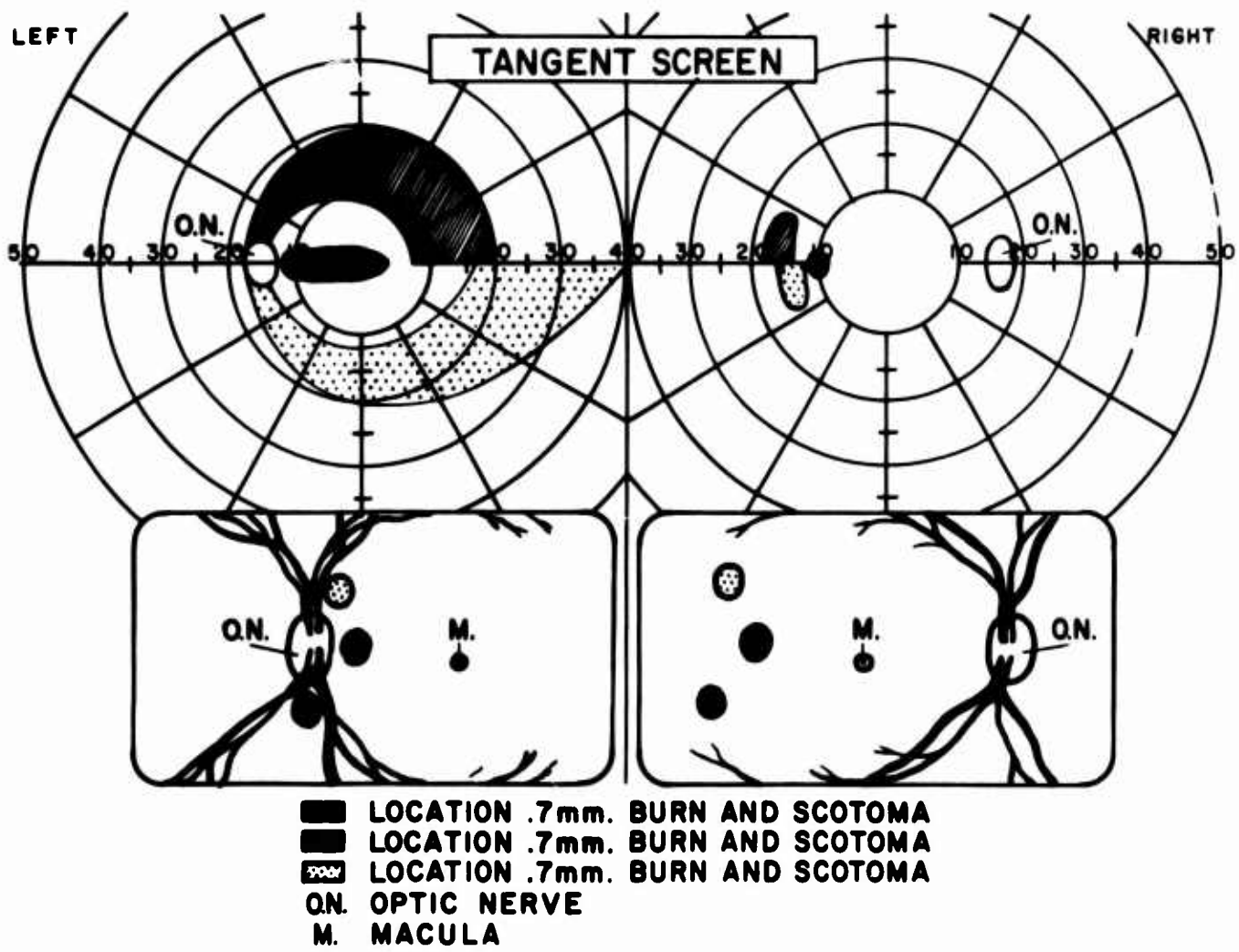


FIGURE 7. Schematic drawing of visual field defects resulting from injury to nerve-fiber bundles

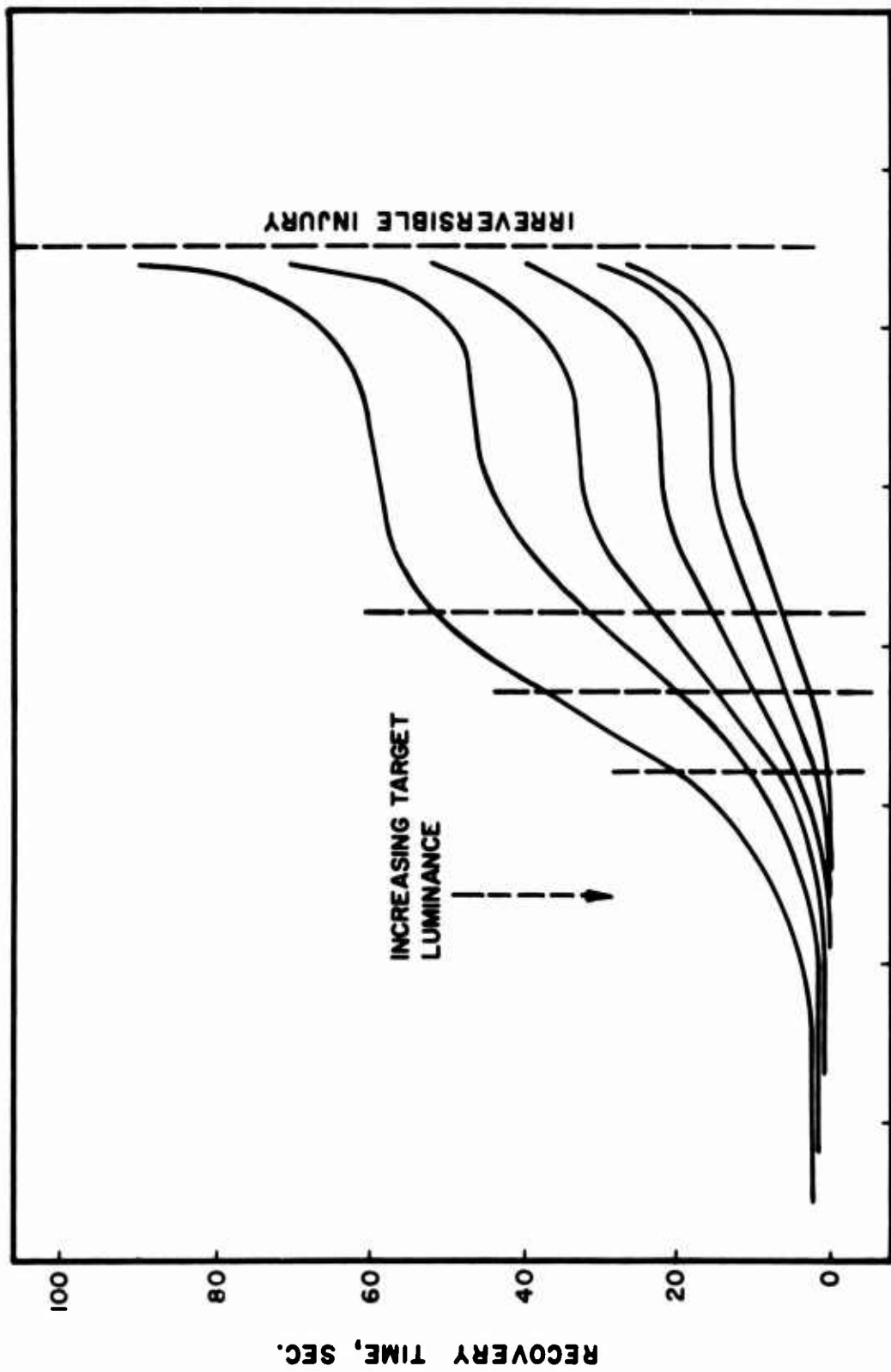


contrasts in a scene subsequently imaged within the area occupied by the afterimage. In order for an object to be seen "through" the afterimage, the object must produce a primary image of sufficient brightness to create detectable contrasts. Against the background of an afterimage, detail that could be detected prior to a flash may be indistinguishable until the afterimage decays to a brightness level permitting perceivable contrasts. As a result, recovery time depends generally upon the integrated incident luminous energy, the luminance of the subsequent scene, and the visual acuity required for perception of the particular detail desired.

#### Effects on Vision

Figure 8<sup>(8)</sup> shows the general form of recovery time as a function of stimulus flash energy--assuming a constant flash duration. Target luminance is the parameter between curves. For very low flash energies, there will be no significant effect on visual function. However, as flash energy is increased, an increase in recovery time becomes apparent. For exposure levels beyond those at which maximum bleaching occurs, recovery times may change very little with an increase in flash energy. However, as the flash energy approaches the threshold for injury, recovery time increases rapidly until injury occurs. At this point, function is lost irreversibly.

The relationship between target luminance and recovery time can also be inferred from an examination of Figure 8. Increasing display



LOG STIMULUS

FIGURE 8. Effect of flash energy and display luminance on flashblindness recovery time

luminances are represented by successively displaced curves in the figure. Note that recovery times decrease with increasing target luminance. Clearly, target luminance is an important variable and recovery times can be significantly reduced by increasing target luminance.

#### IV. PREDICTION METHODS

##### Retinal Burn

Detailed calculations illustrating the techniques employed in determining acceptable separation distances are given in Appendix A. A brief summary of the method is given below:

The total energy per unit area focused into an image on the retina is called the retinal exposure,  $Q_r$  (CALC). This quantity varies inversely as a function of distance to the fireball due to atmospheric attenuation and can be calculated for the human eye--provided atmospheric attenuation and the thermal characteristics of the weapon are known. For the curves contained in this document, a blink reflex of 0.25 seconds is assumed for yields below 1 MT and 0.45 seconds for yields of 1 MT and above.

Experiments using rabbits, plus data obtained from limited studies involving humans, serve as the basis for determining the allowable or safe retinal exposure,  $Q_r^T$ . This is the maximum exposure for which no

burn will be produced (9).

From a practical standpoint, concern over retinal burns occurs only when there is an impairment of vision. However, the relation between impairment of function and minimal ophthalmoscopic detectable lesions is not yet clearly established. To account for the inherent uncertainties, the following safety factors have been introduced:

- a. Calculated retinal exposures,  $Q_r(\text{CALC})$ , are arbitrarily multiplied by a factor of two in an effort to allow for possible inadequacies in weapon data and the method of calculation. Thus  $Q_r = 2Q_r(\text{CALC})$ .
- b. Minimal burn threshold data, determined from experiments on rabbits, are converted to human sub-threshold values by decreasing the measured threshold values,  $Q_r^T(\text{MEAS})$ , by a factor of four. Thus,  $Q_r^T = Q_r^T(\text{MEAS})/4$ .

Briefly,  $Q_r$  is calculated as a function of the distance between the observer and the fireball taking into account weapon characteristics, atmospheric transmission, and properties of the eye. The allowable distance of nearest approach (safe separation distance) is then obtained by comparing values of  $Q_r$  to values of  $Q_r^T$ , also calculated as a function of the distance between observer and fireball. The safe separation distance, measured along the earth's surface, is the distance at which  $Q_r = Q_r^T$ .

Since  $Q_r$  is dependent on the total masses of air and water vapor in the path between detonation and observer, safe separation distances vary with both detonation altitude and observer (flight) altitude. Figure 9 illustrates the model used to take these geometrical factors into account in the results presented in Figures 13-116.

Figure 10 shows a plot of  $Q_r$  and  $Q_r^T$  vs. horizontal range. The point of intersection of these curves ( $Q_r = Q_r^T$ ) defines the minimum allowable distance of approach for one particular burst and flight altitude combination. To generate an "envelope" curve such as shown in Figure 11, large numbers of  $Q_r$  and  $Q_r^T$  curves must be examined. This was done using a computer program and the results are contained in Figures 13-116. For distances inside the boundaries defined by these curves, there is the possibility of eye injury as a result of retinal burns. For distances outside the boundaries, no injury is predicted.

### Flashblindness

Flashblindness envelopes are generated in much the same manner as are the retinal burn envelopes, i. e., a calculated exposure,  $E_r$ , is compared to an allowable exposure,  $E_r^A$ . However, in this case, the calculation of the exposure is somewhat more complicated than in the case for retinal burns. A brief description of the approach is given here with a detailed description appearing in Appendix B.

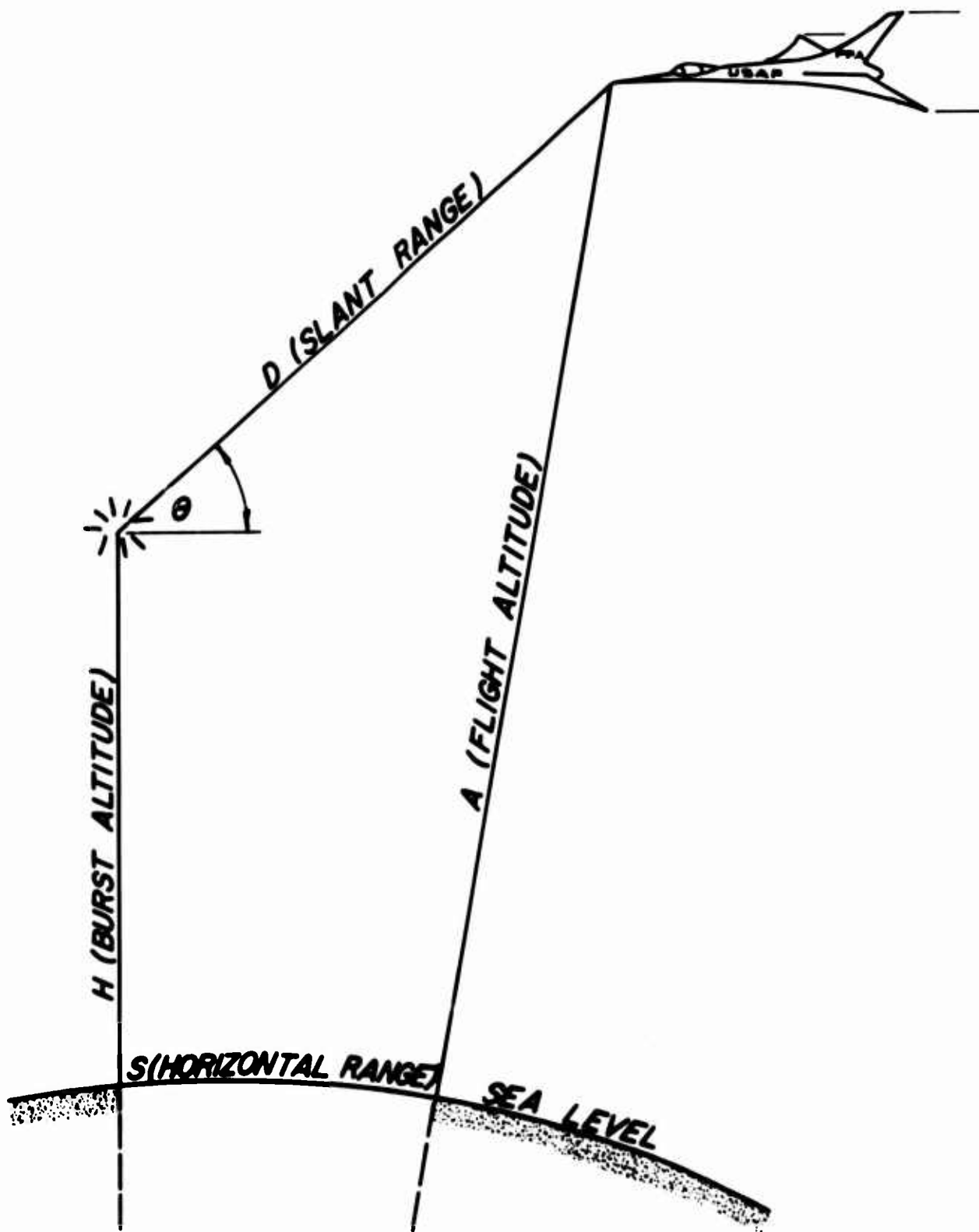


FIGURE 9. Model used for calculating transmission of the atmosphere

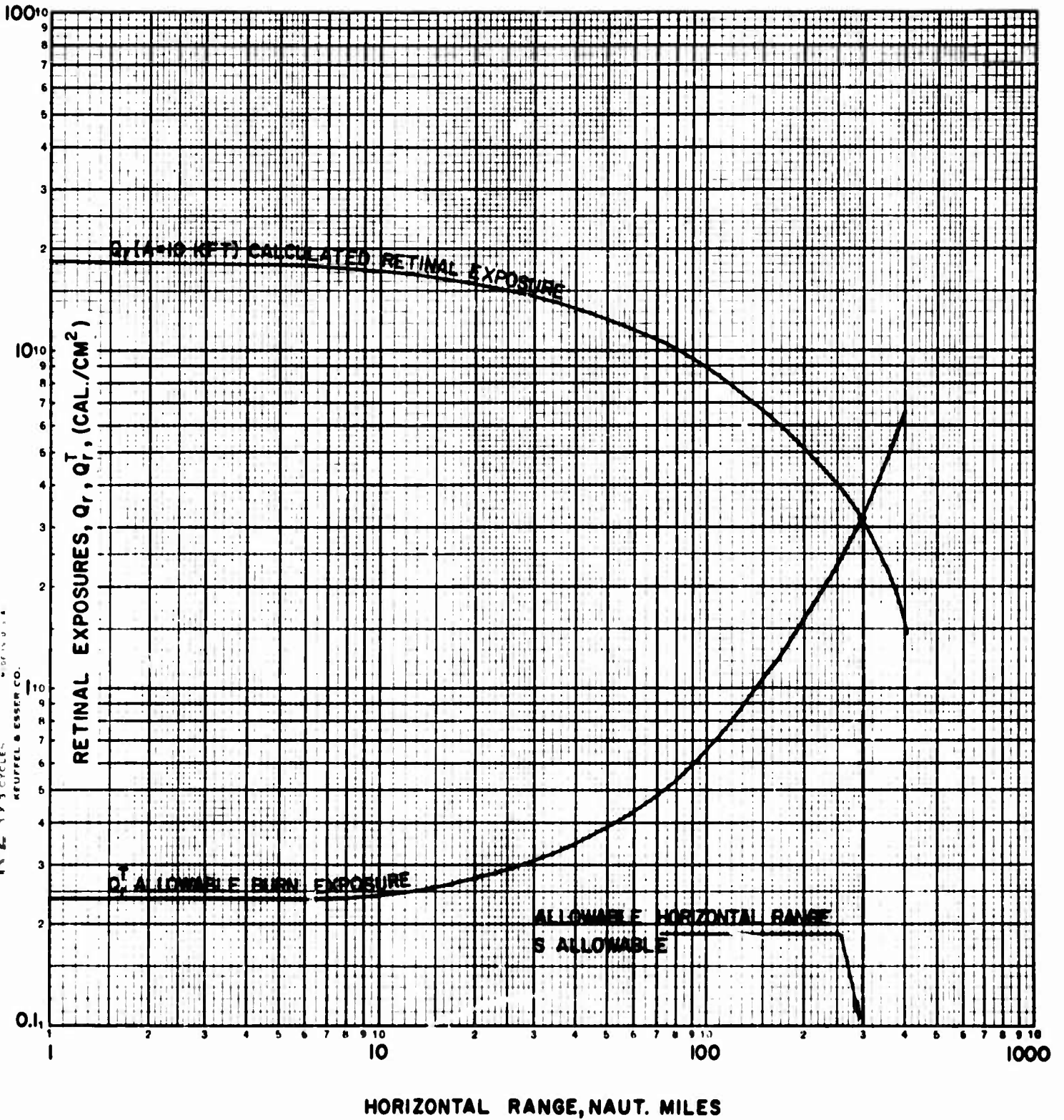


FIGURE 10. Threshold distance determination.

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 2 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100  
 —  
 —

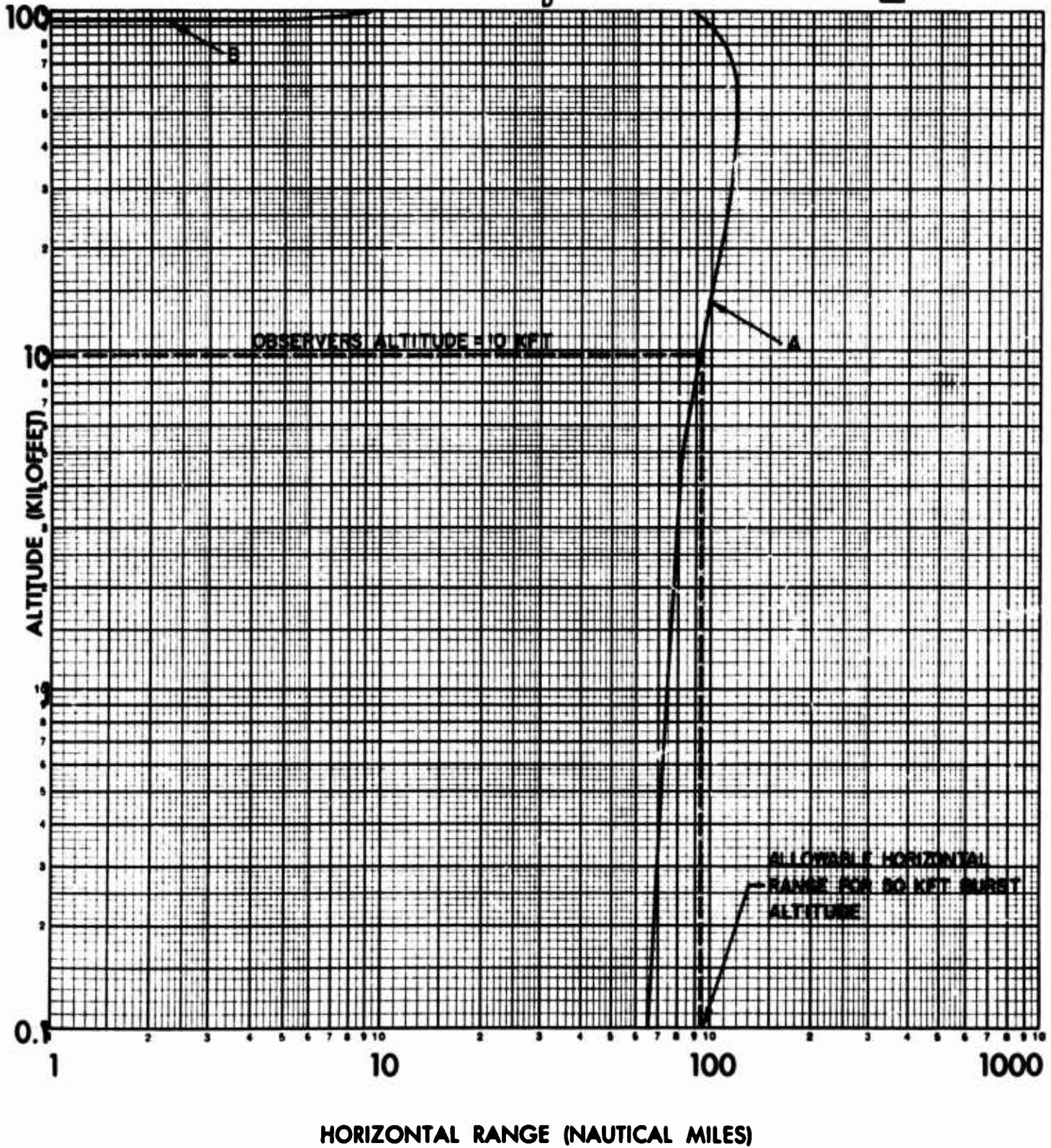


FIGURE 11. Typical retinal burn safe separation envelope.



If the image of the fireball falls directly on the fovea and the image is approximately the size of the macula (or larger), a significant period of flashblindness can result--even though no burn is produced. For this case, calculation of the exposure is accomplished exactly as for retinal burns except that the exposure is expressed in troland-seconds. However, if the fireball subtends an angle less than about three degrees (one millimeter image diameter) it is possible to "look around" the afterimage using the para-fovea area where acuity is still relatively high<sup>(10)</sup>. Thus, a very small afterimage in the macula may be annoying but it does not present a significant decrement in visual acuity. Accordingly, recovery time is computed for a foveal exposure from the direct (unscattered) radiation only when the image of the fireball is equal to or greater than one millimeter. When the image of the fireball is less than one millimeter, it is assumed that the limiting stimulus will be presented to the fovea by diffuse radiation that reaches the retina after being scattered from the air, clouds, ground or water, and by the clear media of the eye itself. Calculation of this component of the luminous energy is in principal much more complex than is the calculation of the direct unscattered radiation that makes up the image. Estimation of the scattered component is accomplished through an adaptation of the method described by Vos<sup>(11)(12)</sup>. Exposures calculated in this way are compared with threshold exposures (for a specified recovery time) determined in laboratory experiments using humans<sup>(13)</sup>. As before, the condition  $E_r = E_r^A$  defines the safe or acceptable separation distance.

According to the procedures discussed above, the curves presented in Figures 13-116, describe distances at which visual acuity will return to 20/120 at the center of the fovea, or at 1-1/2 degrees from the center of the fovea, within 10 seconds under typical cockpit lighting conditions. Figure 12 shows a typical flashblindness envelope.

## V. MISSION PLANNING

The charts (Figures 13-116) included in this section can be used to assess the retinal burn and flashblindness hazard in planning nuclear strike missions. It is assumed that, for planning purposes, the following are known:

- 1) Weapon yield
- 2) Detonation altitude
- 3) Observer altitude
- 4) Day or night detonation

With the charts and this information, allowable separation distances or "danger-zones" can be established. The term "danger-zone" does not mean prohibited zone, but merely that appropriate safety measures should be taken to insure aircrew eye safety while in the zone. Each of the curves has the same format, with altitude given in thousands of feet and horizontal range given in nautical miles. Figures 11 and 12 illustrate the use of the retinal burn and flashblindness charts in determining allowable separation distances. The steps to be followed in using a chart are outlined below:

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 2.0 KT

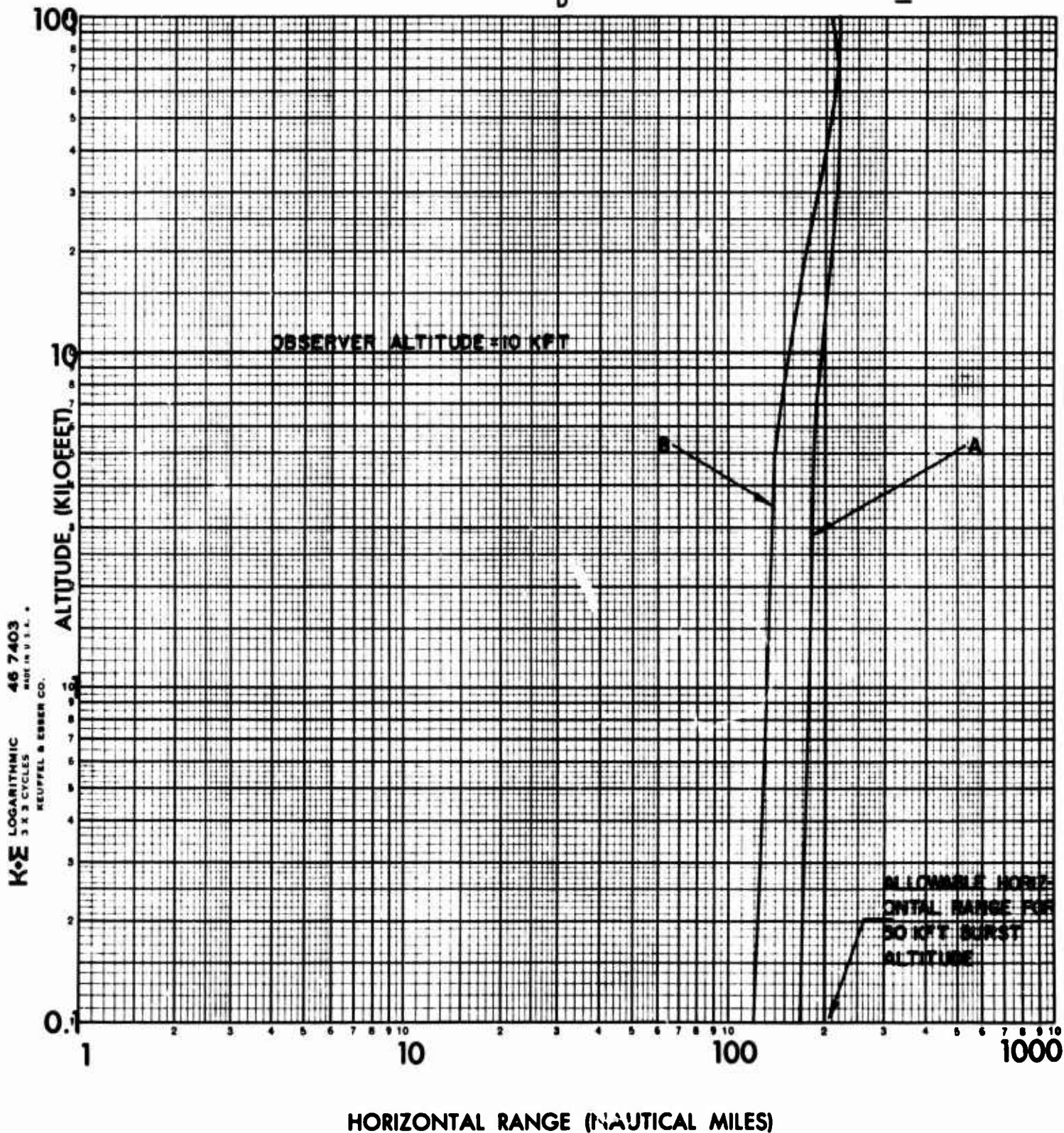
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100
- 
- 



K-E LOGARITHMIC 46 7403 3 X 3 CYCLES KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 12. Typical flashblindness safe separation envelope.

- 1) Select the set of "day" or "night" curves for the weapon yield under consideration. Each curve applies to a particular burst altitude as noted in the legend. Identify the curve which represents the desired burst altitude.
- 2) Select the observer altitude on the ordinate and follow this altitude horizontally to its intersection with the envelope curve.
- 3) The abscissa of the point of intersection is then the allowable separation distance. This value can be used directly on a map, or the slant range can be calculated as follows:

$$\text{Slant Range (Naut. Miles)} = \left[ (\text{Horiz. Range})^2 + \left( \frac{\text{Obs. Alt.} - \text{Burst Alt.}}{6.08} \right)^2 \right]^{1/2}$$

Where Horizontal Range is in nautical miles and both Observer Altitude and Burst Altitude are in kilofeet.

Safe separation envelopes have been calculated for detonations during daylight (with and without a 2% gold visor for protection) and for night detonations. The protection afforded by the gold visor is sufficient to eliminate the hazard of retinal burns for day exposures for all of the situations considered, therefore, no envelopes are presented for this combination of conditions.

It should be emphasized that the "safe separation" distances presented here pertain only to retinal burns or flashblindness and are specific to the exposure conditions assumed, e. g. 0.25 second or 0.45 second blink time, 2.5 mm or

6.5 mm pupil diameter, etc. If an allowable distance for flashblindness is less than an allowable retinal burn distance, the conclusion is simply that retinal burns present the limiting approach distance insofar as these two phenomena are concerned. It may be that in some instances the blast, thermal, or radiation hazard extends to a greater distance than either the flashblindness or retinal burn hazard. In this case, the allowable approach distance is not determined by retinal burns or flashblindness.

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RETINAL BURN AND FLASHBLINDNESS SAFE SEPARATION ENVELOPES

FIGURES 13-116



RETINAL BURN SAFE SEPARATION ENVELOPES

DAY MISSION

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 0.02 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1  
 10  
 25  
 50

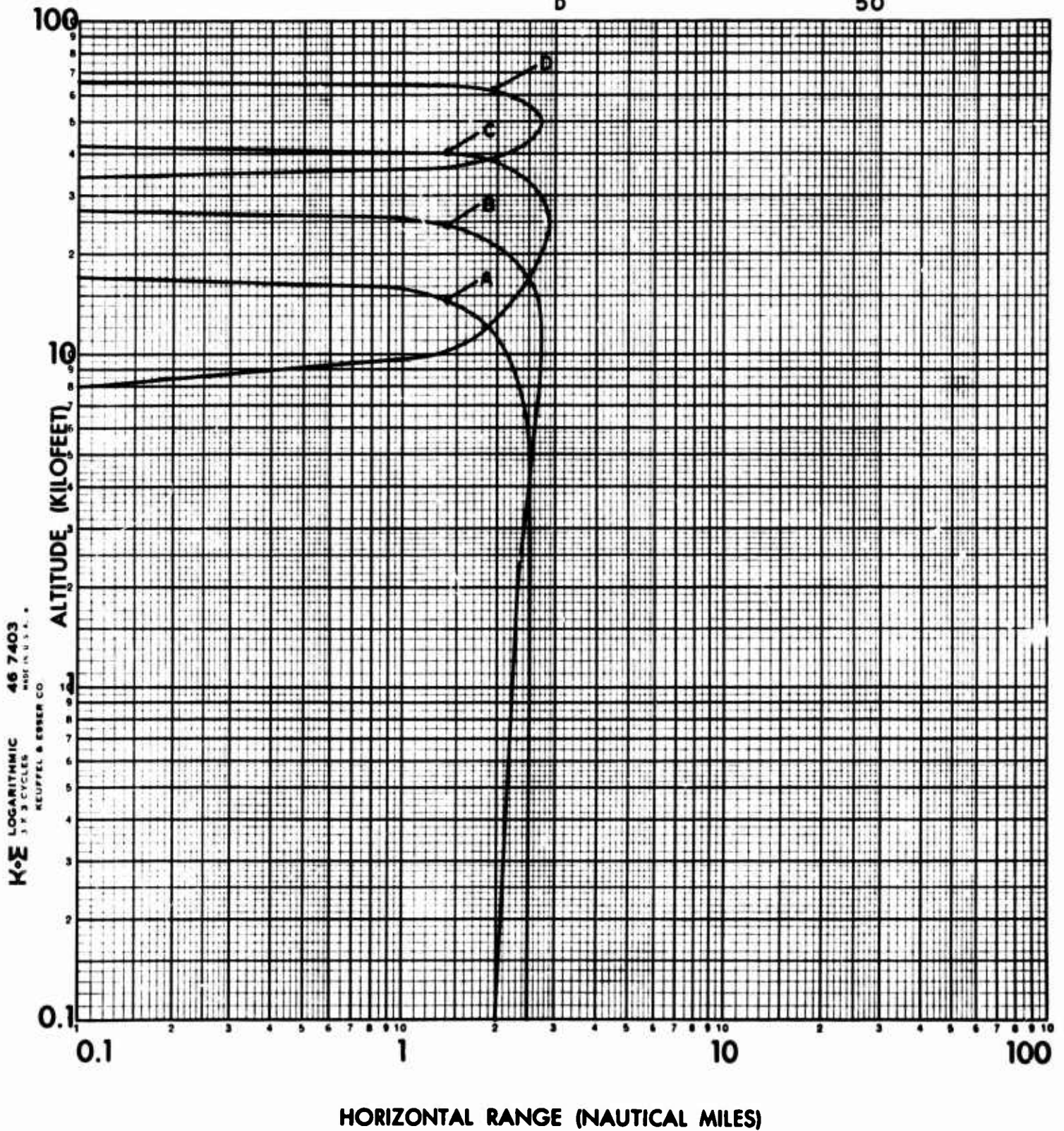


FIGURE 13

# RETINAL BURN

DAY      MISSION

YIELD: 0.02 KT

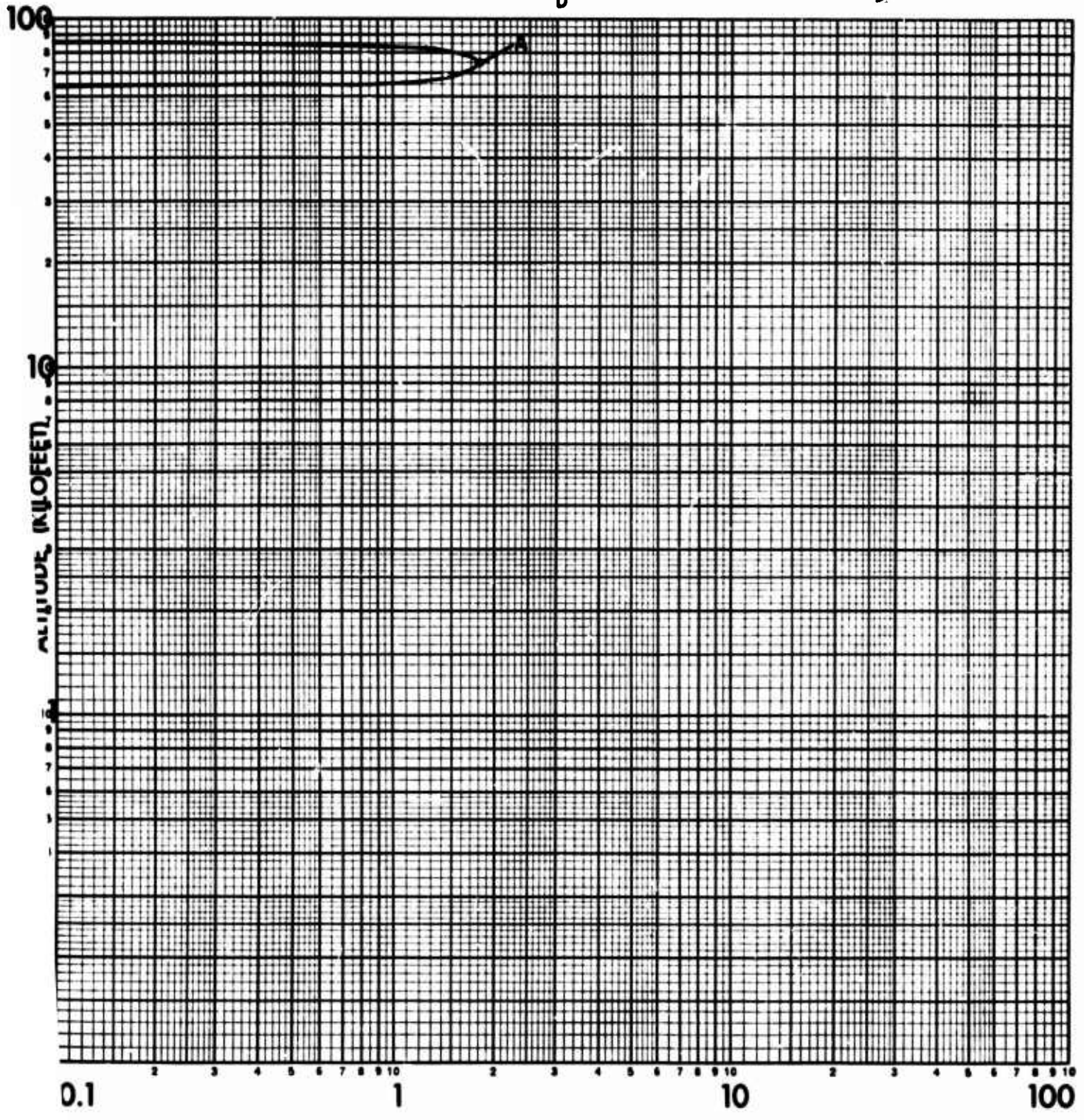
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 75
- 
- 
- 



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 14

No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 0.02 KT

HB = 100 KFT

FILTER: NONE

FIGURE 15

# RETINAL BURN

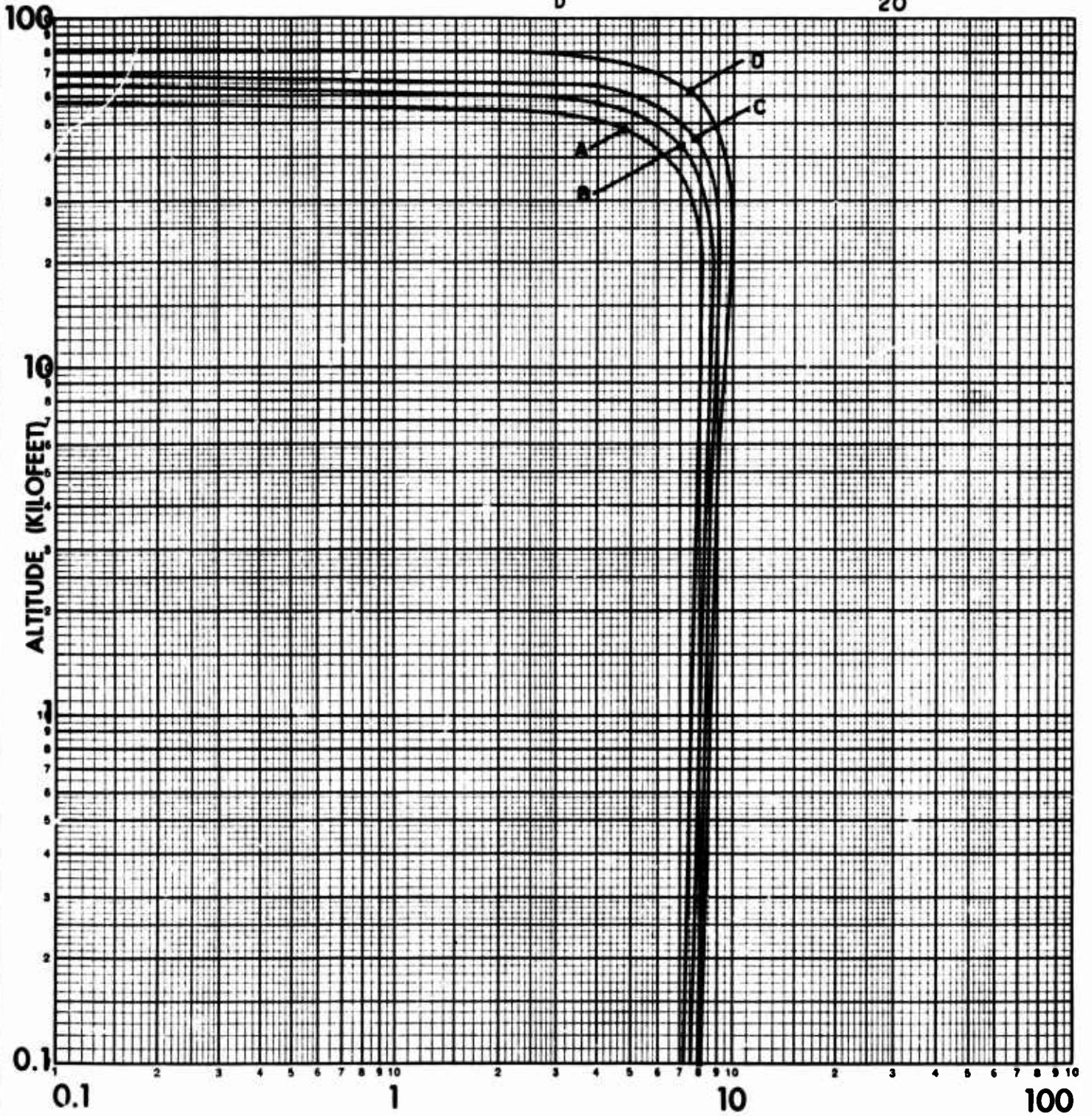
DAY      MISSION  
 YIELD: 0.6 KT  
 FILTER: NONE

SYMBOL

BURST ALTITUDE (Kilofeet)

A  
B  
C  
D

1  
5  
10  
20

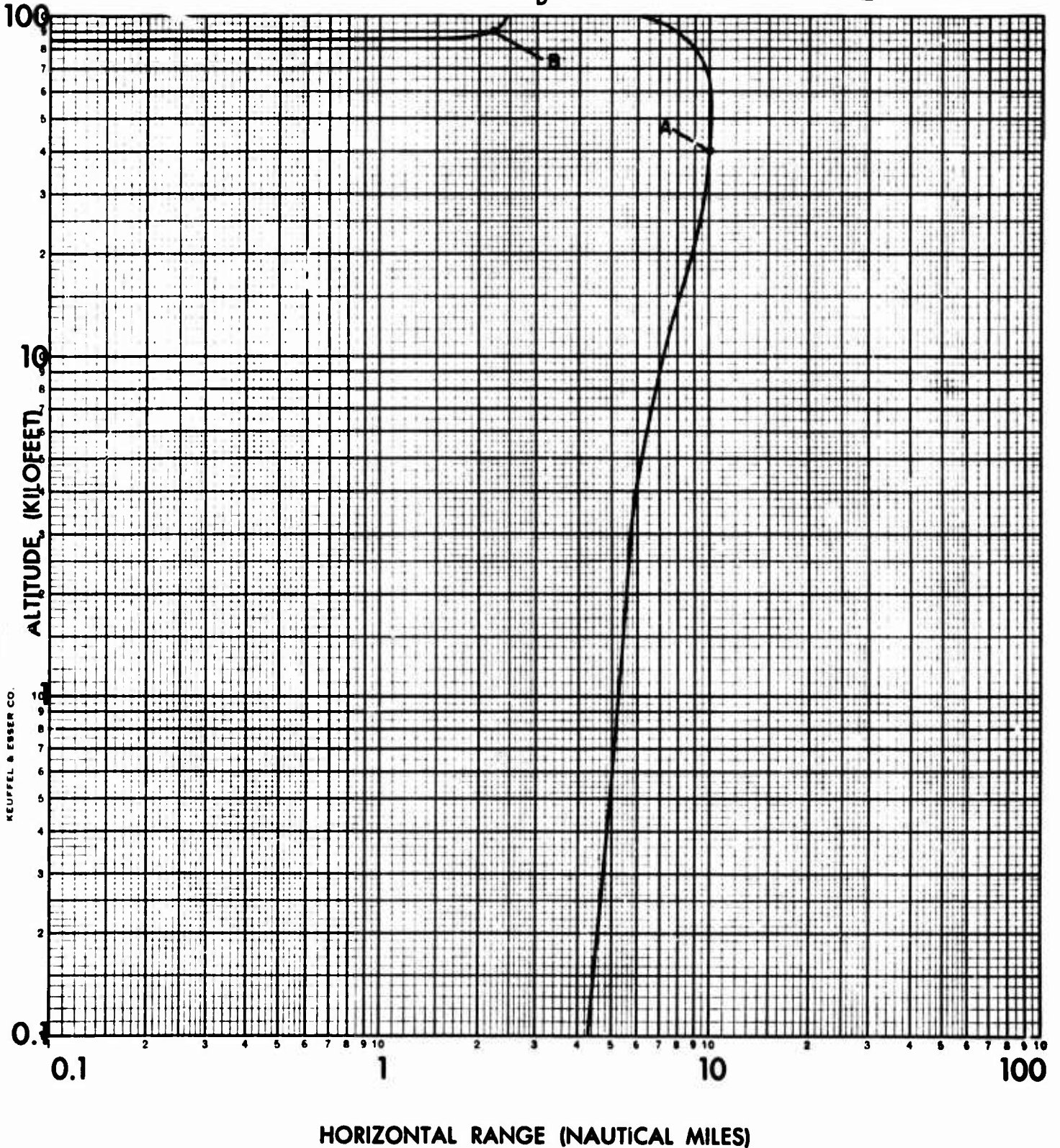


HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 16

# RETINAL BURN

DAY	MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 0.6	KT	A	50
FILTER: NONE		B	100
		C	-
		D	-



K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 17

# RETINAL BURN

DAY    MISSION

YIELD: 2.0 KT

FILTER: NONE

SYMBOL

A

B

C

D

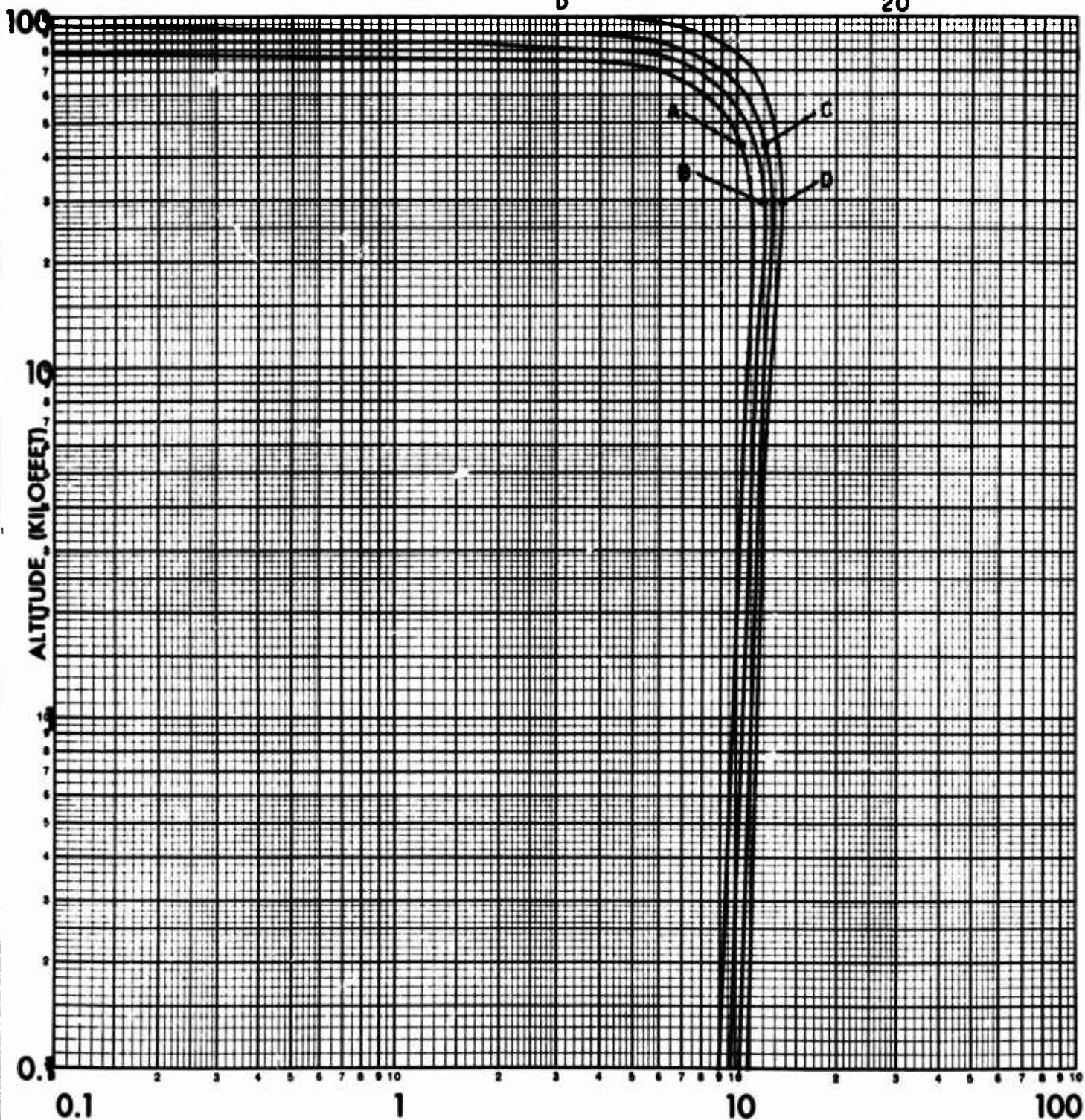
BURST ALTITUDE (Kilofeet)

1

5

10

20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 18

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 2 KT

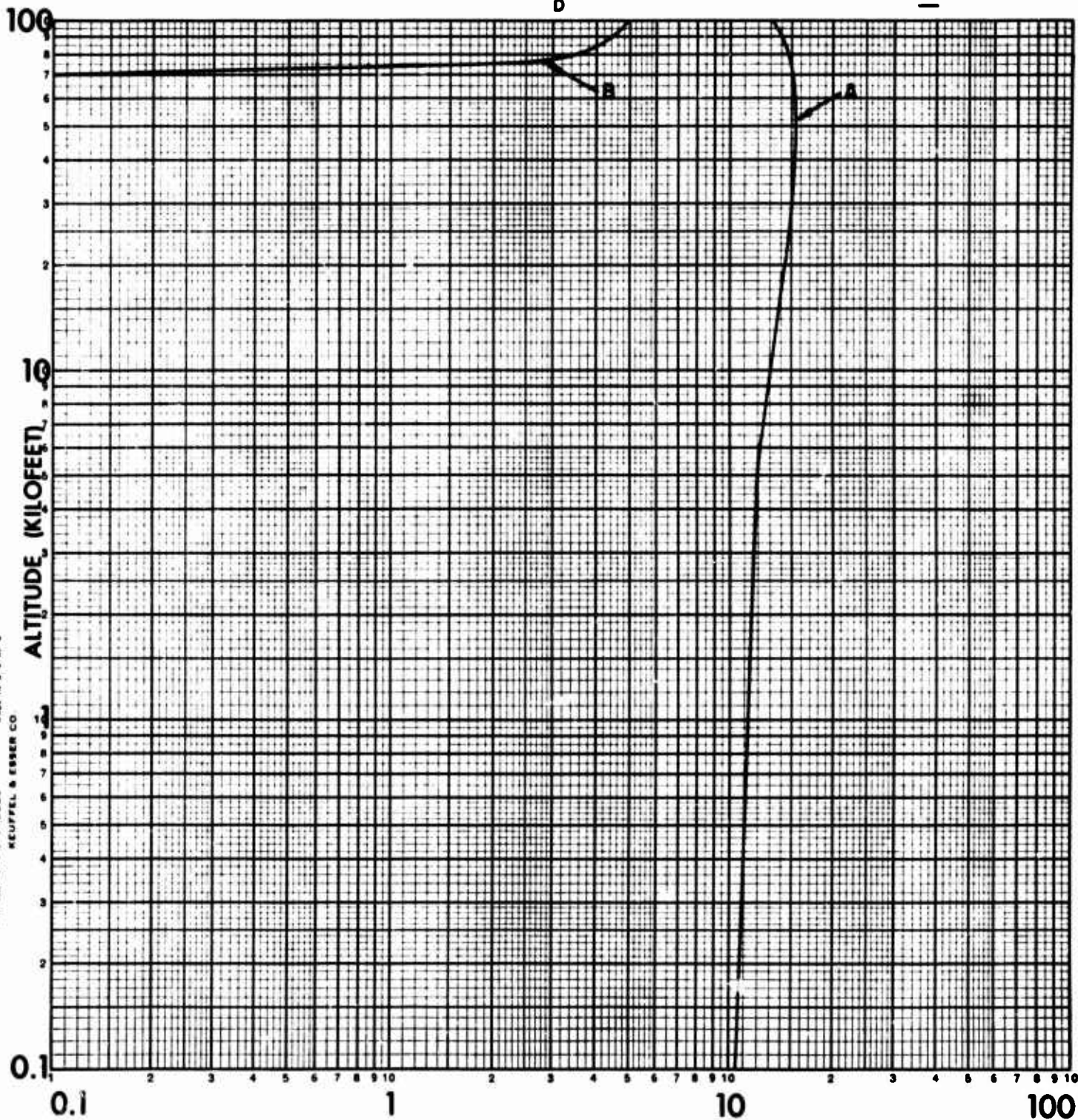
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100
- 
- 



K-O-S LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 19



# RETINAL BURN

DAY    MISSION

YIELD: 10    KT

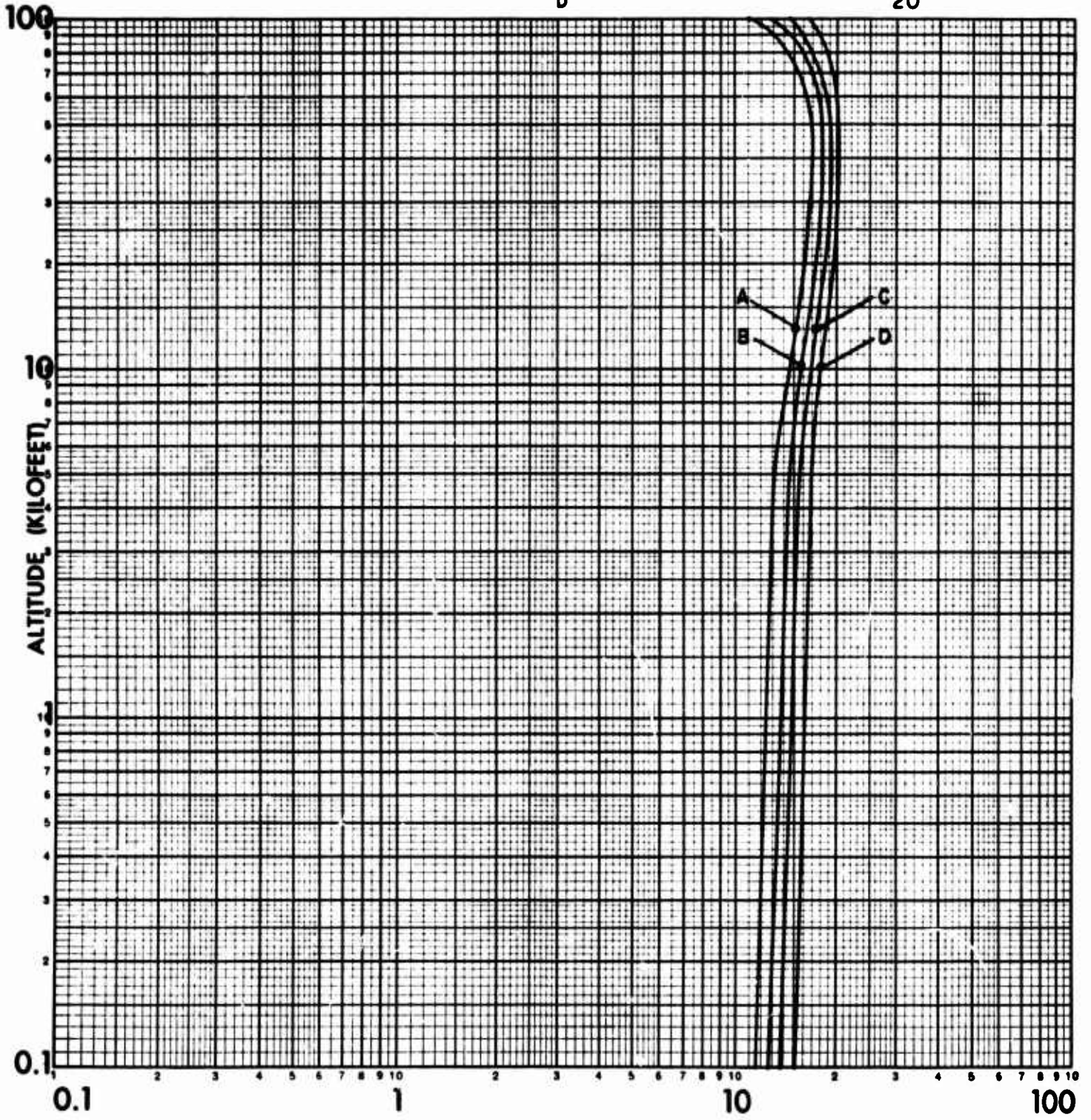
FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20



HORIZONTAL RANGE (NAUTICAL MILES)

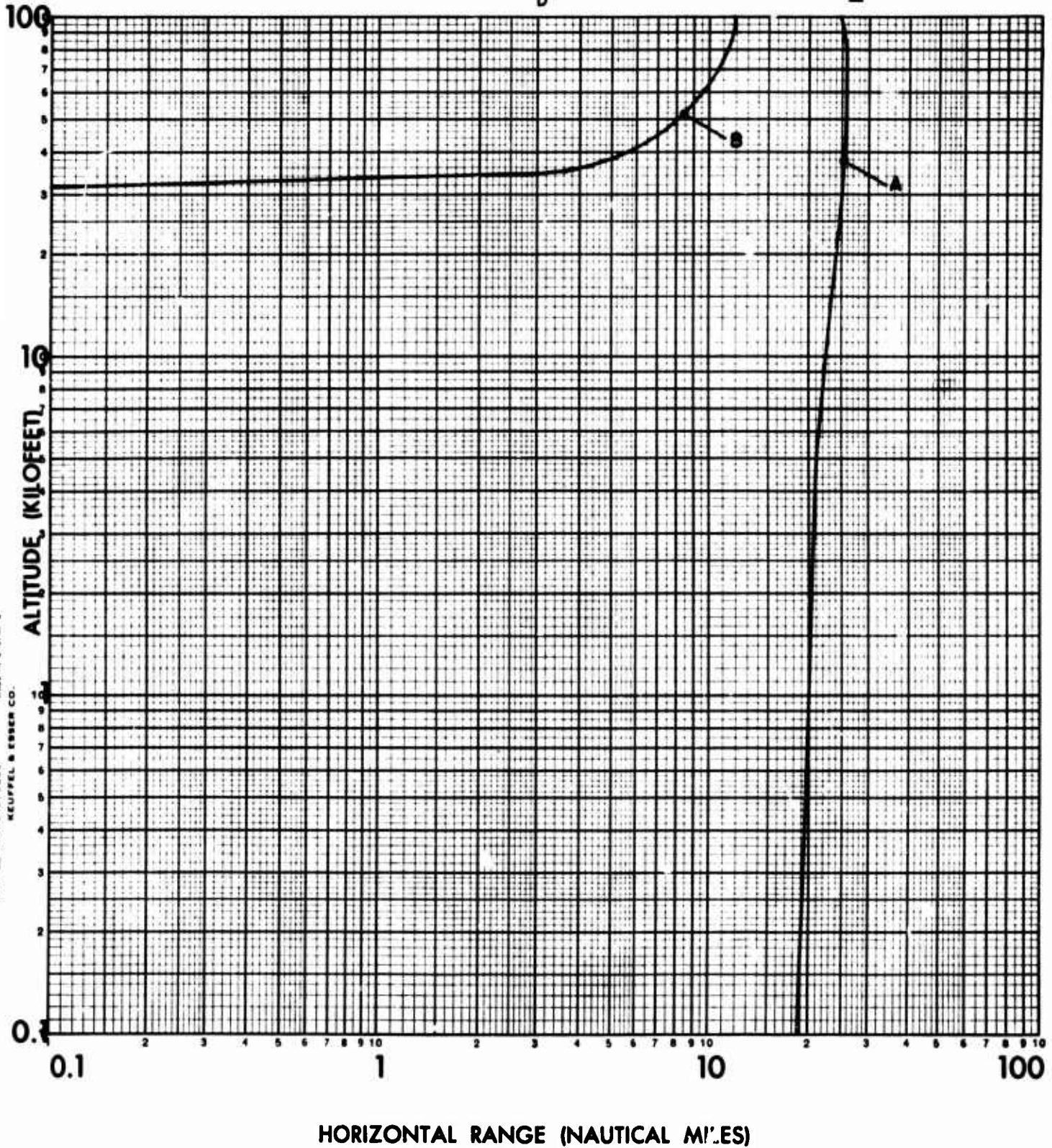
FIGURE 20

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 10 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100  
 -  
 -



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 21

MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 30 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 1
- 5
- 10
- 20

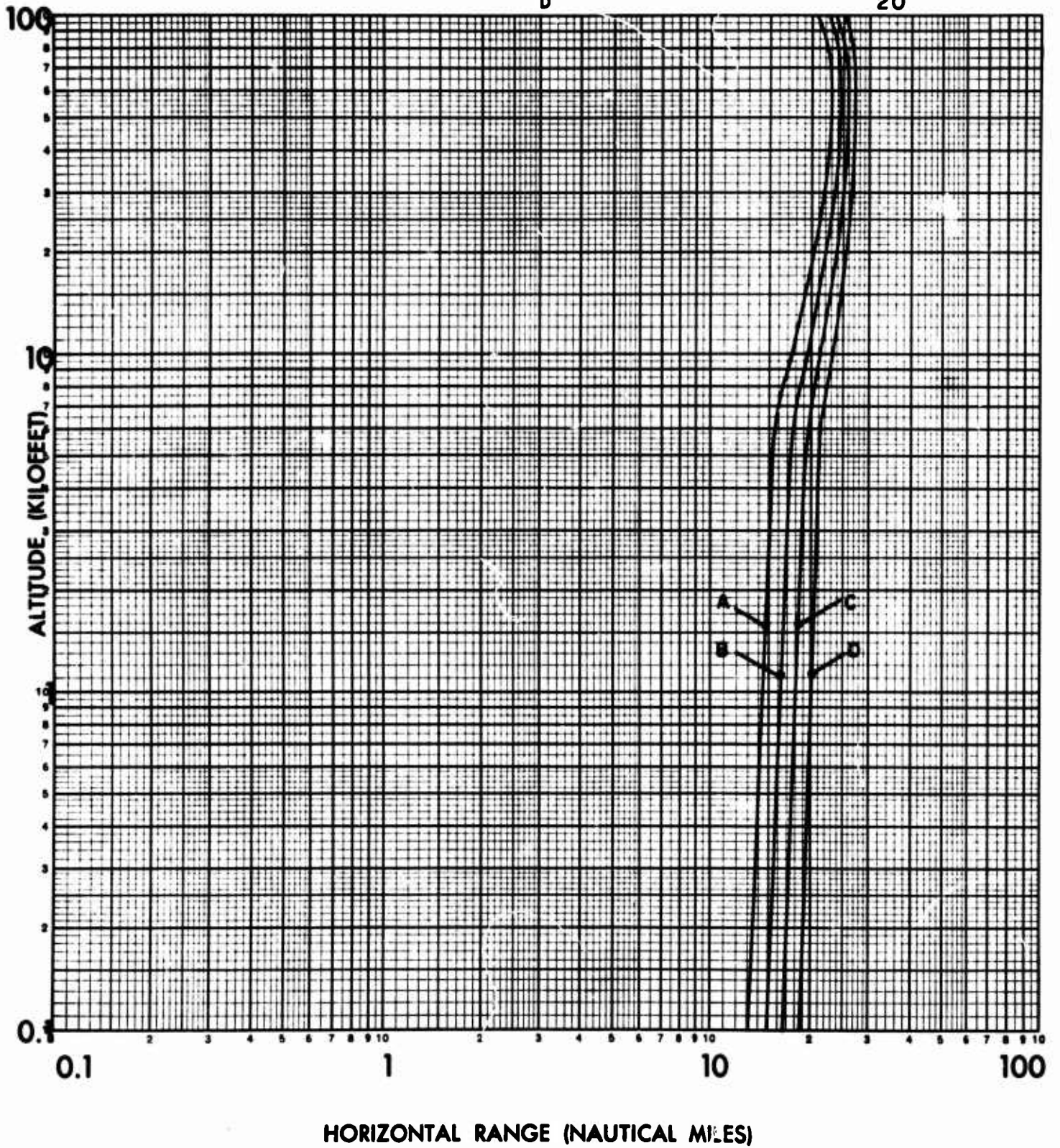


FIGURE 22

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 30 KT

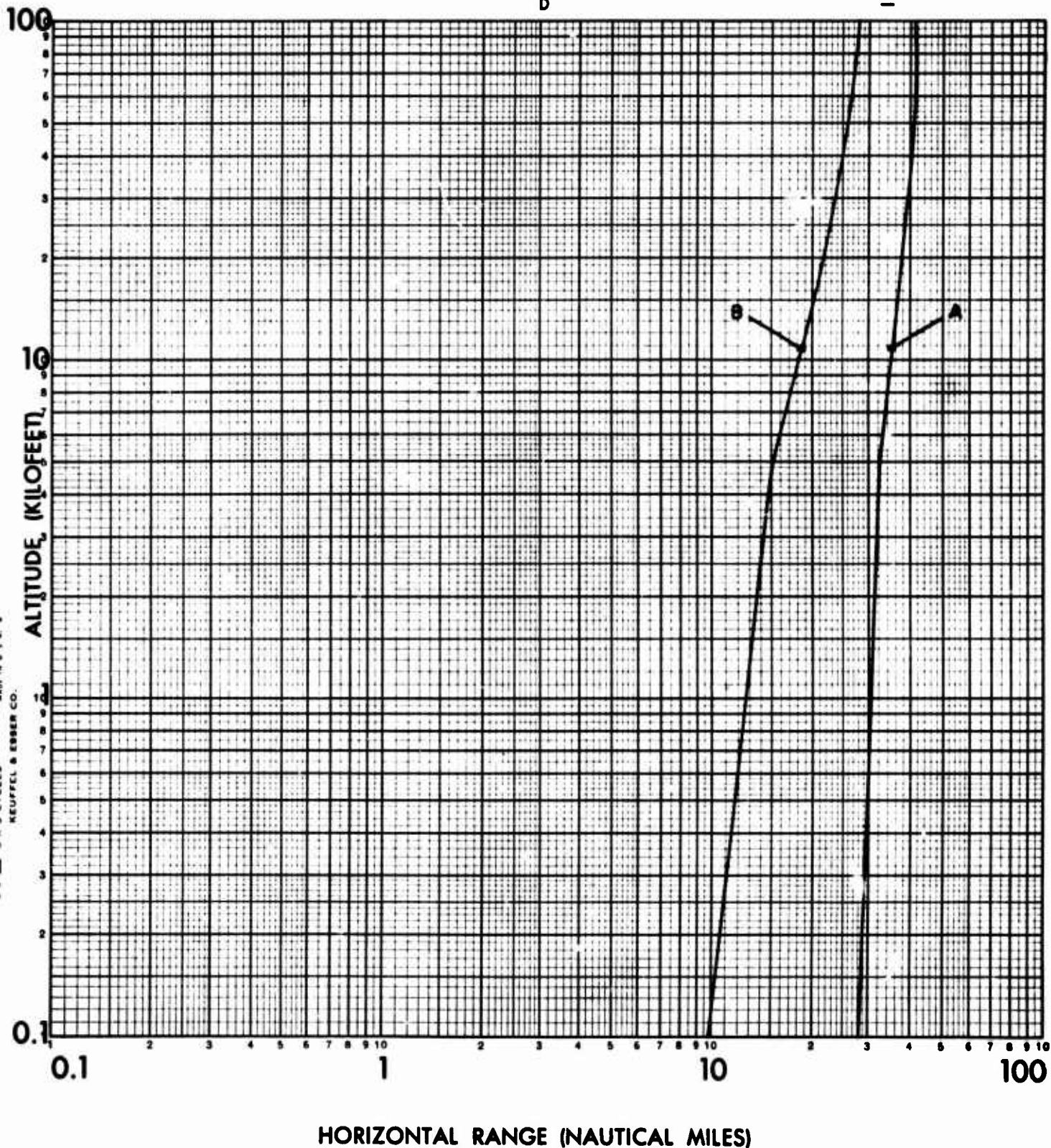
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100
- 
- 



K-E LOGARITHMIC 46 7403 MADE IN U.S.A. KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 23

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 60 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1  
 5  
 10  
 20

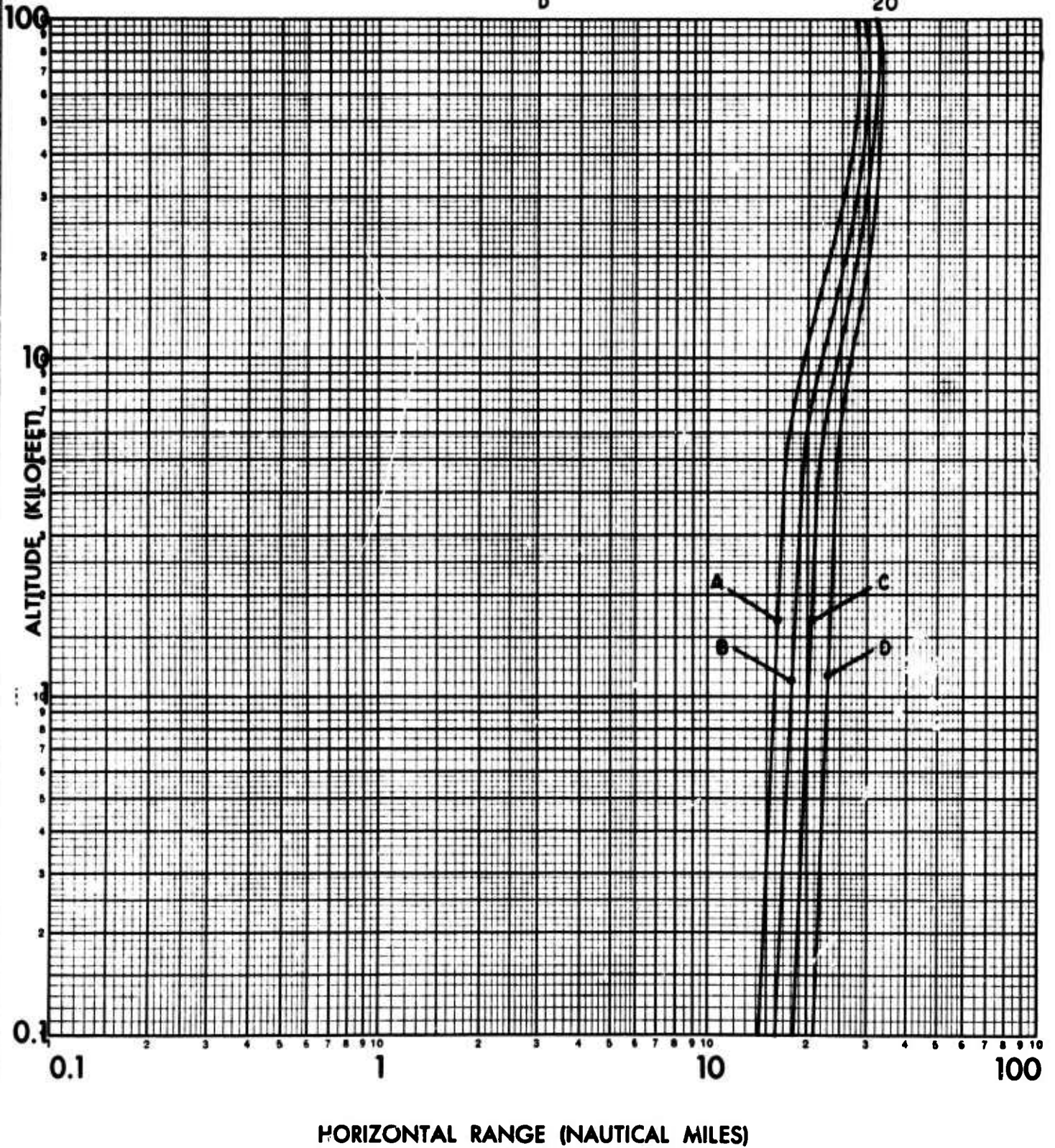
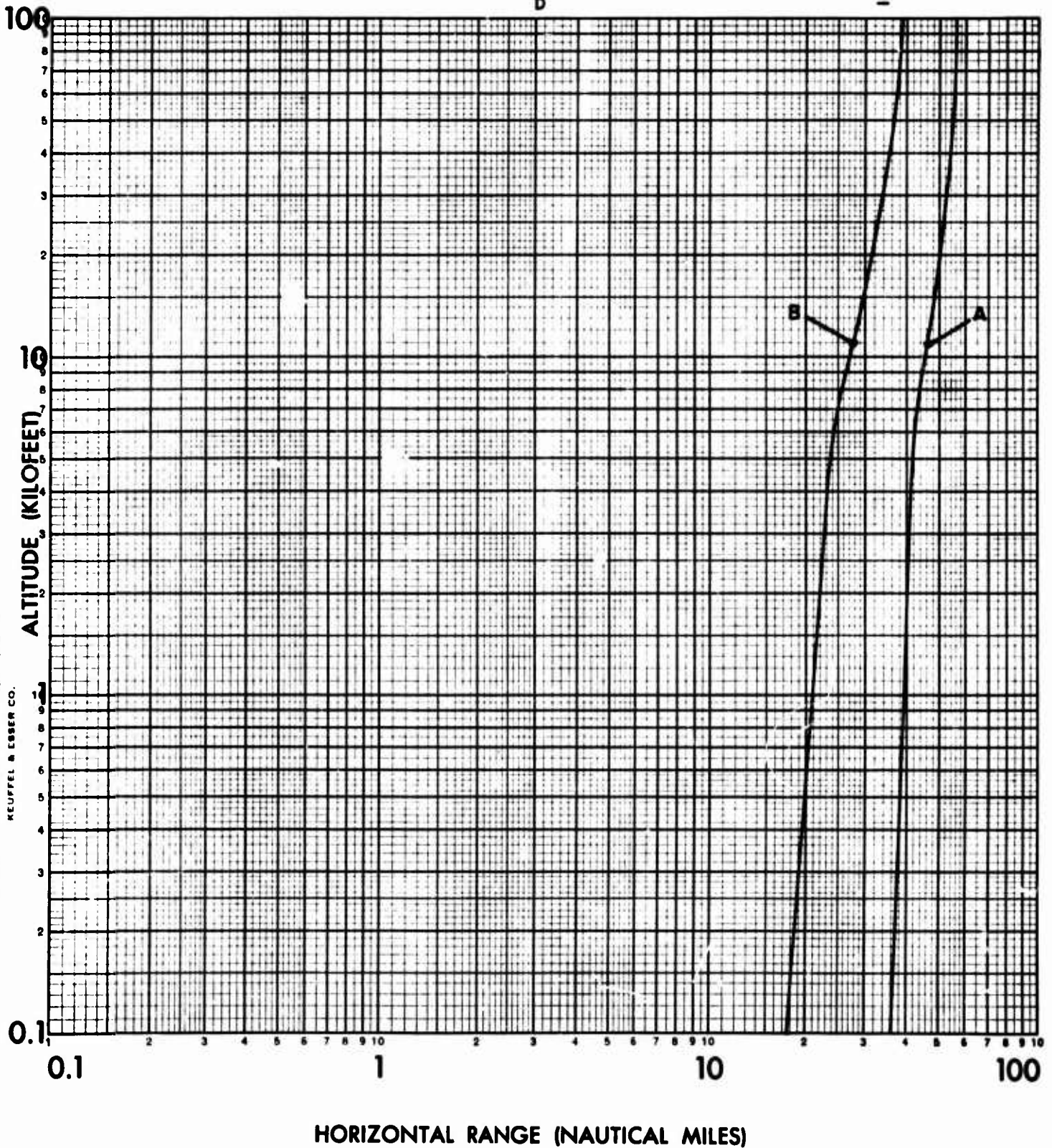


FIGURE 24

# RETINAL BURN

<u>DAY</u>	<u>MISSION</u>	<u>SYMBOL</u>	<u>BURST ALTITUDE (Kilofeet)</u>
YIELD: 60	KT	A	50
FILTER: NONE		B	100
		C	-
		D	-



K&E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO. MADE IN U.S.A.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 25

# RETINAL BURN

DAY      MISSION  
 YIELD: 200 KT  
 FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5.0
C	10.0
D	20.0

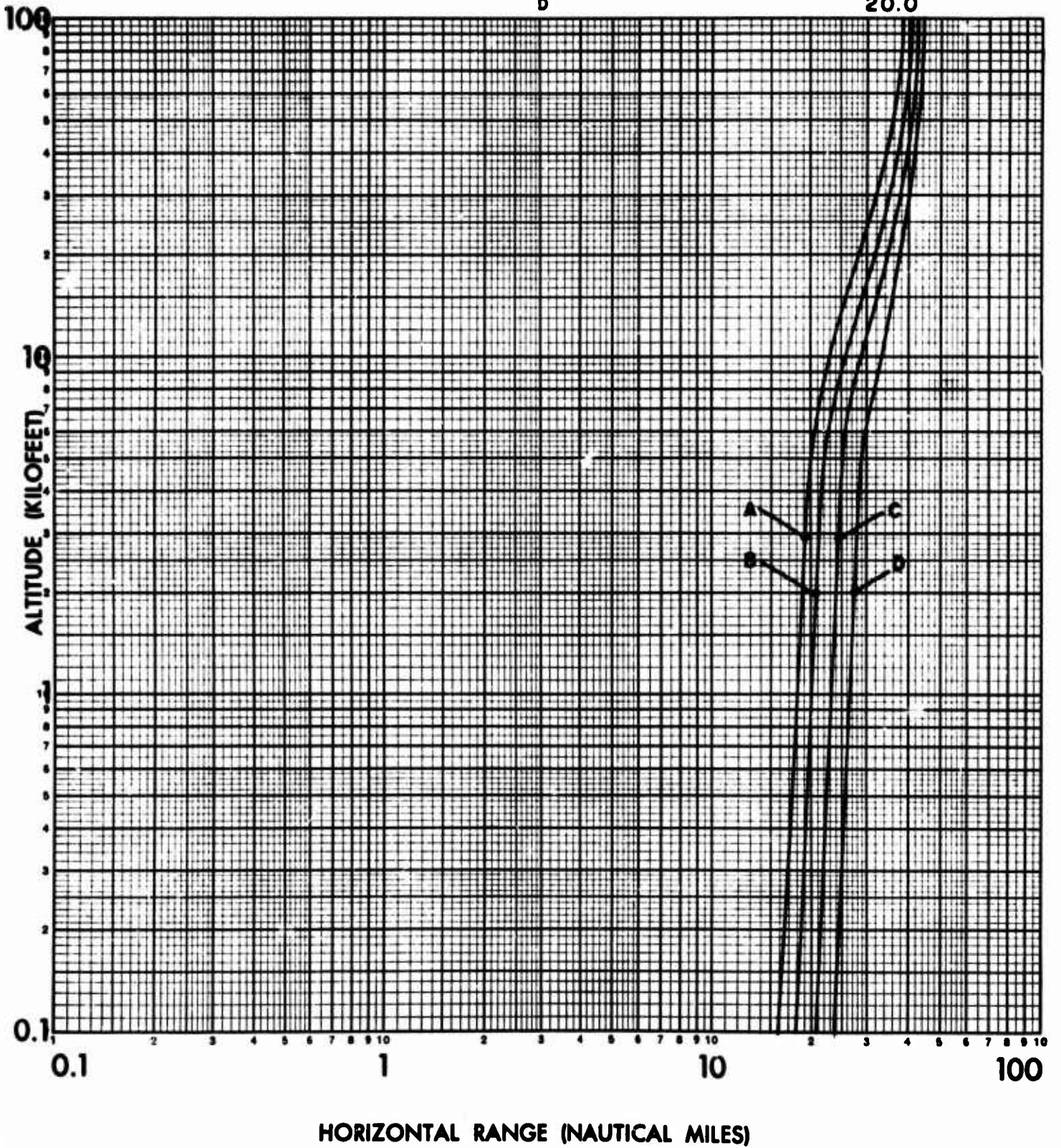


FIGURE 26

# RETINAL BURN

DAY    MISSION

YIELD: 200    KT

FILTER: NONE

SYMBOL

A

B

C

D

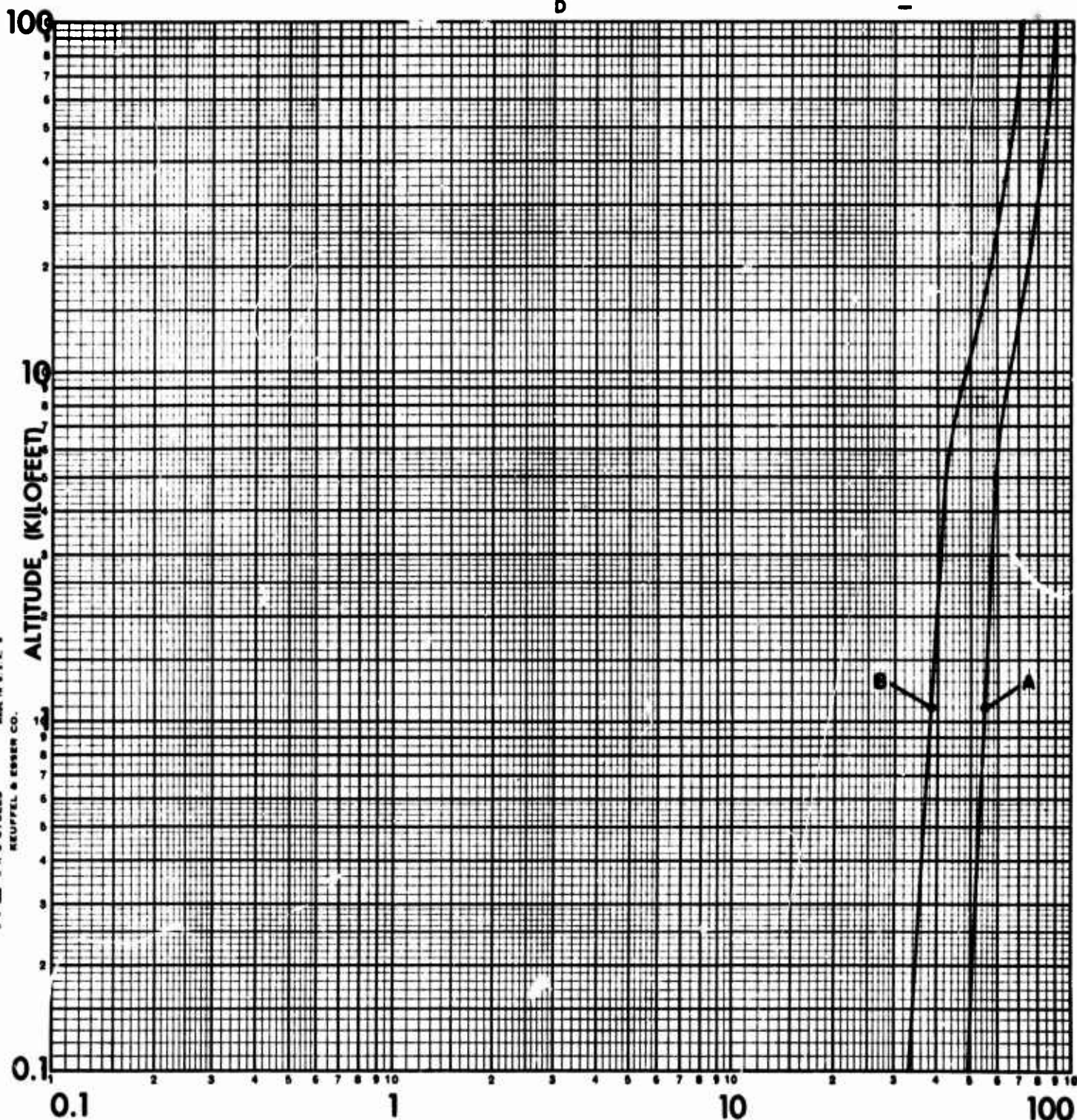
BURST ALTITUDE (Kilofeet)

50

100

-

-



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 27

K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 MADE IN U.S.A.  
 REUFFEL & ESSER CO.



# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 440 KT

FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1.5  
5  
10  
20

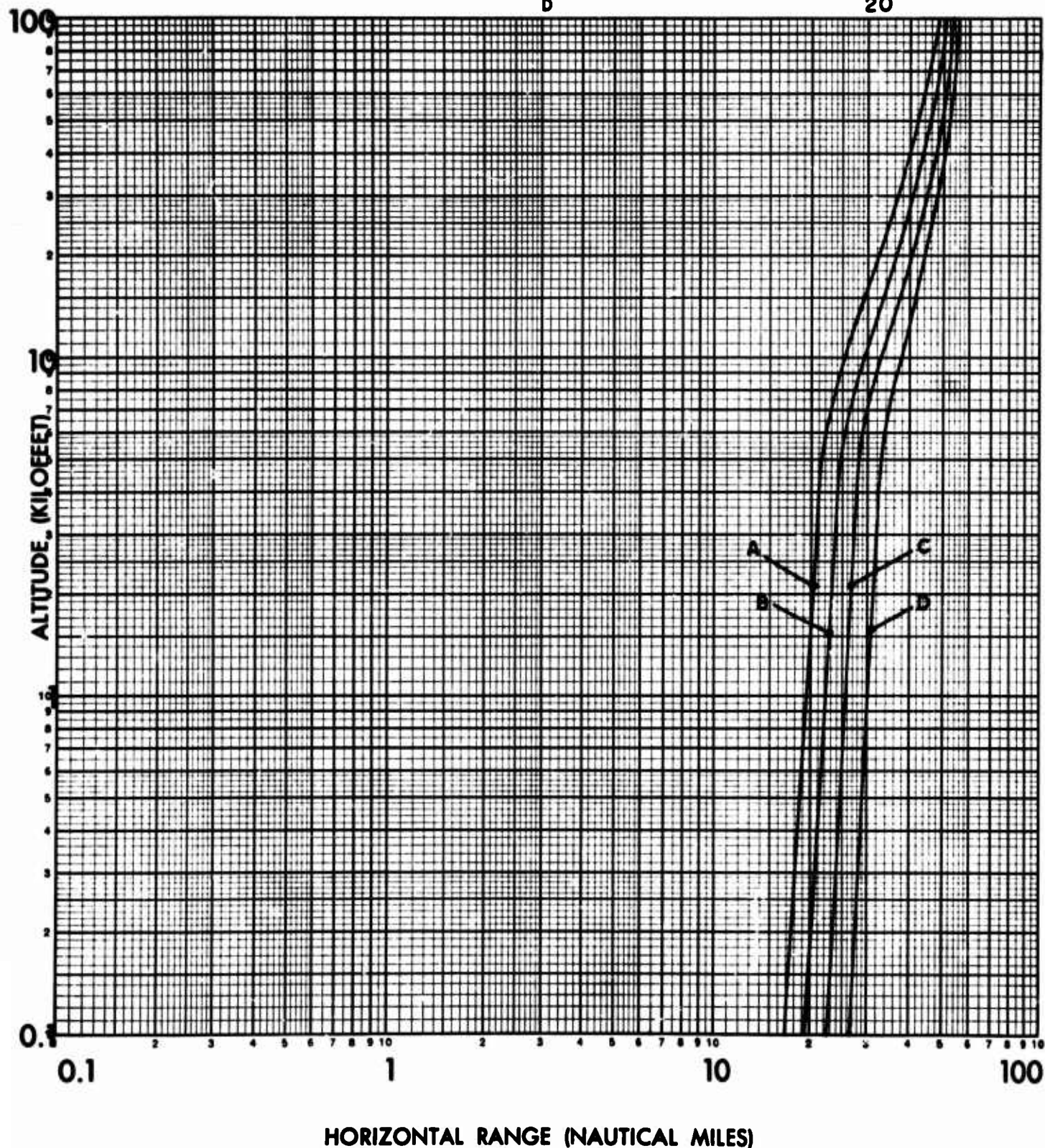


FIGURE 28

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 440 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100  
 -  
 -

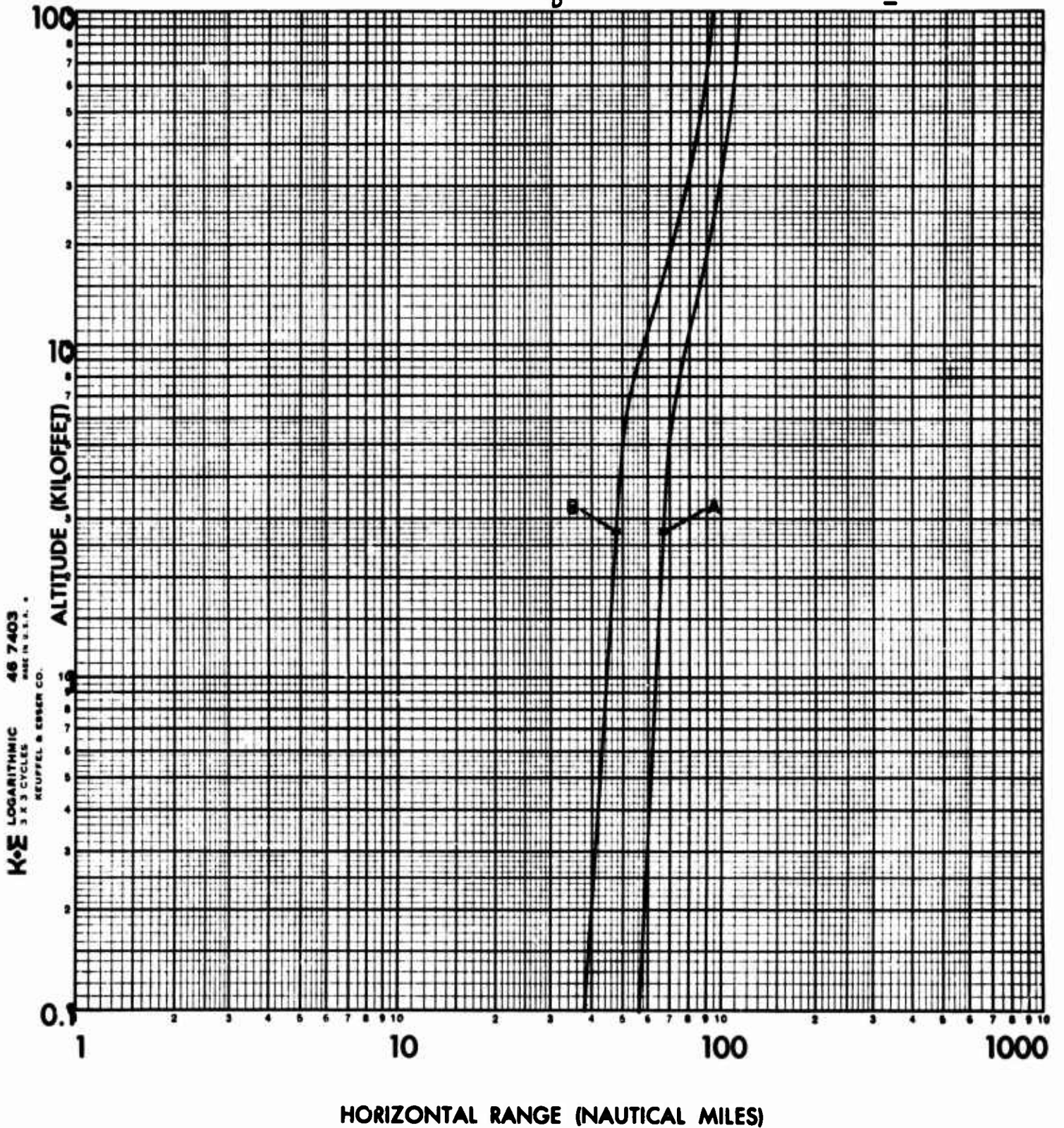


FIGURE 29

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 1000 KT

FILTER: NONE

SYMBOL

A

B

C

D

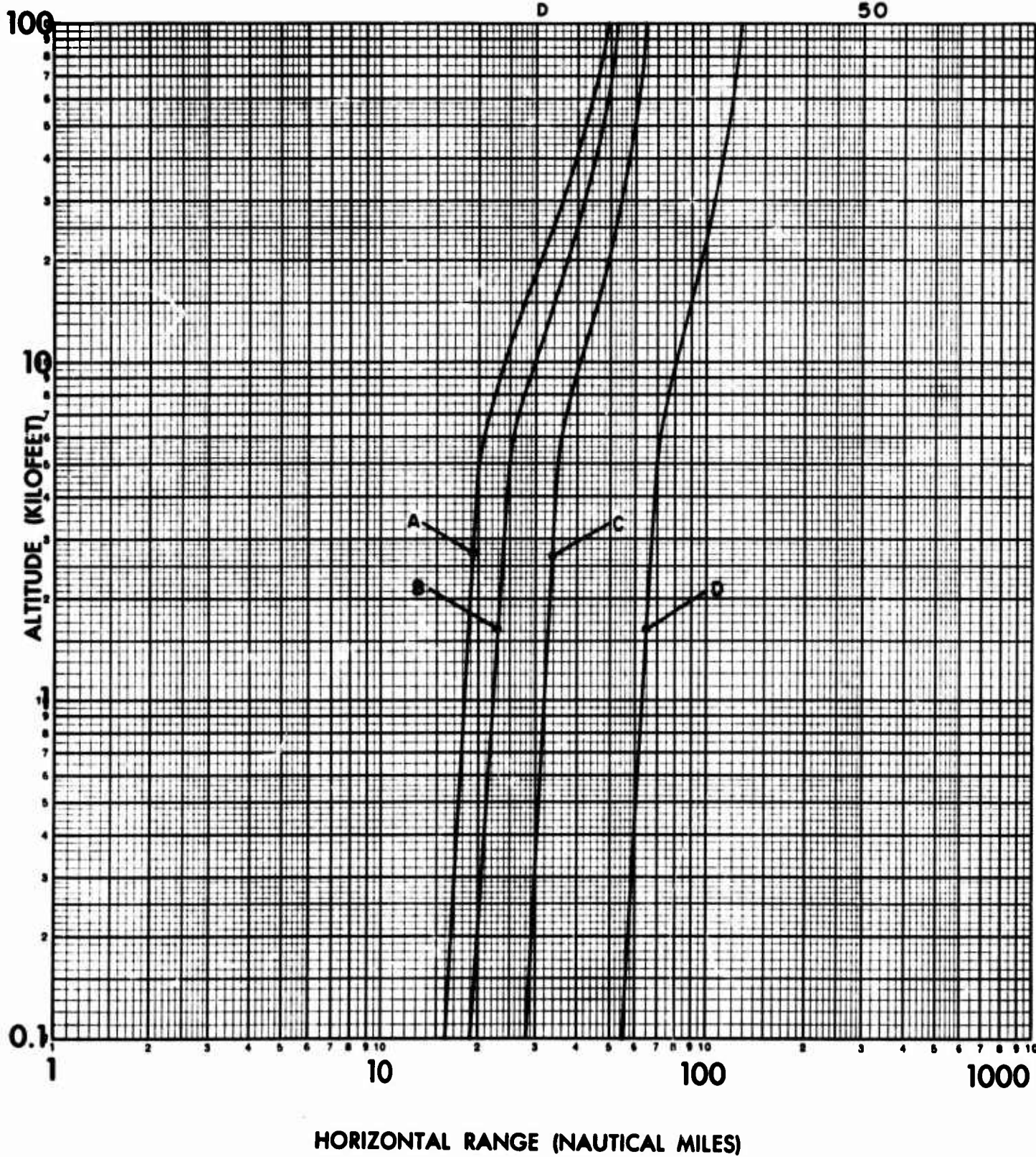
BURST ALTITUDE (Kilofeet)

3

10

25

50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 30

# RETINAL BURN

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 3800 KT

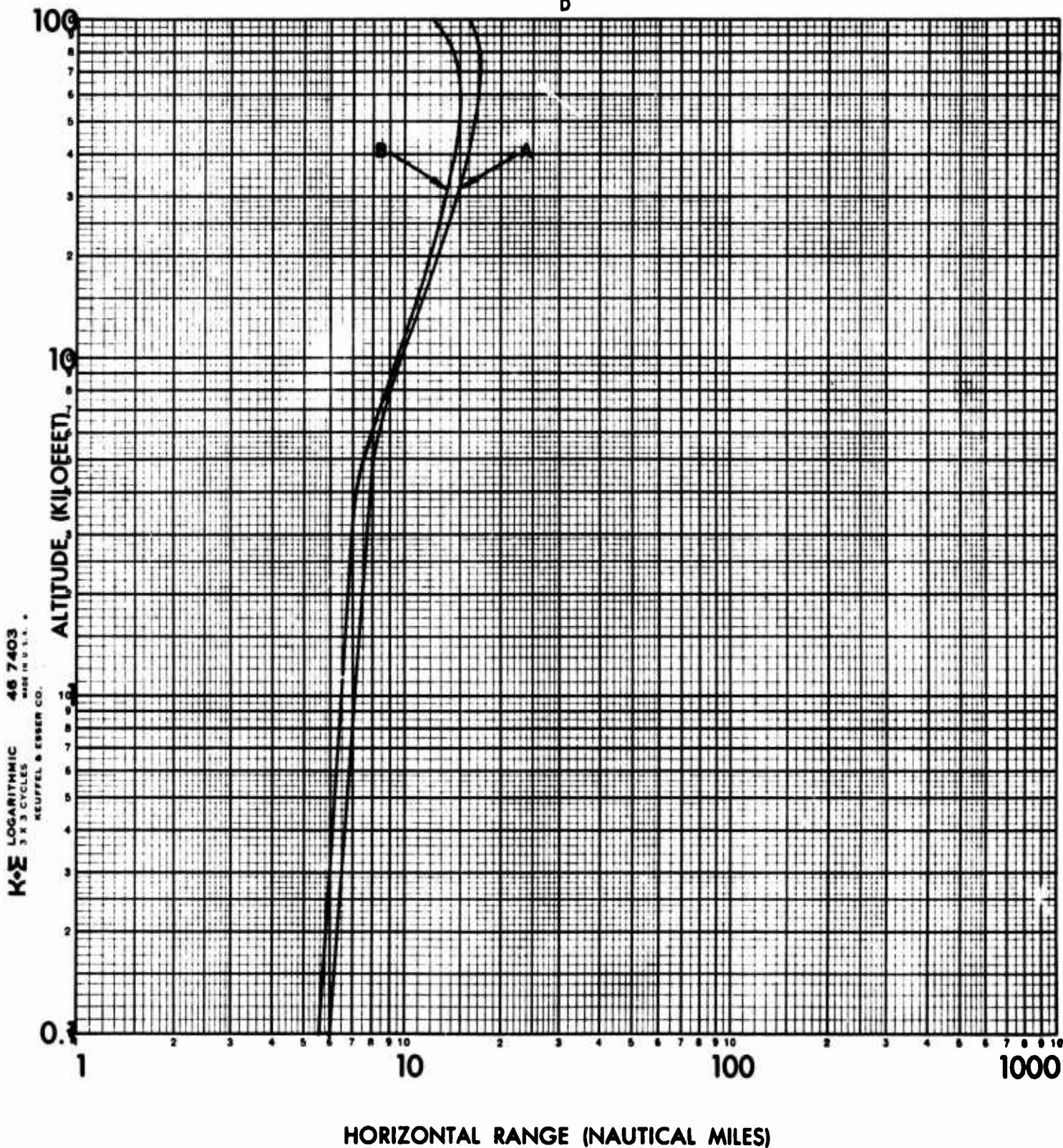
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 4
- 10



K-E LOGARITHMIC 46 7403  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 31

# RETINAL BURN

<u>DAY</u>	<u>MISSION</u>	<u>SYMBOL</u>	<u>BURST ALTITUDE (Kilofeet)</u>
YIELD: <u>3800</u>	KT	A	25
FILTER: <u>NONE</u>		B	50
		C	-
		D	-

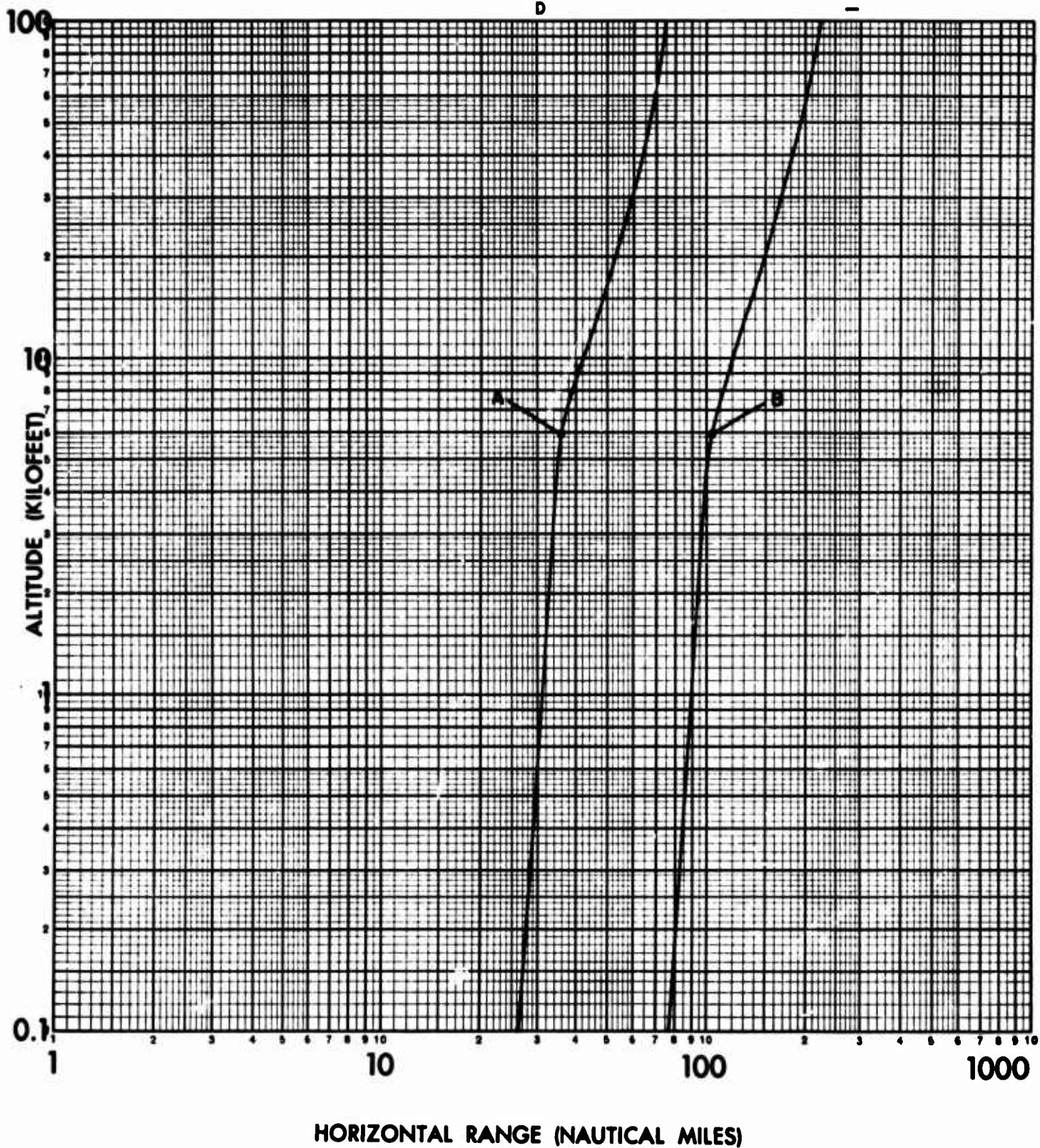


FIGURE 32

No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 9000 KT

HB = 5 KFT and 10 KFT

FILTER: NONE

FIGURE 33

# RETINAL BURN

DAY      MISSION  
 YIELD: 9000 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 25  
 50  
 -  
 -

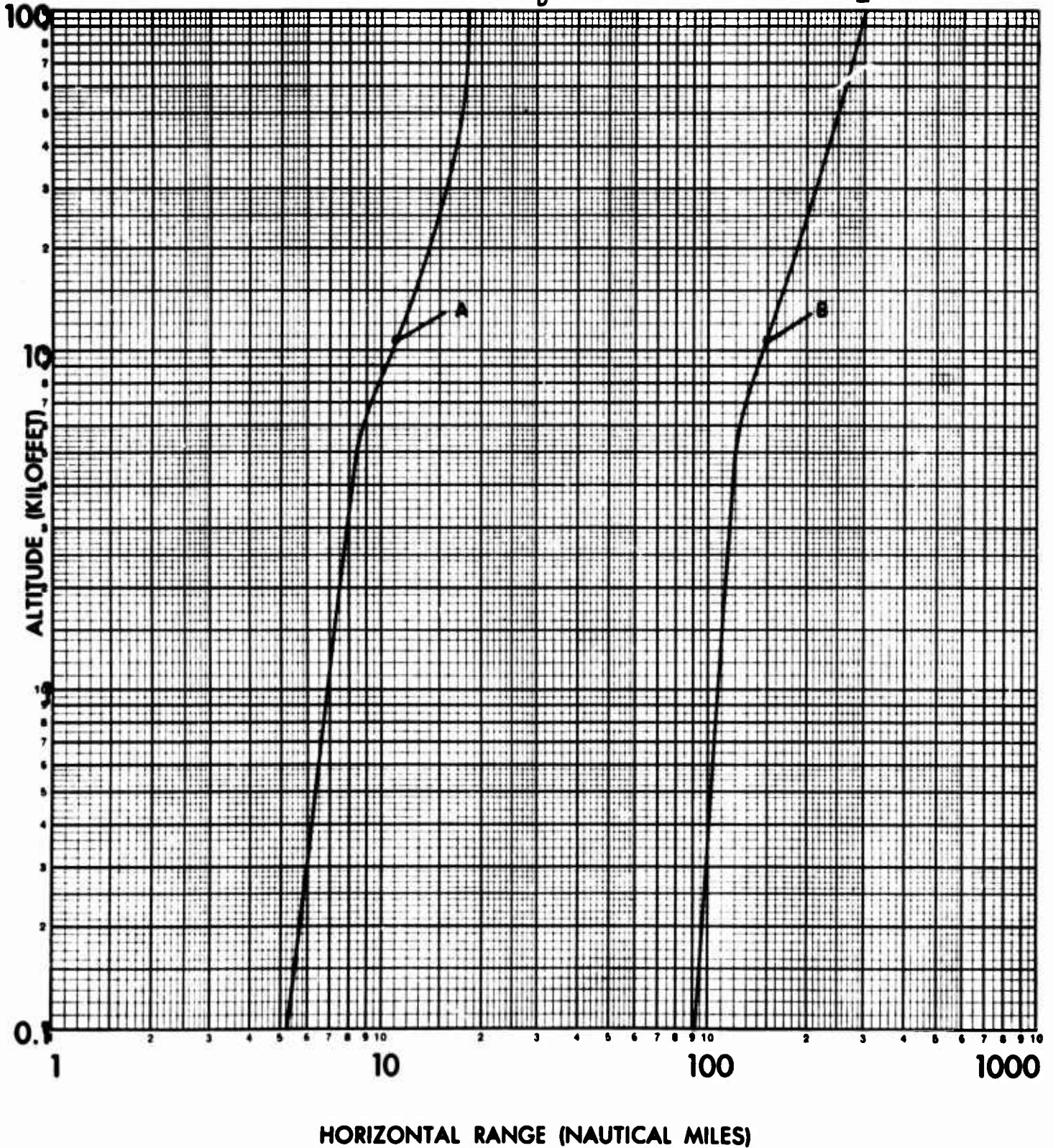


FIGURE 34

# RETINAL BURN

DAY      MISSION  
 YIELD: 23000 KT  
 FILTER: NONE

SYMBOL

BURST ALTITUDE (Kilofeet)

- |   |    |
|---|----|
| A | 6. |
| B | 25 |
| C | 50 |
| D | -  |

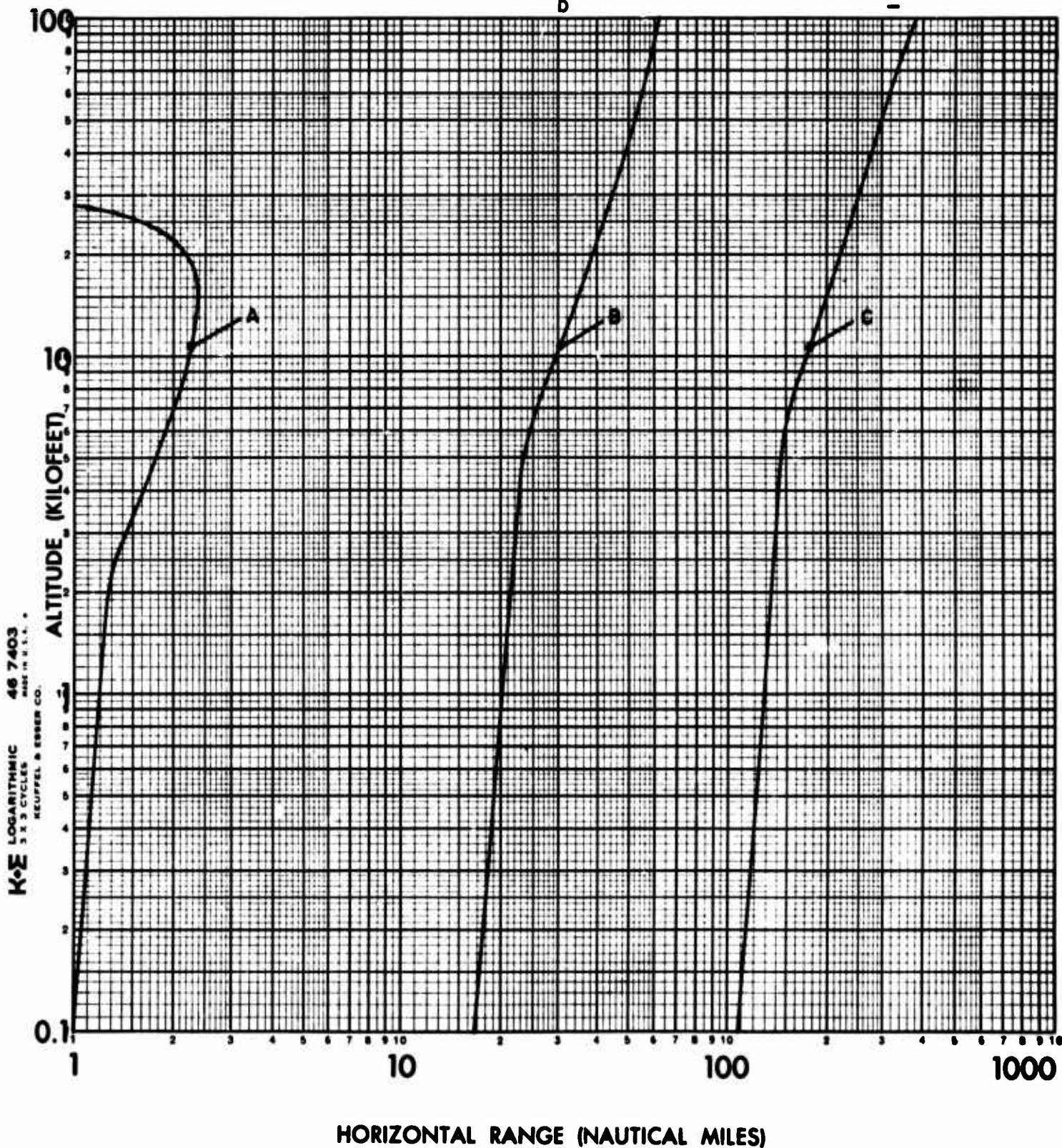


FIGURE 35



No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 23000 KT

HB = 10 KFT

FILTER: NONE

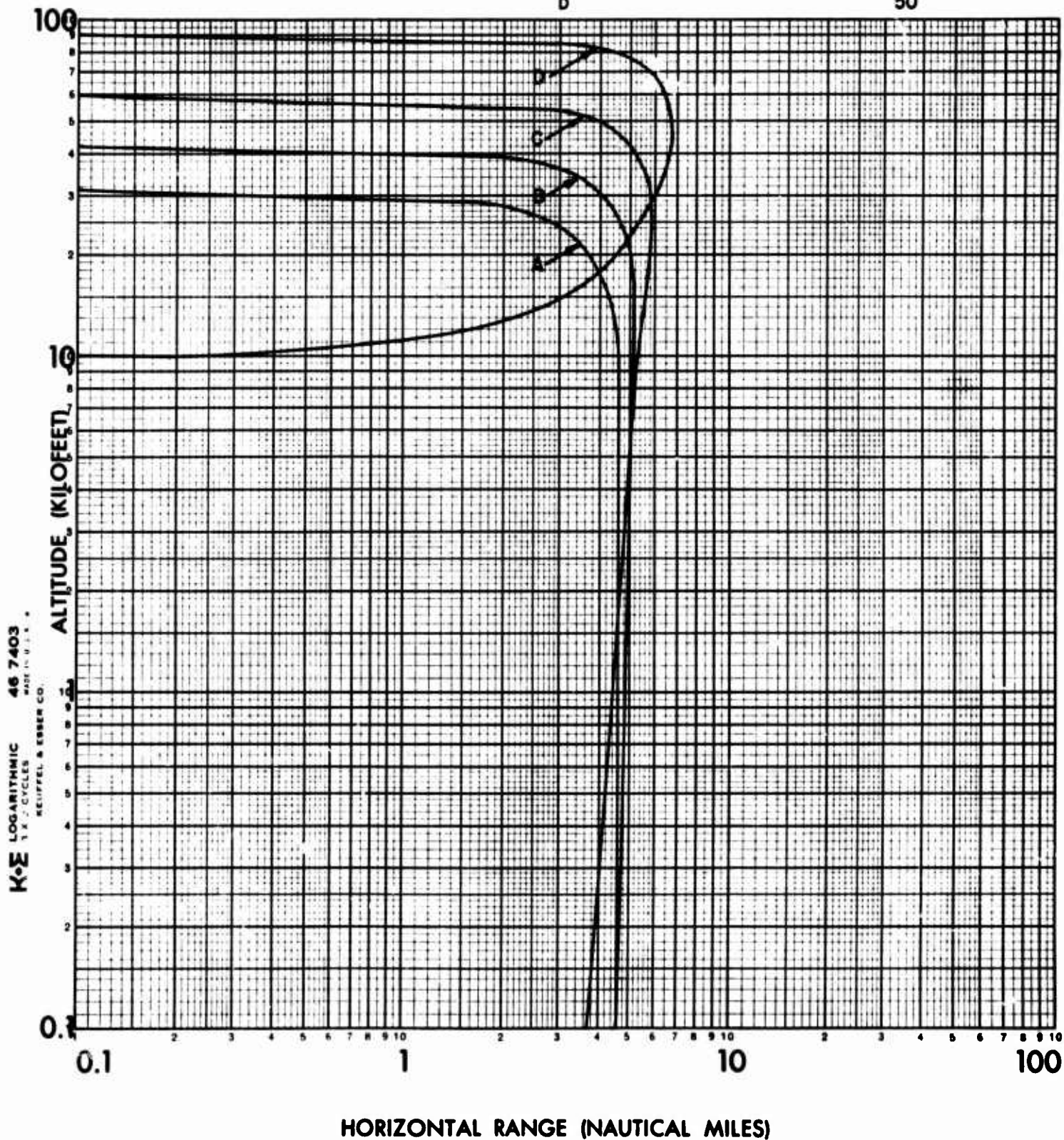
FIGURE 36

RETINAL BURN SAFE SEPARATION ENVELOPES

NIGHT MISSION

# RETINAL BURN

<u>NIGHT</u>	MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: <u>0.02</u>	KT	A	1
FILTER: <u>NONE</u>		B	10
		C	25
		D	50



K&E LOGARITHMIC 46 7403  
 1 X 7 CYCLES  
 REIFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 37

# RETINAL BURN

NIGHT MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 75
- 100
- 
- 

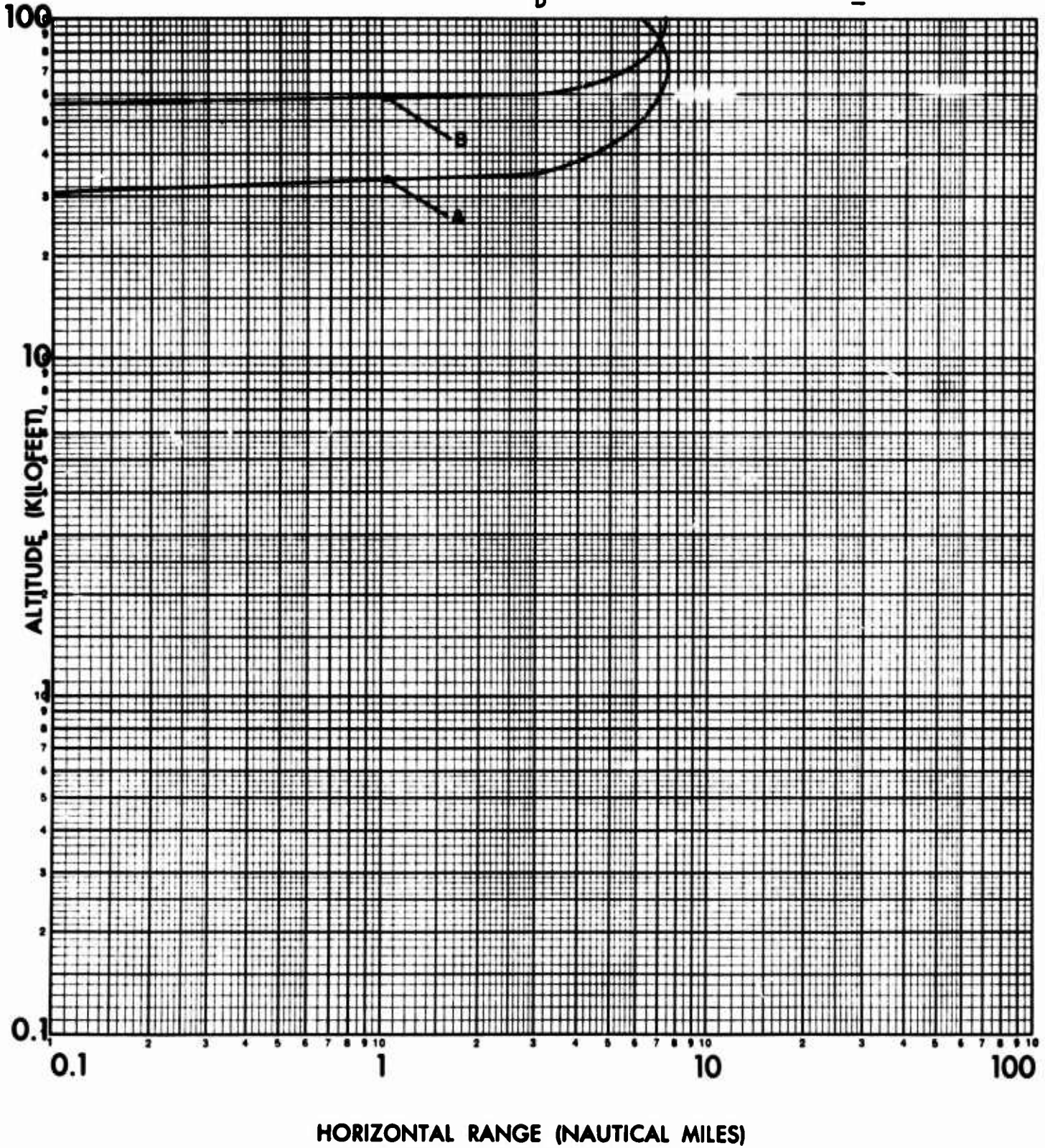


FIGURE 38

# RETINAL BURN

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20

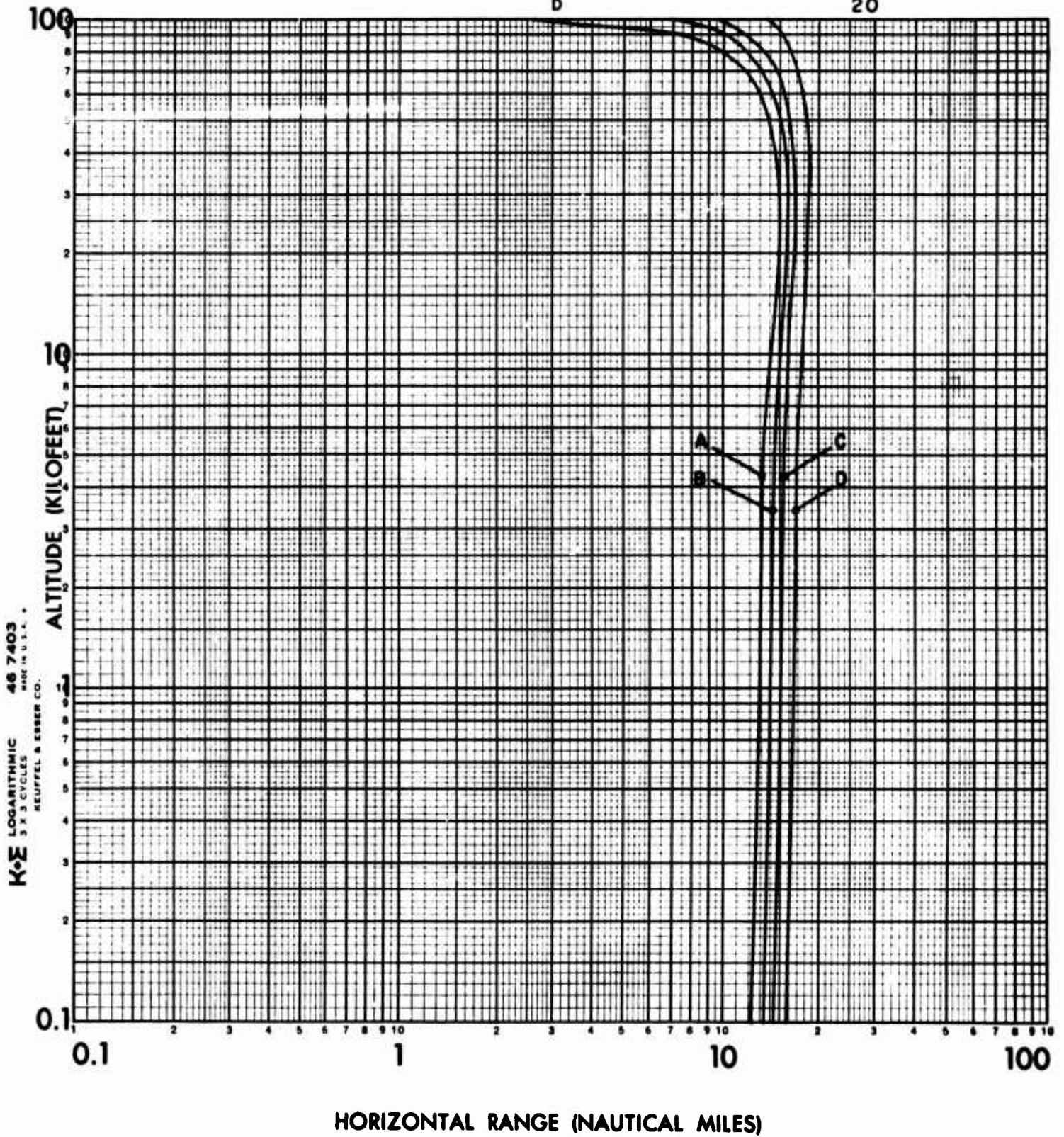


FIGURE 39

# RETINAL BURN

NIGHT MISSION  
 YIELD: 0.6 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100  
 -  
 -

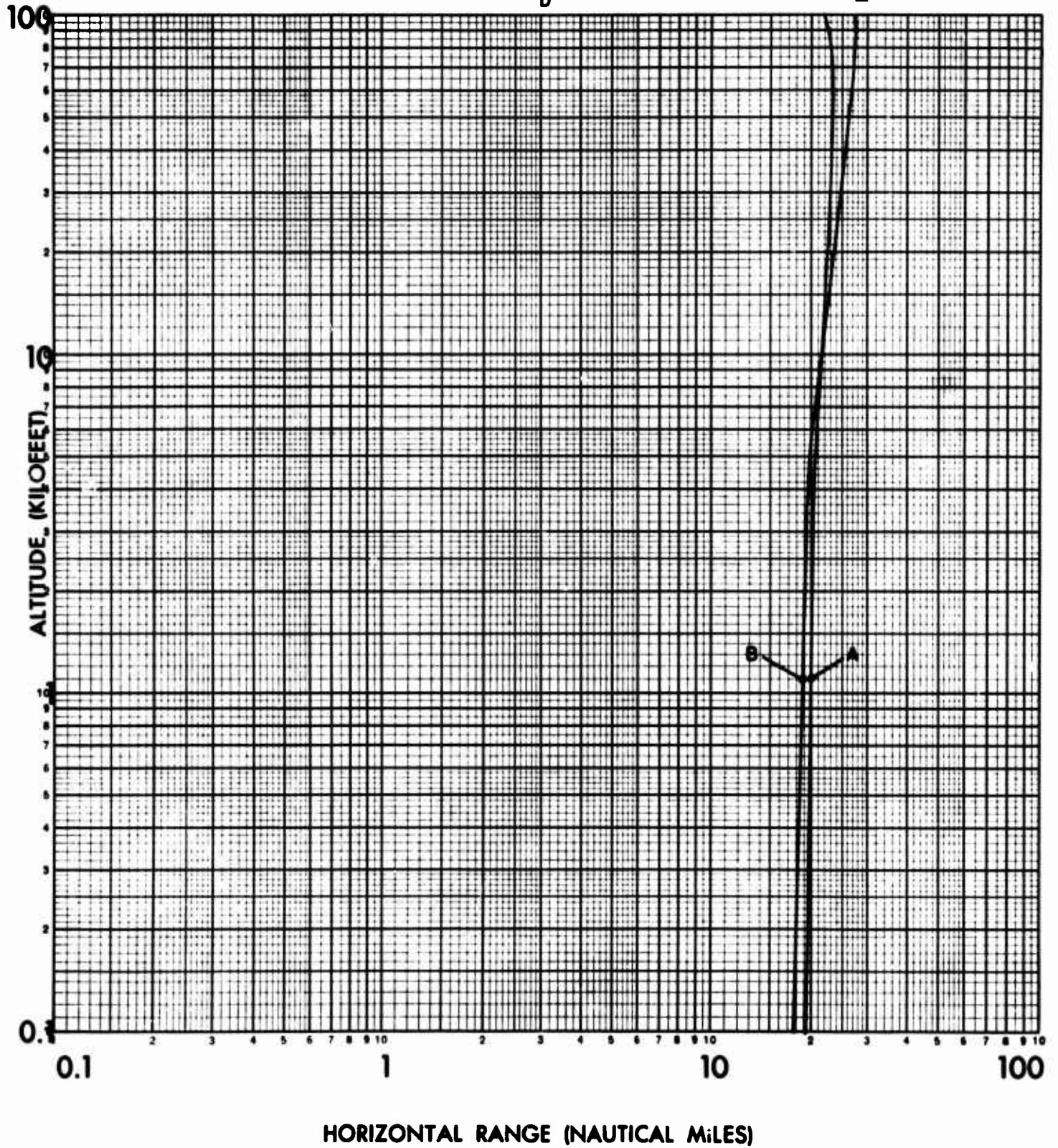


FIGURE 40

# RETINAL BURN

NIGHT MISSION

YIELD: 2.0 KT

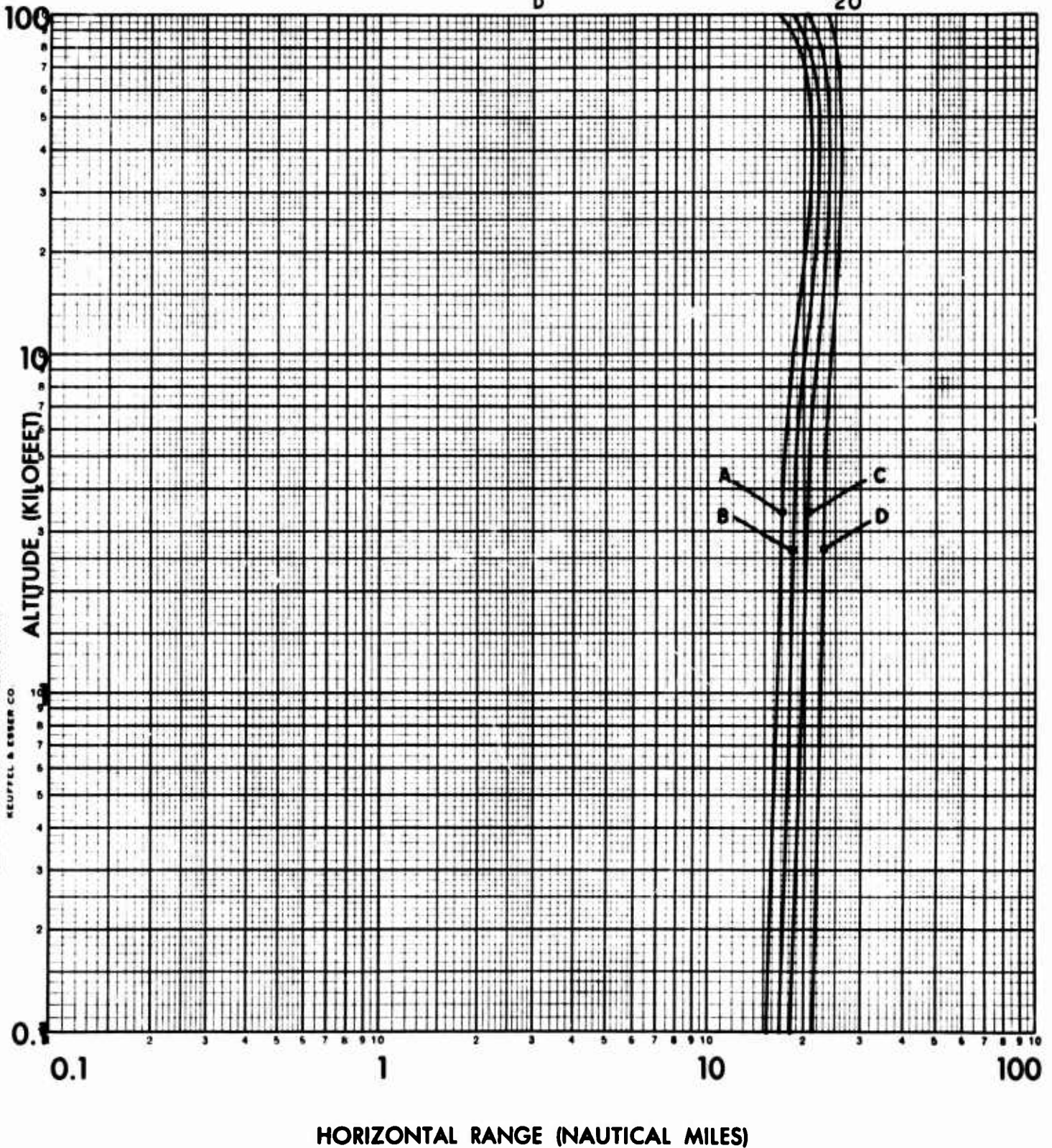
FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20



K&E LOGARITHMIC 46 7403 MADE IN U.S.A. KEUFFEL & ESSER CO.

FIGURE 41

# RETINAL BURN

NIGHT MISSION

YIELD: 2.0 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

—

—

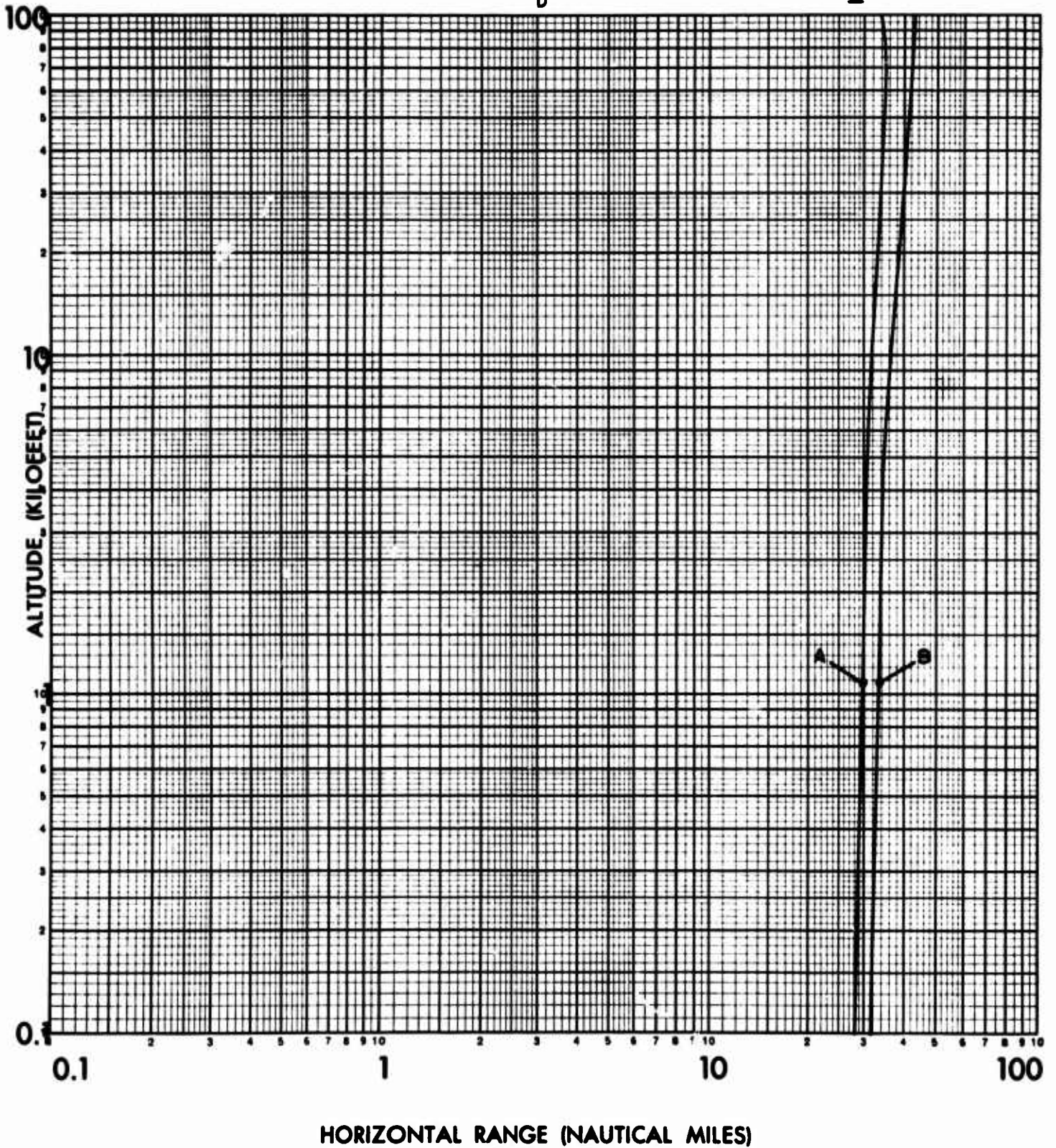


FIGURE 42



# RETINAL BURN

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

1

5

10

20

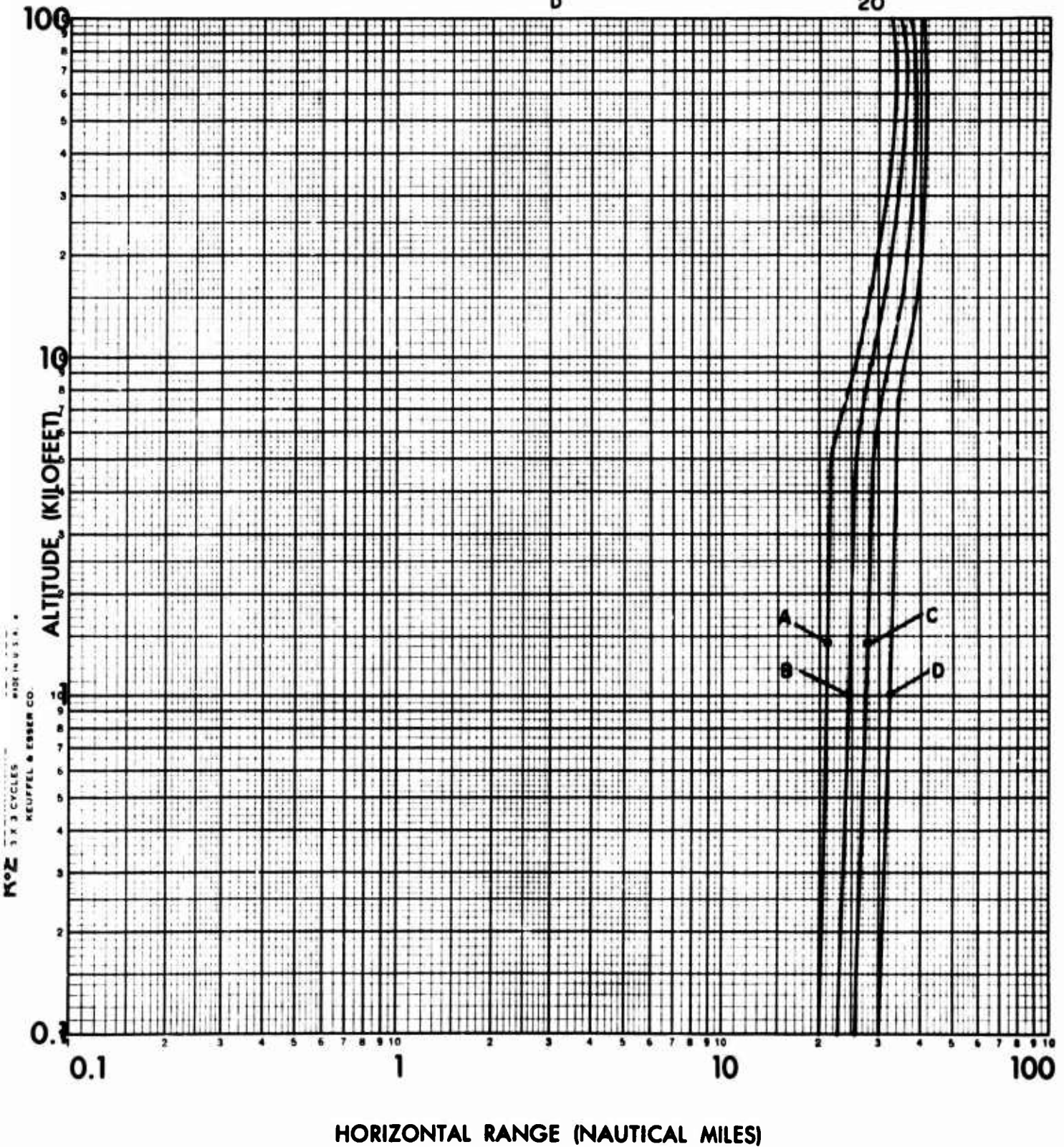


FIGURE 43

# RETINAL BURN

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

-

-

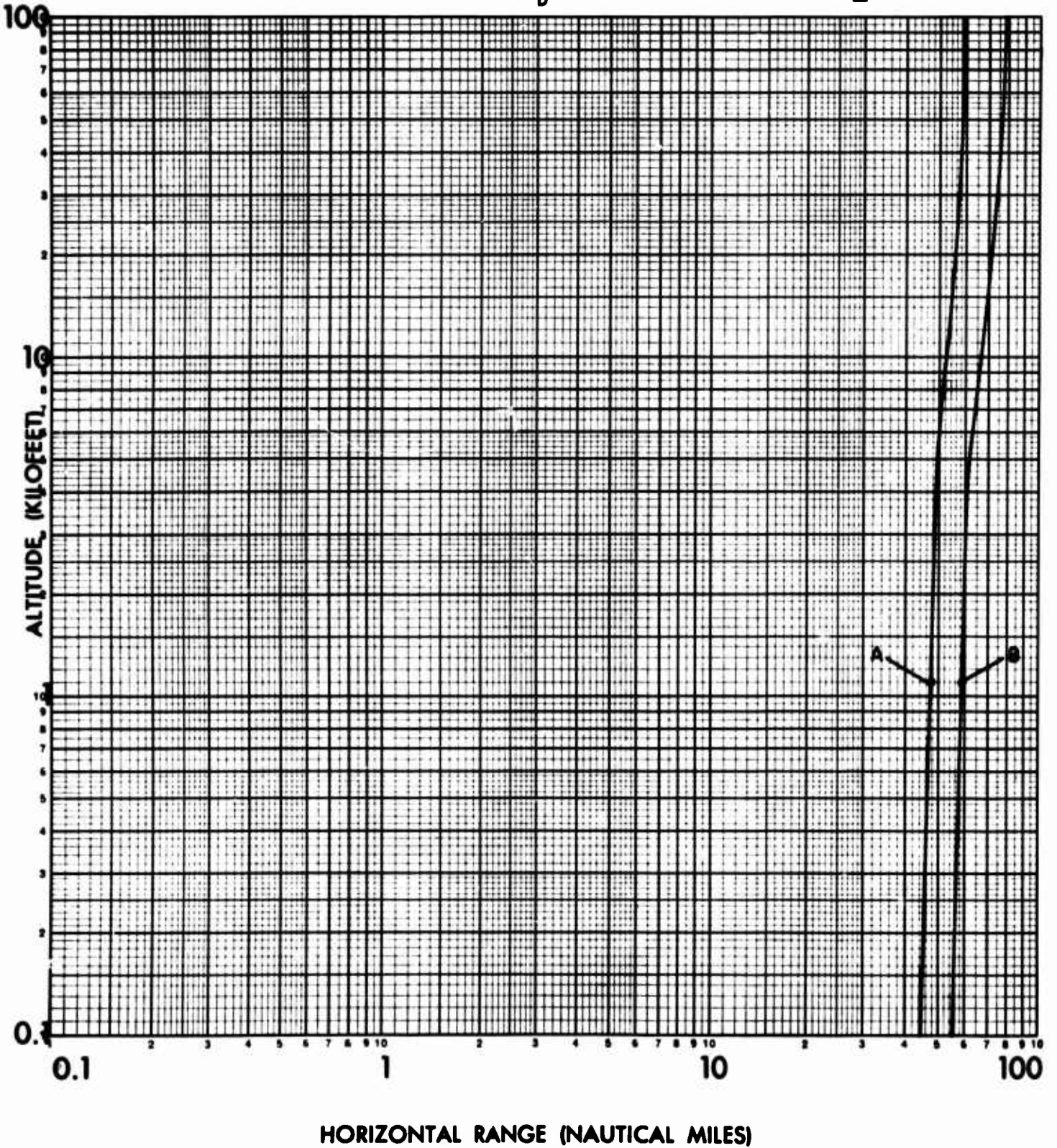


FIGURE 44

# RETINAL BURN

NIGHT MISSION

YIELD: 30 KT

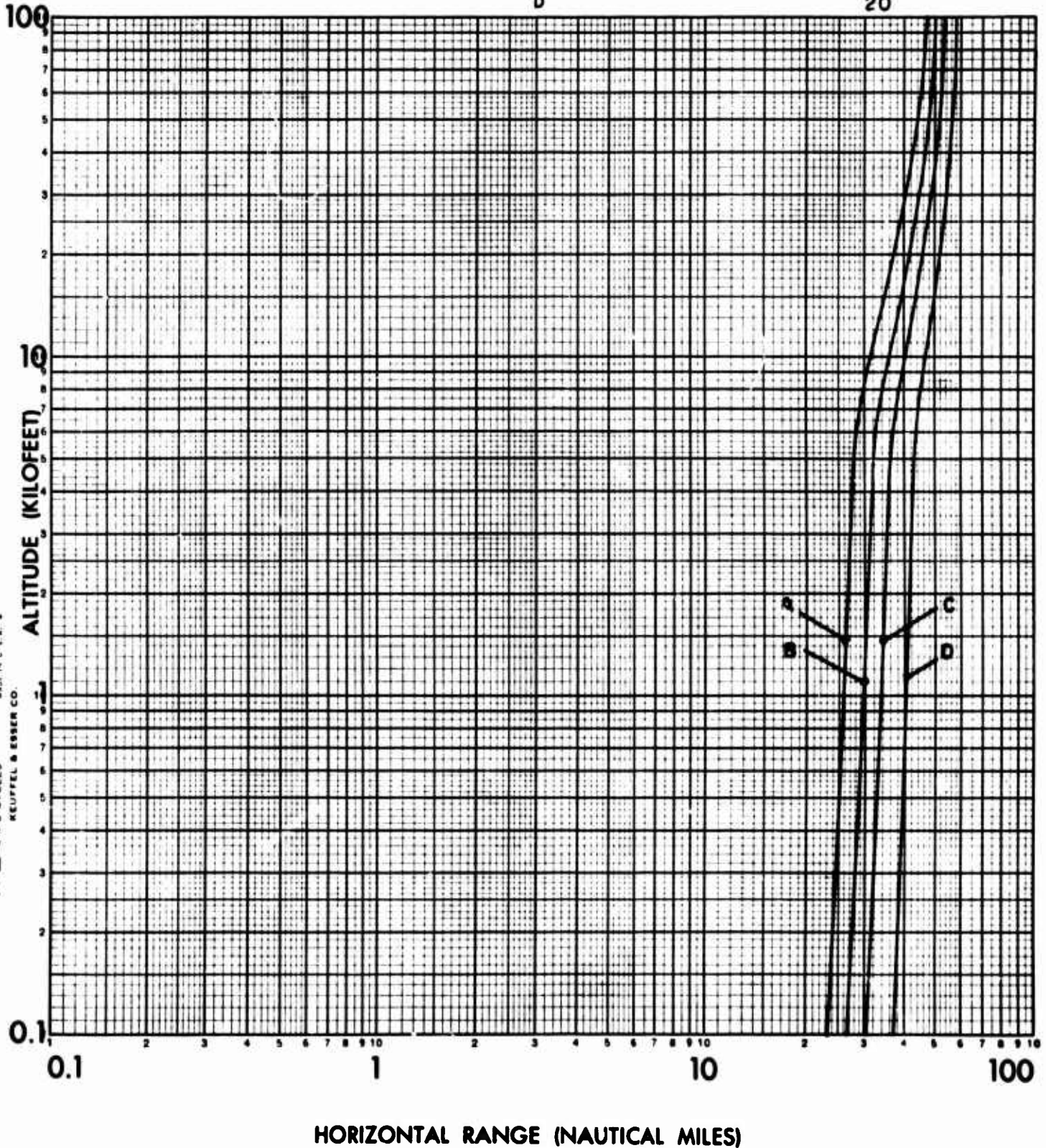
FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20



REFERENCE: 40/403  
 KEUFFEL & ESSER CO.

FIGURE 45

# RETINAL BURN

NIGHT MISSION  
 YIELD: 30 KT  
 FILTER: NONE

SYMBOL

BURST ALTITUDE (Kilofeet)

A

50

B

100

C

-

D

-

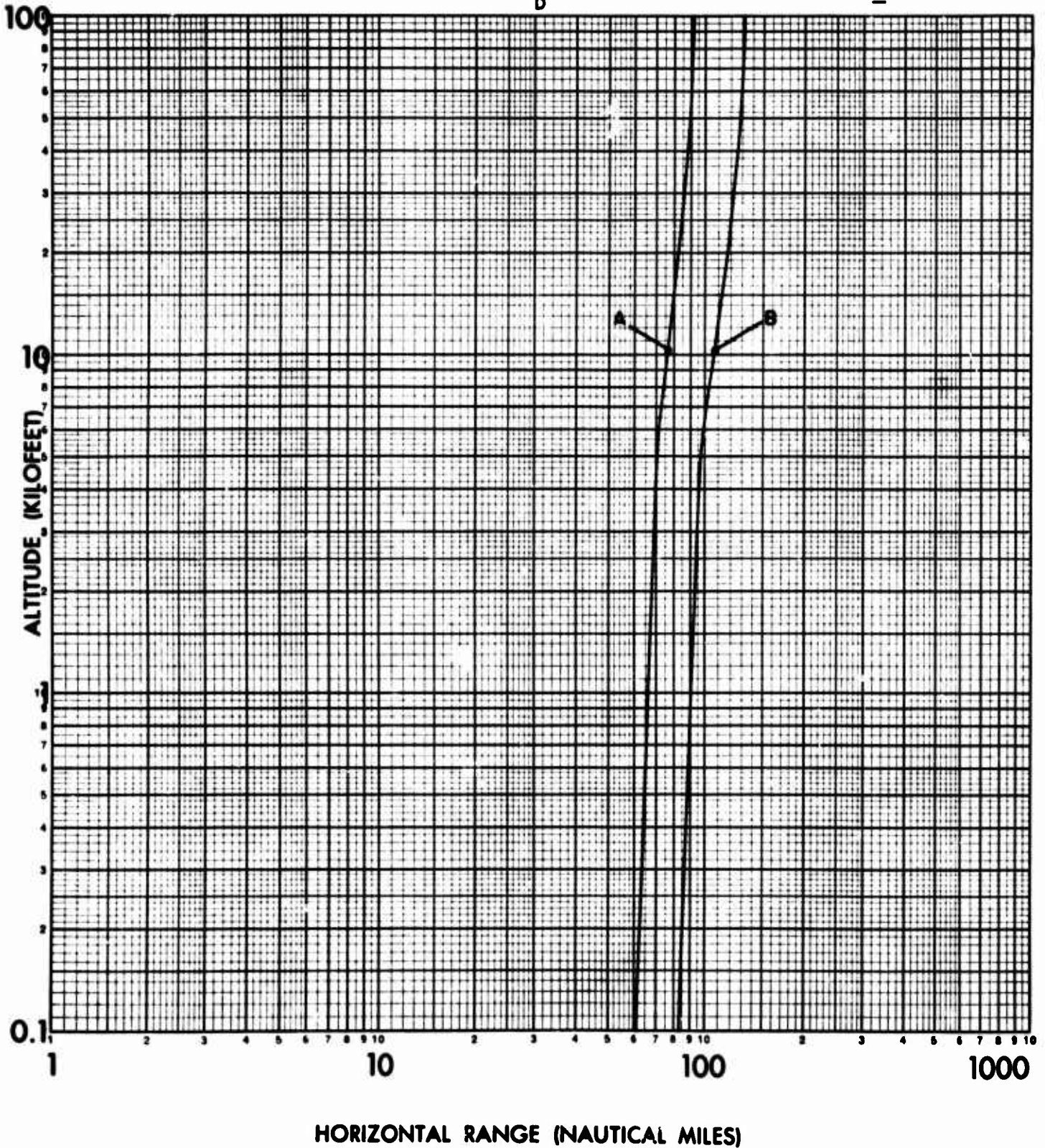


FIGURE 46

# RETINAL BURN

NIGHT MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL

A

B

C

D

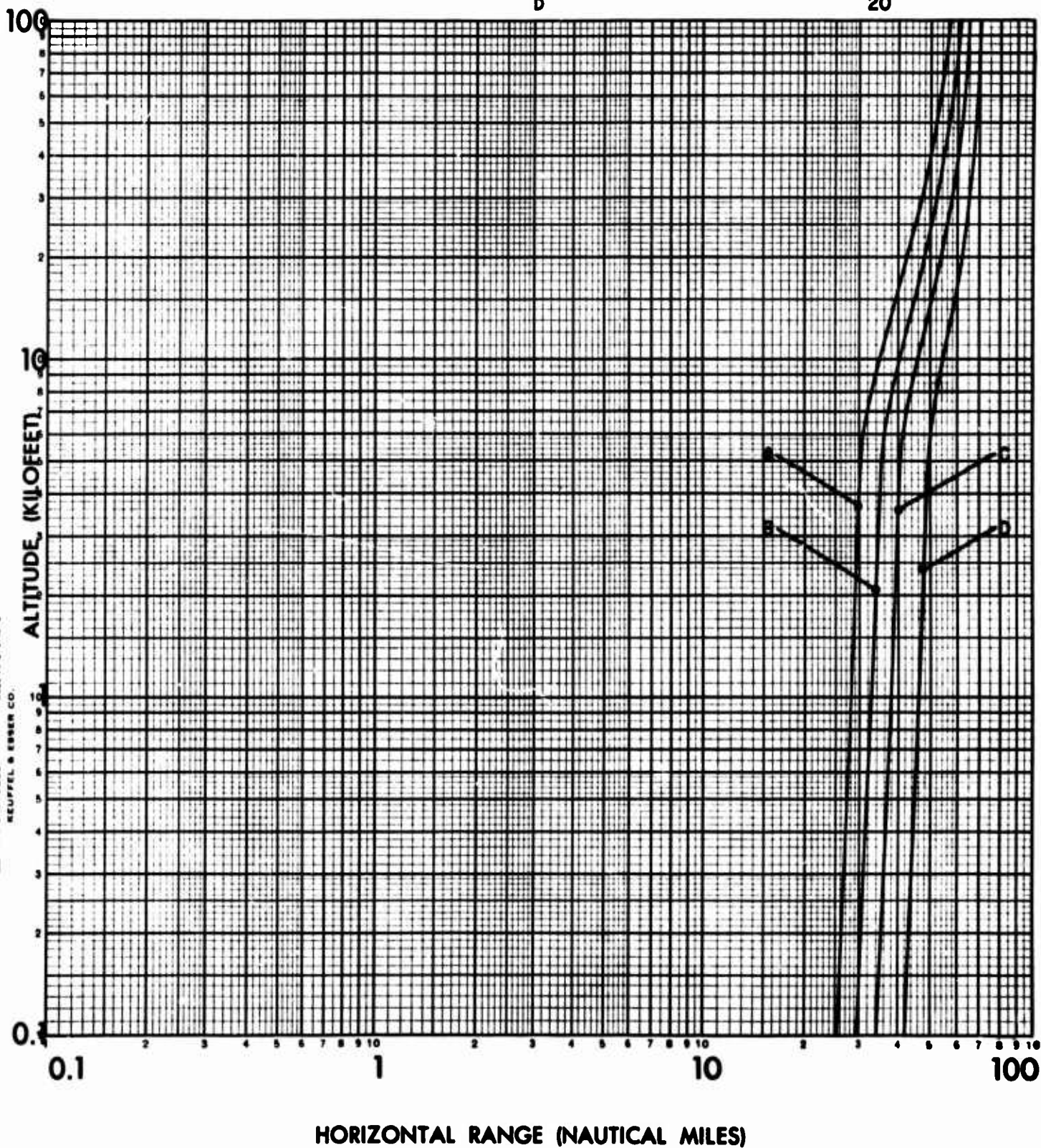
BURST ALTITUDE (Kilofeet)

1

5

10

20



K-E LOGARITHMIC 46 7403  
3 X 3 CYCLES  
MADE IN U.S.A.  
KEUFFEL & ESSER CO.

FIGURE 47

# RETINAL BURN

NIGHT MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

—

—

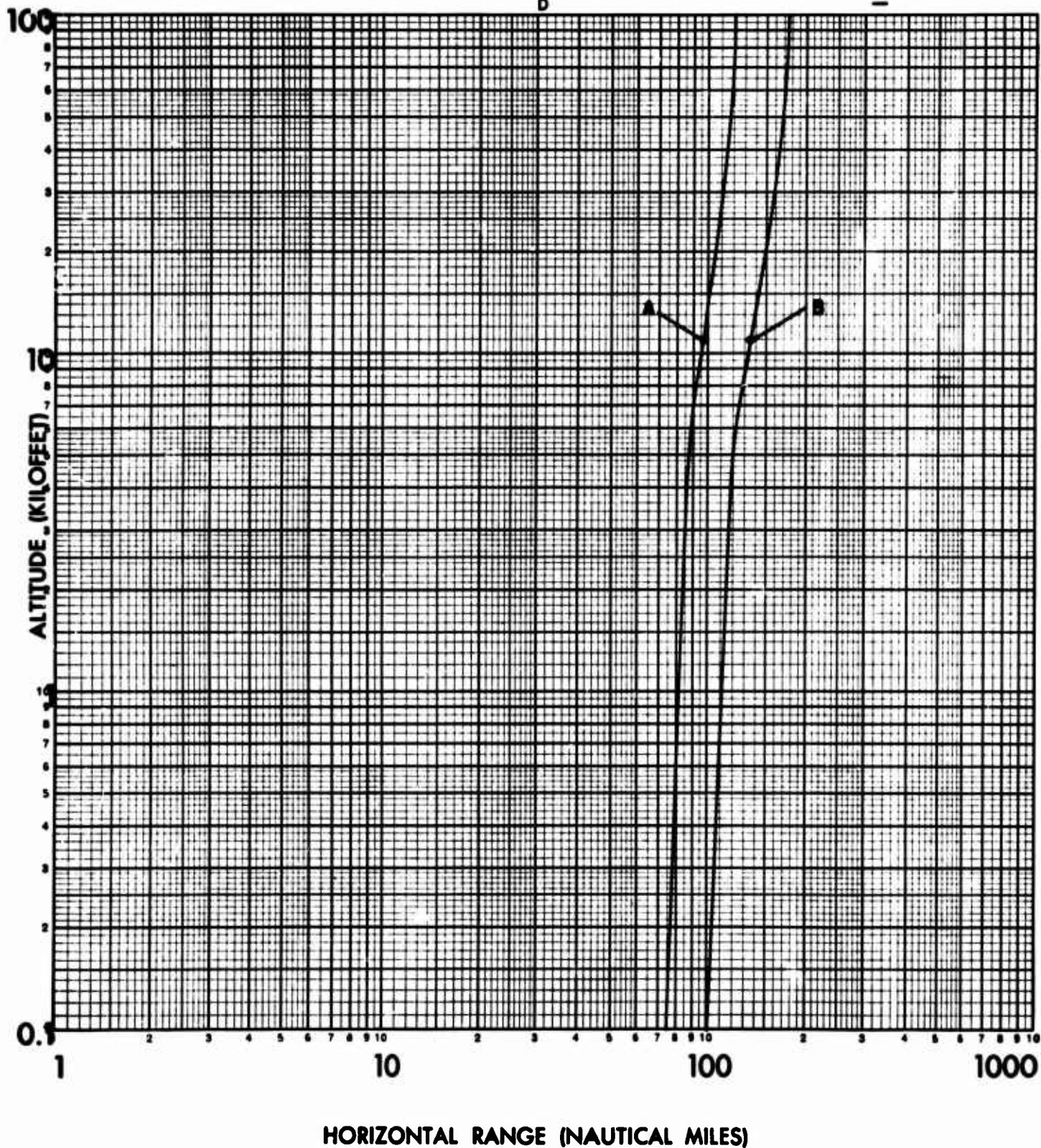


FIGURE 48

# RETINAL BURN

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL

A

B

C

D

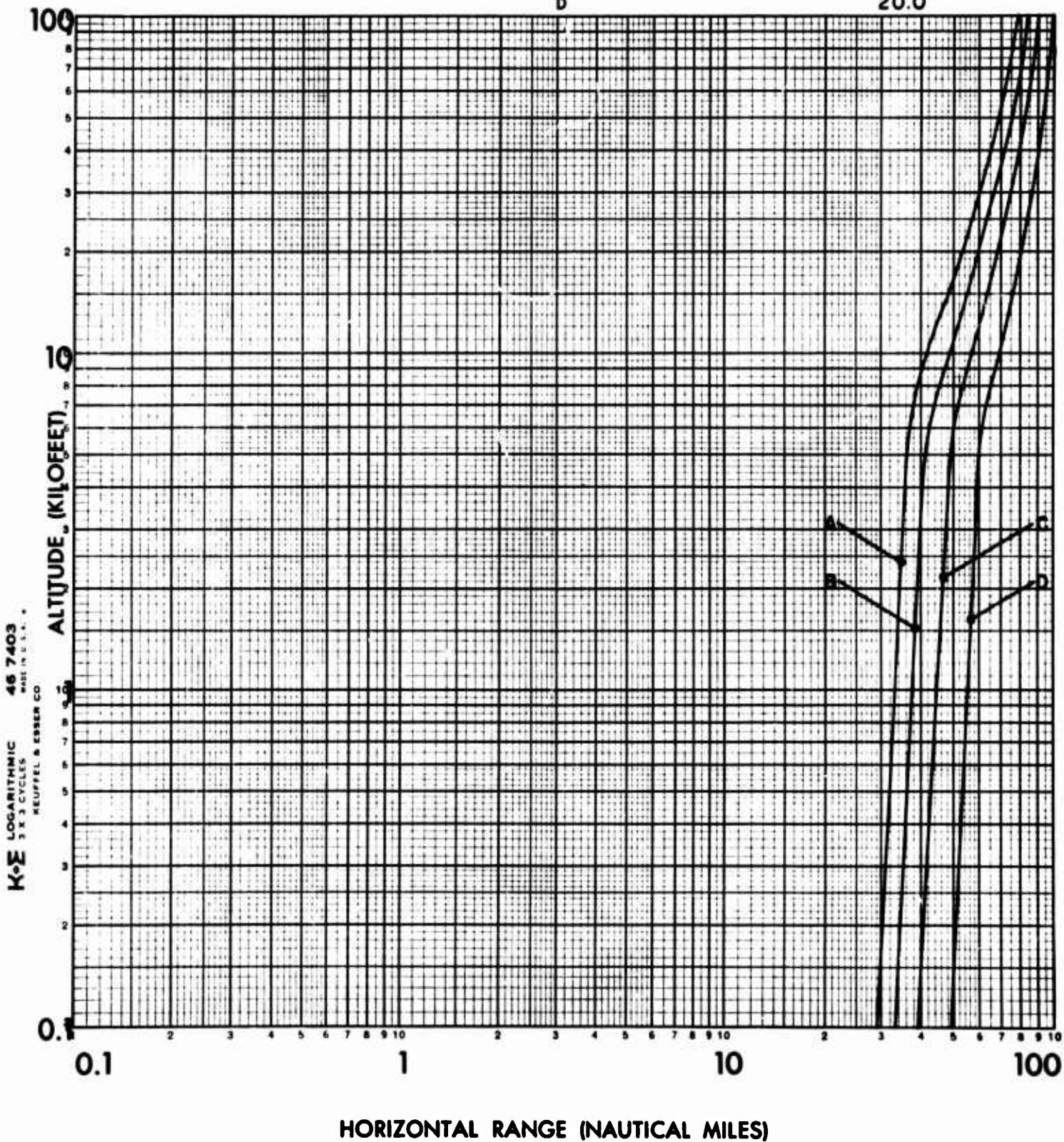
BURST ALTITUDE (Kilofeet)

1.5

5.0

10.0

20.0



K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 MADE IN U.S.A.  
 HEUFFEL & ESSER CO

FIGURE 49

# RETINAL BURN

NIGHT MISSION  
 YIELD: 200 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100  
 -  
 -

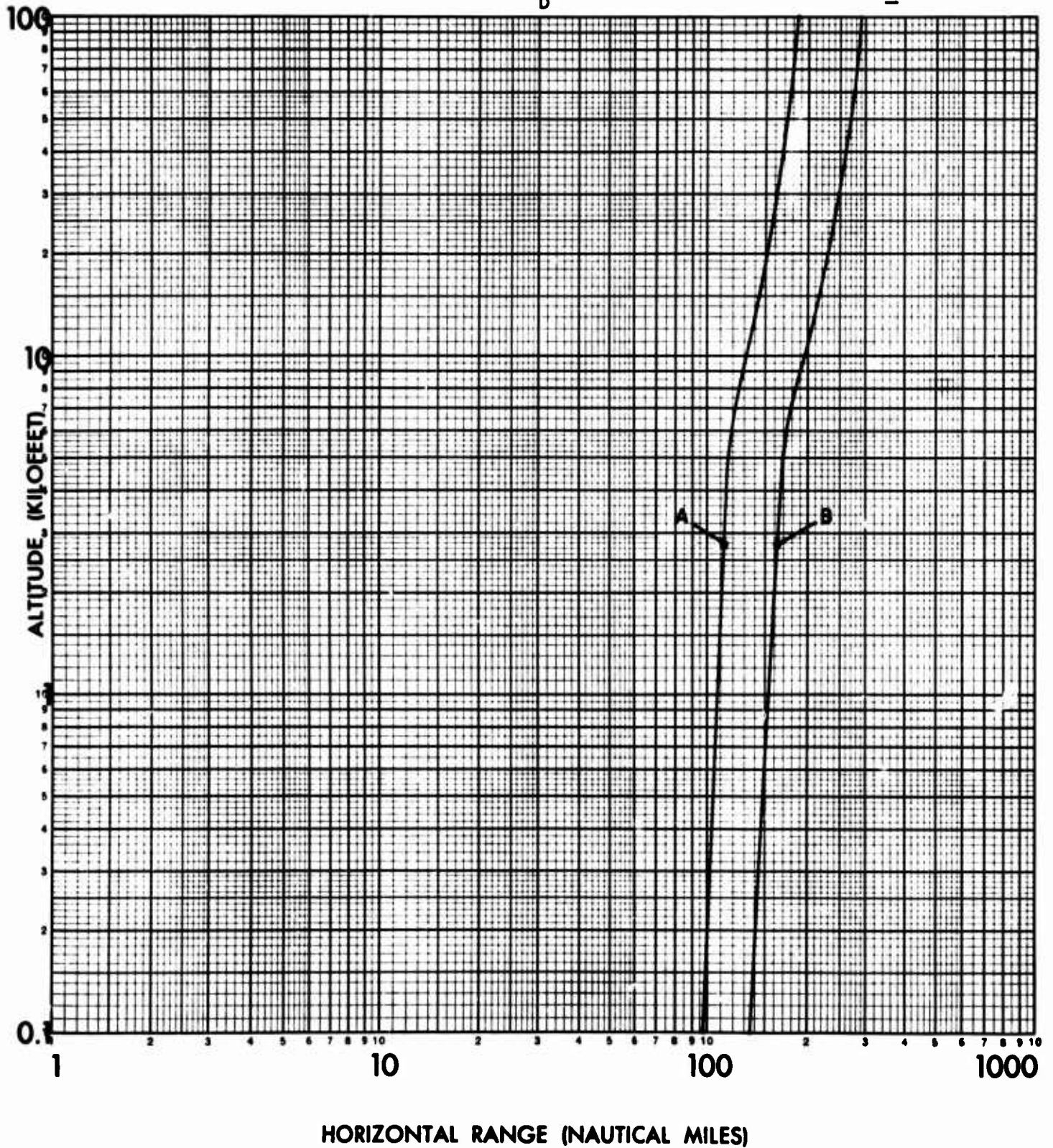


FIGURE 50



# RETINAL BURN

NIGHT MISSION  
 YIELD: 440 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1.5  
 5  
 10  
 20

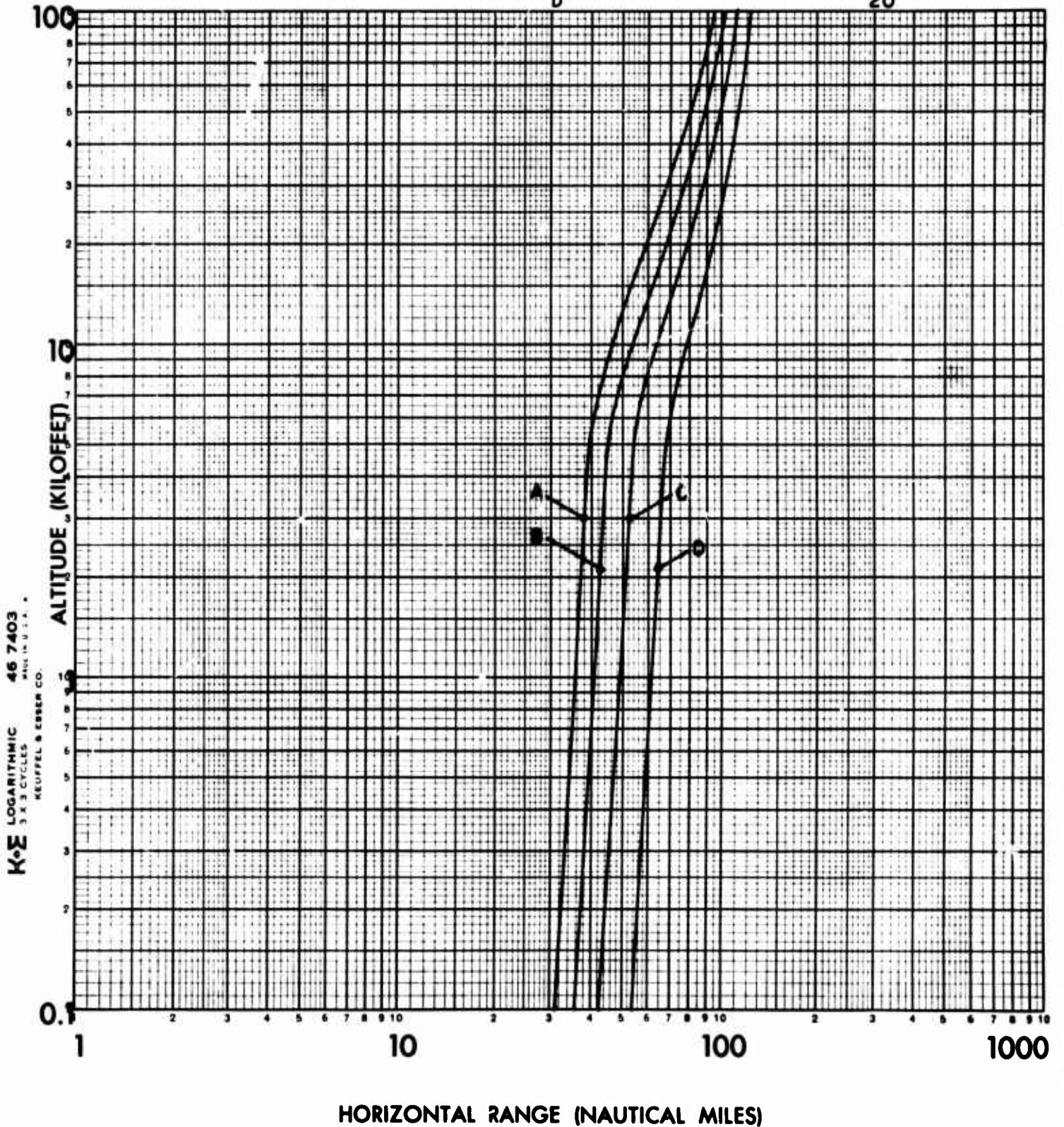


FIGURE 51

# RETINAL BURN

NIGHT MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

-

-

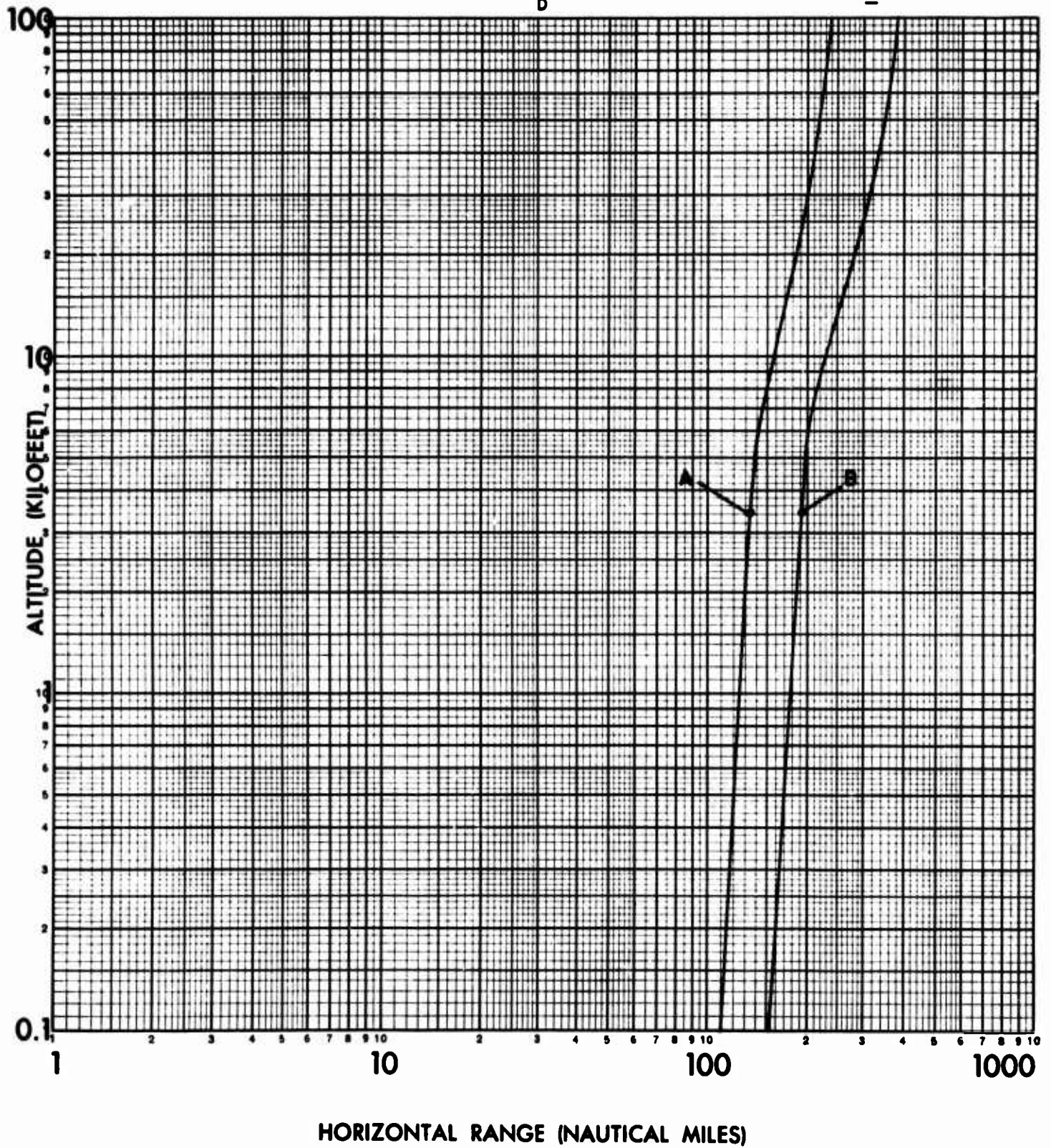
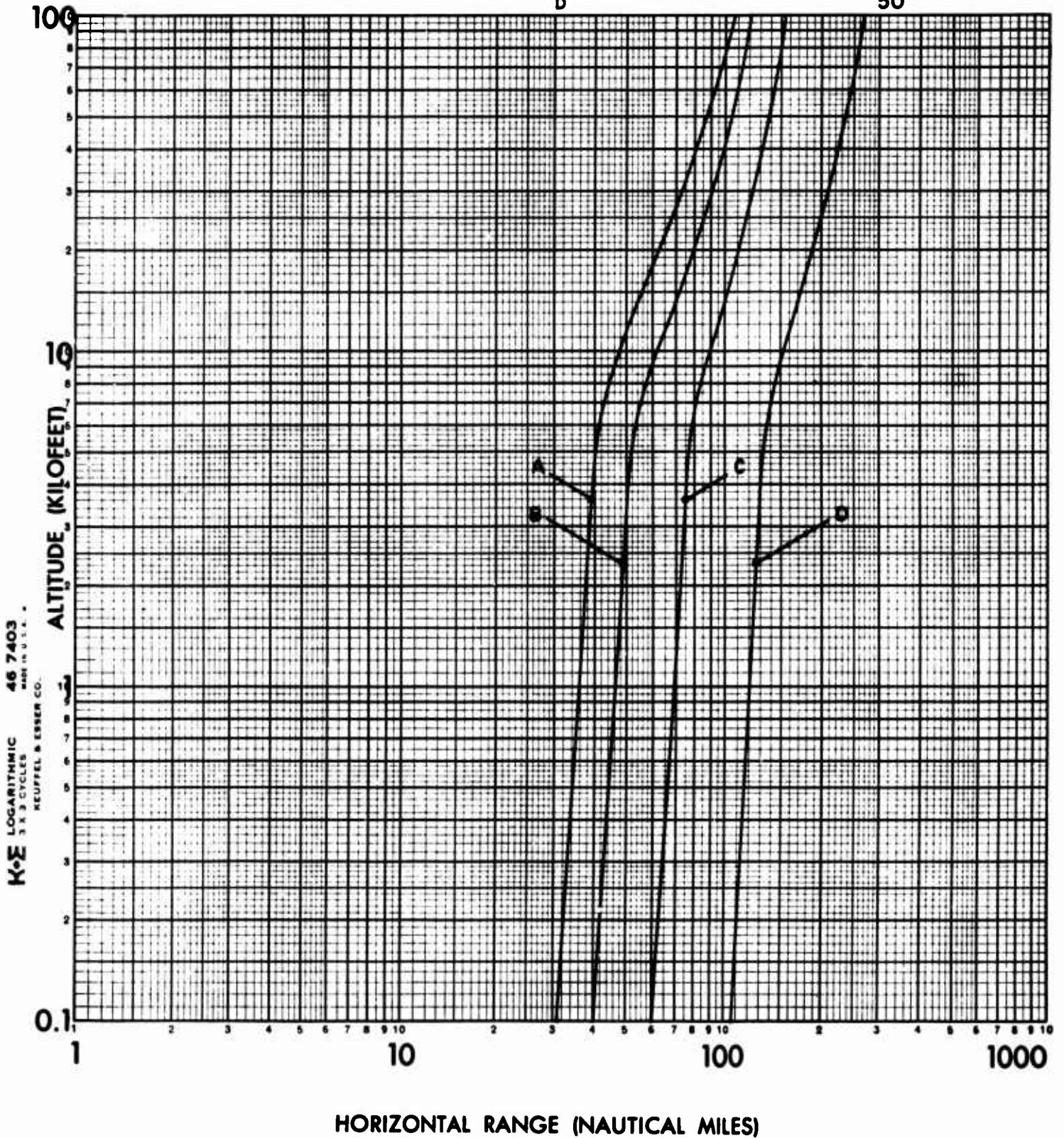


FIGURE 52

# RETINAL BURN

<u>NIGHT</u>	MISSION		SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD:	<u>1000</u>	KT	A	3
FILTER:	<u>NCVE</u>		B	10
			C	25
			D	50



K&E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 53

# RETINAL BURN

NIGHT    MISSION

YIELD: 3800 KT

FILTER: NCNE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

4

10

25

50

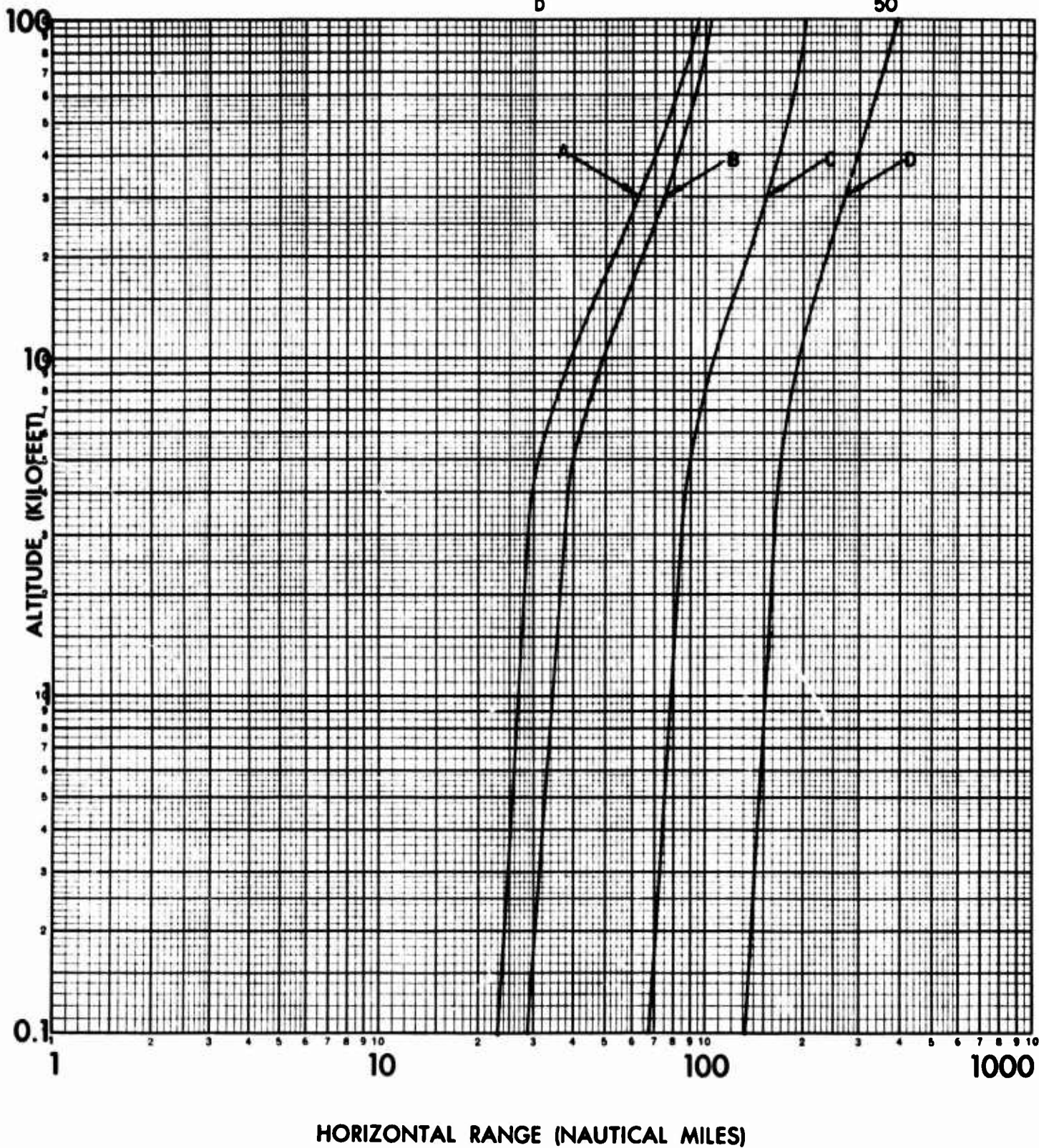


FIGURE 54

# RETINAL BURN

NIGHT MISSION

YIELD: 9000 KT

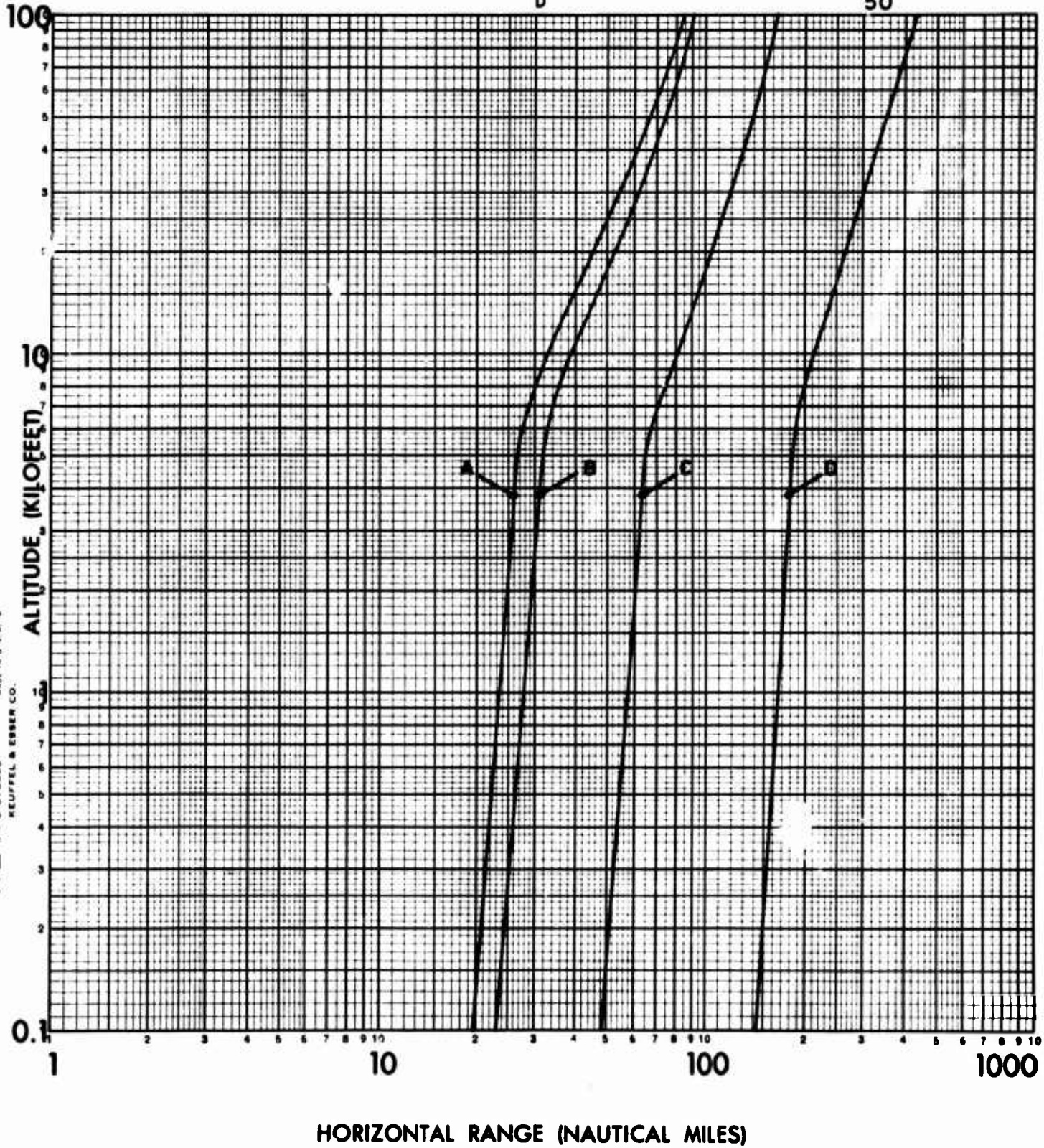
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 5
- 10
- 25
- 50



K-E LOGARITHMIC  
 3 x 3 CYCLES  
 48 7403  
 KEUFFEL & ESSER CO.

FIGURE 55

# RETINAL BURN

NIGHT MISSION

YIELD: 23000 KT

FILTER: NONE

SYMBOL

BURST ALTITUDE (Kilofeet)

A	6
B	10
C	25
D	50

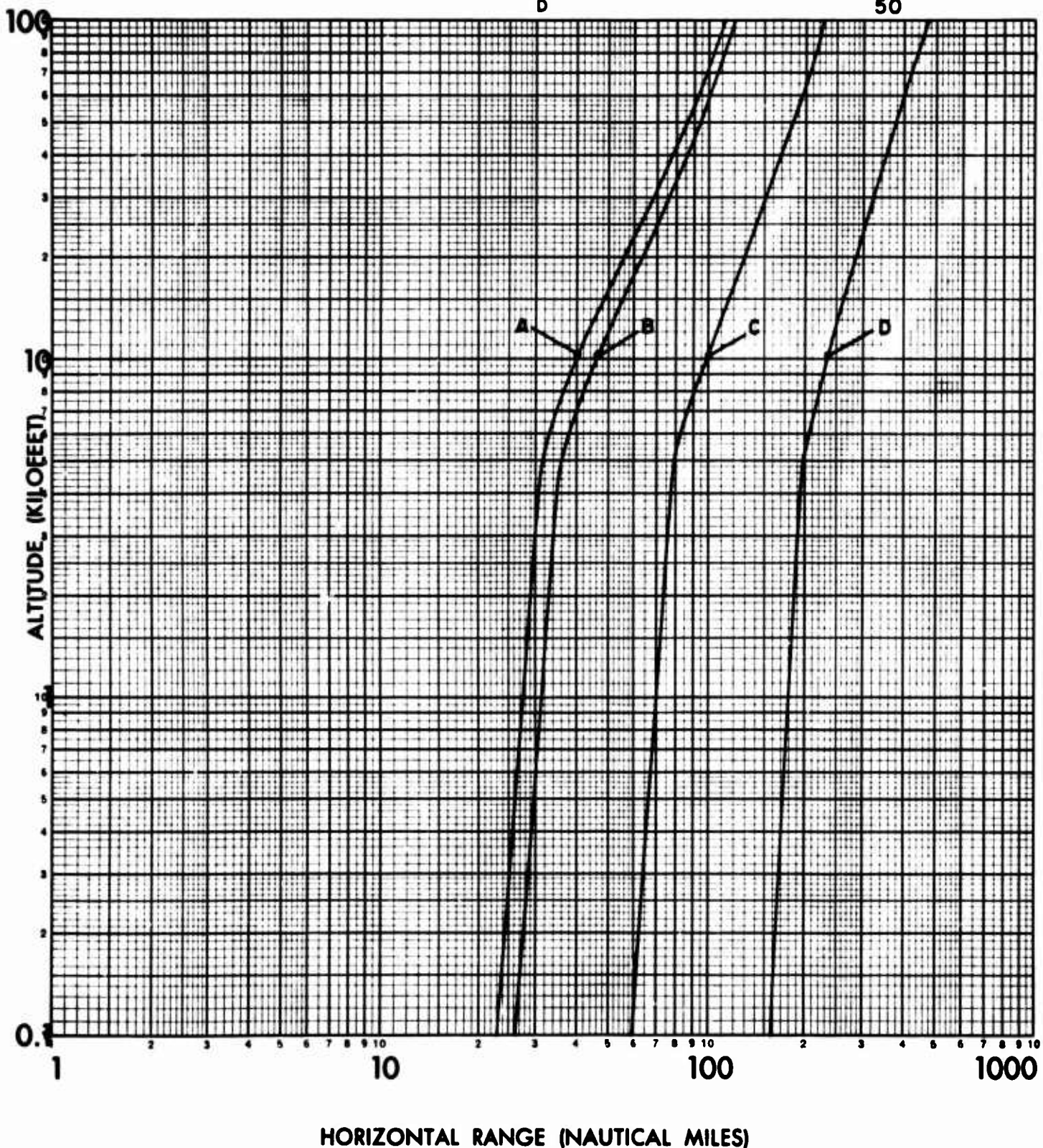


FIGURE 56

FLASHBLINDNESS SAFE SEPARATION ENVELOPES

DAY MISSION

# FLASHBLINDNESS

DAY      MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 1
- 10
- 25
- 50

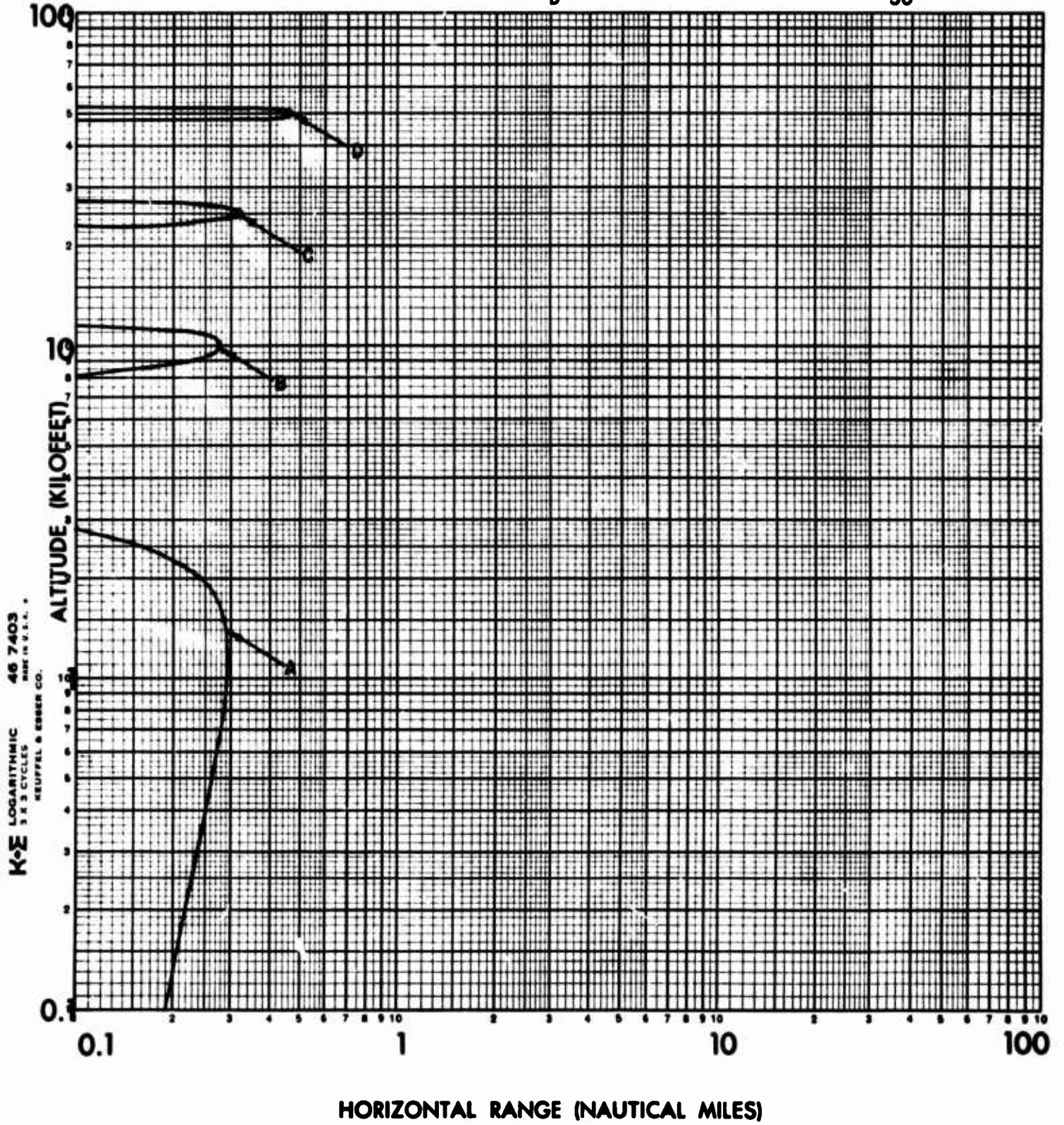


FIGURE 57



# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 0.02 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 75  
 100

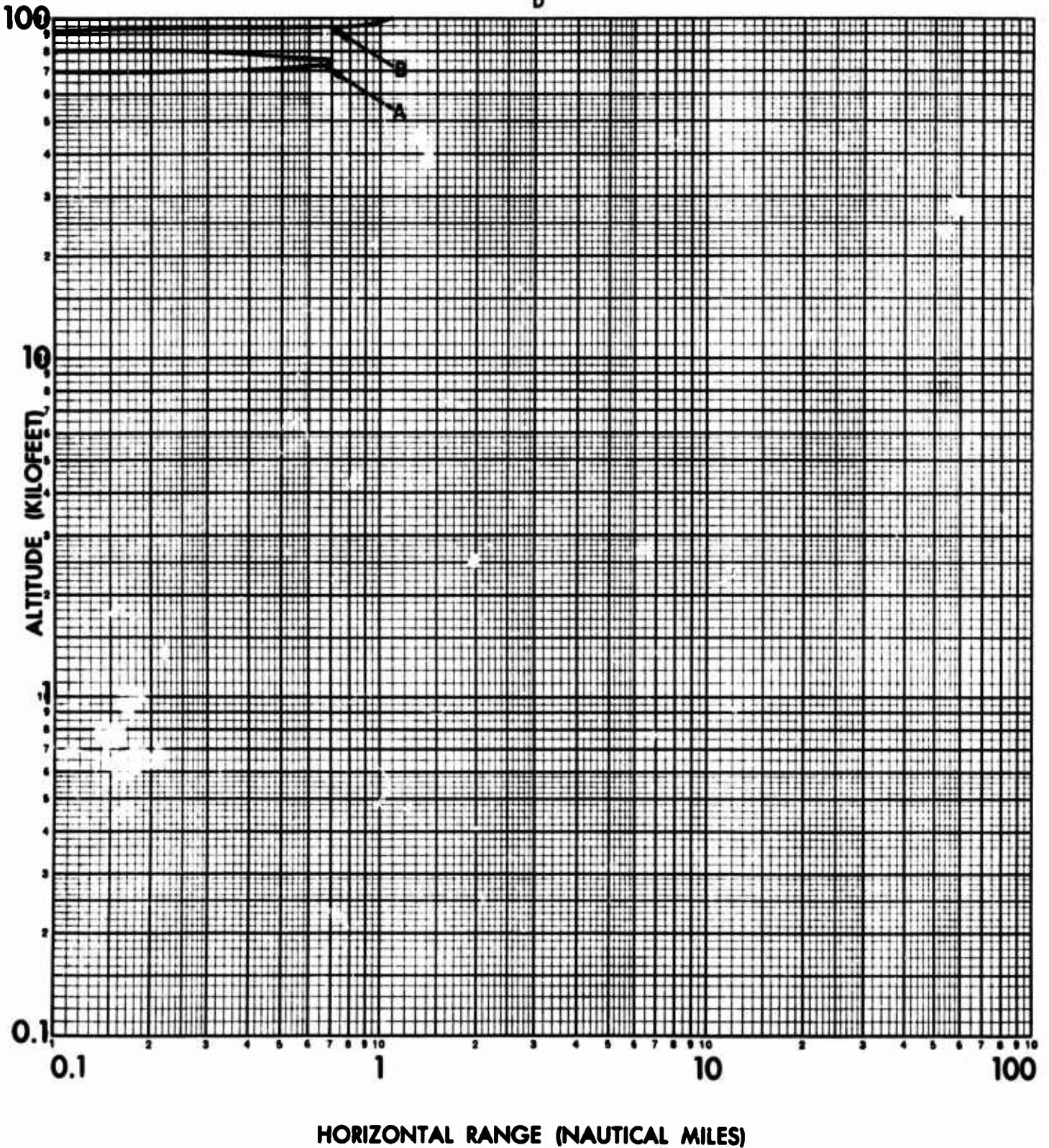


FIGURE 58

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 0.6 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

1

5

10

20

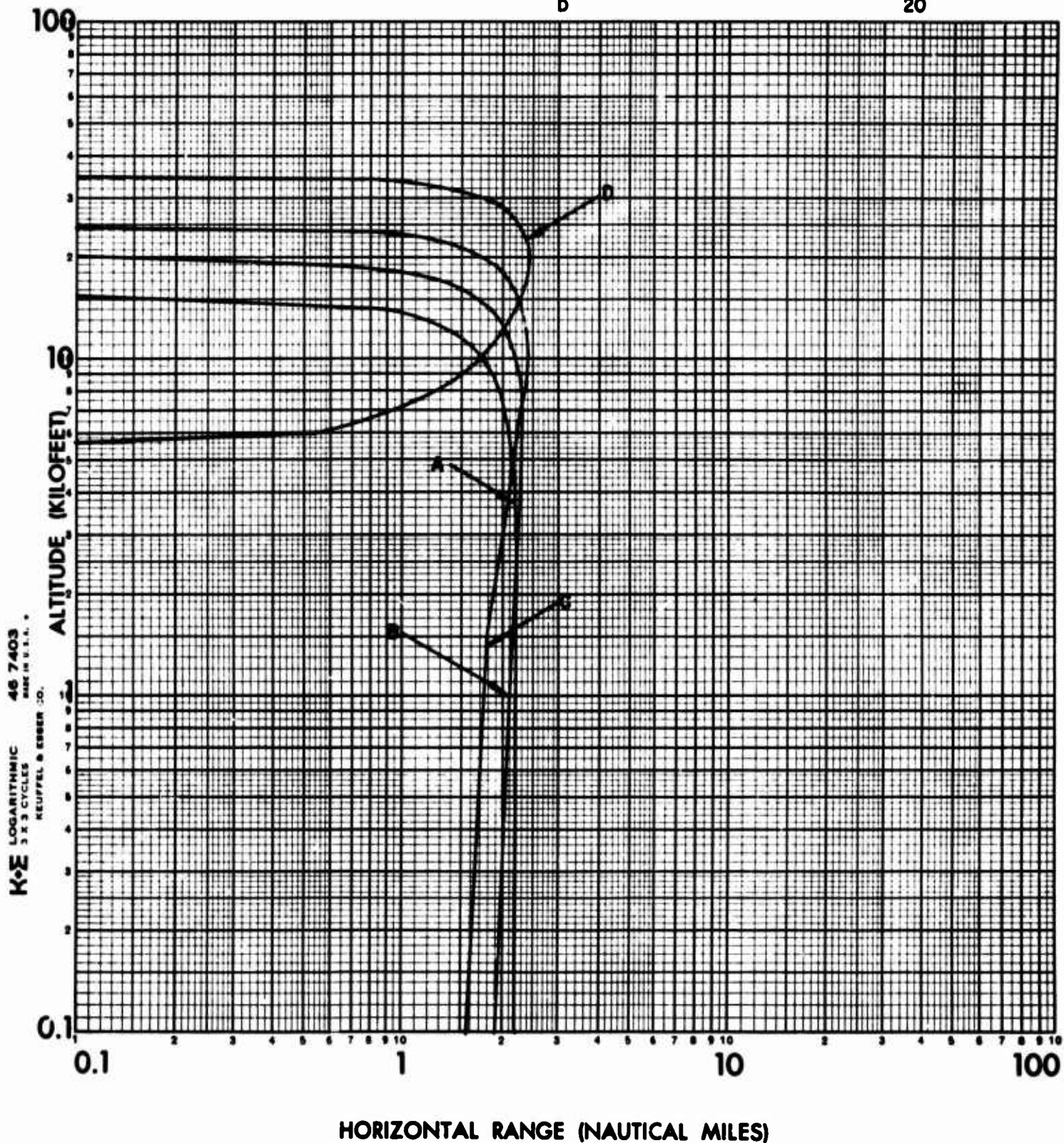


FIGURE 59

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 0.6 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

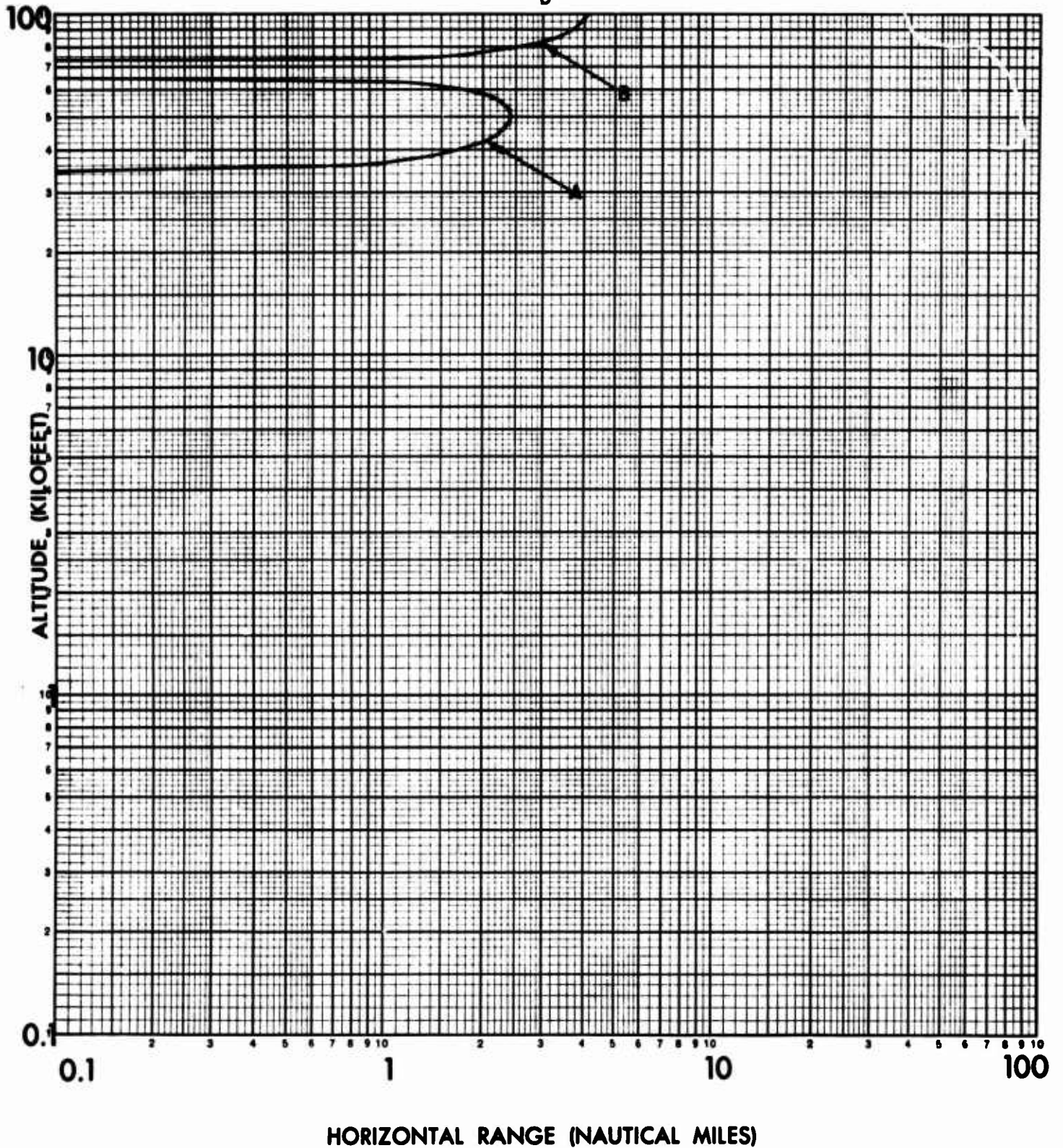


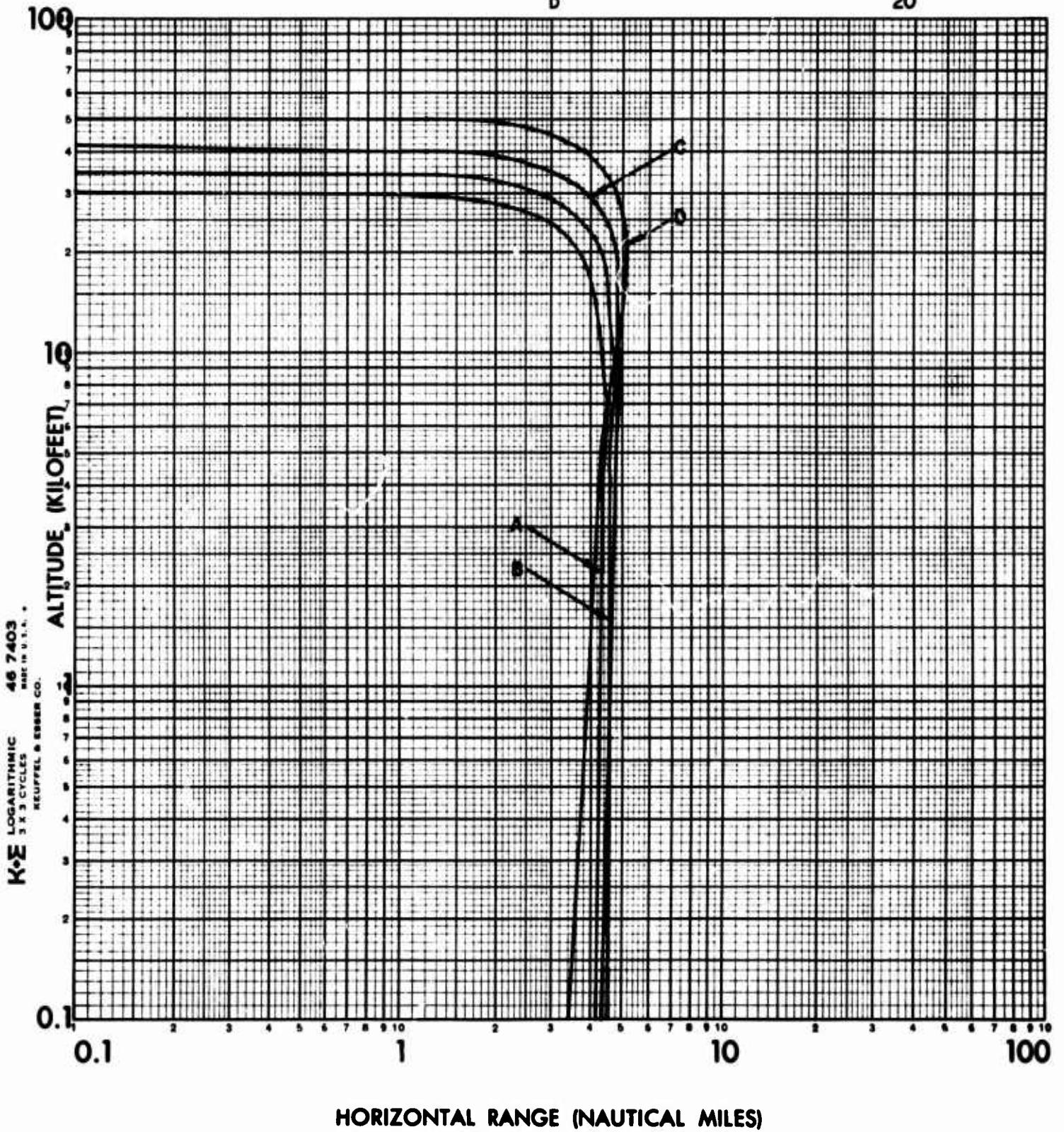
FIGURE 60

# FLASHBLINDNESS

DAY - MISSION  
 YIELD: 2 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1  
 5  
 10  
 20



K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 61

# FLASHBLINDNESS

DAY      MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

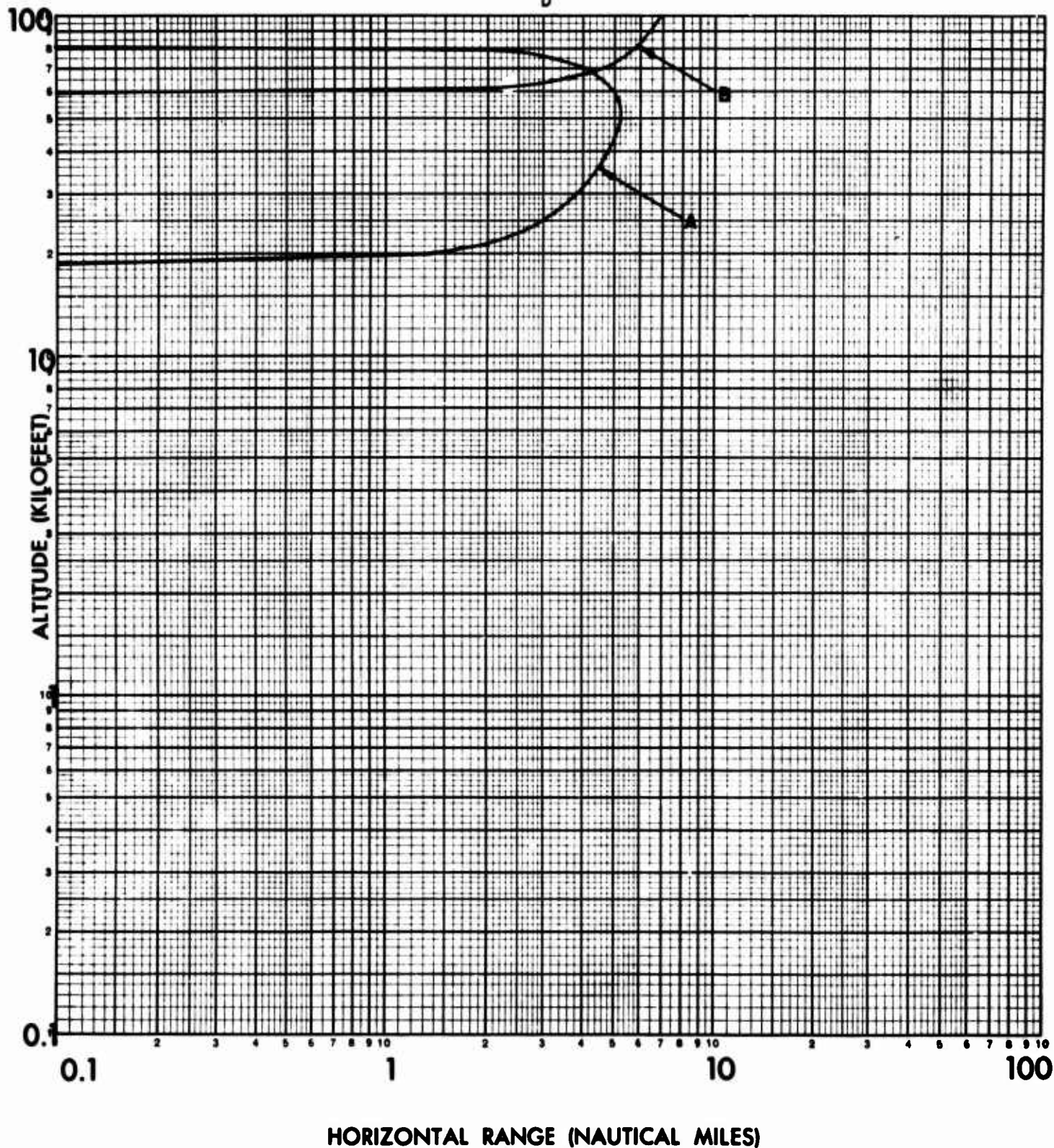


FIGURE 62

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 10 KT

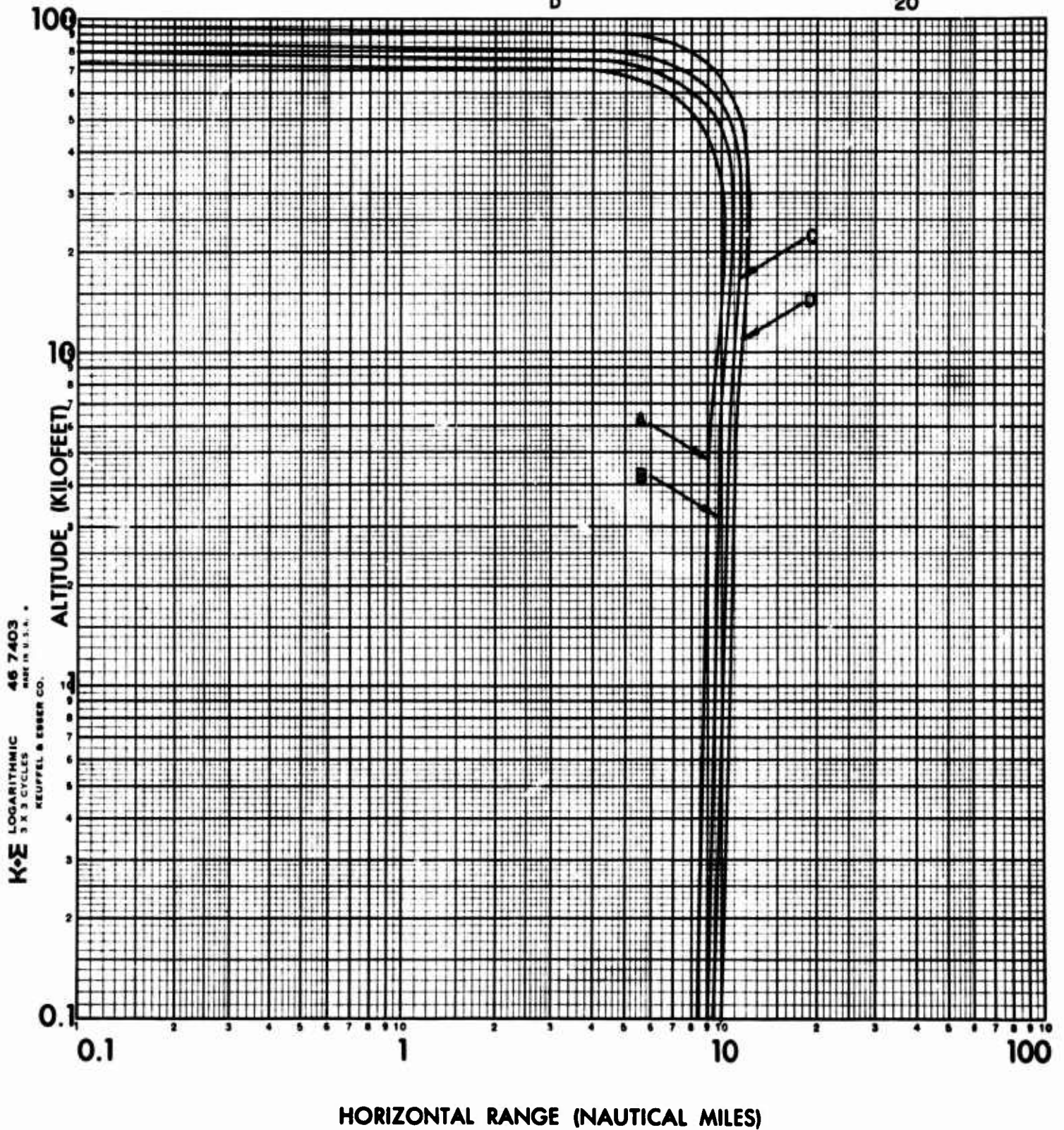
FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20



K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 63

# FLASHBLINDNESS

DAY MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

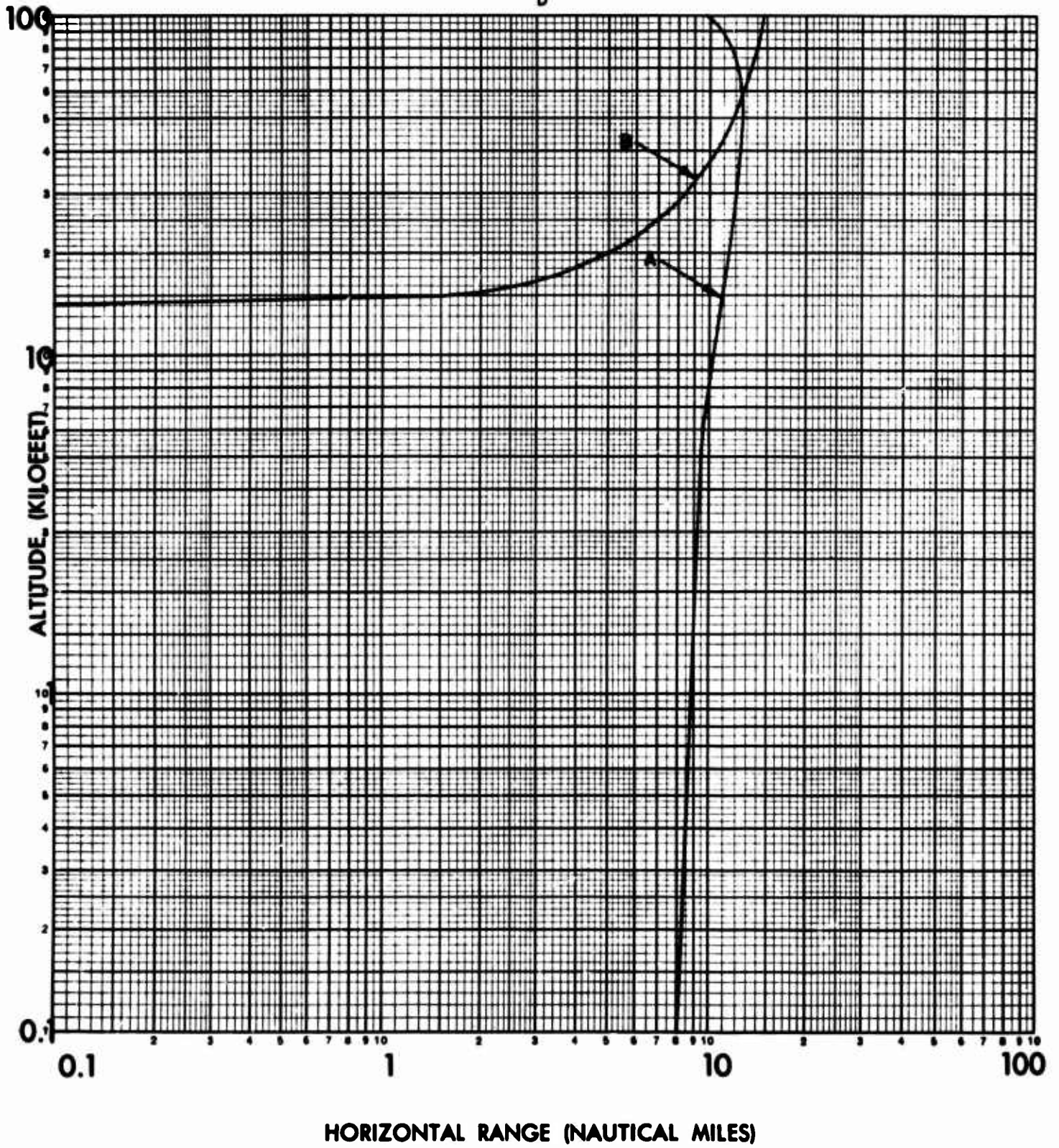
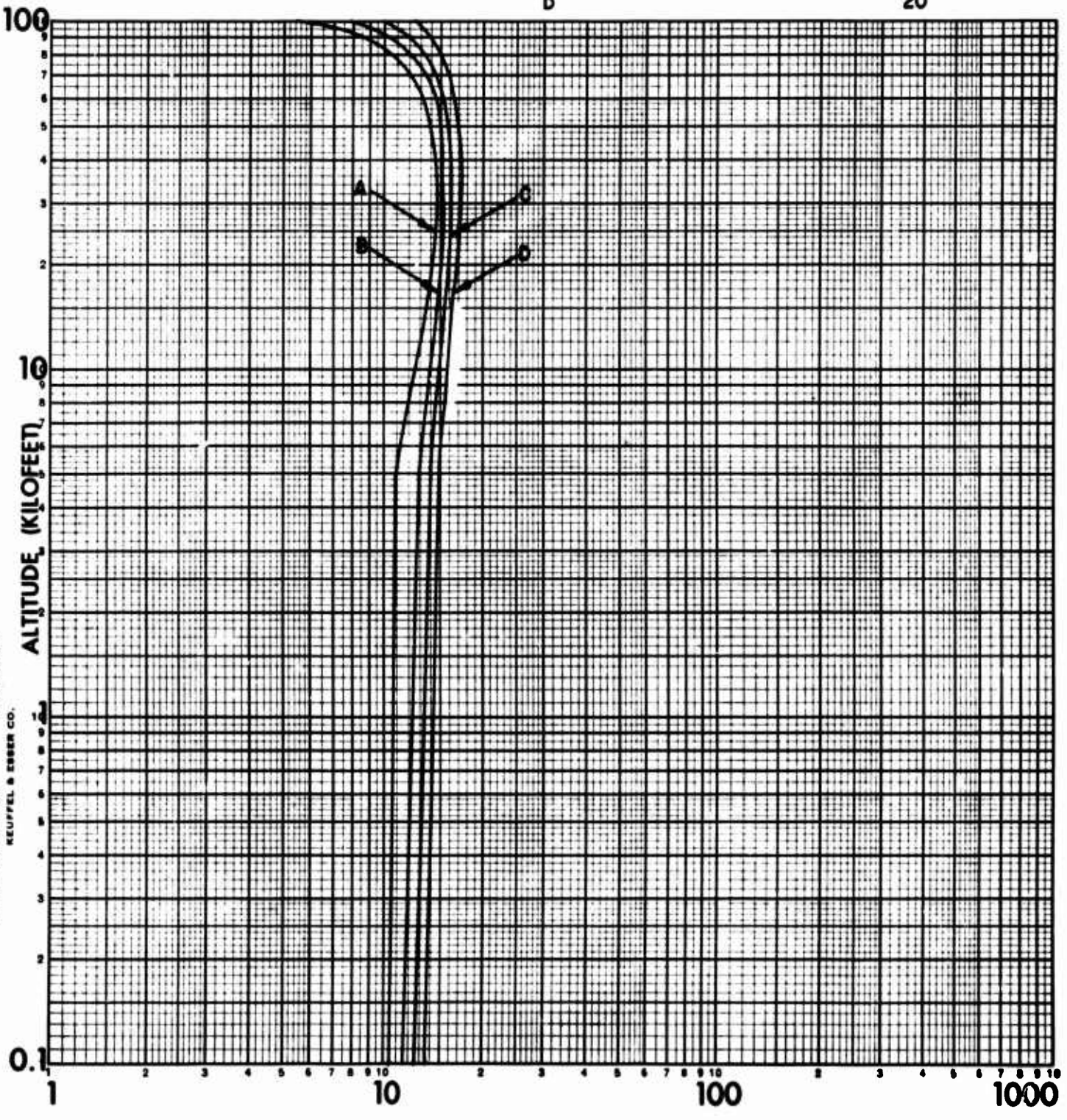


FIGURE 64

# FLASHBLINDNESS

<u>DAY</u>	MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: <u>30</u> KT		A	1
FILTER: <u>NONE</u>		B	5
		C	10
		D	20



K-E LOGARITHMIC 46 7403  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 65



# FLASHBLINDNESS

DAY    MISSION  
 YIELD: 30 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 50  
 100

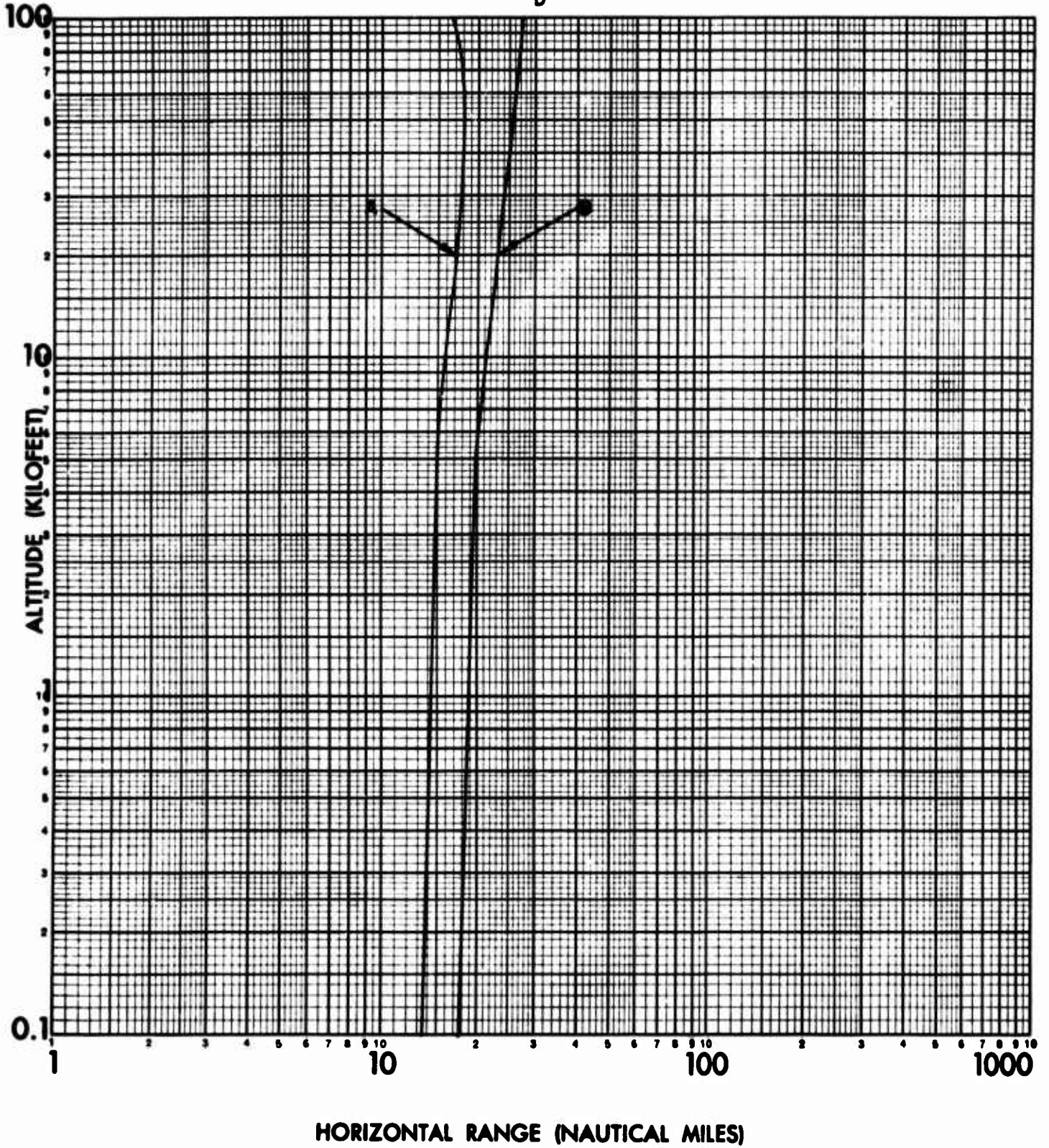


FIGURE 66

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 60 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1  
 5  
 10  
 20

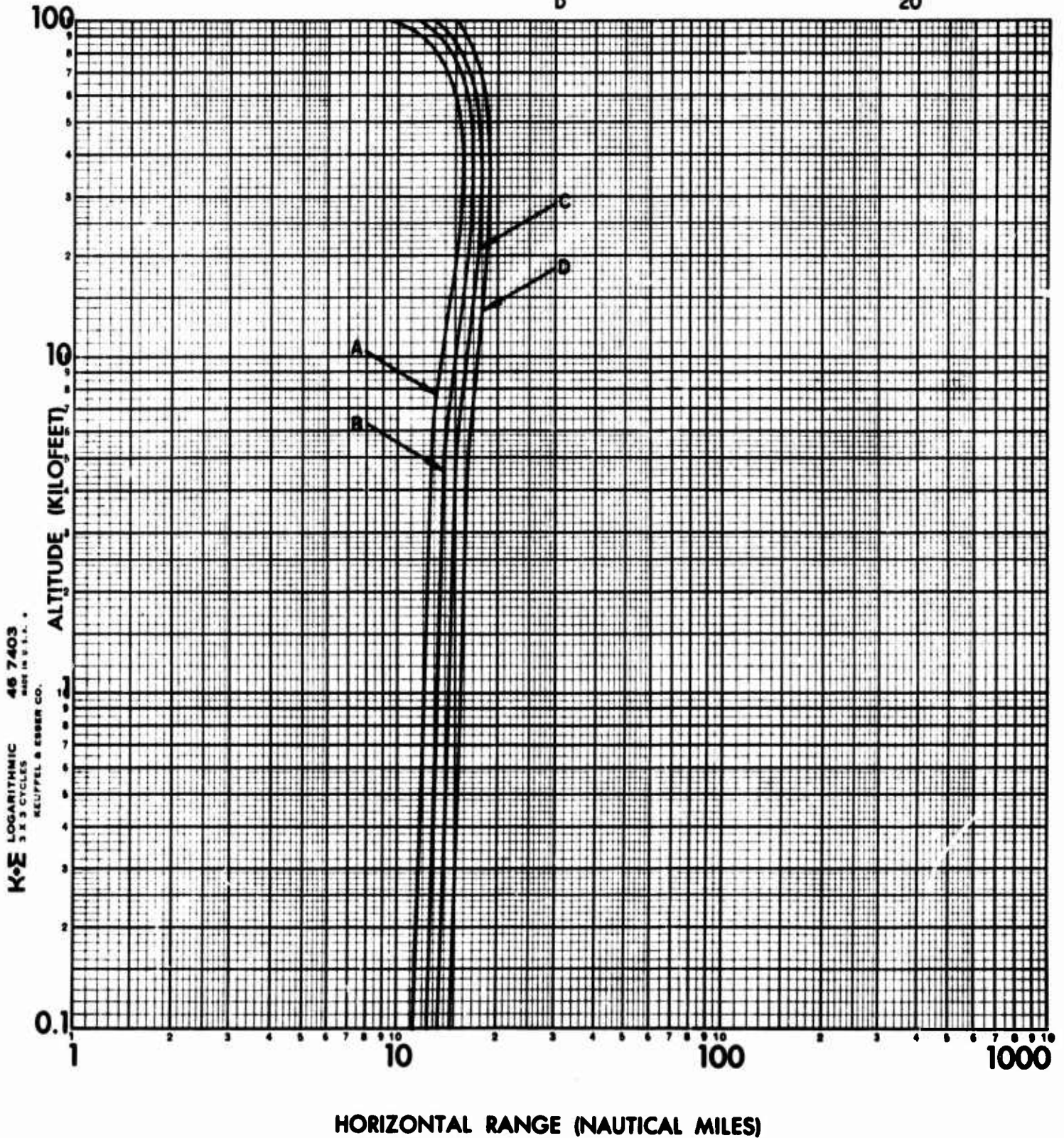


FIGURE 67

# FLASHBLINDNESS

DAY      MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100

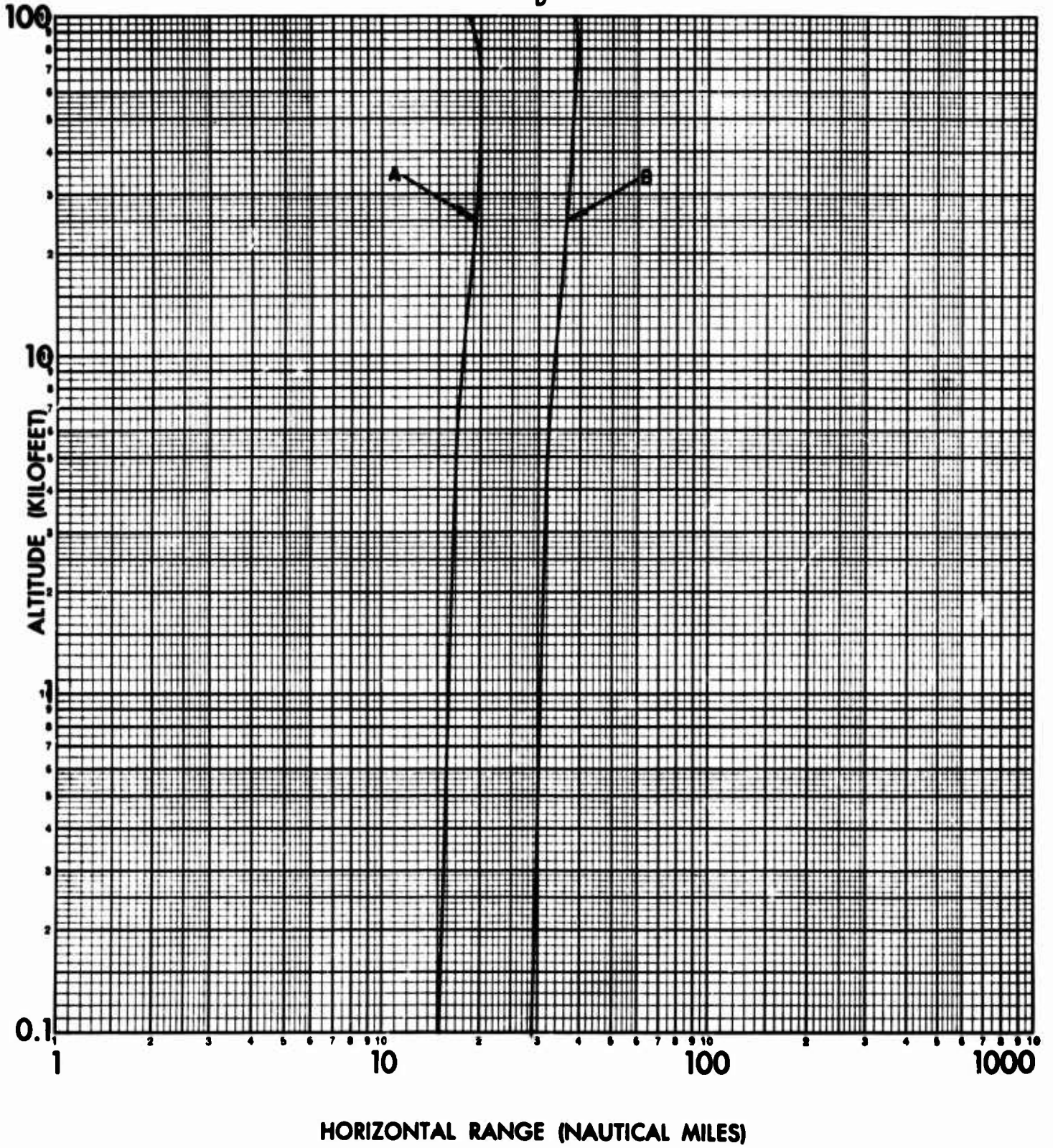


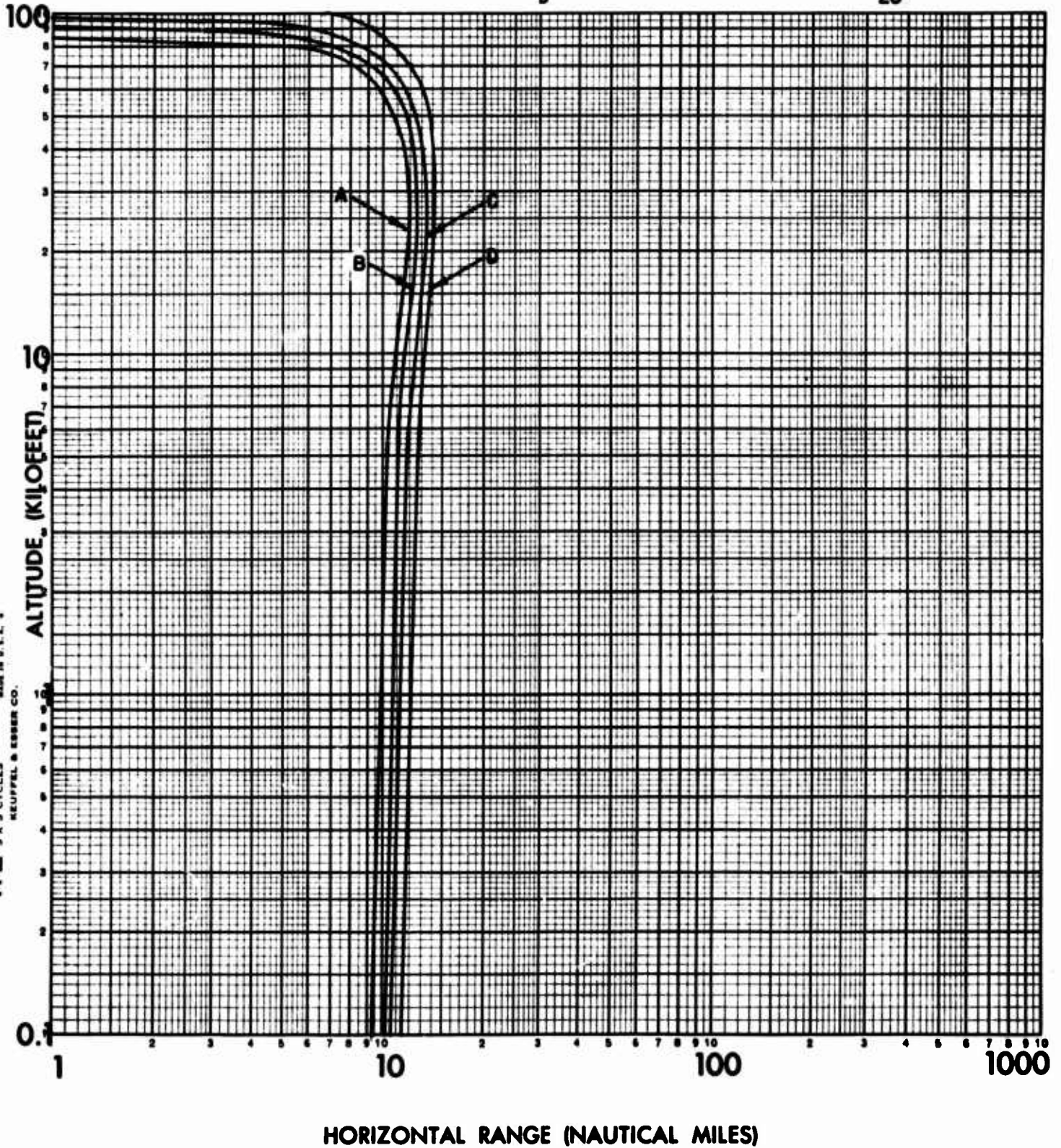
FIGURE 68

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 200 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1.5  
 5  
 10  
 20



K-E LOGARITMIC 46 7403  
 5 X 5 CYCLES  
 MADE IN U.S.A.  
 HEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 69

# FLASHBLINDNESS

DAY      MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

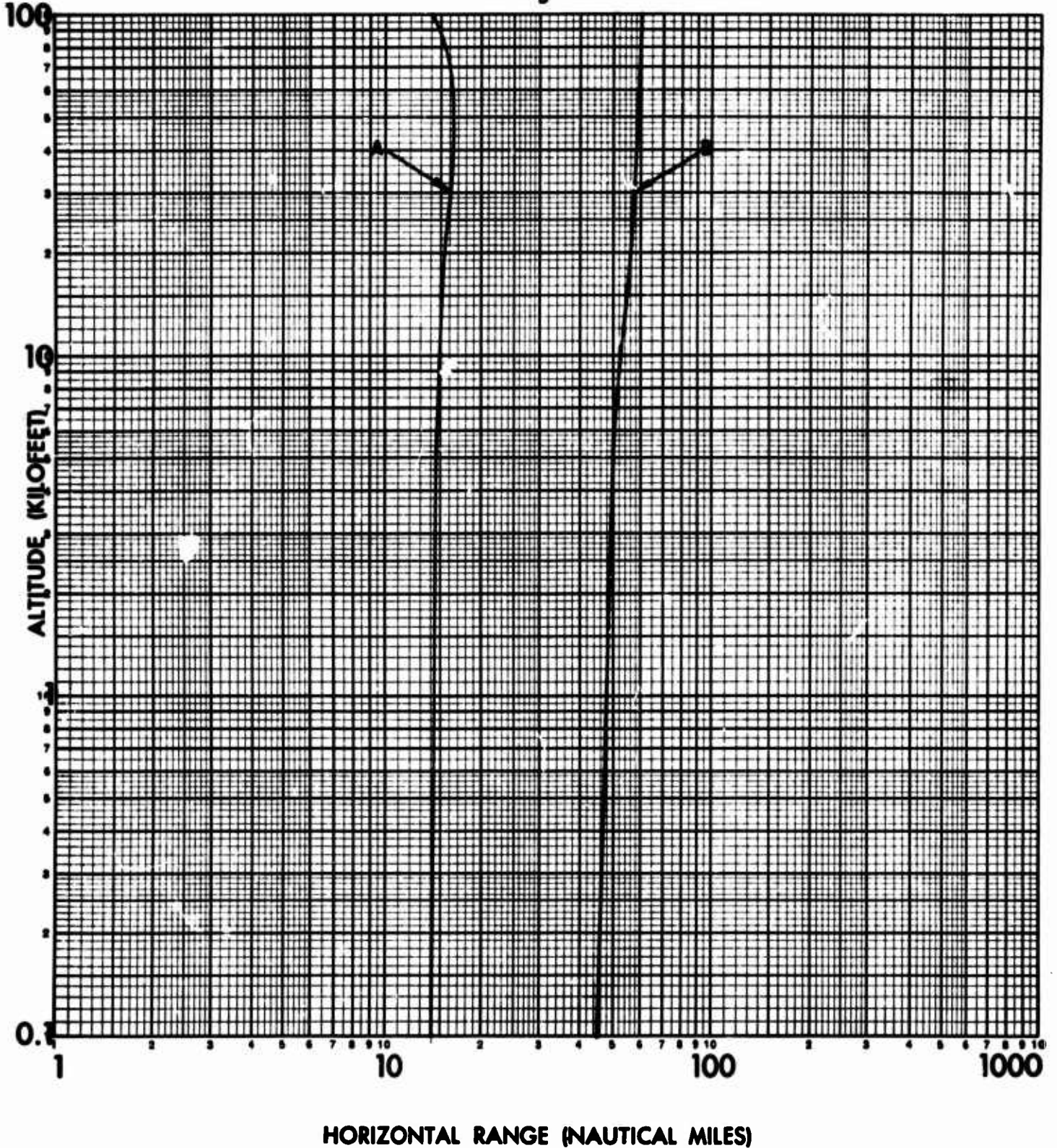


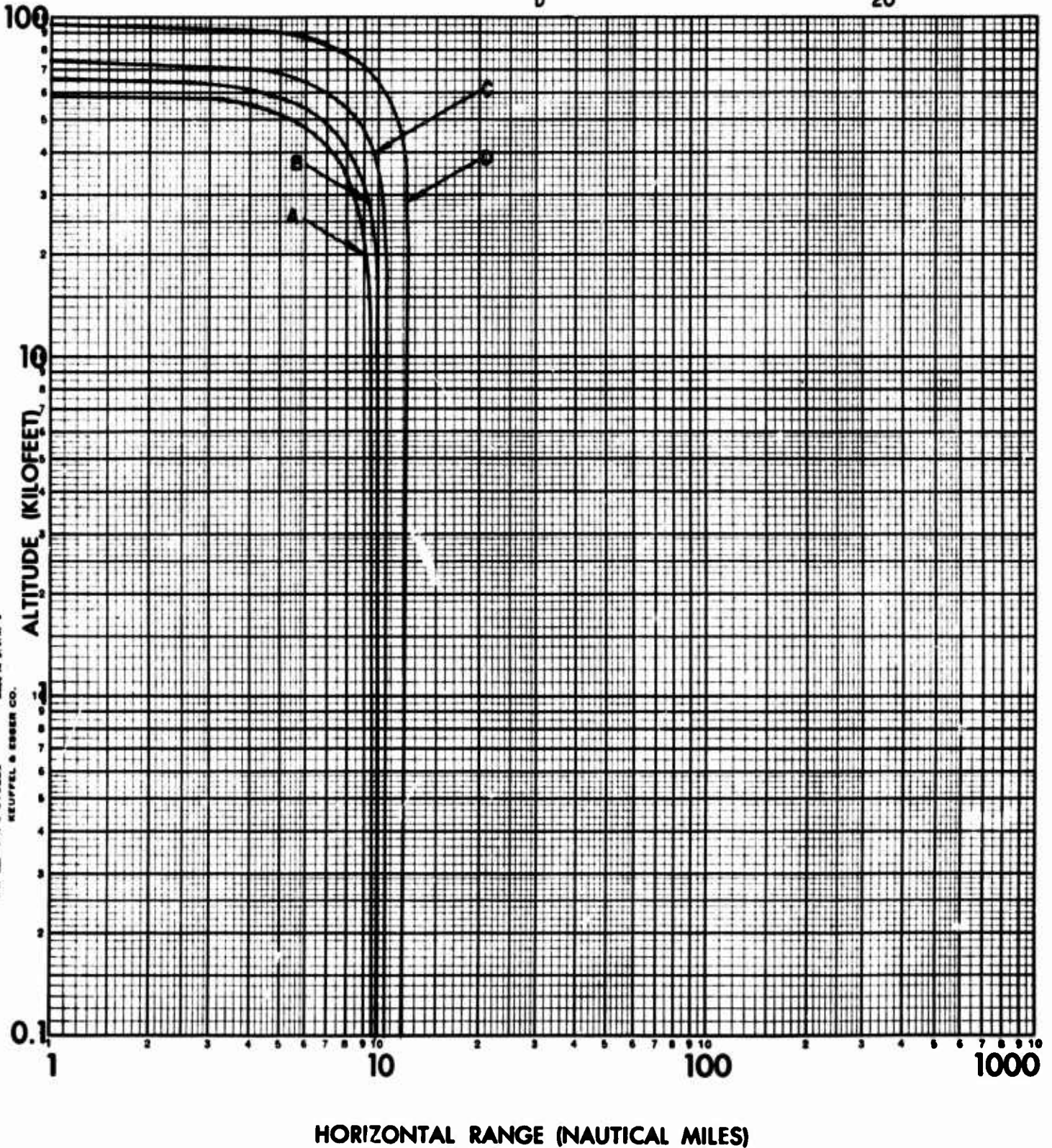
FIGURE 70

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 440 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1.5  
 5  
 10  
 20



K-O-E LOGARITHMIC  
 3 X 3 CYCLES  
 46 7403  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 71

# FLASHBLINDNESS

DAY      MISSION

YIELD: 440 KT

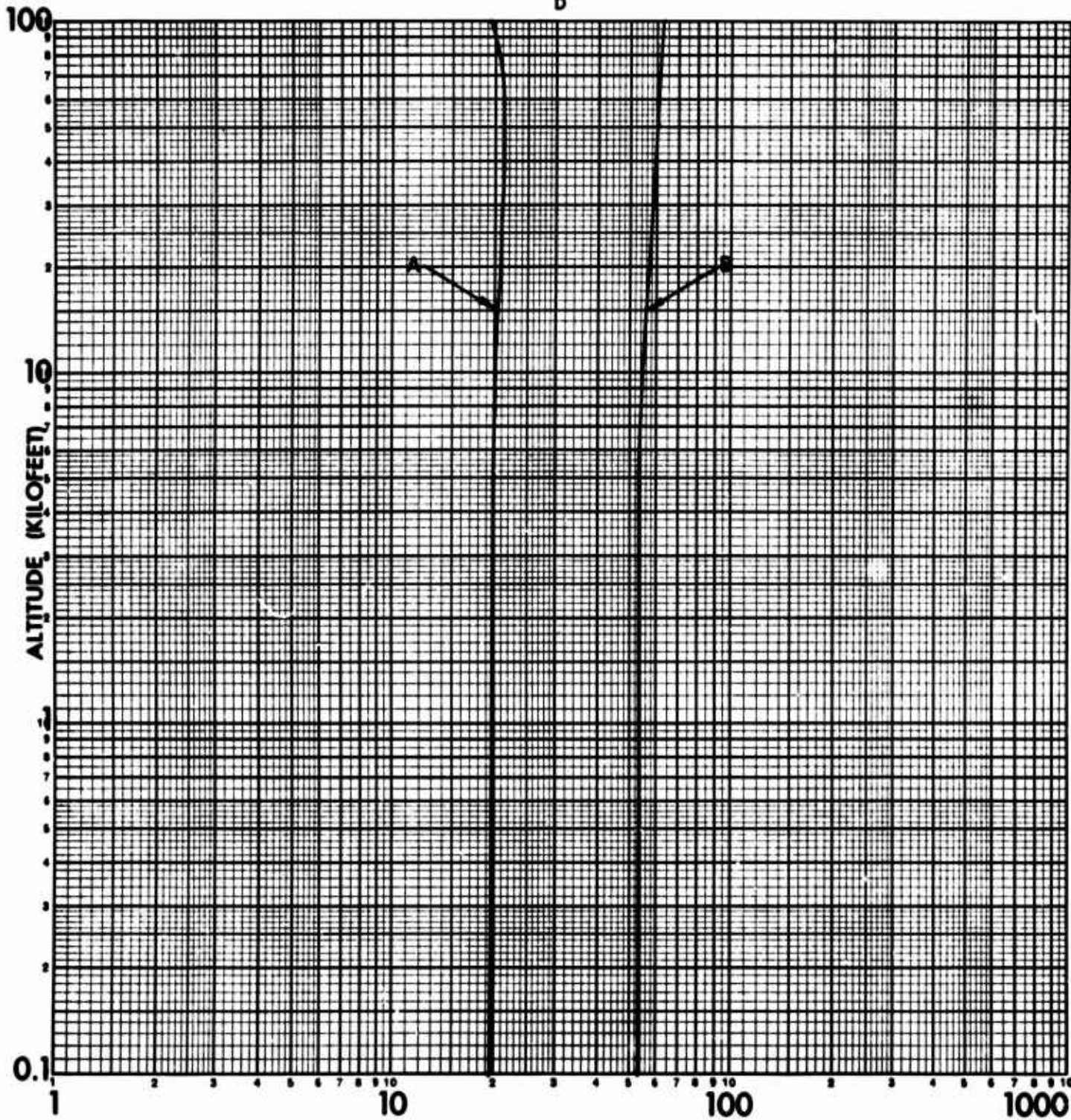
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 72

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 1000 KT

FILTER: NONE

SYMBOL

A

B

C

D

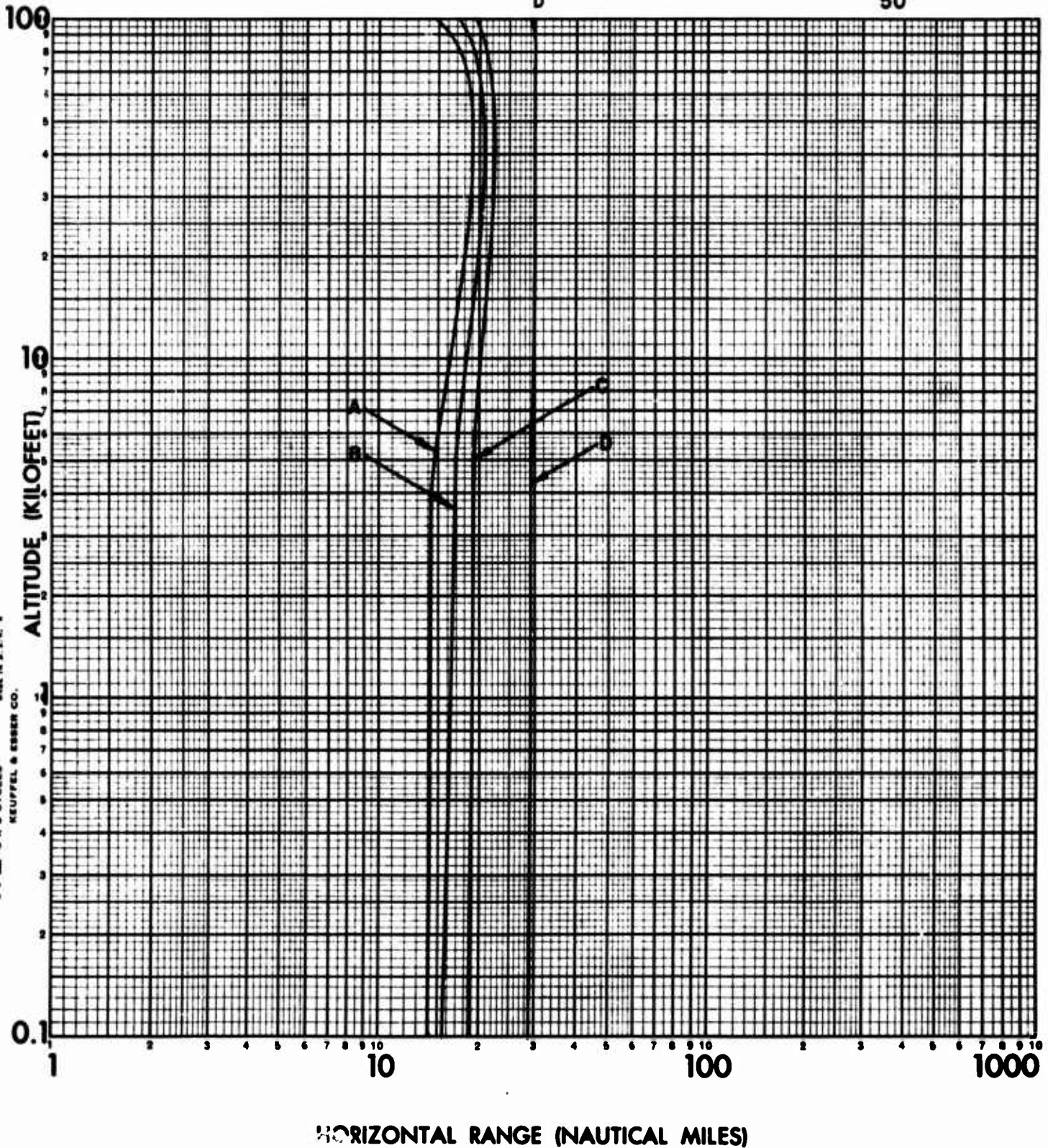
BURST ALTITUDE (Kilofeet)

3

10

25

50



K&E LOGARITHMIC  
 3 X 3 CYCLES  
 43 7403  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 73



# FLASHBLINDNESS

DAY      MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 4
- 10
- 25
- 50

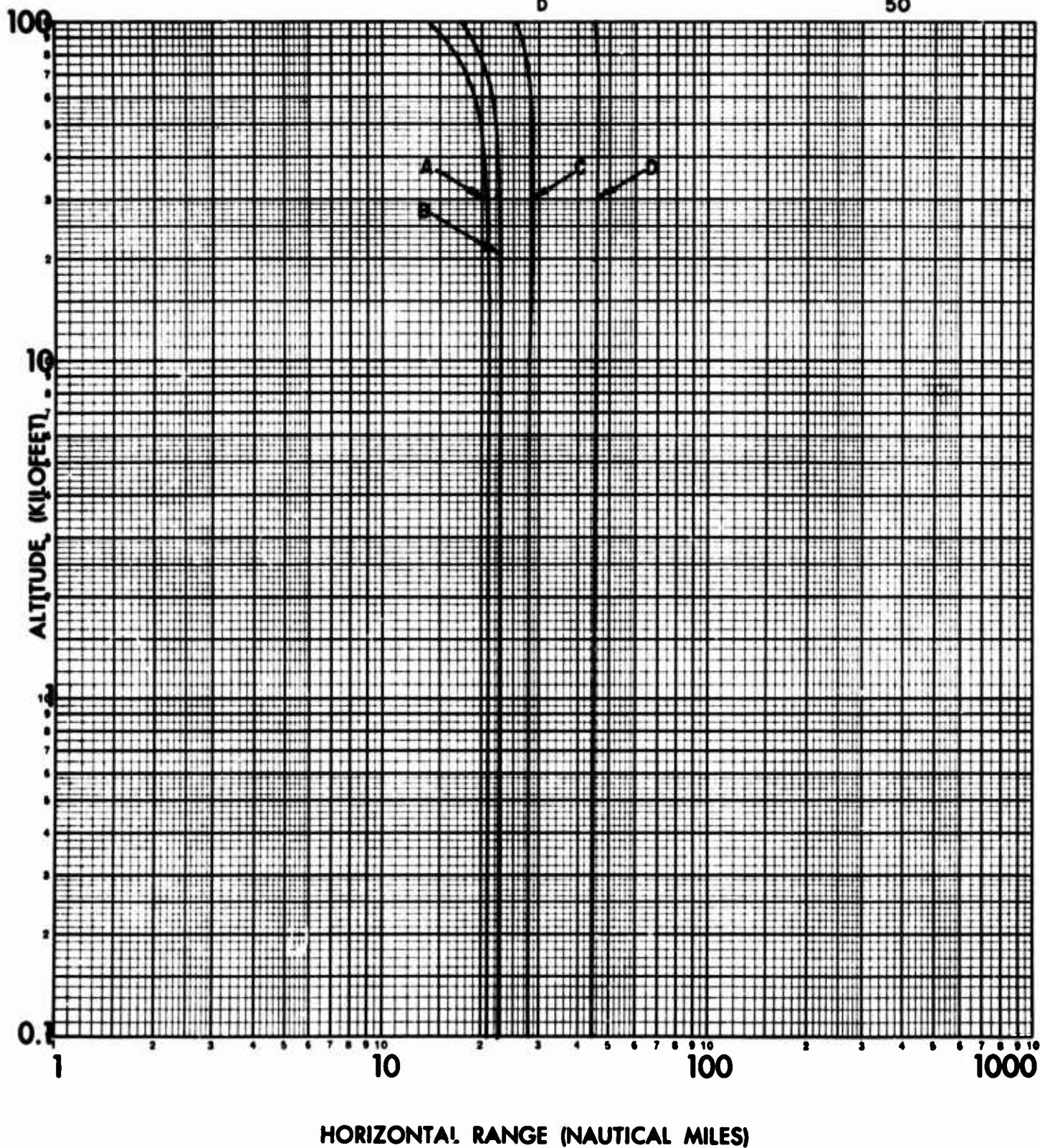


FIGURE 74

# FLASHBLINDNESS

DAY      MISSION

YIELD: 9000 KT

FILTER: NONE

SYMBOL

A

B

C

D

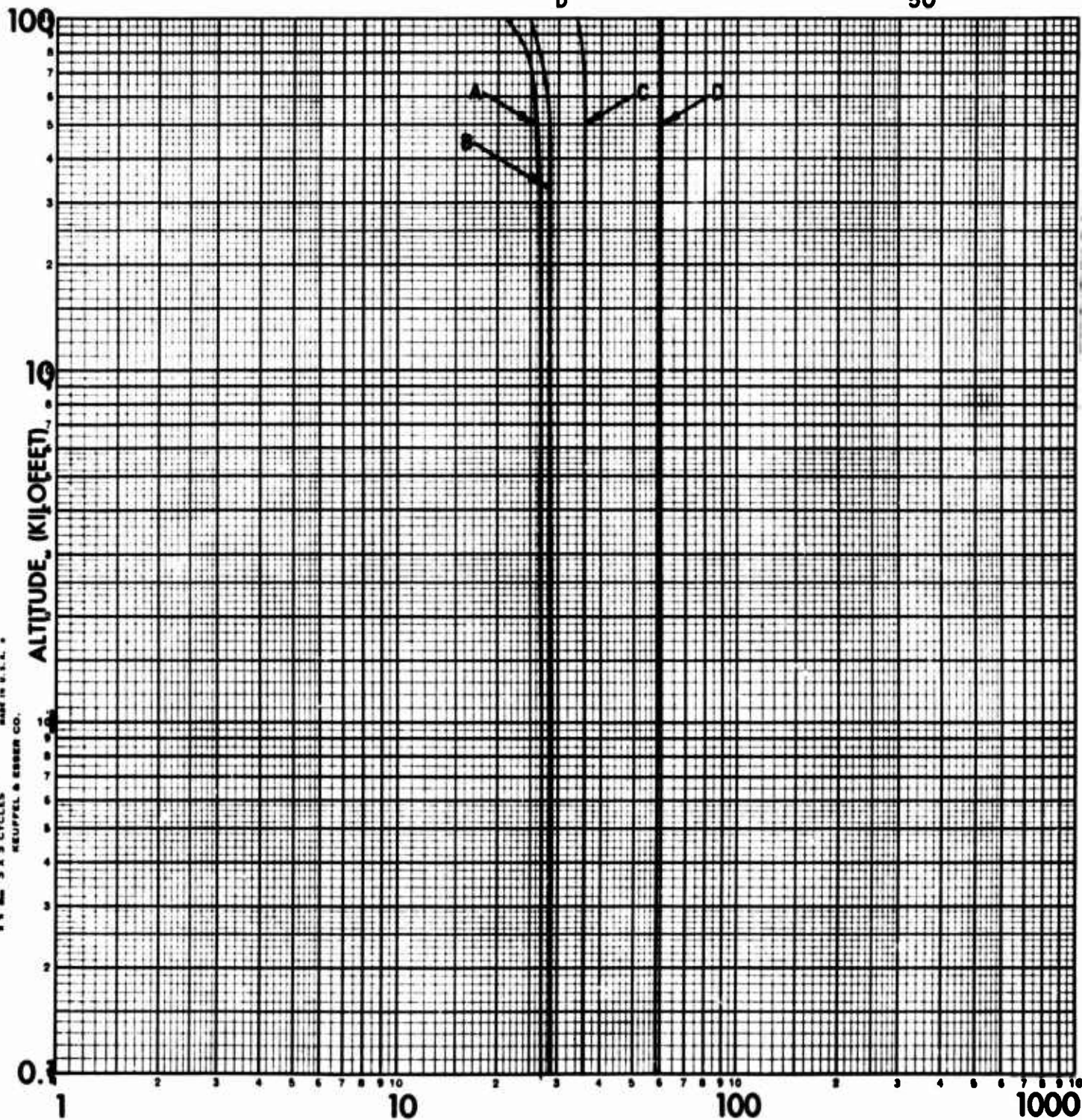
BURST ALTITUDE (Kilofeet)

5

10

25

50



K·E LOGARITHMIC 46 7403  
3 X 3 CYCLES  
MADE IN U.S.A.  
KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 75

# FLASHBLINDNESS

DAY      MISSION

YIELD: 23000 KT

FILTER: NONE

SYMBOL

A

B

C

D

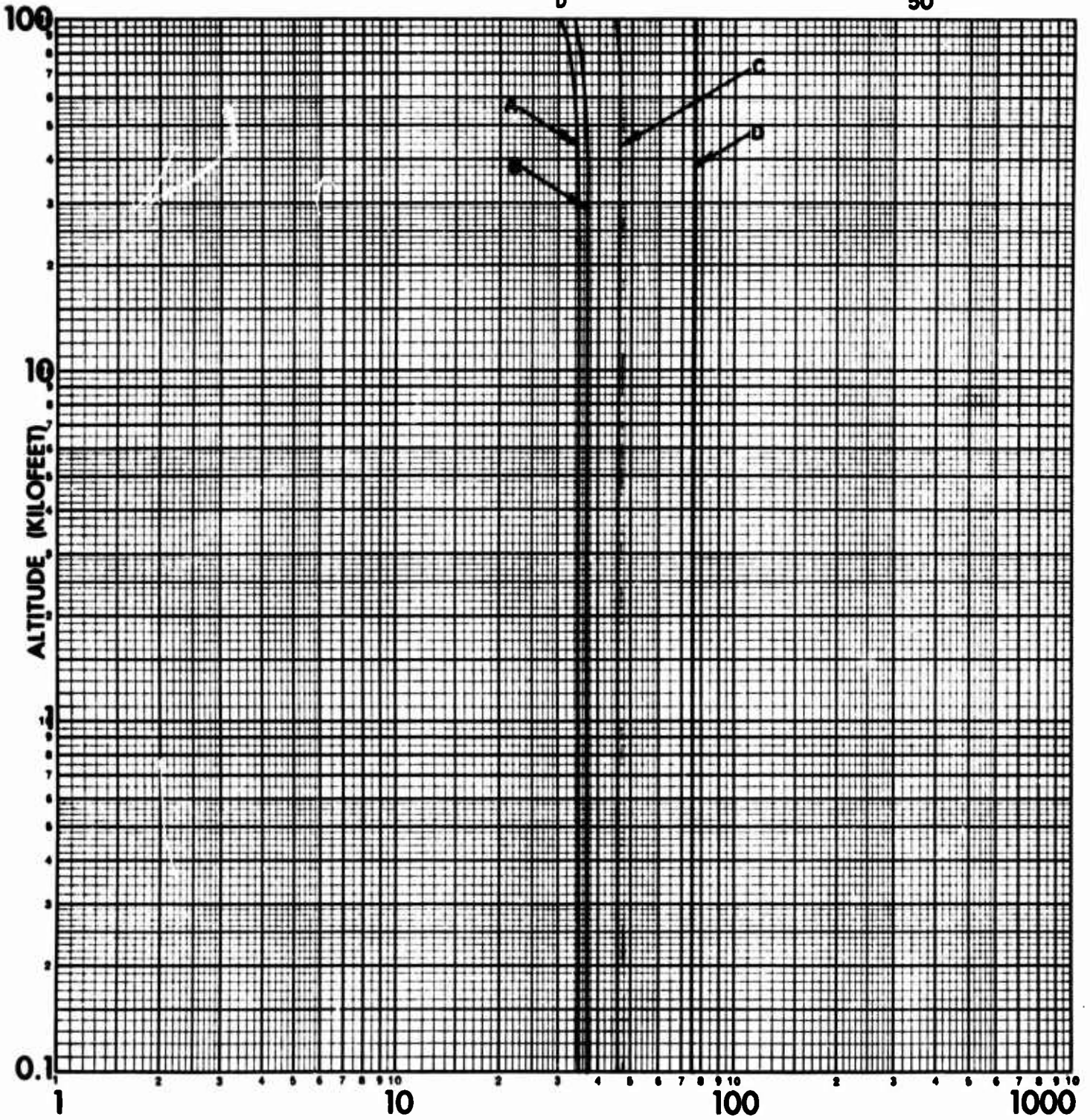
BURST ALTITUDE (Kilofeet)

6

10

25

50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 76

FLASHBLINDNESS SAFE SEPARATION ENVELOPES

NIGHT MISSION

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL

A

B

C

D

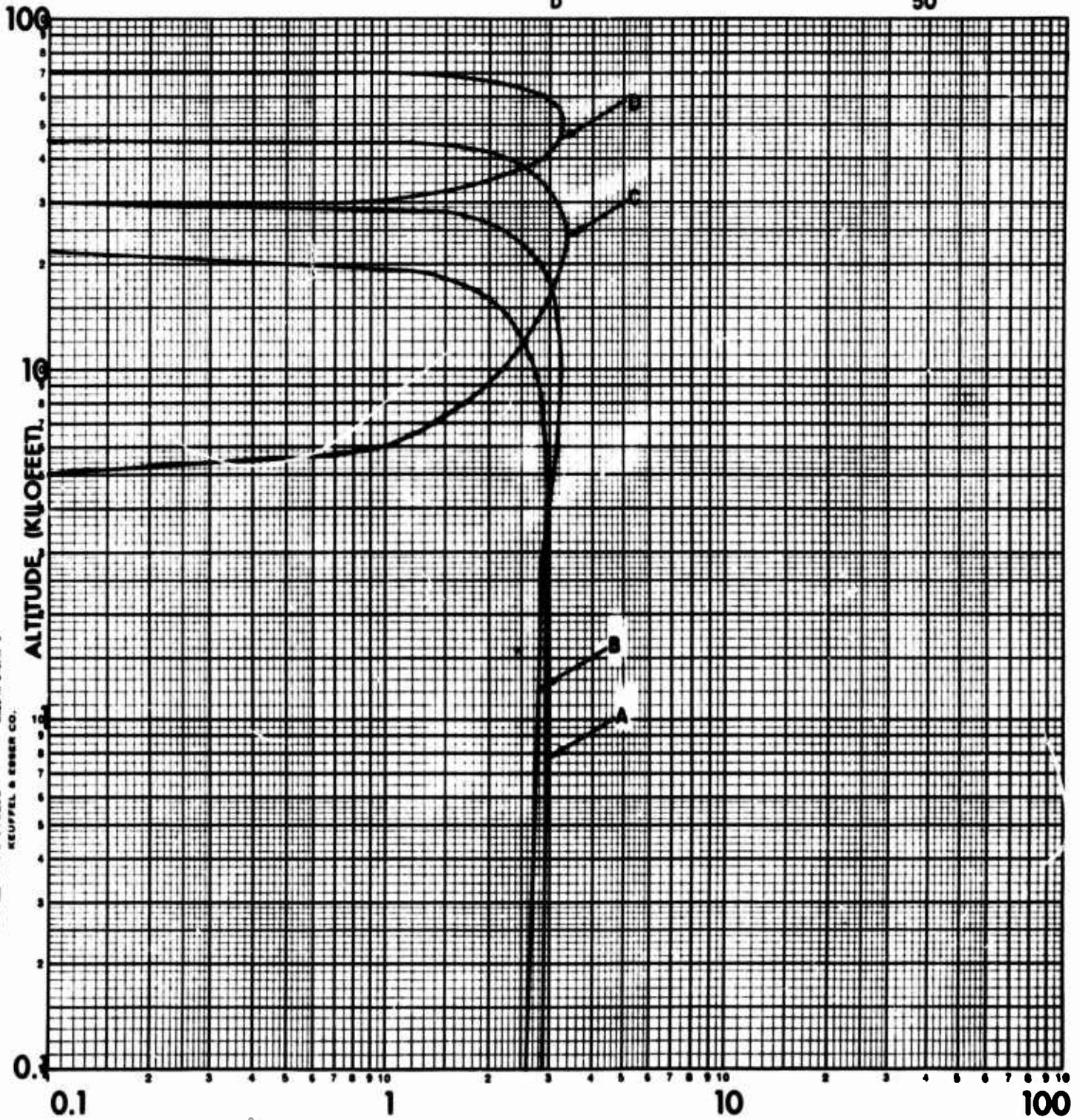
BURST ALTITUDE (Kiloft)

1

10

25

50



K-E LOGARITHMIC 46 7403  
3 X 3 CYCLES  
MADE IN U.S.A.  
KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 77

# FLASHBLINDNESS

NIGHT    MISSION  
 YIELD: 0.02 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 75  
 100

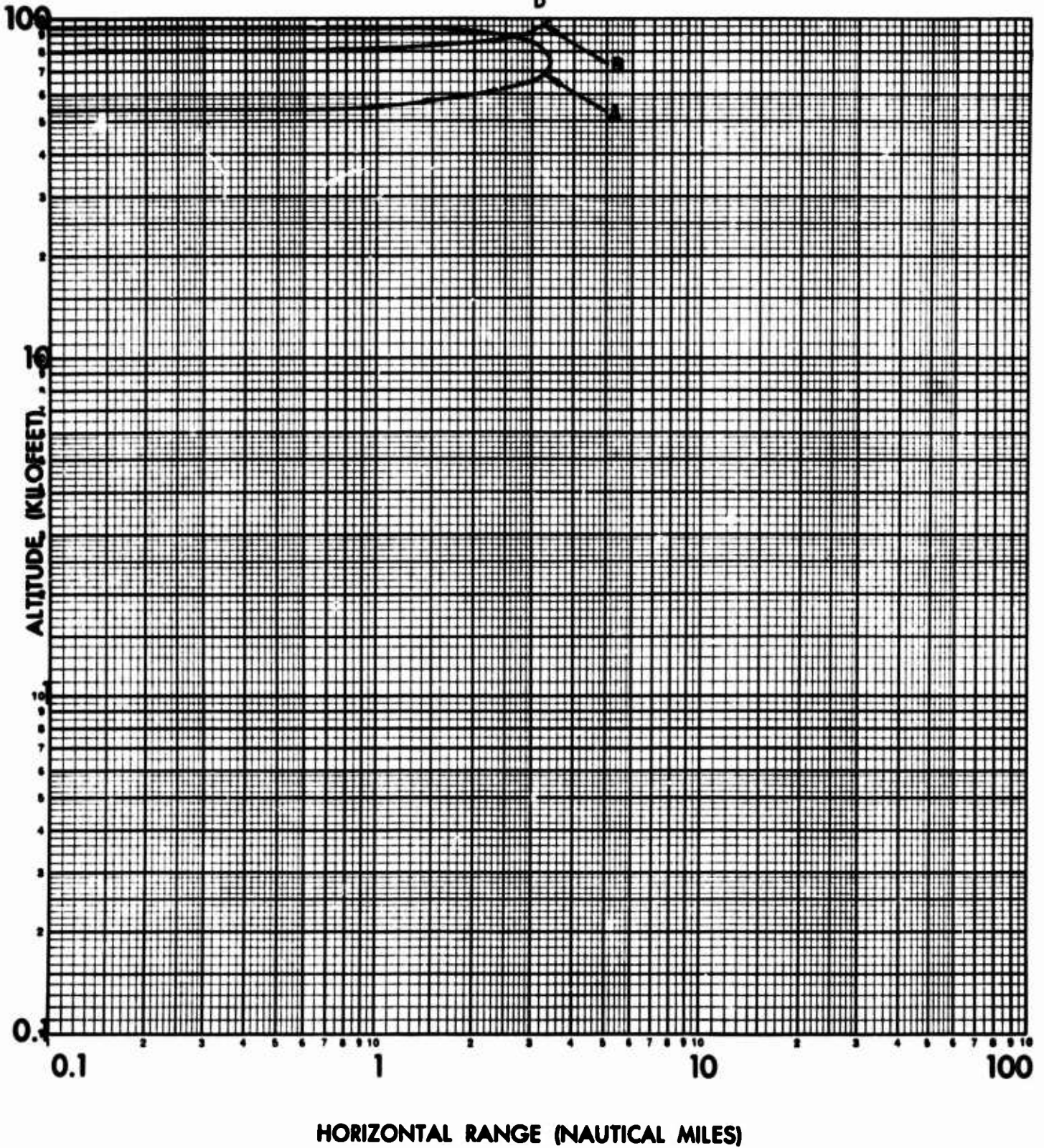


FIGURE 78

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.6 KT

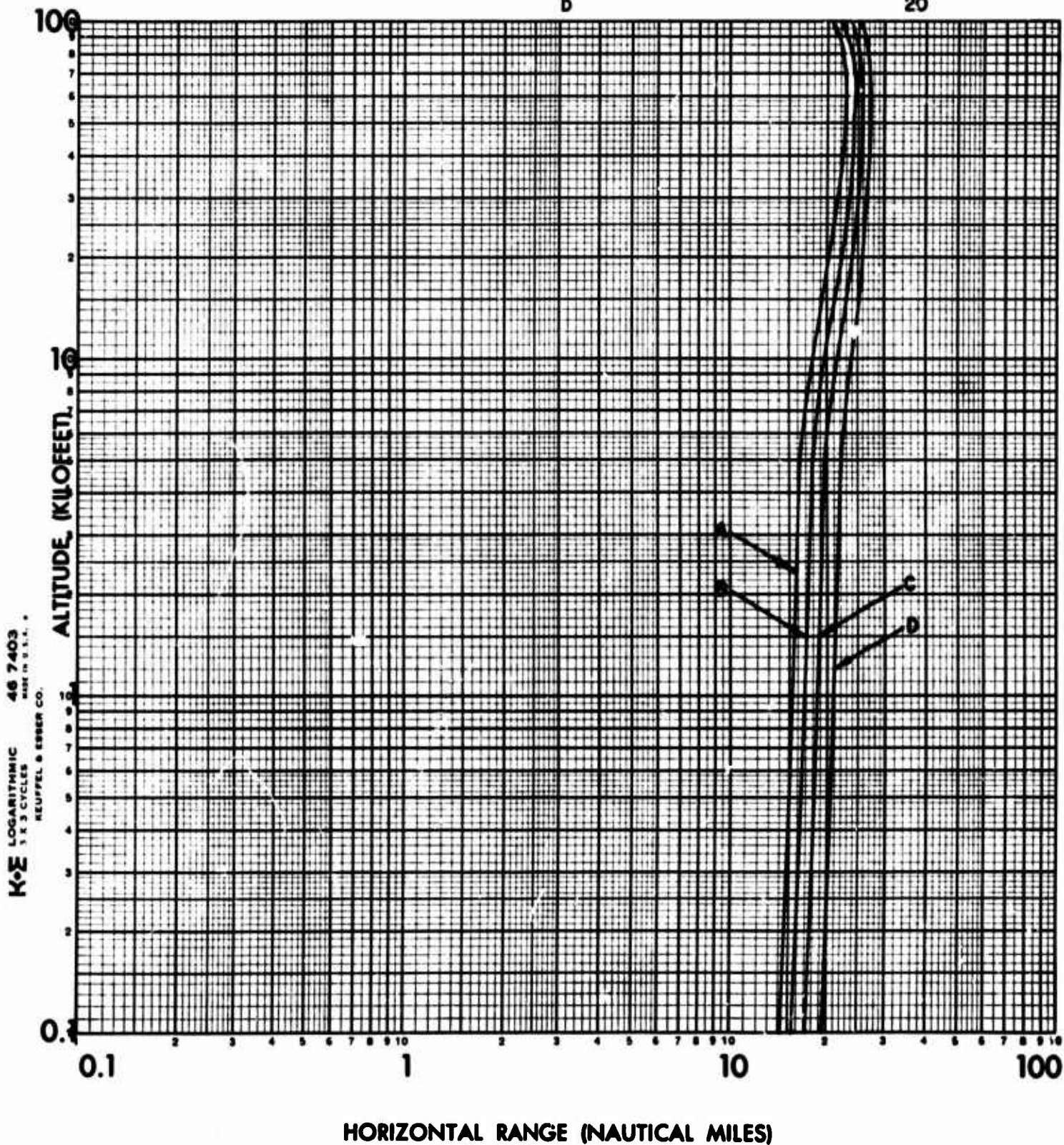
FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 1
- 5
- 10
- 20



K&E LOGARITHMIC 46 7403  
 MADE IN U.S.A.  
 REUFFEL & ESSER CO.

FIGURE 79

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

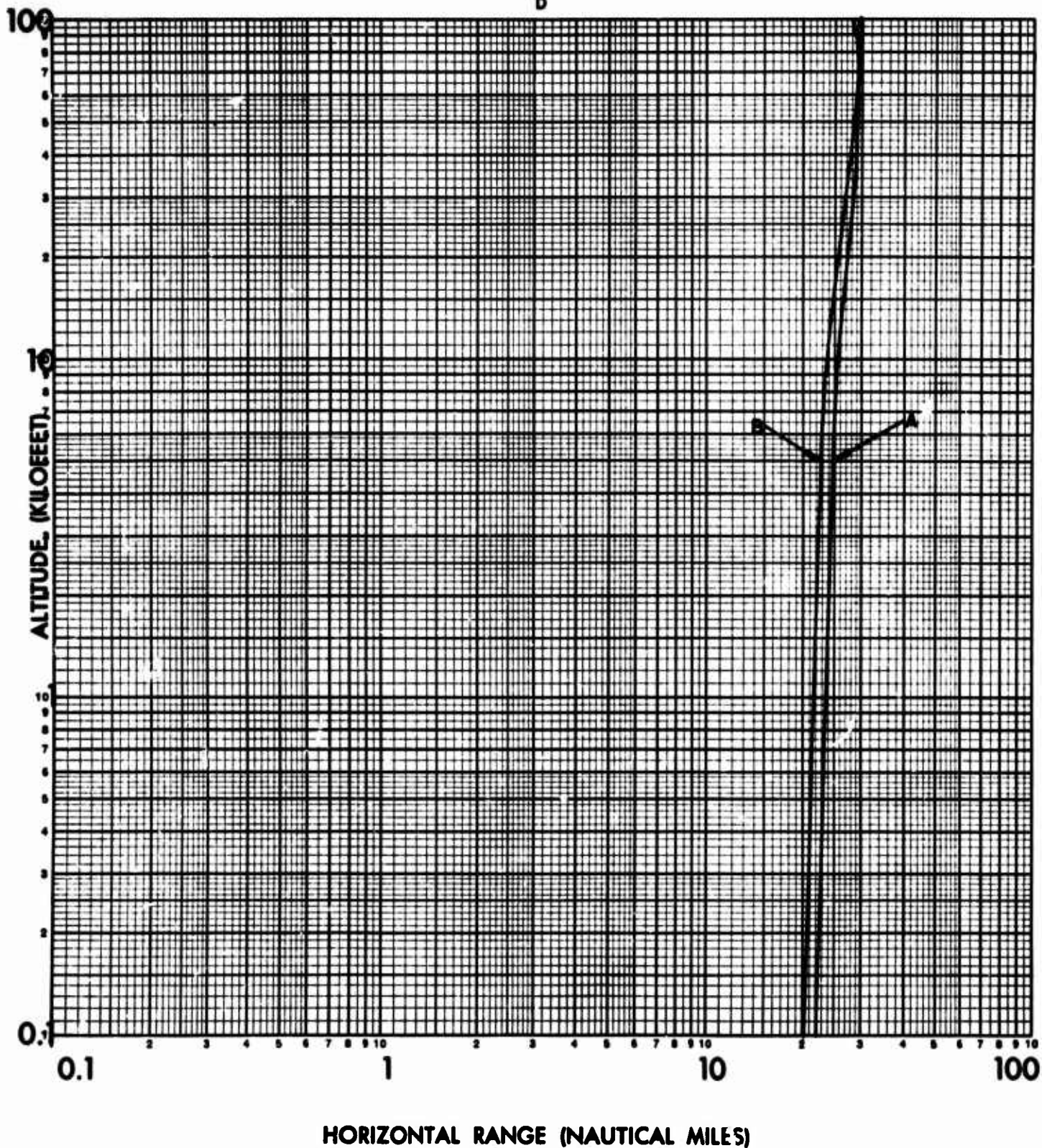


FIGURE 80



# FLASHBLINDNESS

NIGHT      MISSION

YIELD:      2      KT

FILTER:      NONE  

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 1
- 5
- 10
- 20

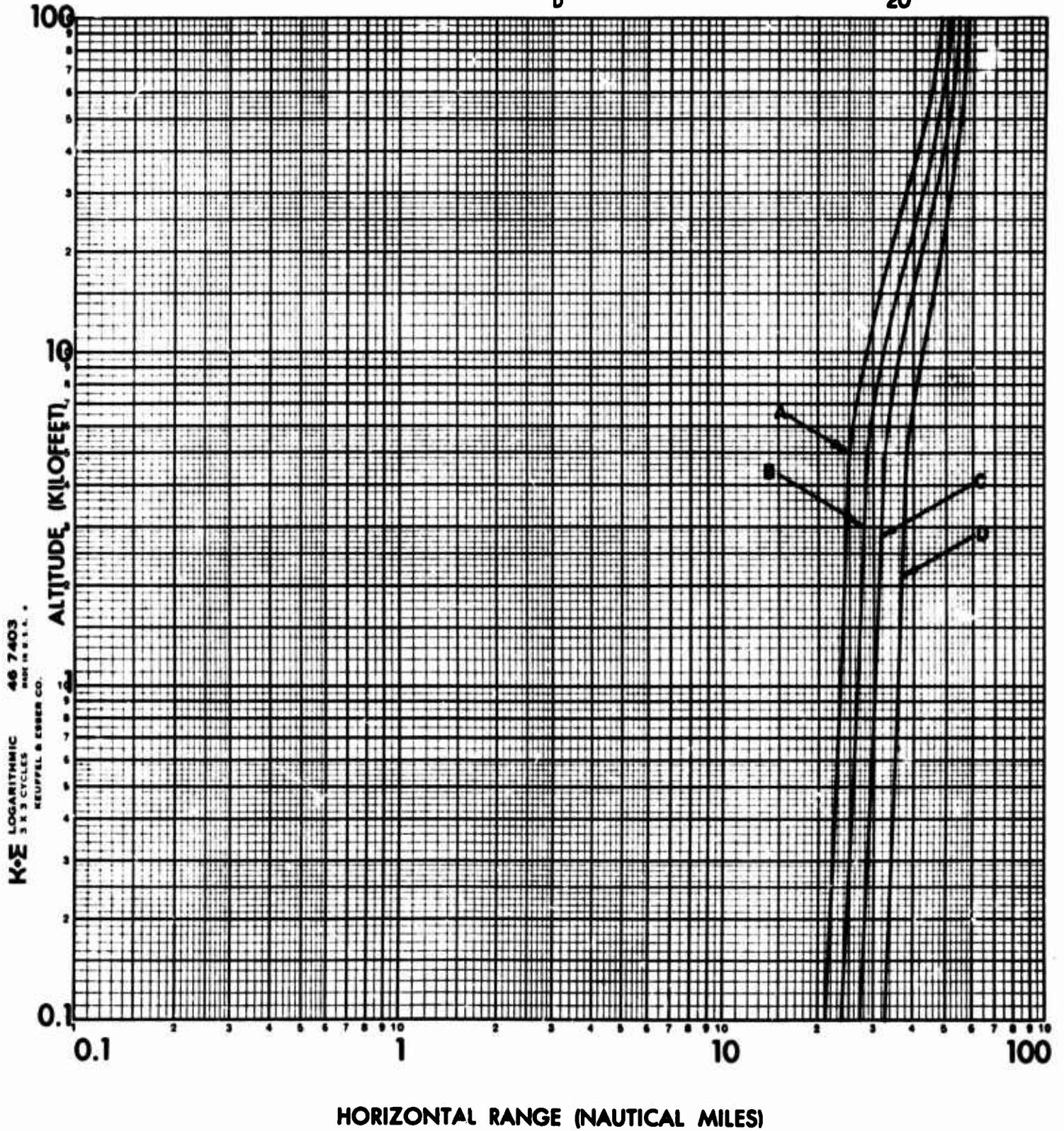


FIGURE 81

# FLASHBLINDNESS

NIGHT MISSION

SYMBOL

BURST ALTITUDE (Kilofeet)

YIELD: 2 KT

A

50

B

100

FILTER: NONE

C

D

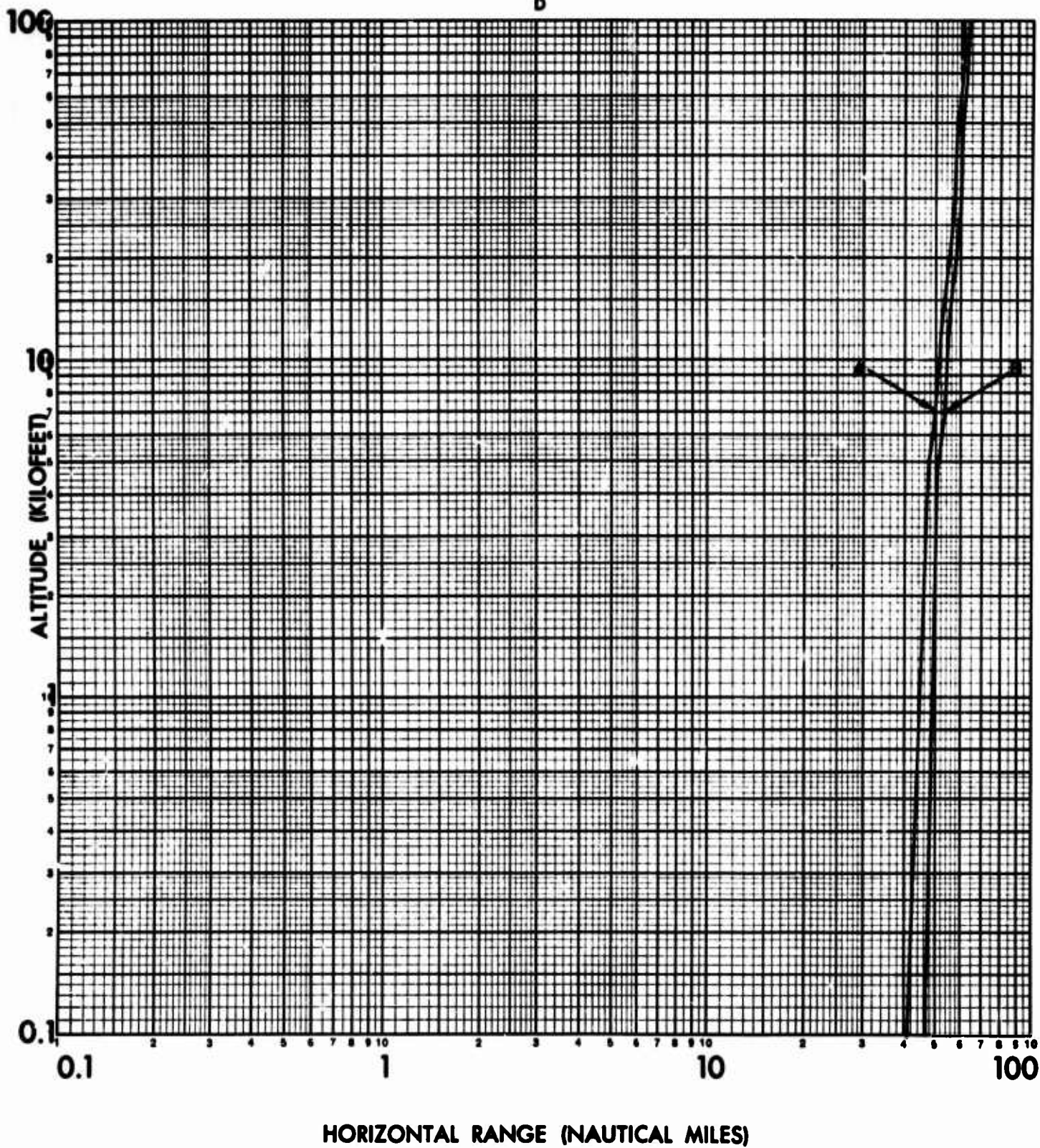


FIGURE 82

# FLASHBLINDNESS

NIGHT MISSION  
 YIELD: 10 KT  
 FILTER: NONE

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1  
 5  
 10  
 20

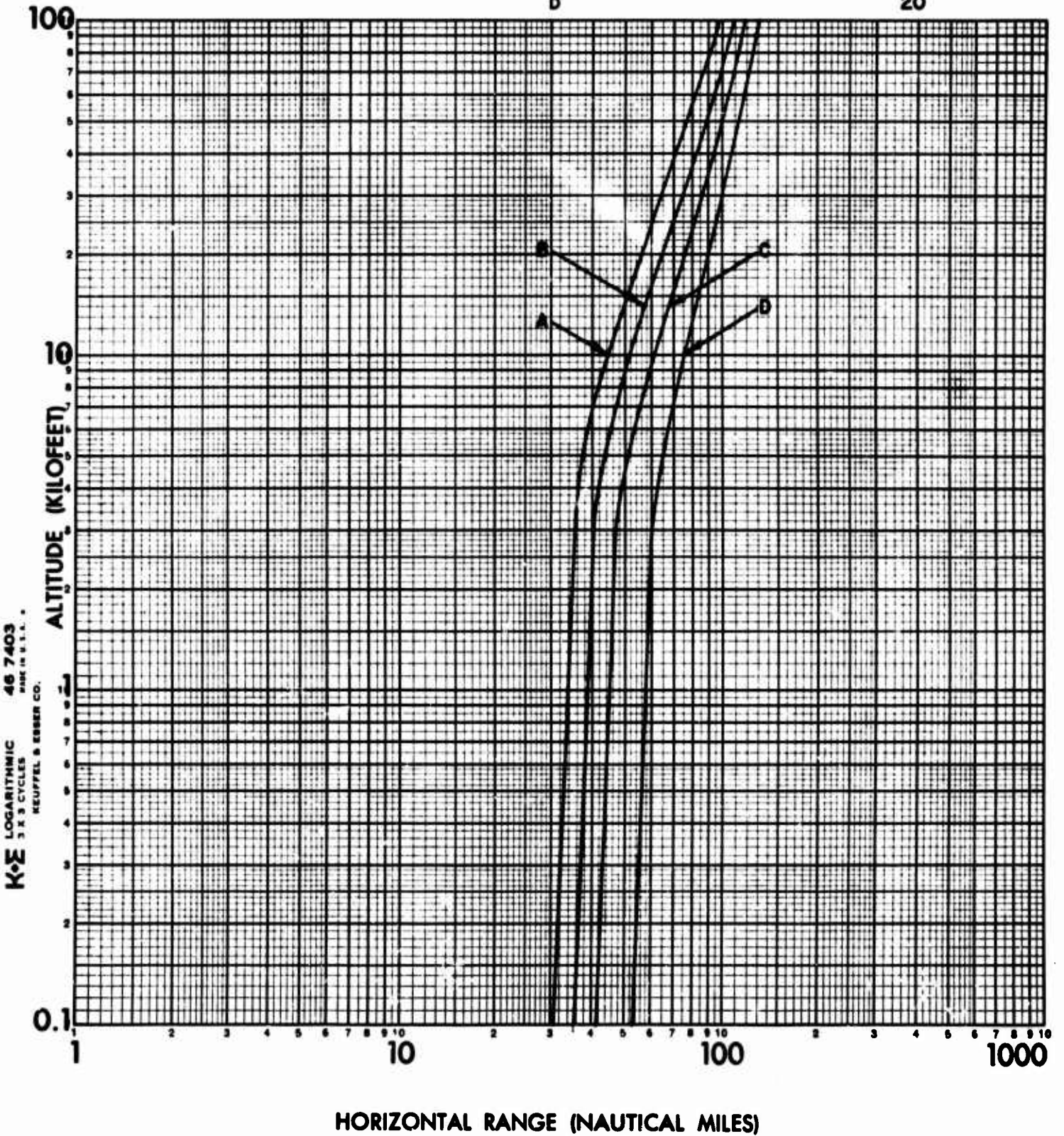


FIGURE 83

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

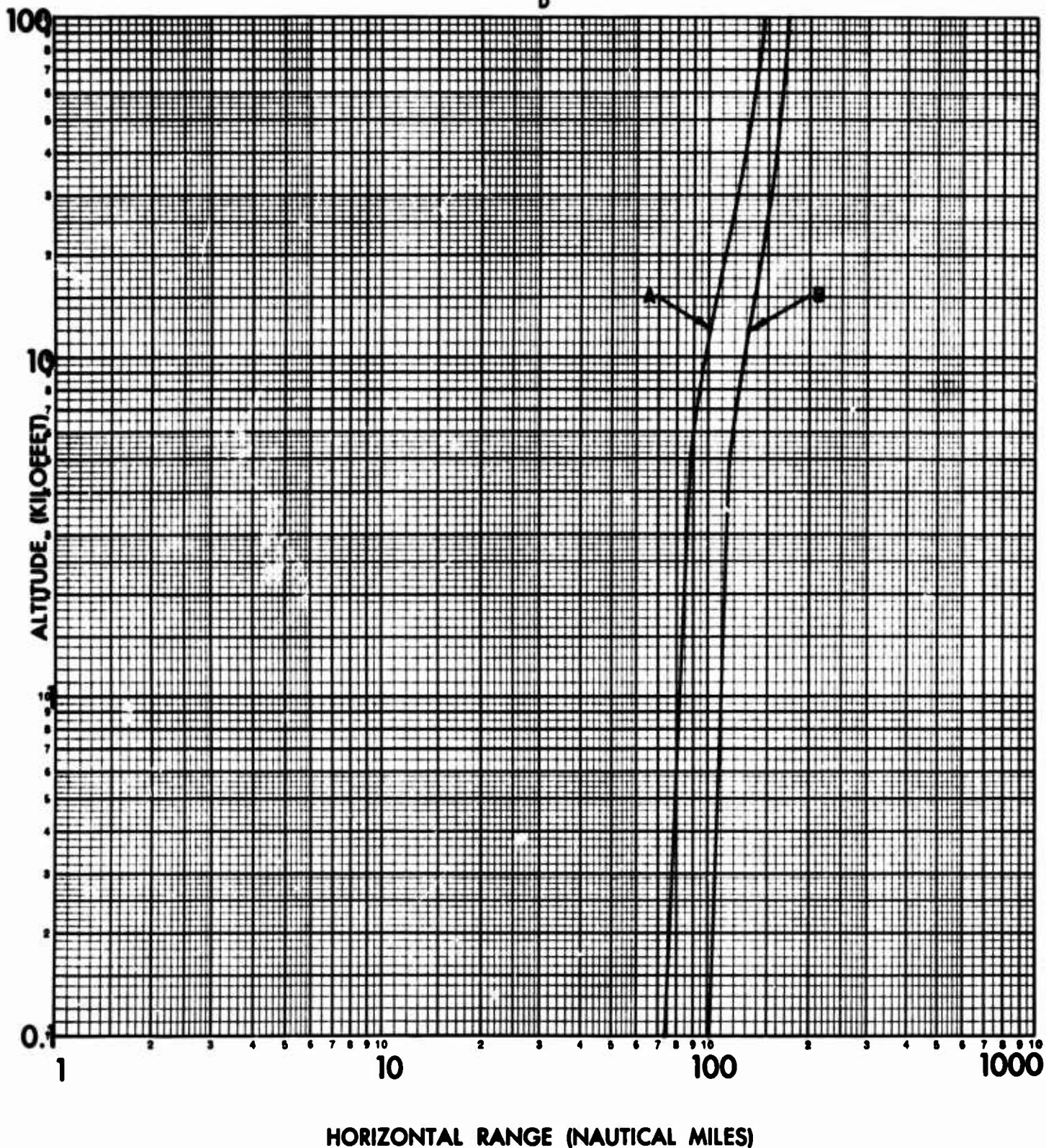


FIGURE 84

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20

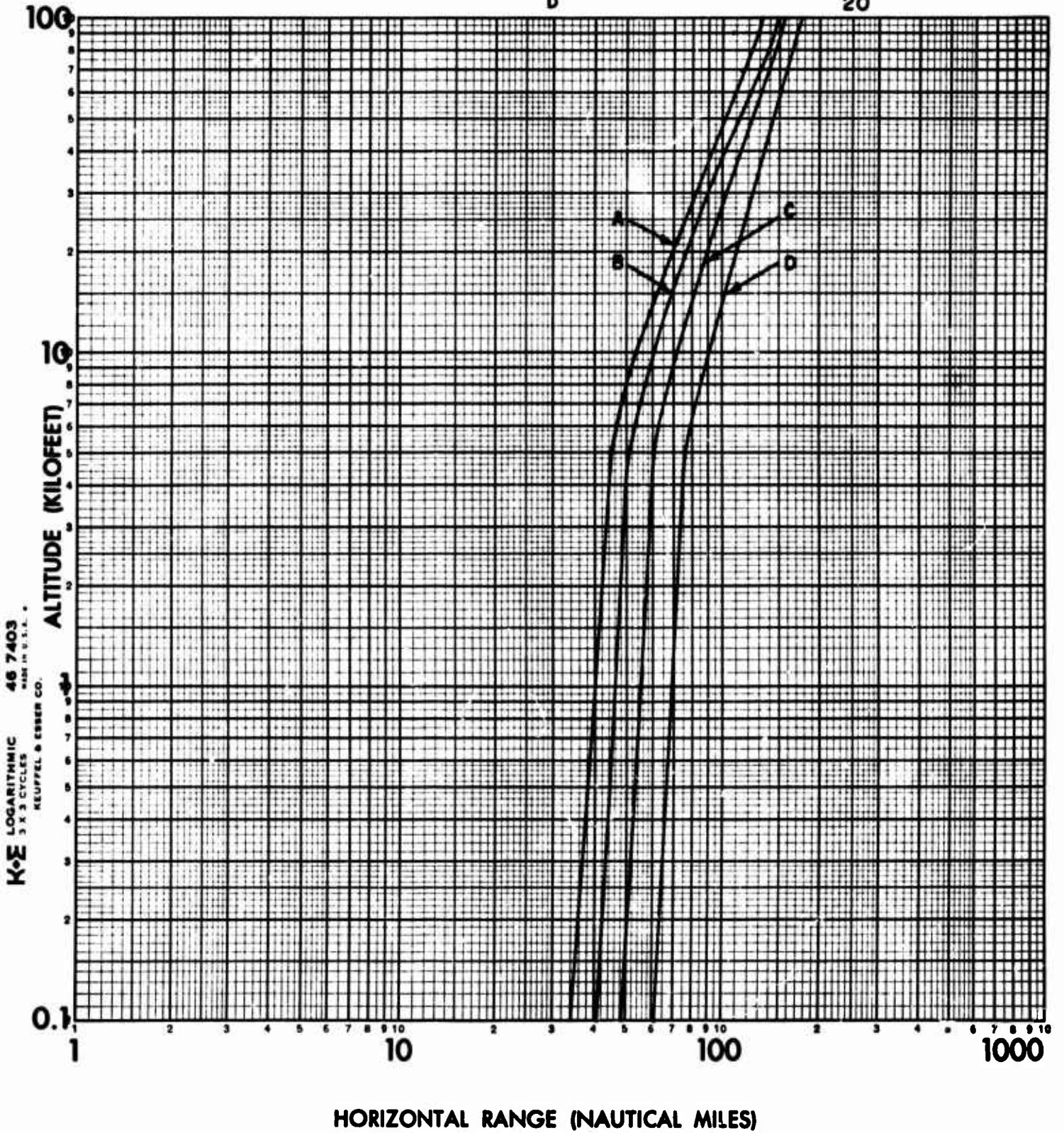


FIGURE 85

# FLASHBLINDNESS

<u>NIGHT</u>	MISSION		SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD:	<u>30</u>	KT	A	50
FILTER:	<u>NONE</u>		B	100
			C	
			D	

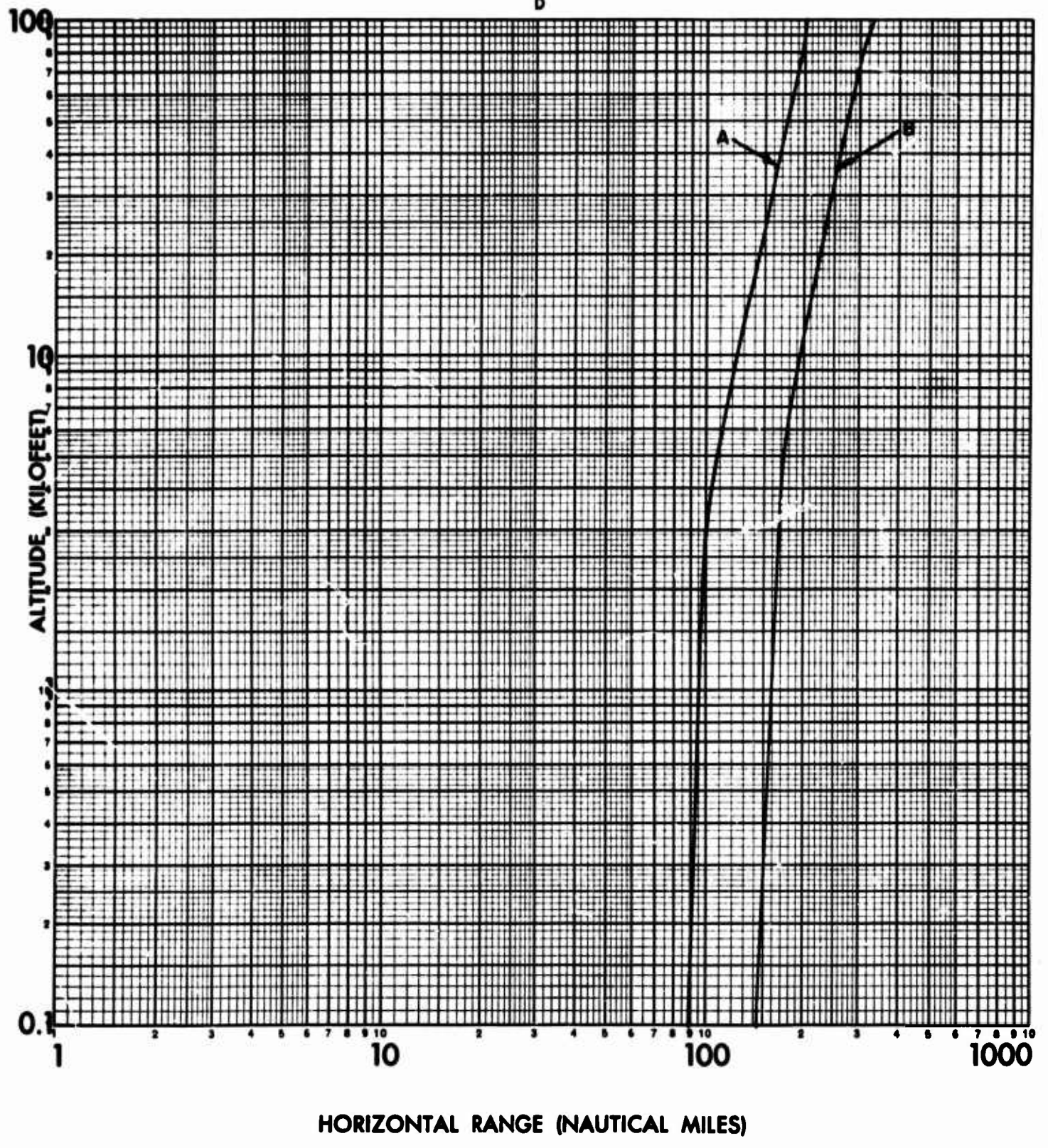
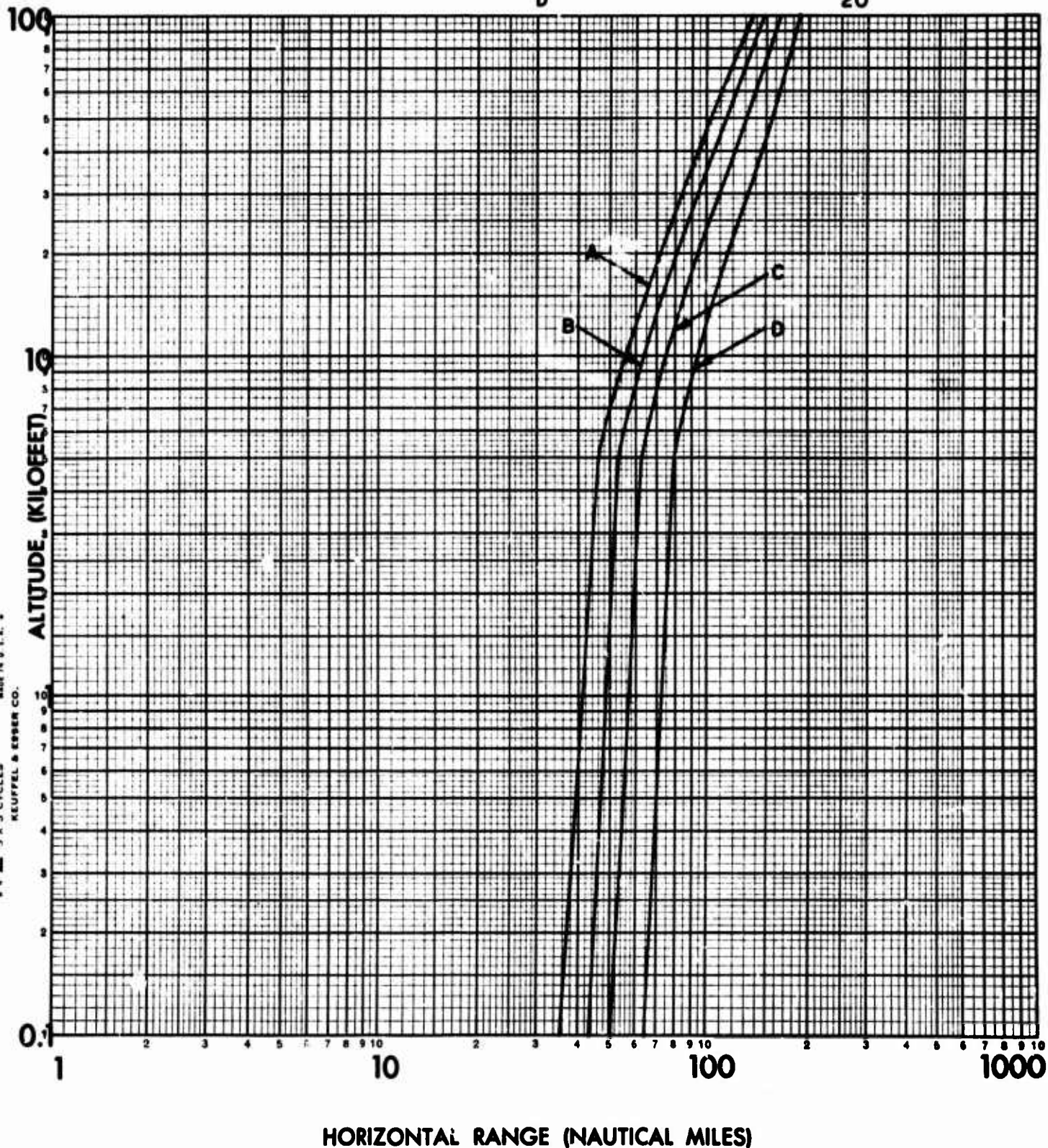


FIGURE 86

# FLASHBLINDNESS

NIGHT MISSION  
 YIELD: 60 KT  
 FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20



K-E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO. MADE IN U.S.A.

FIGURE 87

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

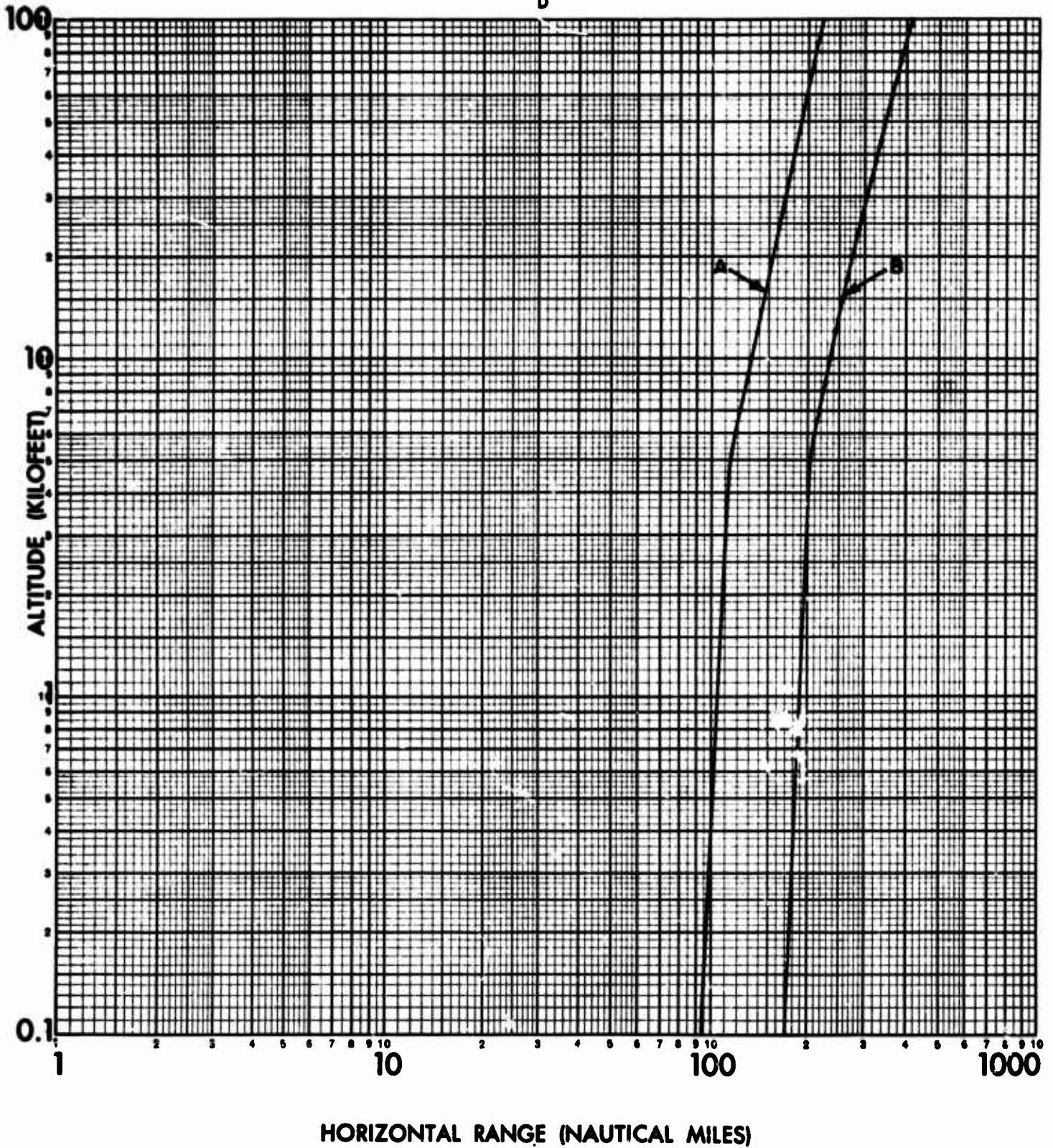


FIGURE 88



# FLASHBLINDNESS

**NIGHT MISSION**

**YIELD: 200 KT**

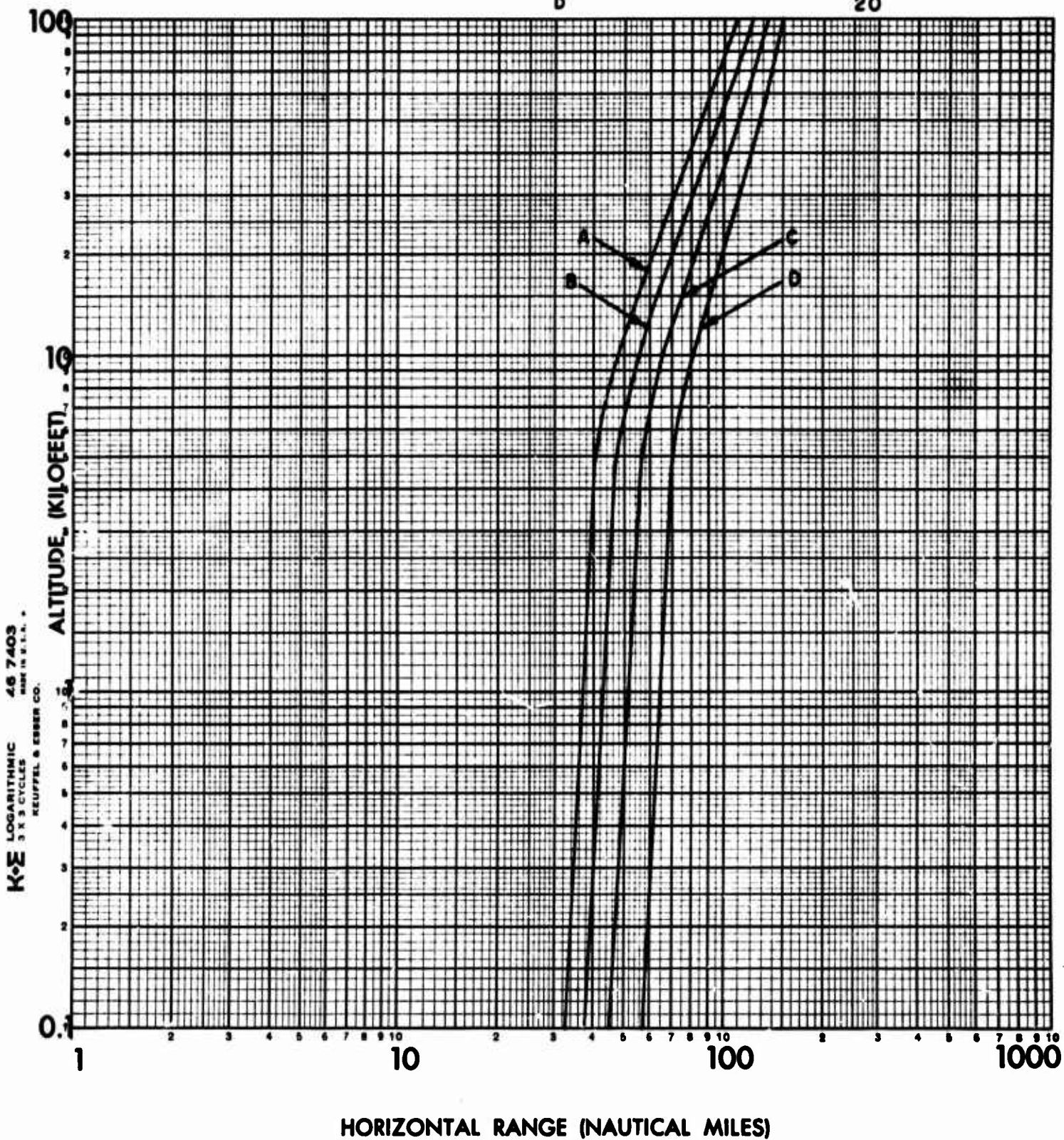
**FILTER: NONE**

**SYMBOL**

- A
- B
- C
- D

**BURST ALTITUDE (Kilofeet)**

- 1.5
- 5
- 10
- 20



K-E LOGARITHMIC 46 7403  
 5 X 5 CYCLES  
 KEUFFEL & ESSER CO.

FIGURE 89

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

50

100

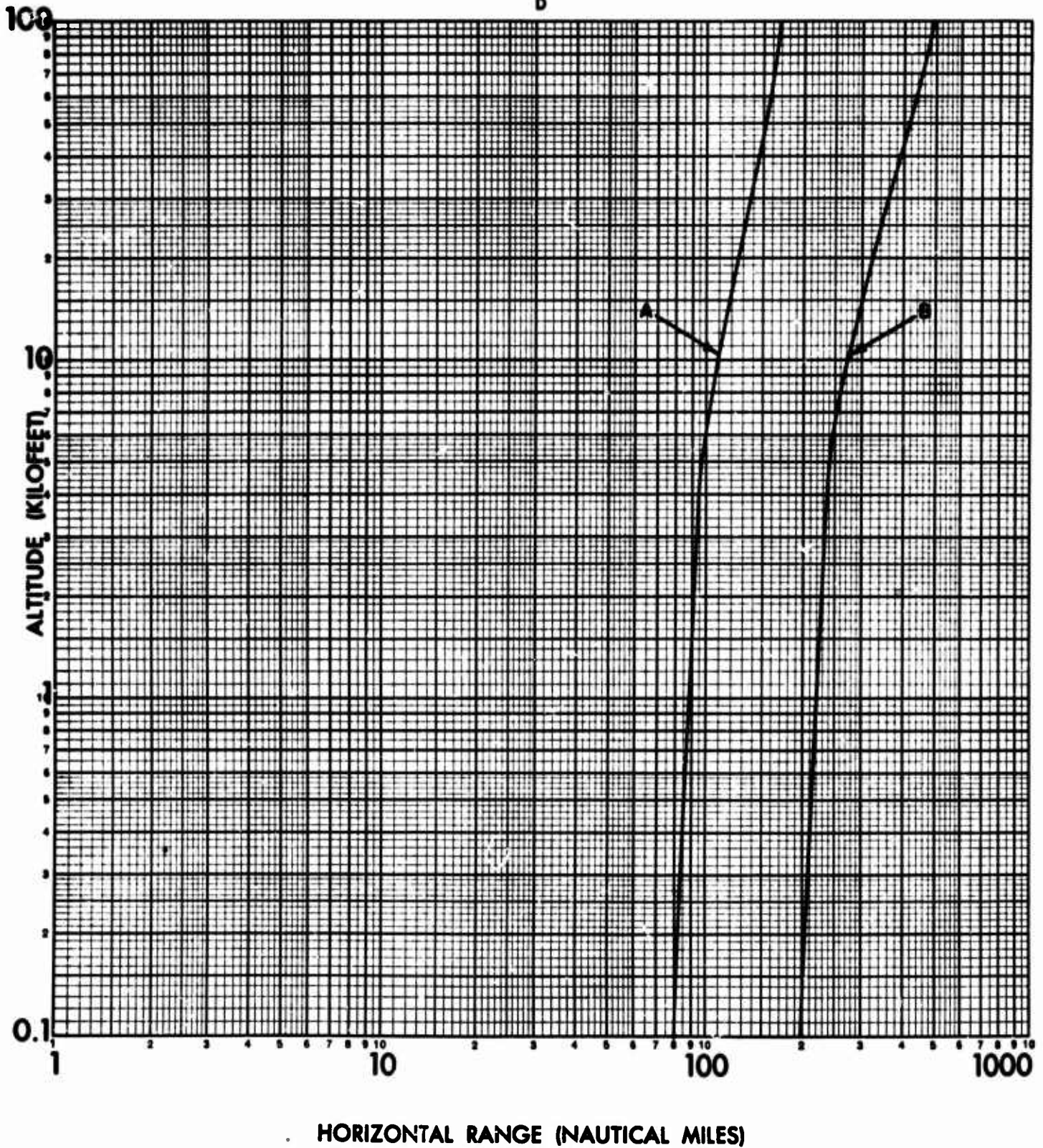


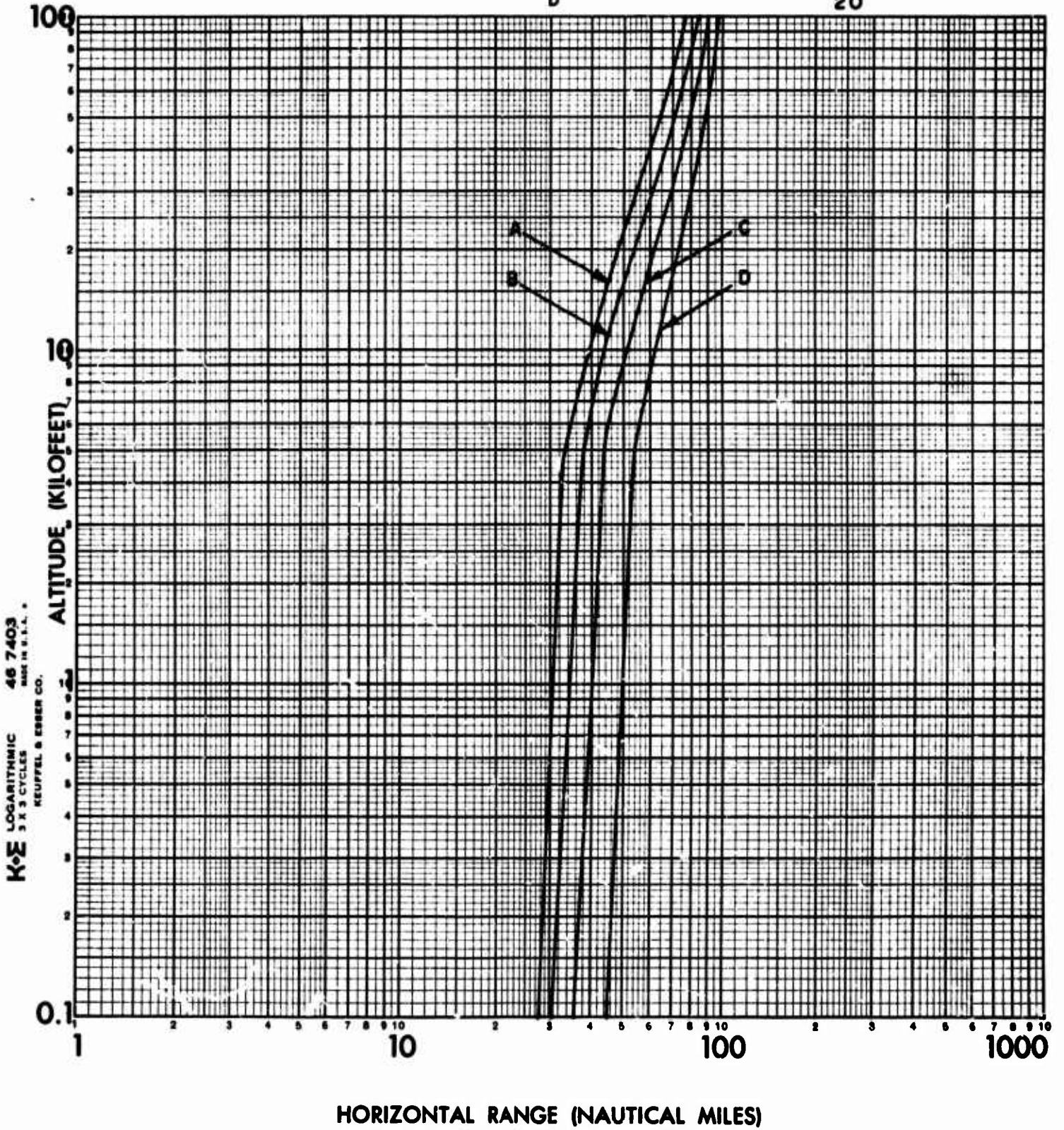
FIGURE 90

# FLASHBLINDNESS

NIGHT MISSION  
 YIELD: 440 KT  
 FILTER: NONE

SYMBOL:  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1.5  
 5  
 10  
 20



K&E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO.  
 MADE IN U.S.A.

FIGURE 91

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

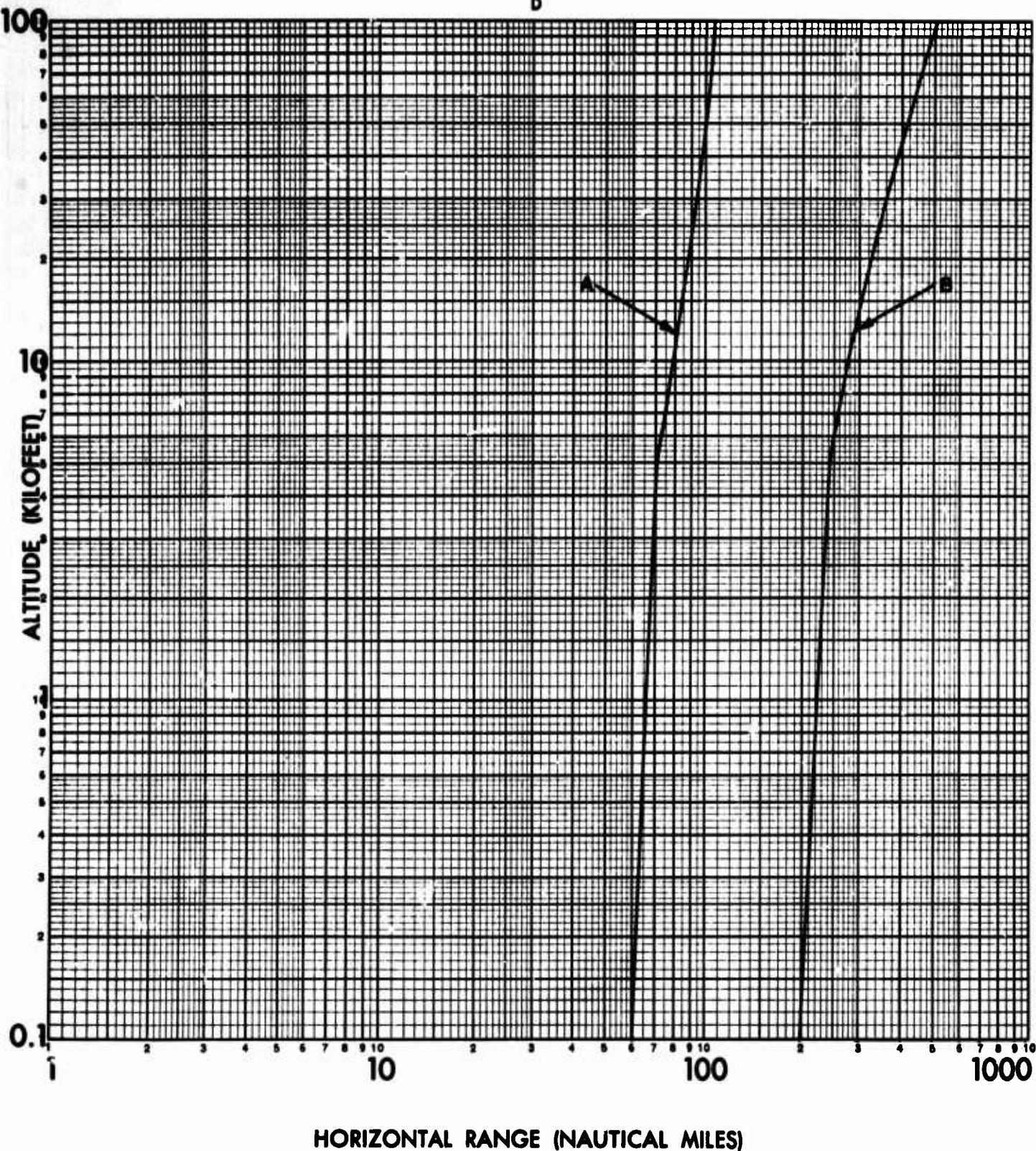


FIGURE 92

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 1000 KT

FILTER: NONE

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

3

10

25

50

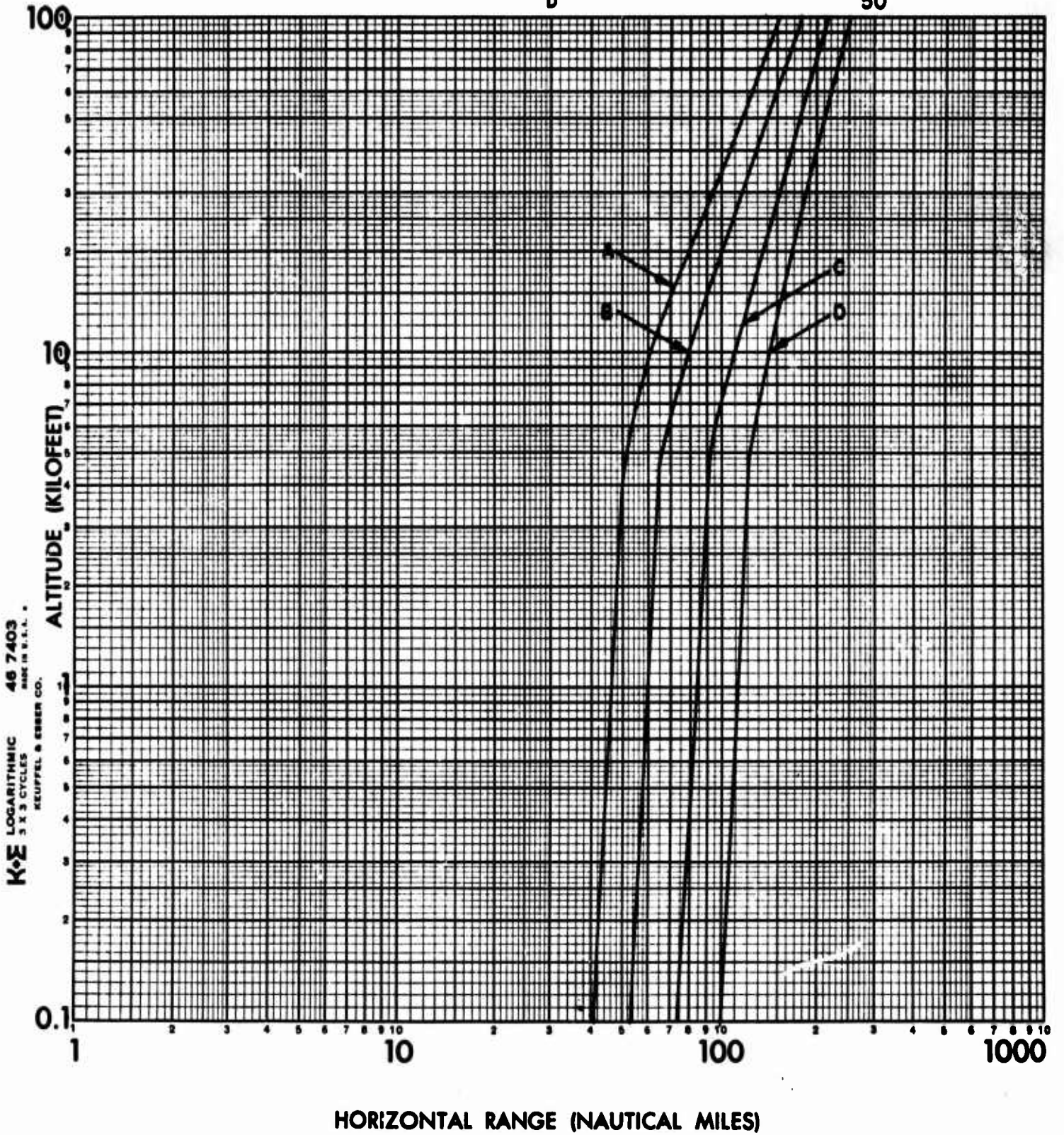


FIGURE 93

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 4
- 10
- 25
- 50

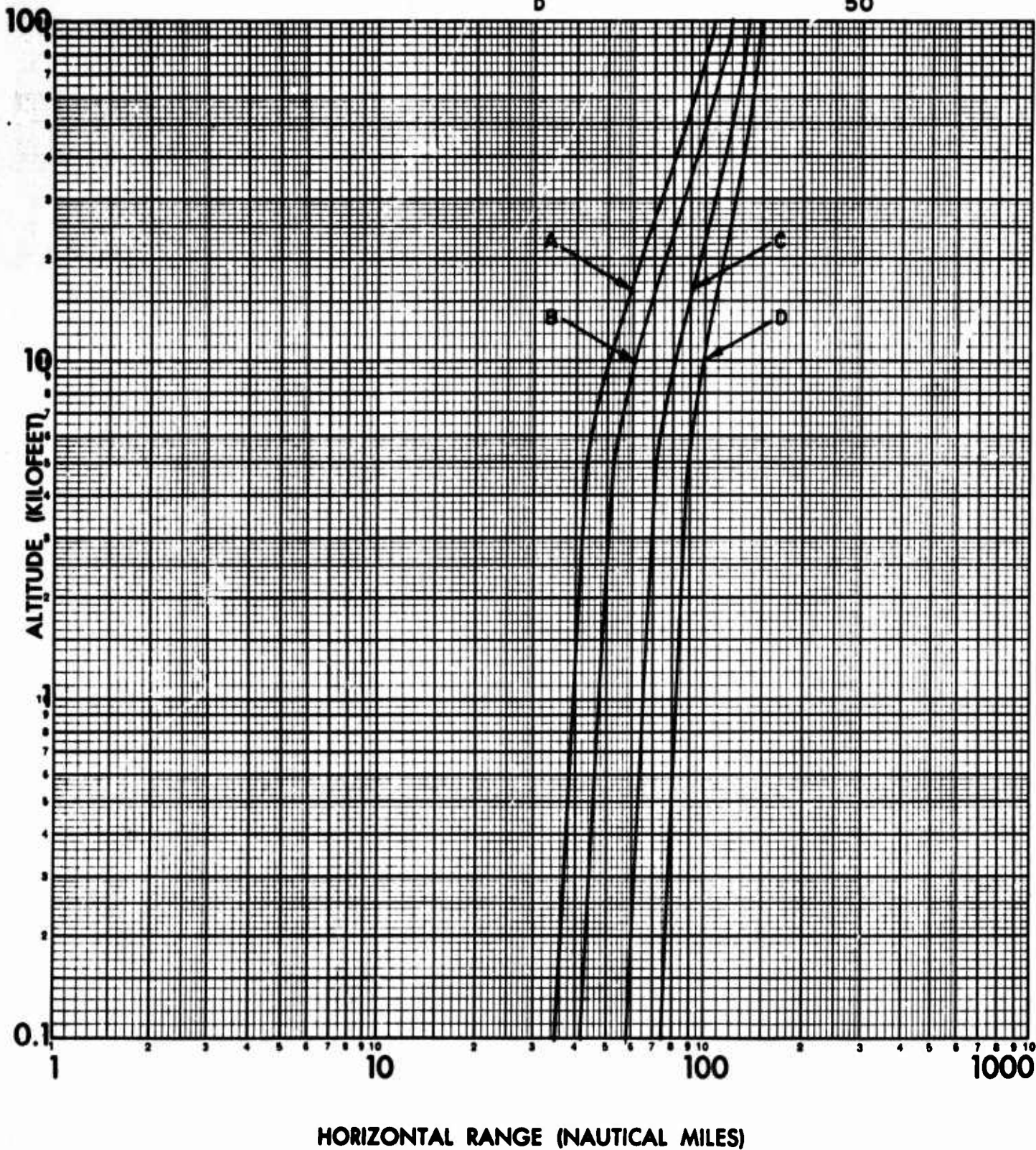


FIGURE 94

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 9000 KT

FILTER: NONE

SYMBOL

BURST ALTITUDE (Kilofeet)

A

5

B

10

C

25

D

50

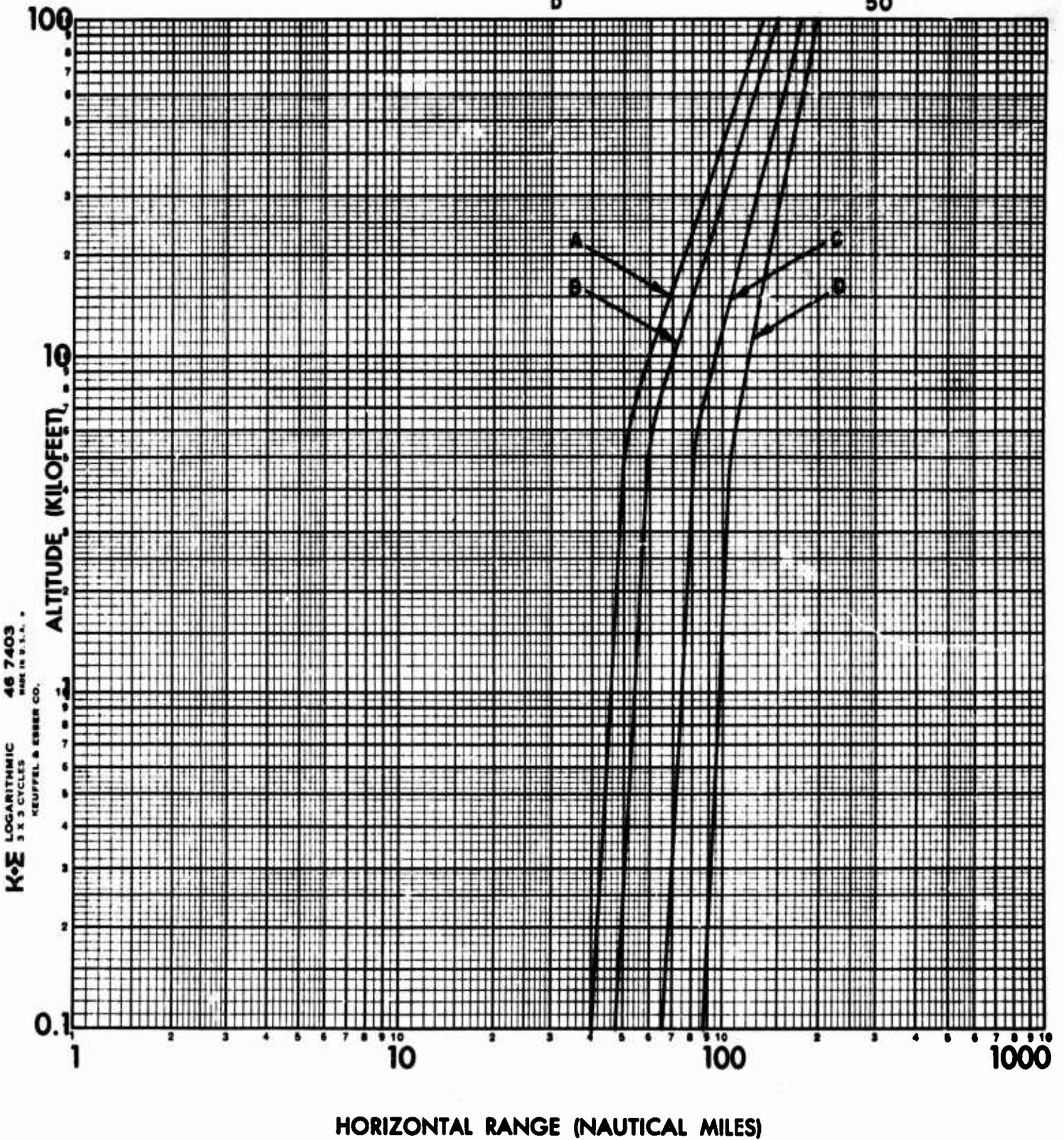


FIGURE 95

# FLASHBLINDNESS

NIGHT MISSION

YIELD: 23000 KT

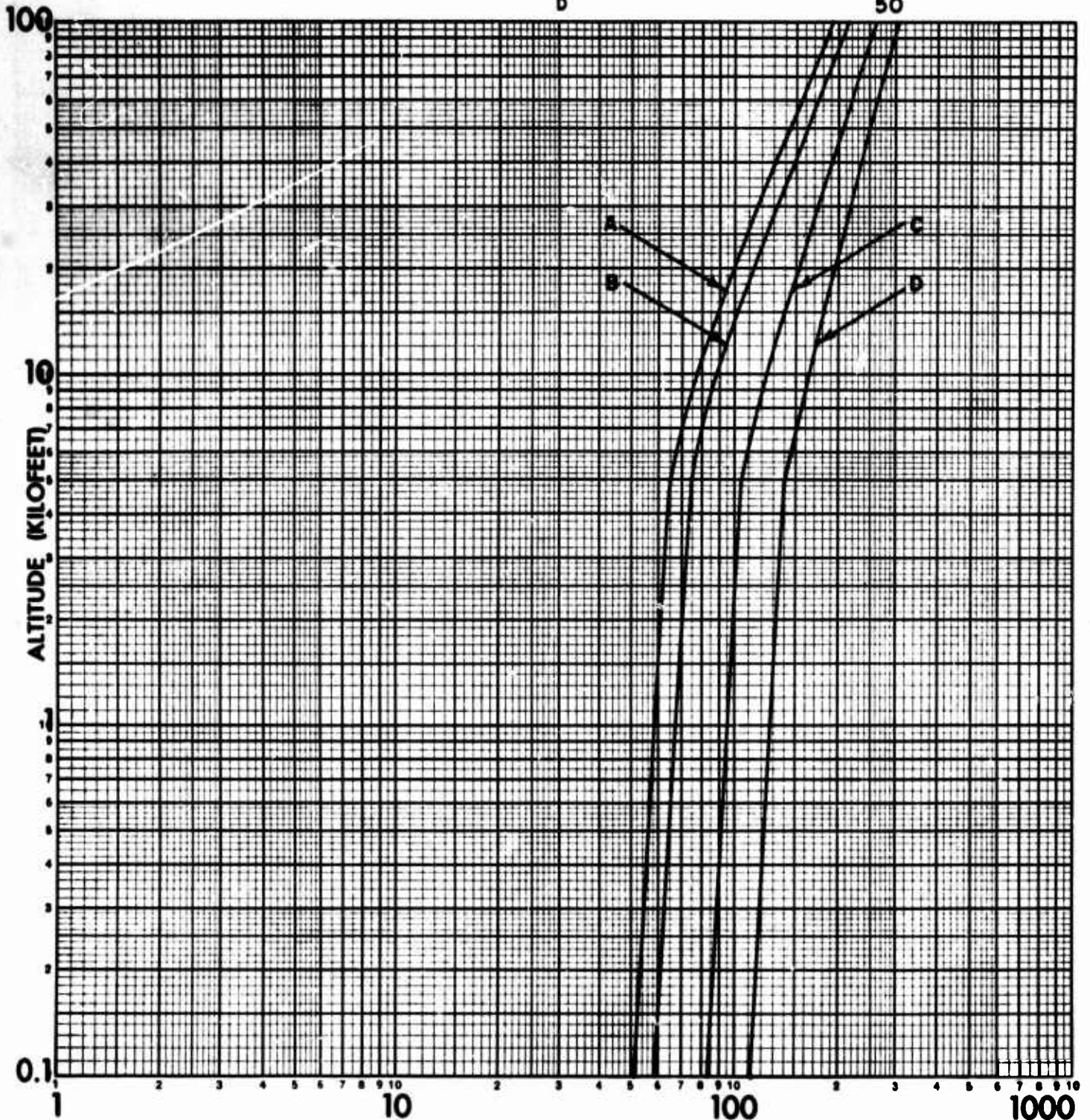
FILTER: NONE

SYMBOL.

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

6  
10  
25  
50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 96



FLASHBLINDNESS SAFE SEPARATION ENVELOPES

DAY MISSION WITH 2% FILTER

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 0.02 KT

FILTER: 2%

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

1

10

25

50

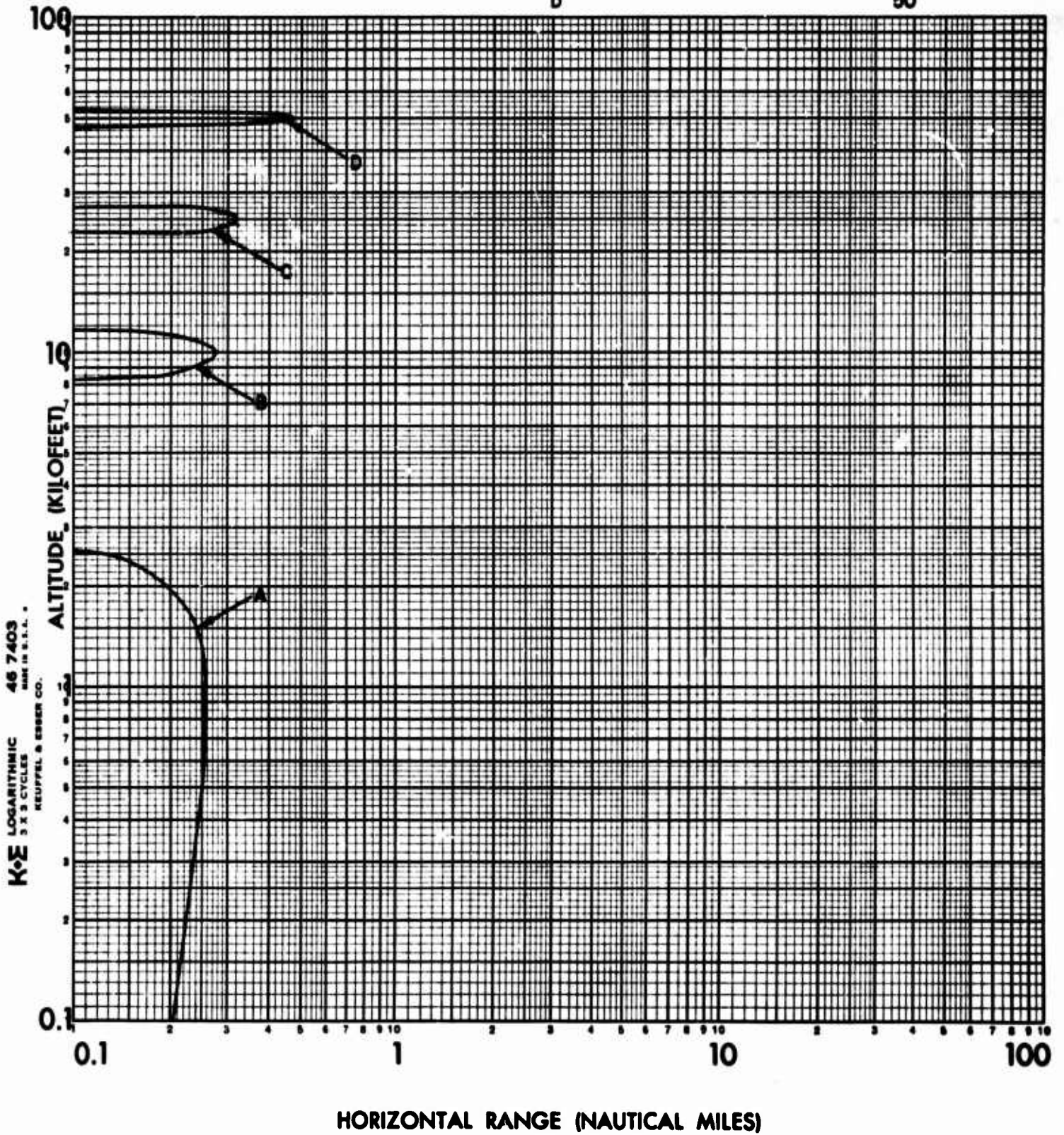


FIGURE 97

# FLASHBLINDNESS

DAY      MISSION

YIELD: 0.02 KT

FILTER: 2%

SYMBOL

A

B

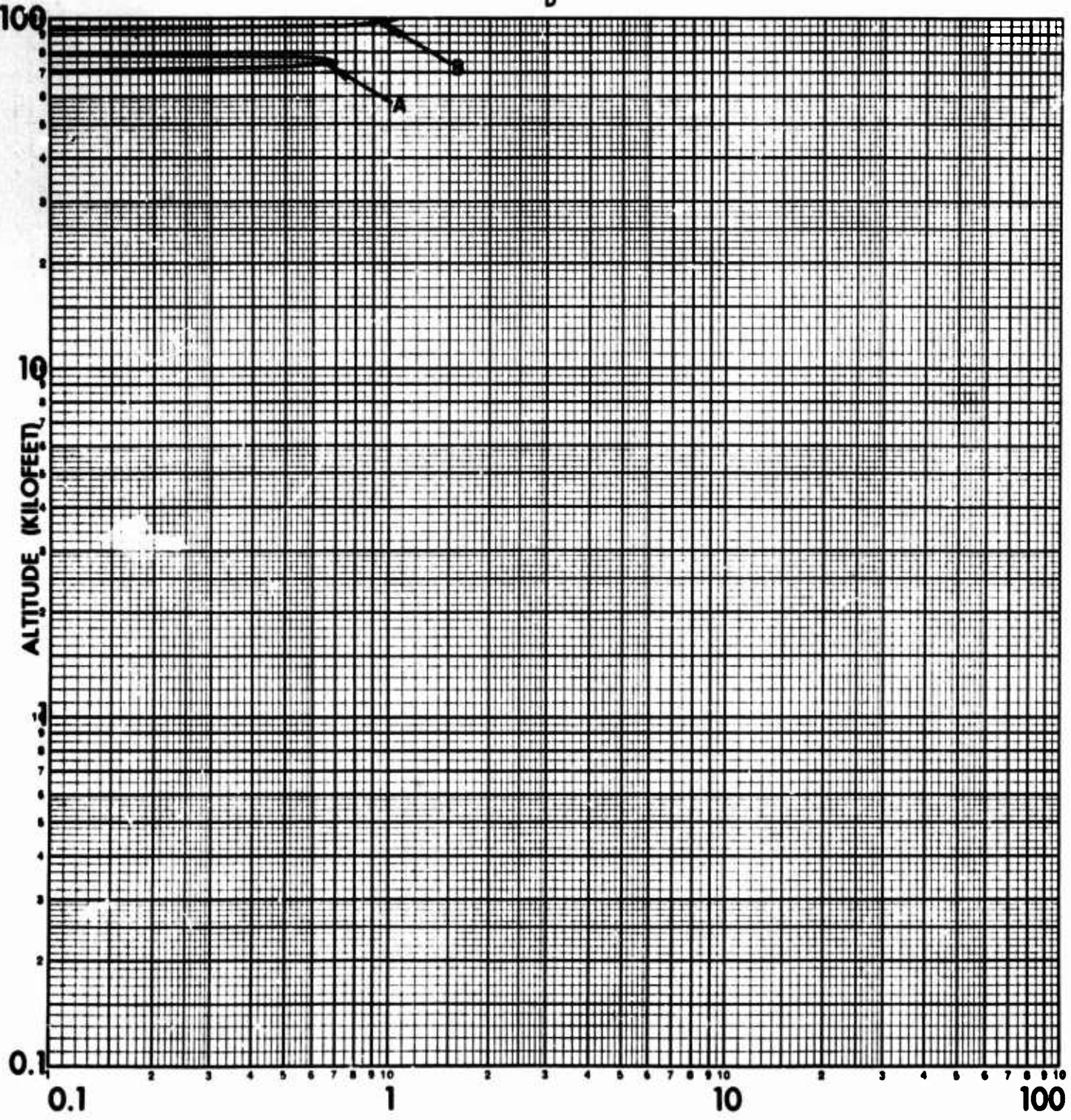
C

D

BURST ALTITUDE (Kilofeet)

75

100



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 98

# FLASHBLINDNESS

DAY MISSION

YIELD: 0.6 KT

FILTER: 2%

SYMBOL

A

B

C

D

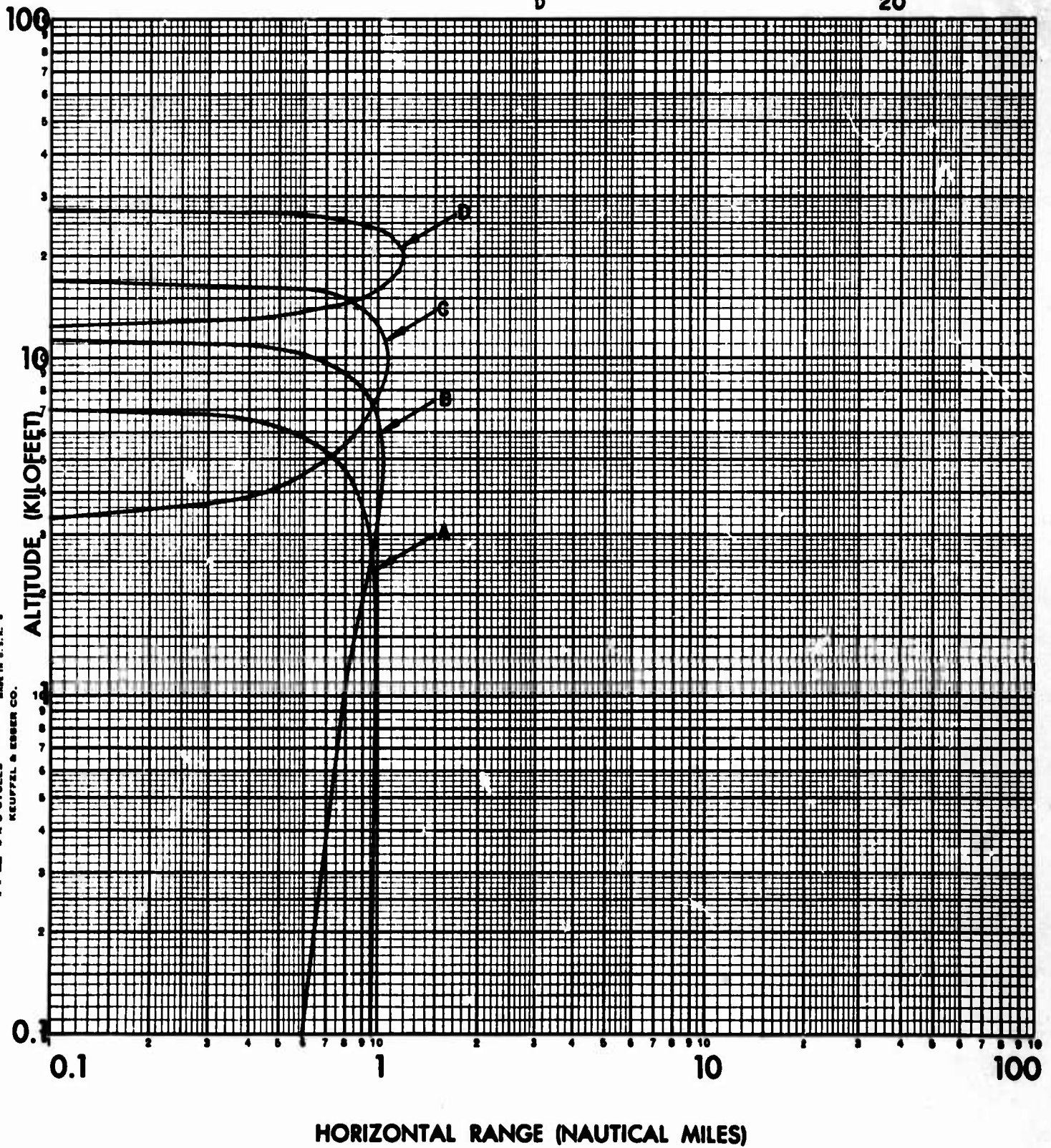
BURST ALTITUDE (Kilofeet)

1

5

10

20



K&E LOGARITHMIC 46 7403 MADE IN U.S.A. KEUFFEL & ESSER CO.

FIGURE 99

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 0.6 KT

FILTER: 2%

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

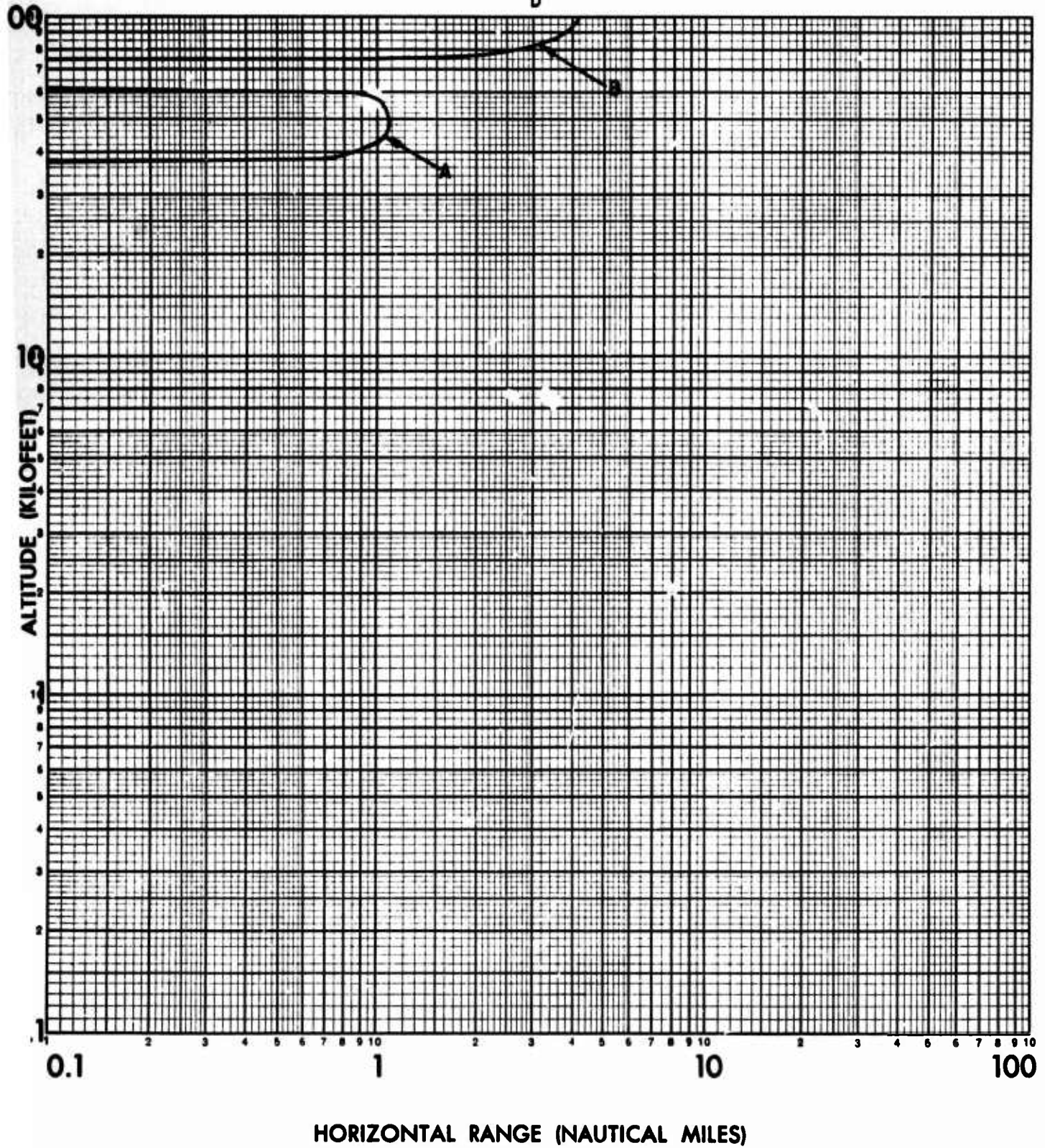


FIGURE 100

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 2 KT

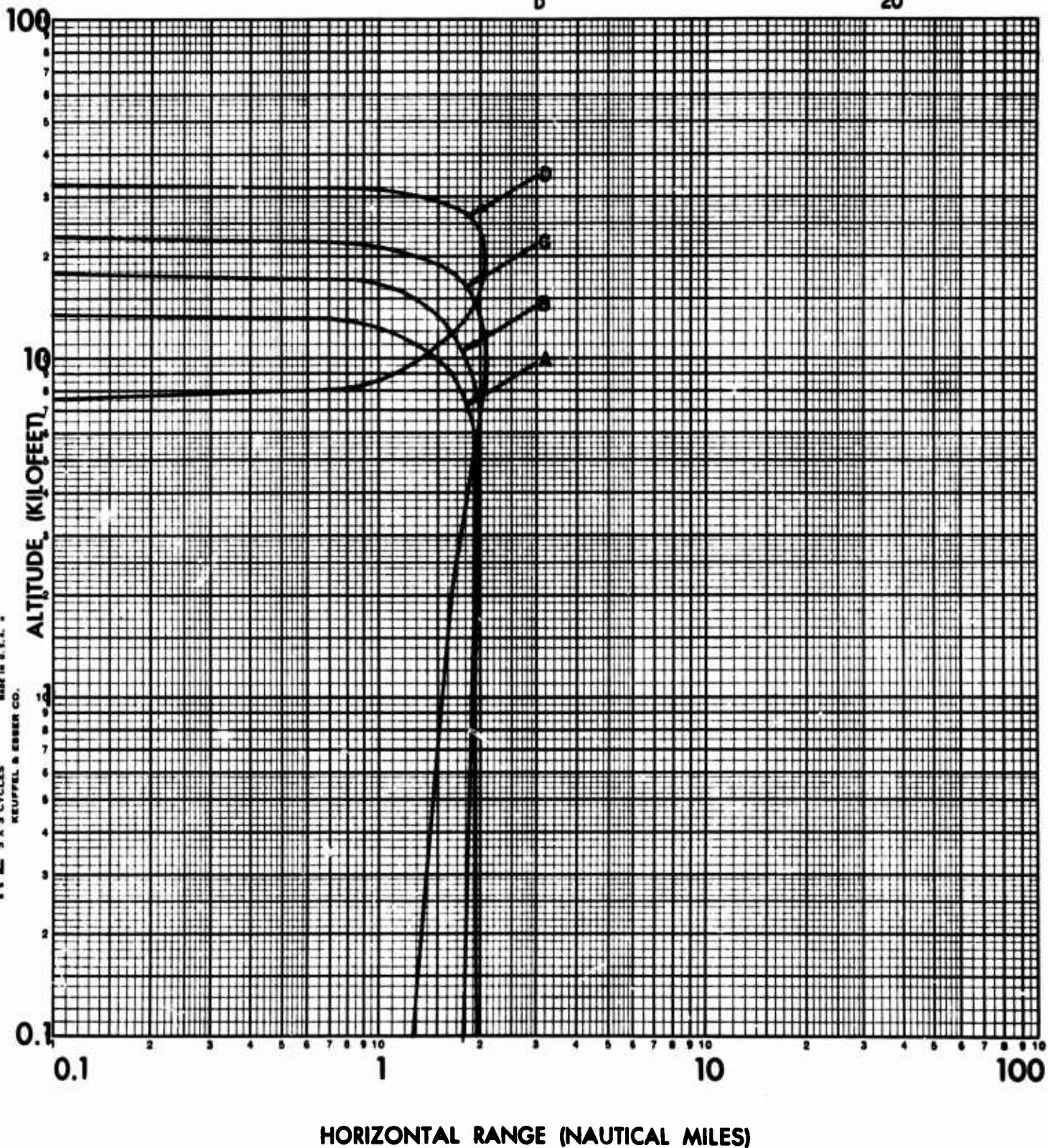
FILTER: 2%

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 1
- 5
- 10
- 20



K-5 LOGARITHMIC  
 5 X 5 CYCLES  
 46 7403  
 MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

FIGURE 101

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 2 KT

FILTER: 2%

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

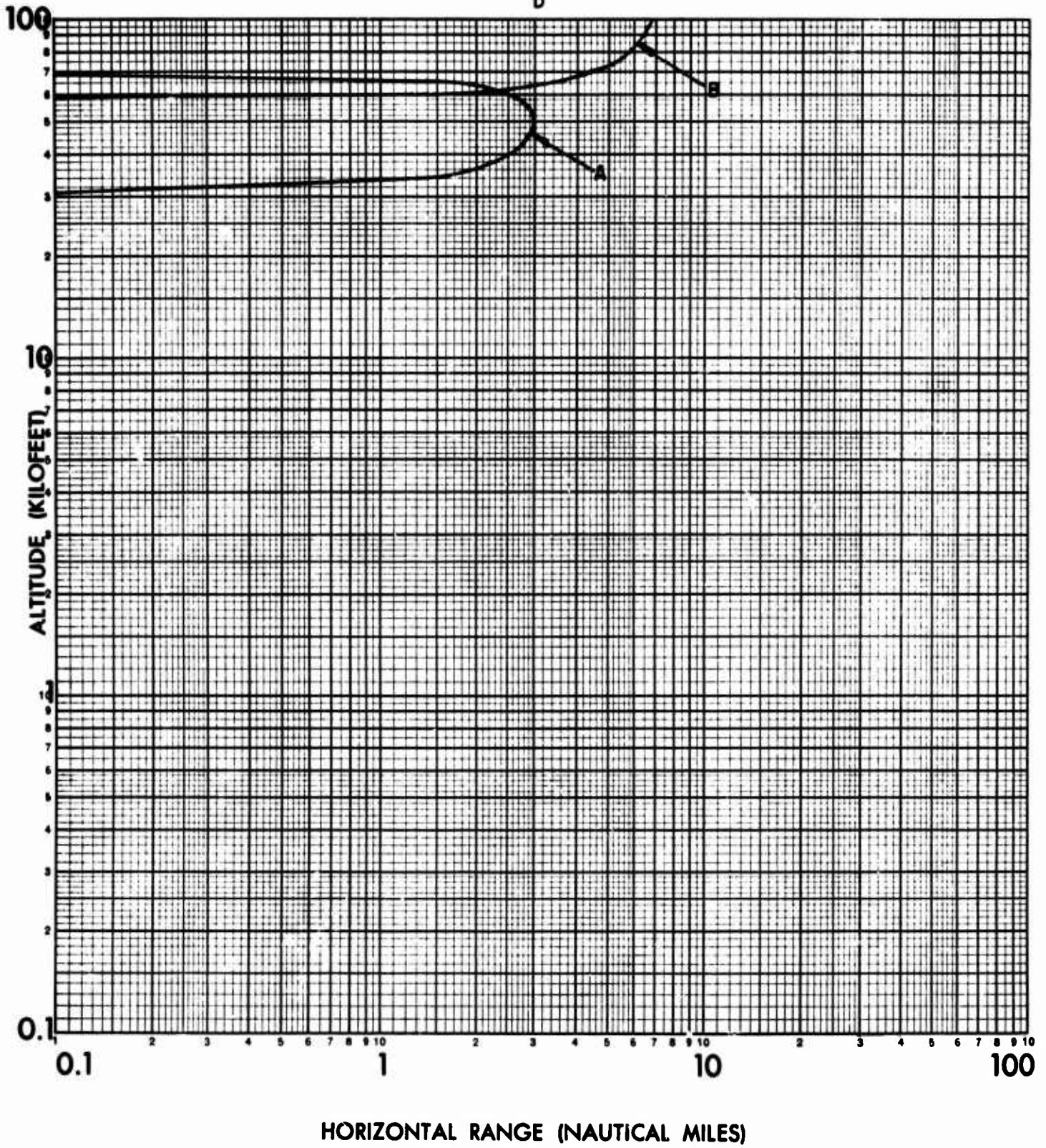


FIGURE 102

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 10 KT

FILTER: 2%

SYMBOL

A

B

C

D

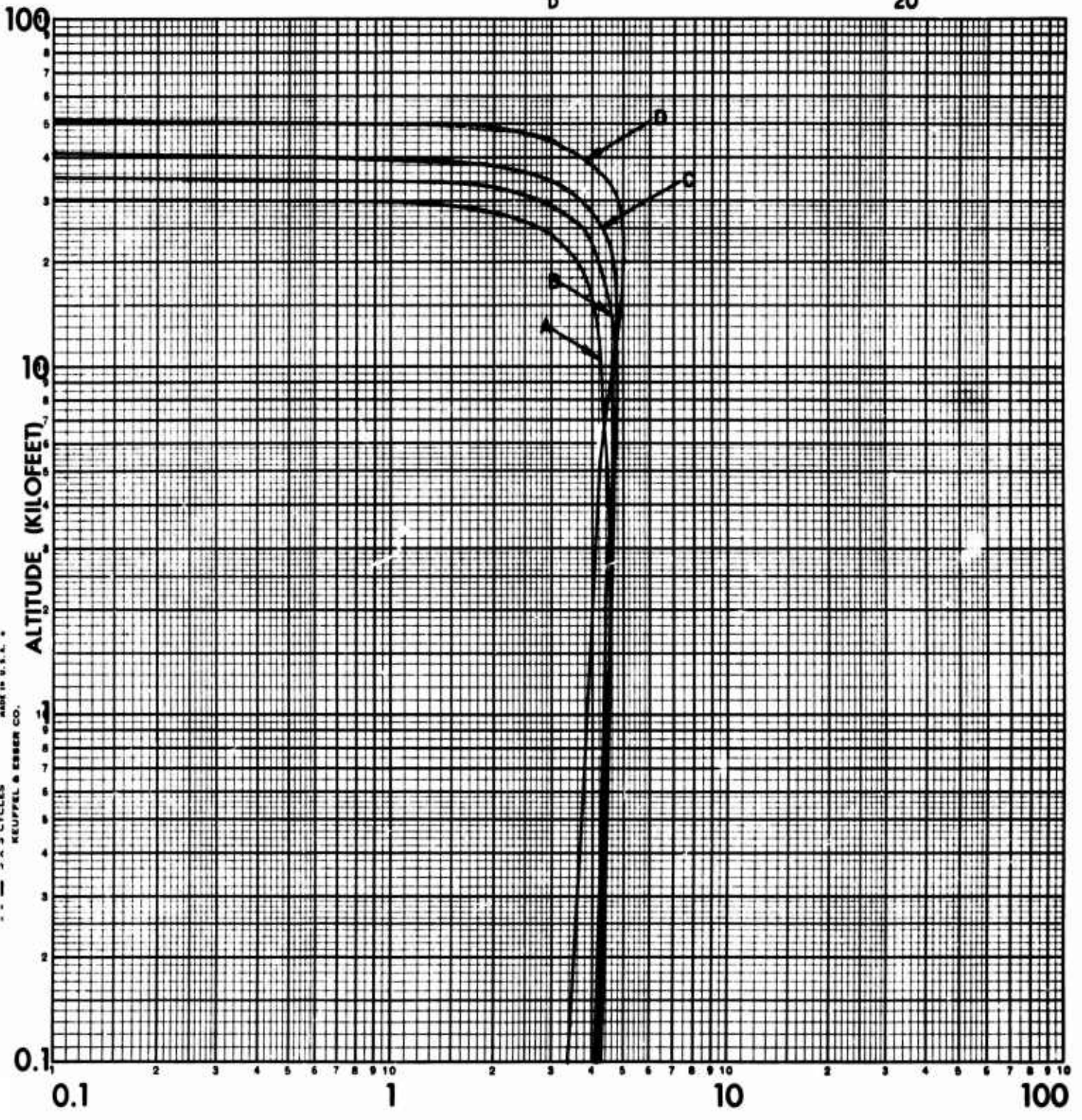
BURST ALTITUDE (Kilofeet)

1

5

10

20



MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 103



# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 10 KT

FILTER: 2%

SYMBOL

A

B

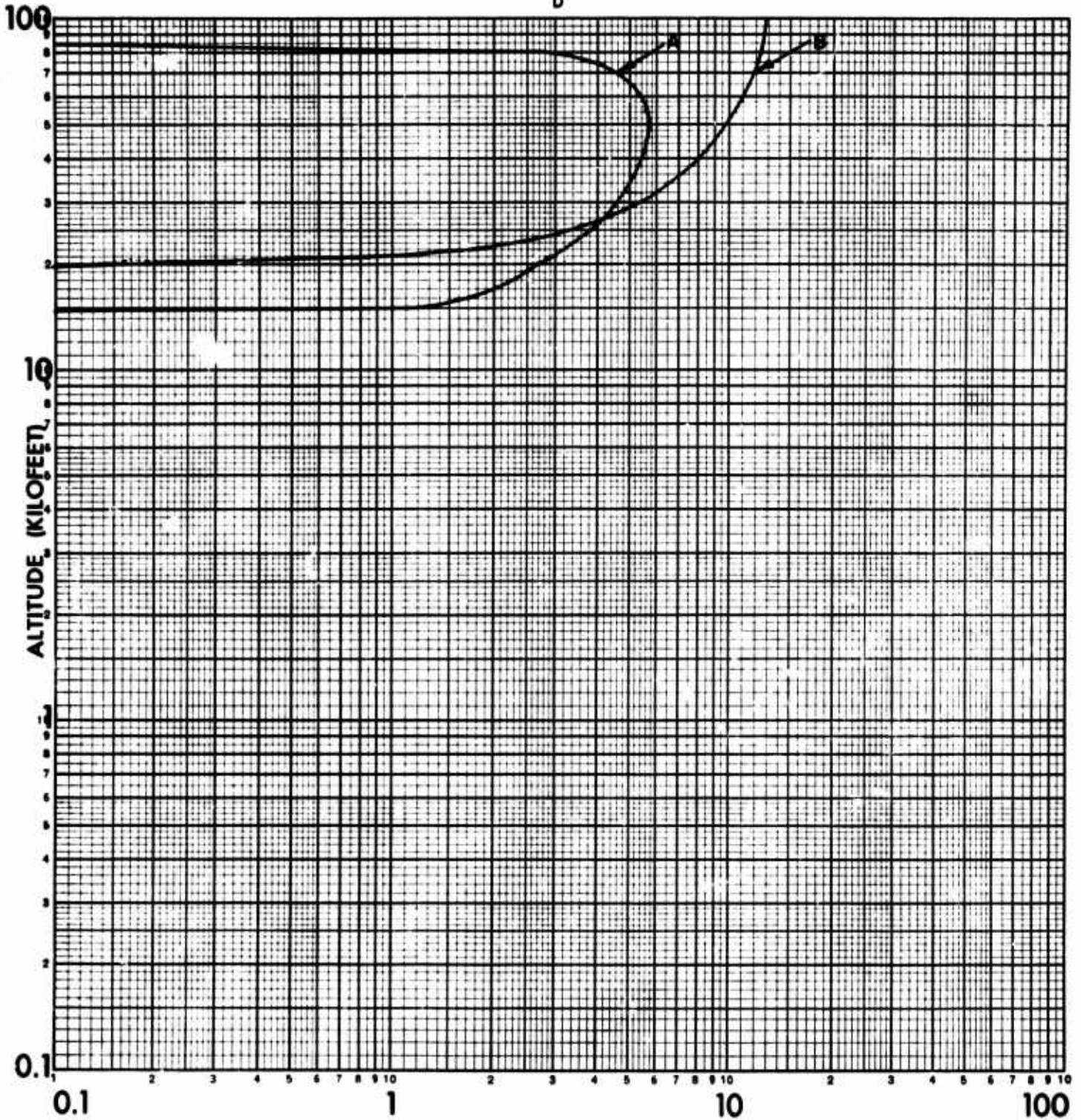
C

D

BURST ALTITUDE (Kilofeet)

50

100



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 104

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 30 KT

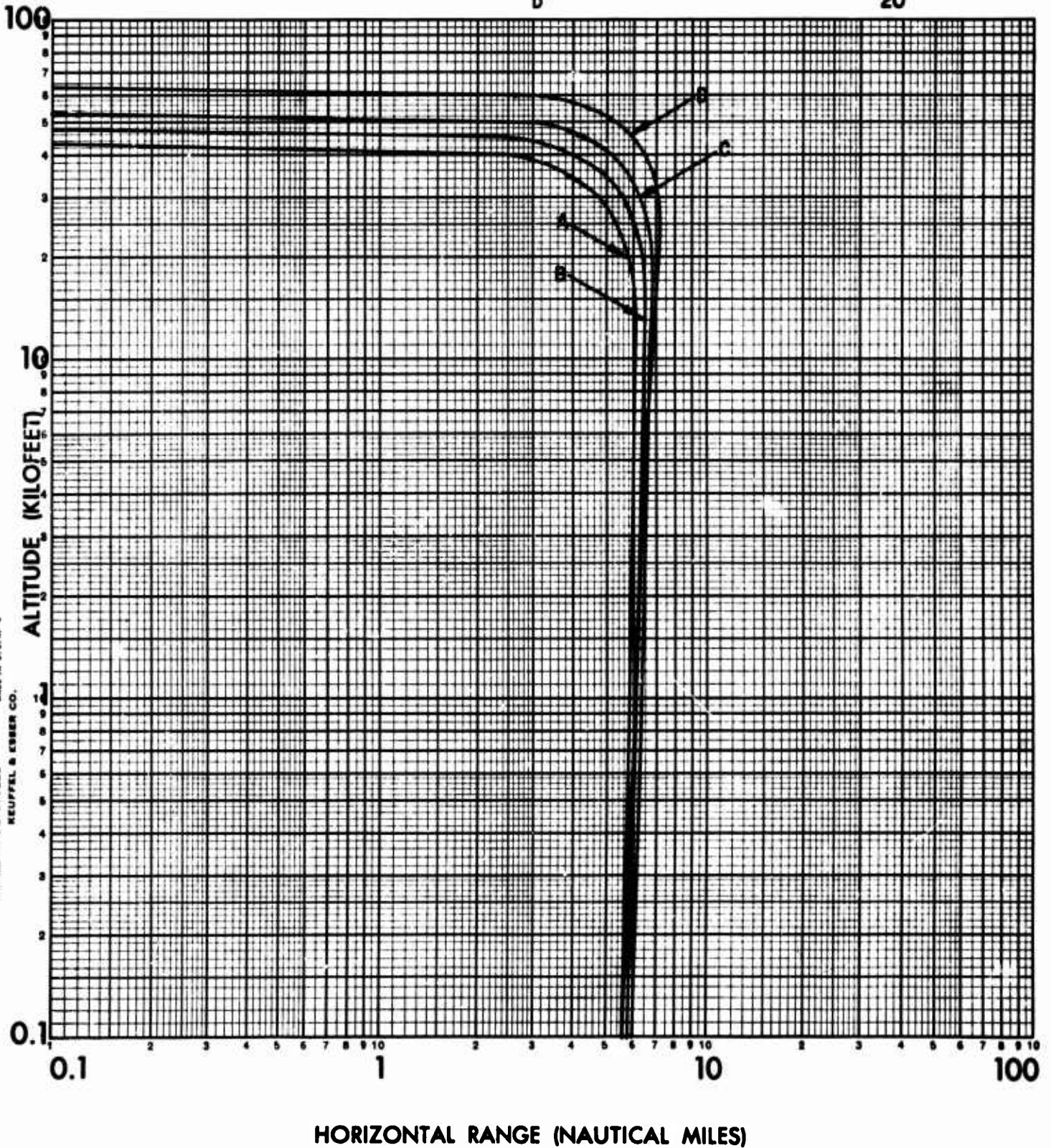
FILTER: 2%

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilo feet)

1  
5  
10  
20



100 7500  
 MADE IN U.S.A.  
 NEUFFEL & ESSER CO.

FIGURE 105

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_

YIELD: 30 KT

FILTER: 2%

SYMBOL

A

B

C

D

BURST ALTITUDE (Kilofeet)

50

100

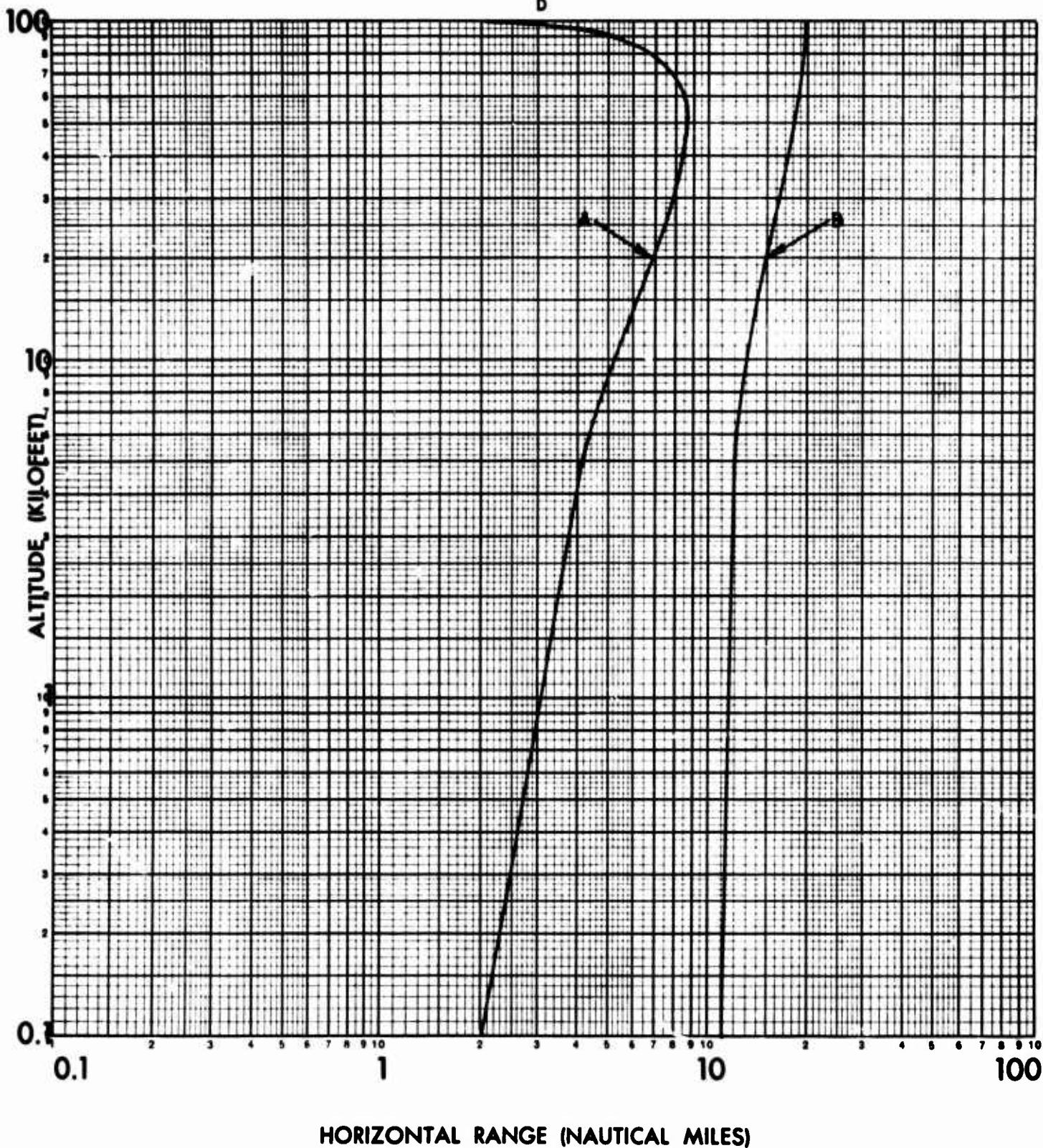


FIGURE 106

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 60 KT  
 FILTER: 2%

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

1  
5  
10  
20

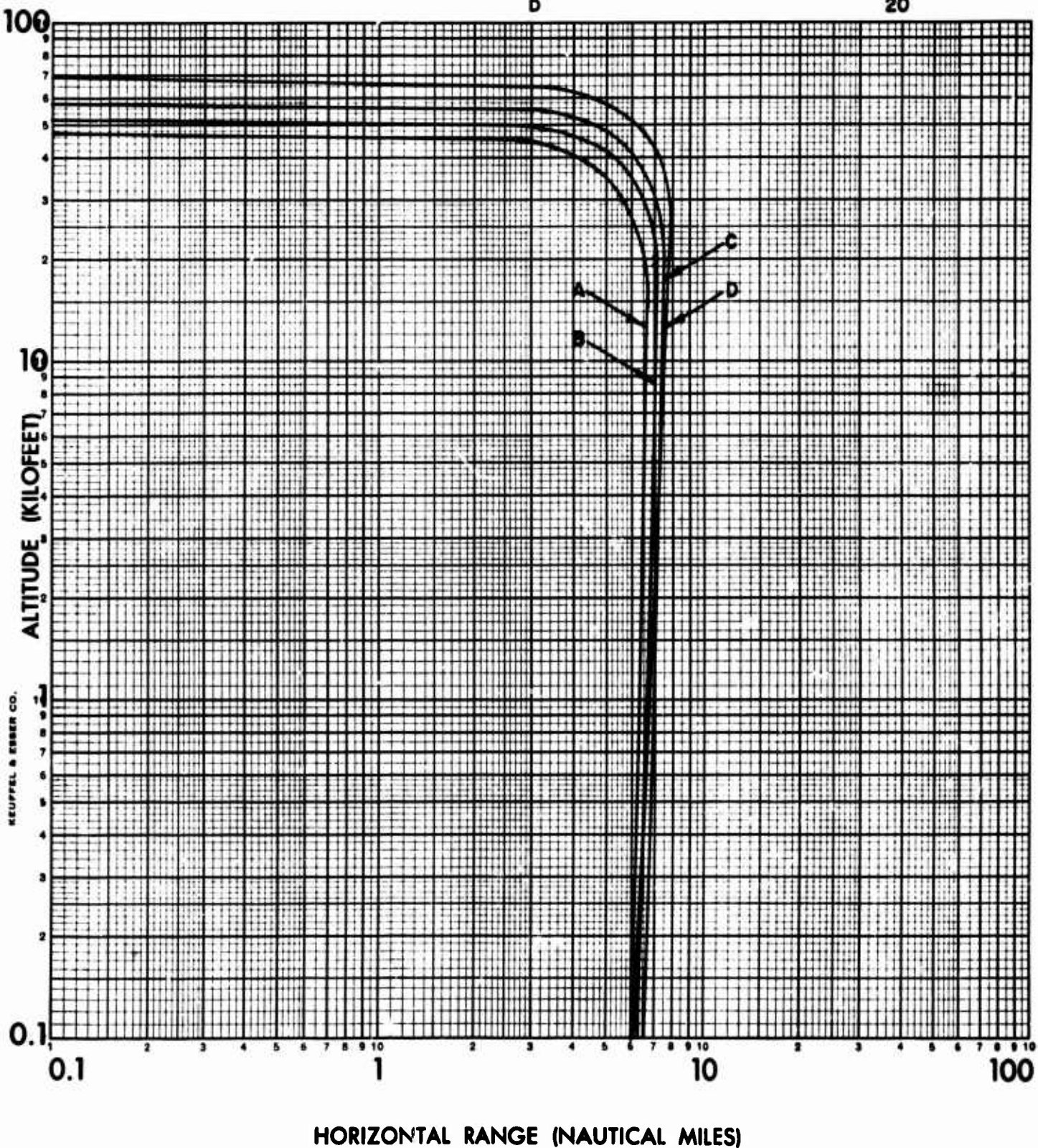


FIGURE 107

# FLASHBLINDNESS

**DAY** \_\_\_\_\_ **MISSION** \_\_\_\_\_  
**YIELD:** 60 **KT**  
**FILTER:** 2%

**SYMBOL**  
**A**  
**B**  
**C**  
**D**

**BURST ALTITUDE (Kilofeet)**  
**50**  
**100**

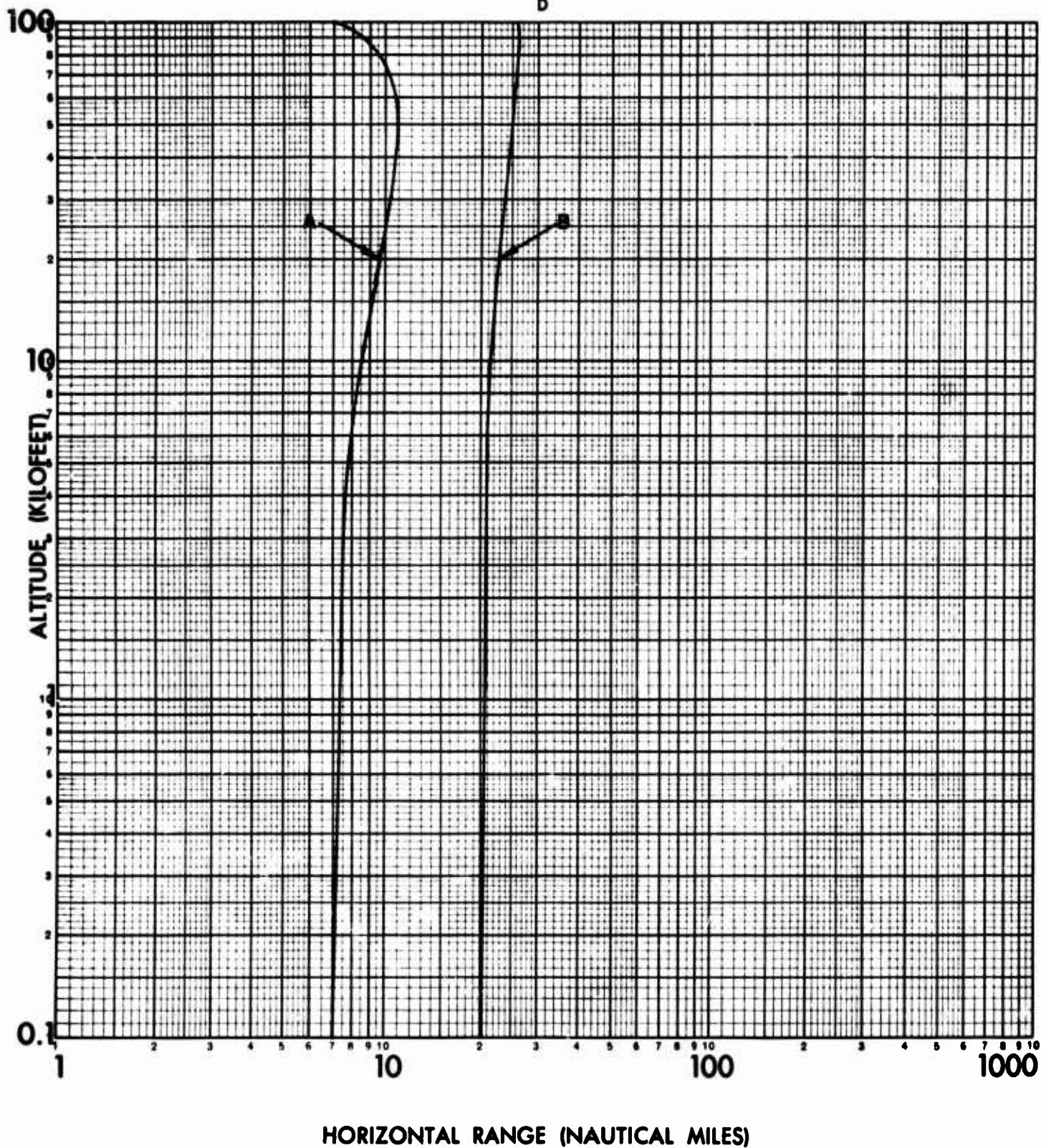


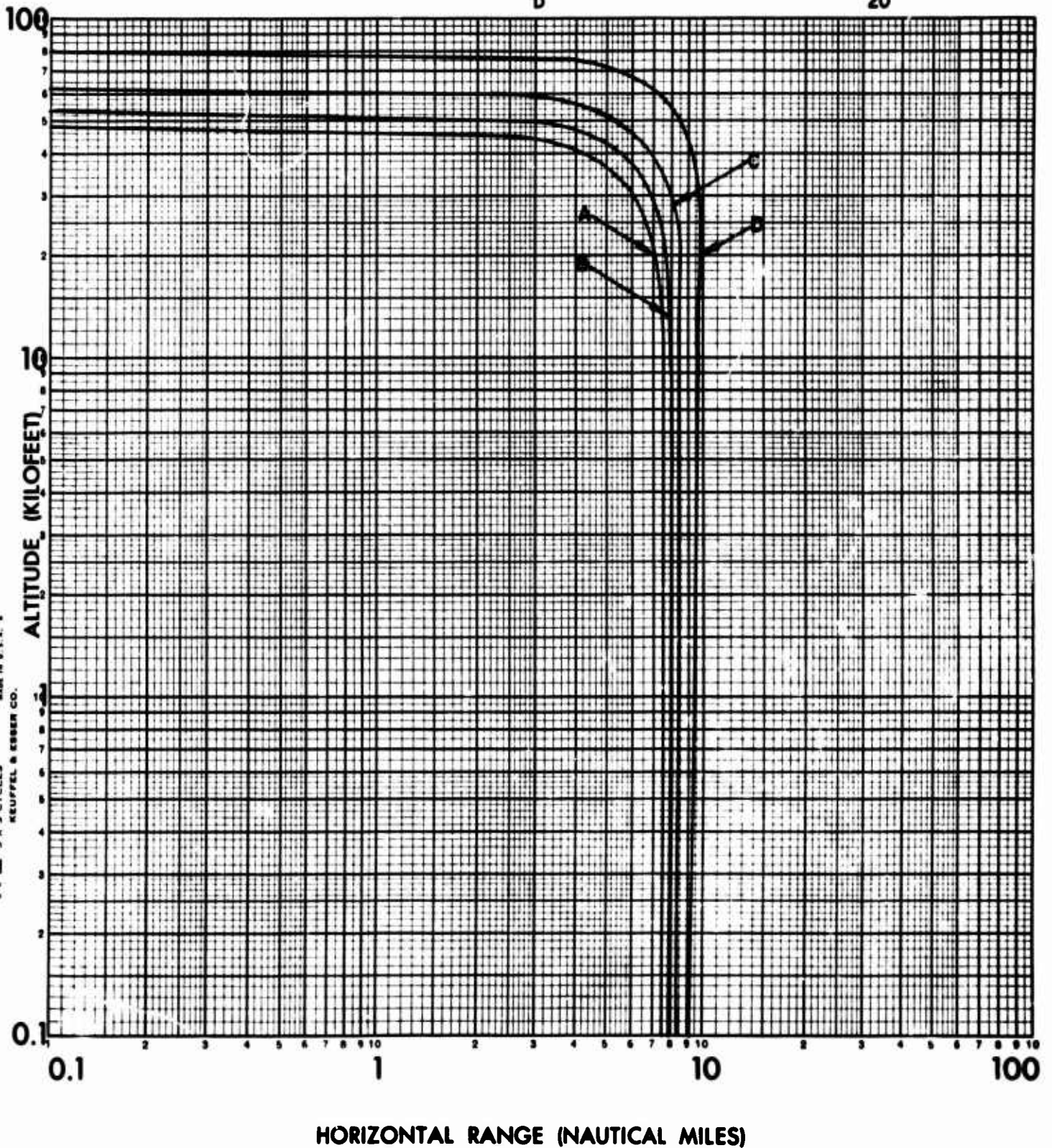
FIGURE 108

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 200 KT  
 FILTER: 2%

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 1.5  
 5  
 10  
 20



K-E LOGARITHMIC 46 7403 MADE IN U.S.A. KEUFFEL & ESSER CO.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 109

# FLASHBLINDNESS

DAY      MISSION

YIELD: 200 KT

FILTER: 2%

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

- 50
- 100

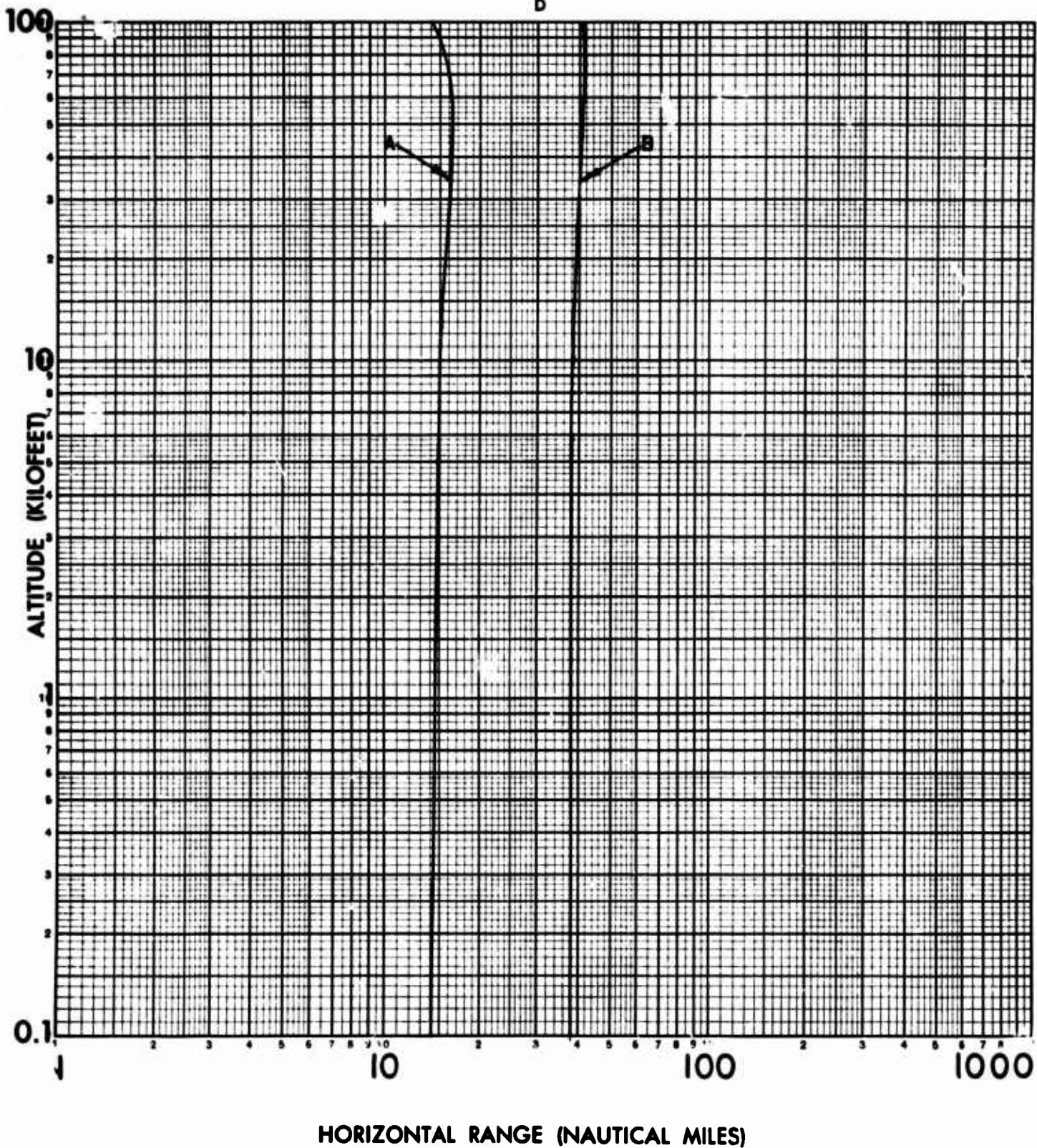


FIGURE 110

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 440 KT  
 FILTER: 2%

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofoot)  
 15  
 5  
 10  
 20

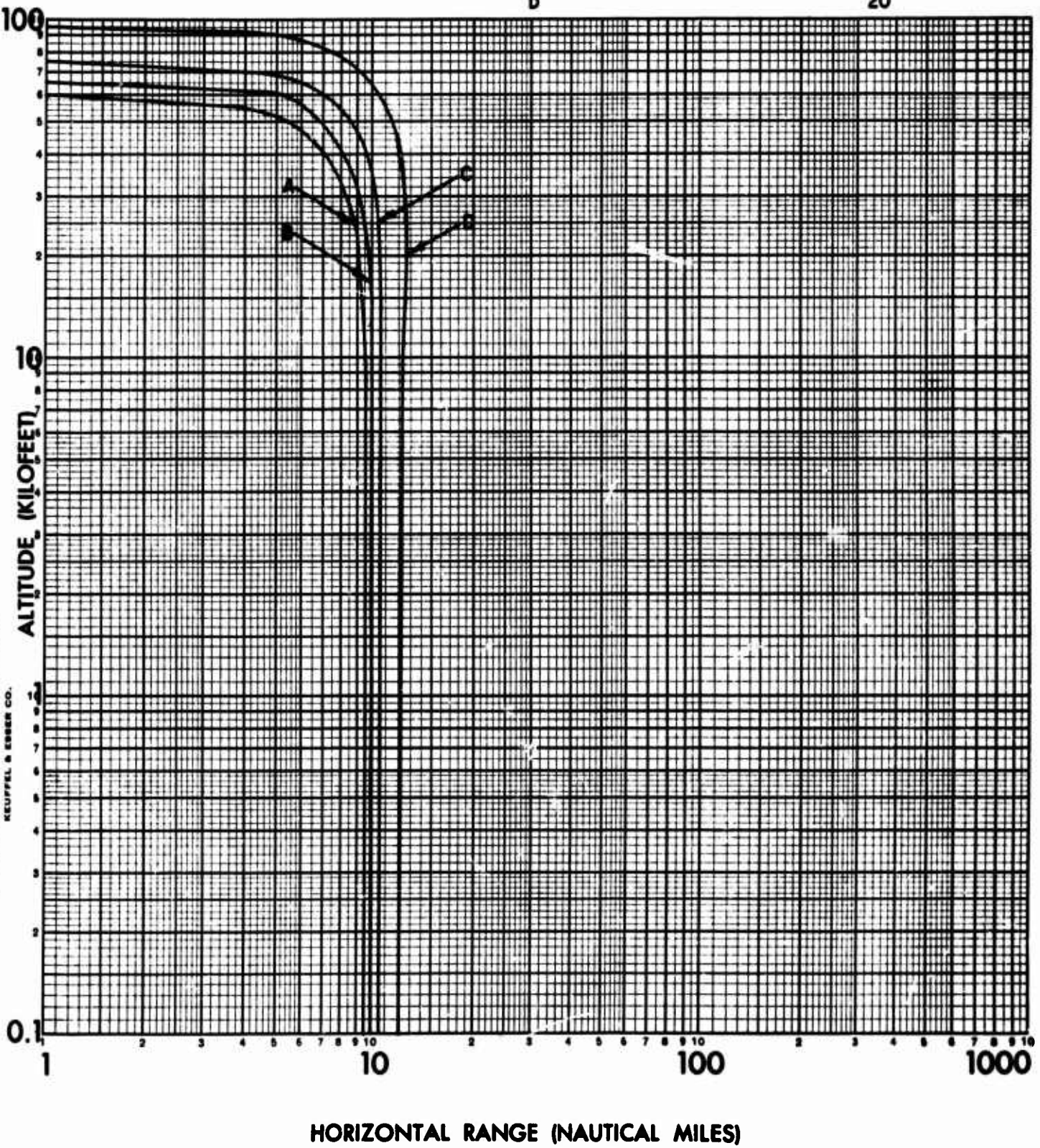


FIGURE 111



# FLASHBLINDNESS

DAY MISSION

YIELD: 440 KT

FILTER: 2%

SYMBOL

- A
- B
- C
- D

BURST ALTITUDE (Kilofeet)

50

100

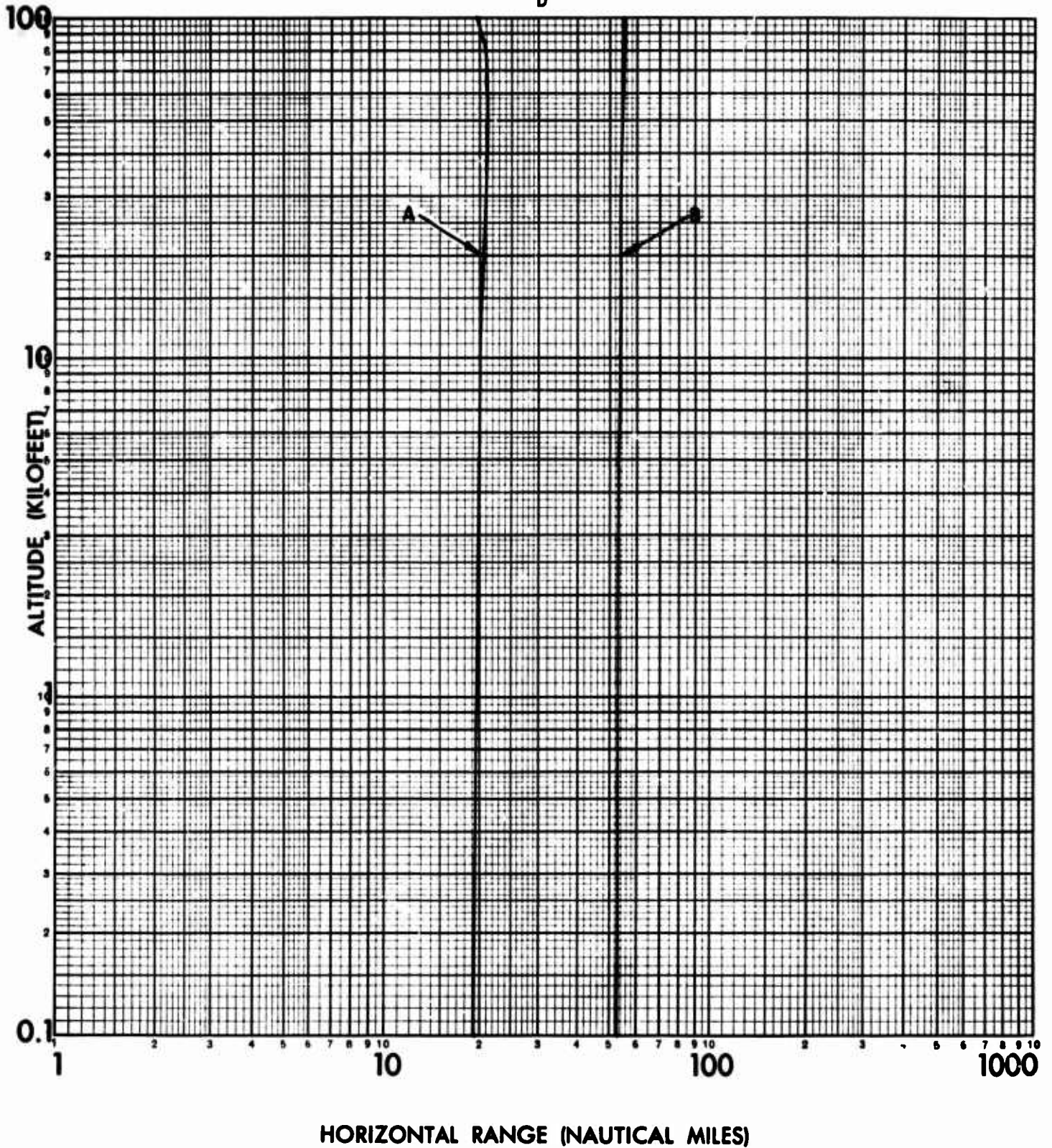


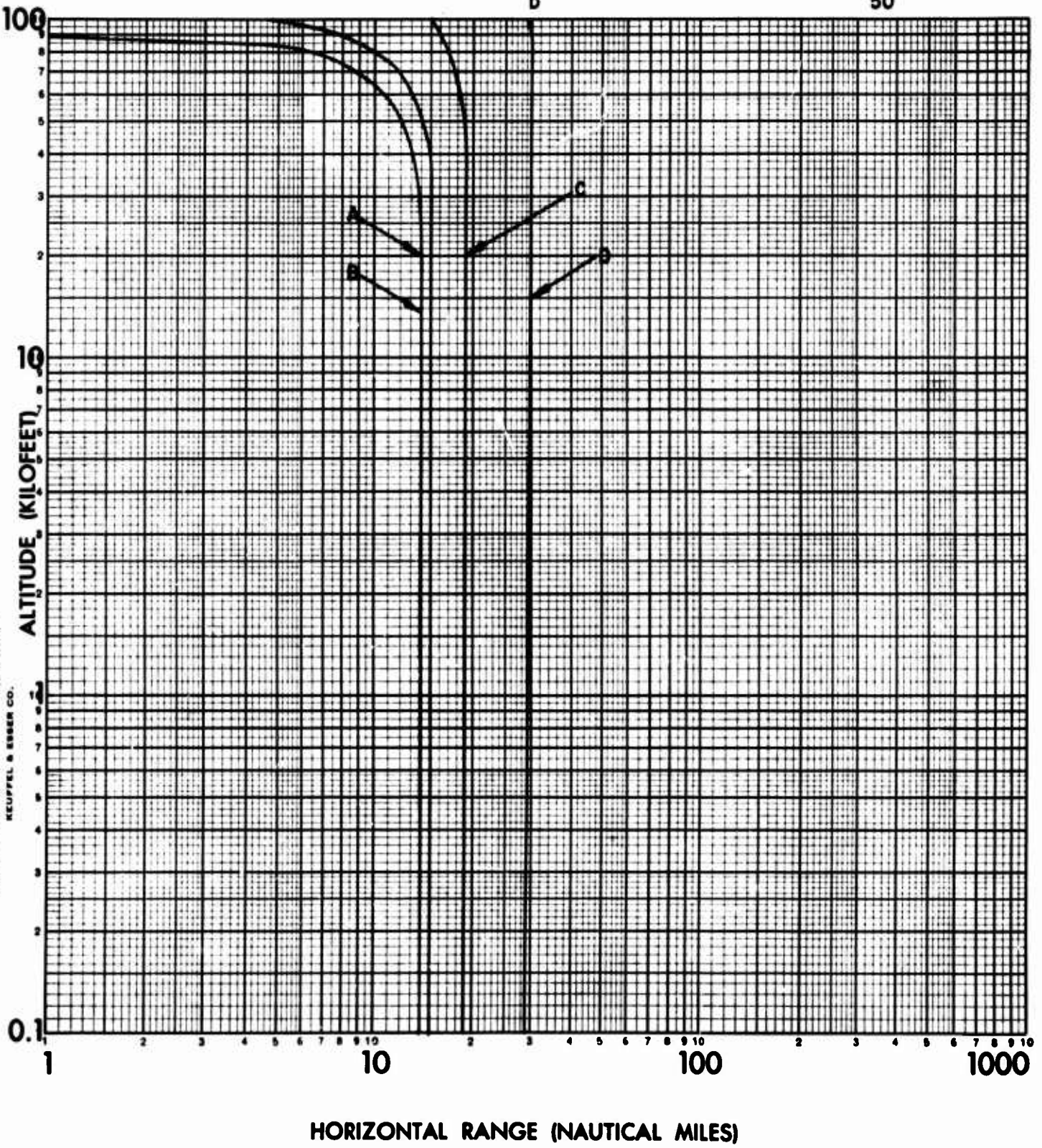
FIGURE 112

# FLASHBLINDNESS

DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 1000 KT  
 FILTER: 2%

SYMBOL  
 A  
 B  
 C  
 D

BURST ALTITUDE (Kilofeet)  
 3  
 10  
 25  
 50



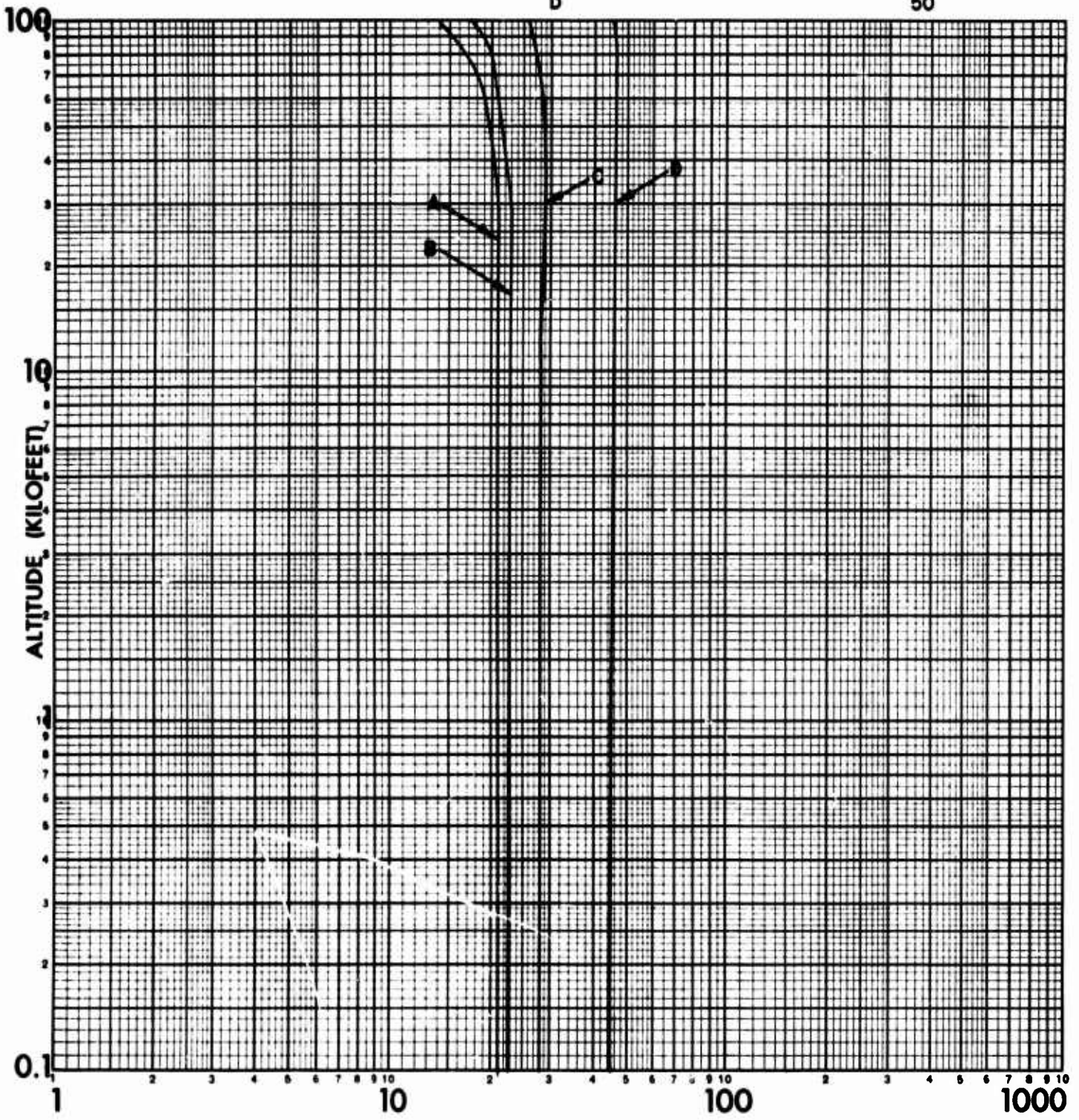
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 113

MADE IN U.S.A.  
 KEUFFEL & ESSER CO.

# FLASHBLINDNESS

<u>DAY</u>	<u>MISSION</u>	<u>SYMBOL</u>	<u>BURST ALTITUDE (Kilofeet)</u>
YIELD: <u>3800</u>	KT	A	4
FILTER: <u>2%</u>		B	10
		C	25
		D	50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 114

# FLASHBLINDNESS

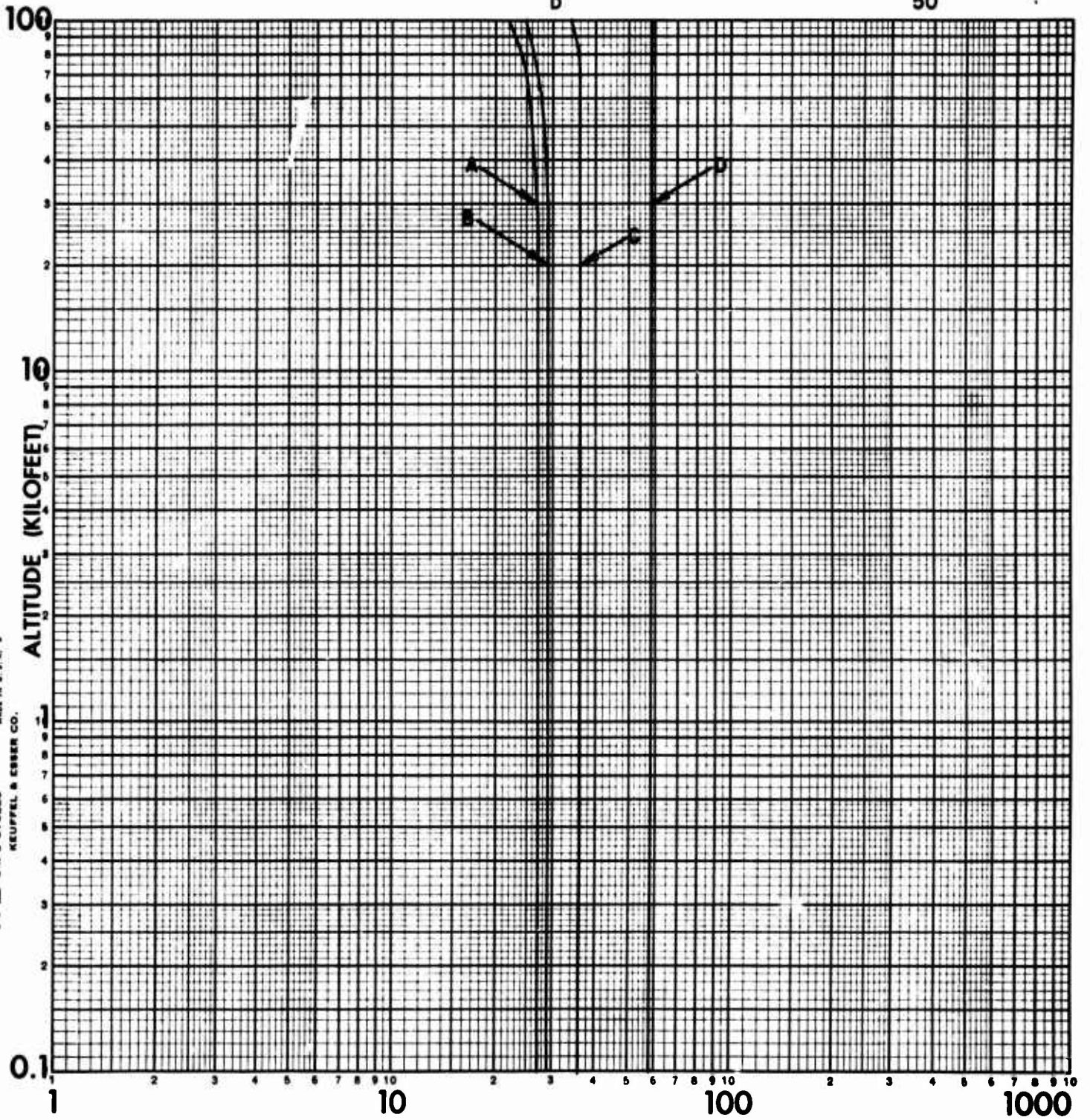
DAY \_\_\_\_\_ MISSION \_\_\_\_\_  
 YIELD: 9000 KT  
 FILTER: 2%

SYMBOL

A  
B  
C  
D

BURST ALTITUDE (Kilofeet)

5  
10  
25  
50



K&E LOGARITHMIC 46 7403  
 3 X 3 CYCLES  
 KEUFFEL & ESSER CO.  
 MADE IN U.S.A.

HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 115

# FLASHBLINDNESS

DAY      MISSION  
 YIELD: 23000 KT  
 FILTER: 2%

SYMBOL

BURST ALTITUDE (Kilofeet)

A

6

B

10

C

25

D

50

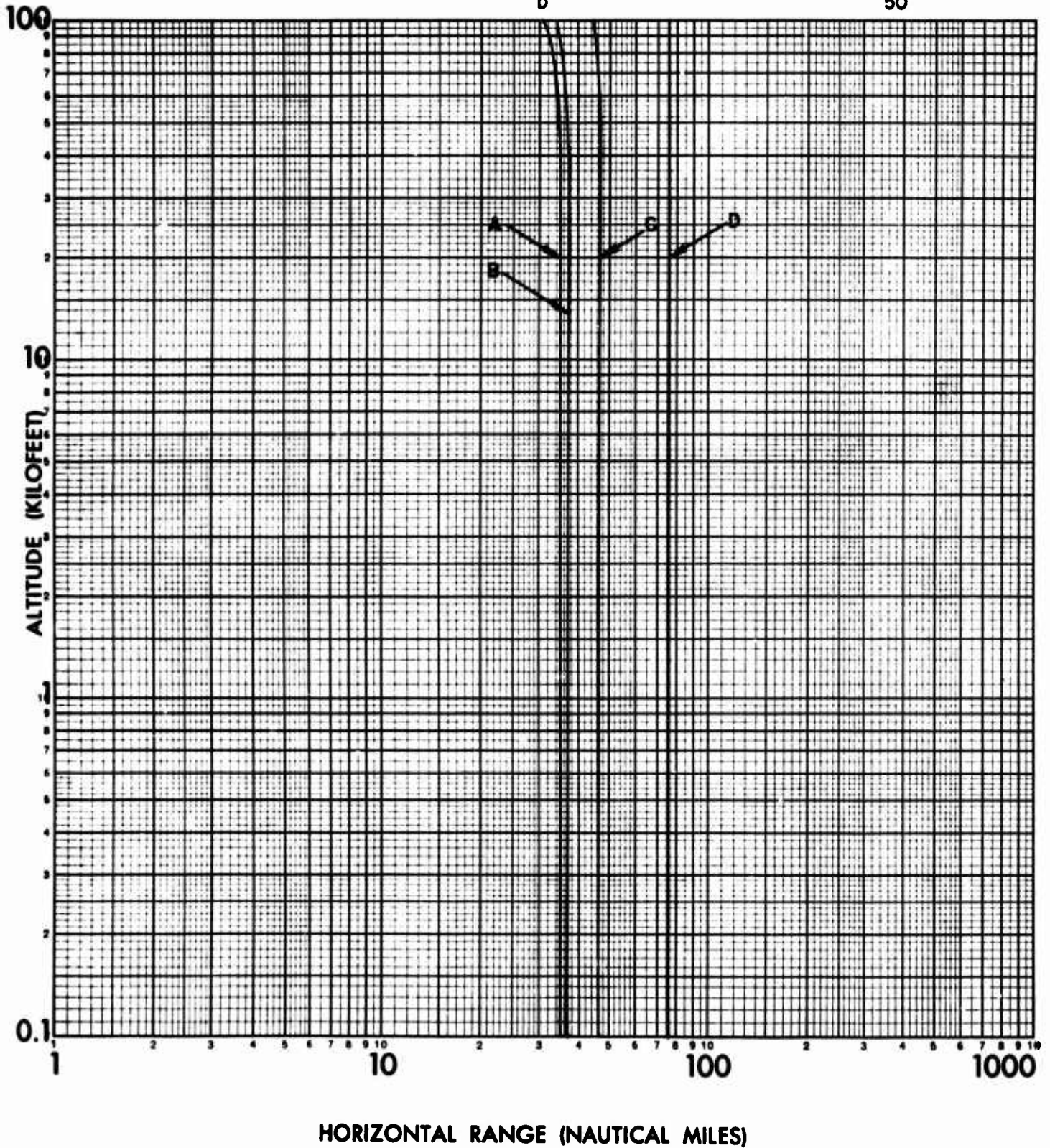


FIGURE 116

APPENDIX A  
RETINAL BURN CALCULATIONS

## APPENDIX A - RETINAL BURN CALCULATIONS

The method for calculating retinal burn envelopes is essentially an elaboration on the method of Allen and Richey<sup>(A-1)(A-2)</sup>. Basically, the thermal energy given off by a fireball in the time necessary for the human eye to blink is calculated from the thermal characteristics of the weapon. This energy is attenuated by the atmosphere (air and water vapor), the aircraft canopy, pilot's visor, and the clear media of the eye and the retinal irradiance,  $Q_r$ , is determined as a function of distance from the fireball. These values are then compared to the allowable retinal exposure,  $Q_r^T$ , which has also been determined as a function of distance. The computer program which generates the envelopes given in this handbook uses a mathematical convergence technique to determine the allowable horizontal range, i. e., the distance measured along the surface of the earth at which  $Q_r = Q_r^T$ . A series of such calculations for several different observer altitudes defines one particular envelope.

The calculations given below are intended to illustrate the model used in the actual computer program and also to demonstrate a simplified technique which can be used to approximate threshold distances without the use of a computer. It should be noted that the approximation model described uses a so-called "flat-earth", i. e., the earth's curvature is not taken into account, whereas the computer program described in Appendix C takes into account the curvature of the earth. Generally, allowable horizontal ranges calculated

by the approximation method are somewhat greater than would be predicted by the computer program using the "round earth"-technique.

In order to hand-calculate an allowable horizontal range, the following parameters must be known in advance:

1. Blink Time,  $t_B$  (0.25 seconds for yield below 1000 KT; 0.45 seconds for 1000 KT and above).
2. Weapon yield,  $W$ , in kilotons.
3. Weapon burst height,  $H$ , in kilofeet (thousands of feet).
4. Observer altitude,  $A$ , in kilofeet.
5.  $f$ -stop of the human eye ( $f=6.8$  for a day mission;  $f=2.6$  for a night mission;  $f=3.4$  for a day mission with 2% gold visor).

The value for "k" (fraction of thermal radiation given off by the weapon in time  $t_B$ ) is obtained from Figures A-1 or A-2. The sea level fireball diameter,  $DFB_o$ , is obtained from Figures A-3 or A-4, and the value is then corrected from sea level to the burst height  $H$  by:

$$DFB_H = DFB_o \times \sigma^{-1/3} \quad (1)$$

where

$\sigma$  = ratio of the air density at height  $H$  to the standard sea level air density.

Table A-1 lists values of  $\sigma^{-1/3}$  for several burst heights. A linear interpolation will suffice for any burst height not listed in this table.



The maximum anticipated retinal exposure,  $Q_r$ , is then calculated as a function of the horizontal distance,  $S$ , using the expression

$$Q_r(S) = 2 \left[ \frac{a p k W T_e T_x \times 10^{12}}{4 \pi f^2 (DFB_H)^2} \cdot T_a(S) \right] \text{ (cal/cm}^2\text{)} \quad (2)$$

Here,

$Q_r(S) = 2Q_r(\text{CALC})$ , with the factor 2 introduced as an arbitrary safety factor\*

$a = 0.79$  = Fraction of the thermal energy radiated which is located in the spectral region effective in producing retinal damage ( $350 \text{ m}\mu < E < 1500 \text{ m}\mu$  assuming a  $5800^\circ \text{K}$  black-body radiator).

$p = 1/3$  = Fraction of total weapon yield converted to thermal energy (low-altitude detonations).

$k$  = Fraction of thermal energy released during time  $t_B$ .

$W$  = Yield of the weapon in kilotons.

$T_e = 0.8$  = Average transmission of clear media of the eye (assumed  $5800^\circ \text{K}$  black-body spectrum).

$T_a(S)$  = Average transmission of the atmosphere for horizontal distance  $S$ .

$T_x = 0.9$  = Maximum transmission of aircraft canopy or windows.

\*Refer to page 22

$f = \frac{F}{d_p}$  = Ratio of the effective focal length of the eye-lens system to the diameter of the pupil.

$DFB_H$  = Assumed average fireball diameter in centimeters during exposure time,  $t_B$ .

and

$$T_a(S) = \exp \left( -k_A^{\text{eff}} m \right) \times \exp \left( -k_w^{\text{eff}} w \right) \quad (3)$$

For  $H \neq A$ , i. e. for an observer altitude different than the altitude of the detonation,

$$m = \frac{\rho_{A0}}{q_A (\text{cm}^{-1})} \frac{[(H-A)^2 + S^2]^{1/2}}{|H-A|} \times \left| \exp \left[ -q_A (\text{kft}^{-1}) A \right] - \exp \left[ -q_A (\text{kft}^{-1}) H \right] \right| \quad (4)$$

and

$$w = \frac{\rho_{w0}}{q_w (\text{cm}^{-1})} \frac{[(H-A)^2 + S^2]^{1/2}}{|H-A|} \times \left| \exp \left[ -q_w (\text{kft}^{-1}) A \right] - \exp \left[ -q_w (\text{kft}^{-1}) H \right] \right| \quad (5)$$

Here,

$m$  = amount of air per unit area in path between the observer and the detonation in  $\text{gm}/\text{cm}^2$ .

$w$  = amount of percipitable water (water vapor) in the path between the observer and the detonation in  $\text{gm}/\text{cm}^2$ .

$k_A^{\text{eff}}$  = effective narrow-beam extinction coefficient for air  
 =  $6.218 \times 10^{-5} (\text{cm}^2/\text{gm})$

$$k_w^{eff} = \text{effective narrow-beam extinction coefficient for water vapor}$$

$$= 2.409 \times 10^{-2} \text{ (cm}^2\text{/gm)}$$

$$q_A = \text{air lapse rate}$$

$$= 0.041 \text{ (kilofoot}^{-1}\text{)} = 1.34 \times 10^{-6} \text{ (cm}^{-1}\text{)}$$

$$q_w = \text{moisture lapse rate}$$

$$= 0.1645 \text{ (kilofoot}^{-1}\text{)} = 5.43 \times 10^{-6} \text{ (cm}^{-1}\text{)}$$

$$\rho_{A_0} = \text{sea level air density}$$

$$= 1.4 \times 10^{-3} \text{ Typical of values measured over open water in the Pacific}$$

$$\rho_{w_0} = \text{sea level water vapor density}$$

$$= 2.2 \times 10^{-5} \text{ (gm/cm}^3\text{) Typical of values measured over open water in the Pacific}$$

For  $A = H$ , i. e. altitude of observer the same as the altitude of the detonation:

$$m = \rho_{A_0} e^{-q_A \text{ (kft}^{-1}\text{)}A} \times S, \quad (6)$$

and

$$w = \rho_{w_0} e^{-q_w \text{ (kft}^{-1}\text{)}A} \times S \quad (7)$$

where  $S$  = distance between observer and detonation in centimeters.

The curve  $Q_r(S)$  can be plotted as a function of the distance,  $S$ , on suitable paper and compared with the curve for the allowable retinal exposure

$$Q_r^T(S) = 1/4 Q_r^T(\text{MEAS})(S).$$

The curve  $Q_r^T(S)$ , extrapolated to humans as previously discussed, may be determined from laboratory measurements as follows:

1. Image diameters corresponding to various distances,  $S$ , are calculated from:

$$d_i(\text{mm}) = \frac{F \times (\text{DFB}_H(\text{cm})) \times 3.28 \times 10^{-5}}{[S^2 + (H-A)^2]^{1/2}}$$

where  $F$  = focal length of eye (17 mm).

$\text{DFB}_H$  = fireball diameter, KILOFEET.

$(H-A)$  = difference in burst and observer altitudes, KILOFEET.

$S$  = horizontal range, KILOFEET.

2. From Figure A-5, determine values of  $Q_r^T(\text{MEAS})$  for each  $d_i$  calculated. Values for  $Q_r^T(\text{MEAS})$  may thus be found as a function of  $S$ .  $Q_r^T(\text{MEAS})$  is then extrapolated to humans\* through the relation  $Q_r^T = 1/4Q_r^T(\text{MEAS})$ .
3. The allowable horizontal range,  $S$ , is the value at which the  $Q_r^T$  and  $Q_r$  curves intersect, i. e. the distance at which  $Q_r^T = Q_r$ .

Figure A-6 (A-3)(A-4) can be used to generate additional  $Q_r^T$  vs.  $d_i$  curves (for blink times,  $t_B$ , other than 250 and 450 msec) by merely sectioning the family of curves at the chosen blink time. The values of  $Q_r^T$  thus defined

\*Refer to page 22

for the selected  $t_B$  can be plotted as a function of  $d_i$  -- as in Figure A-5.

Because low yield weapons, up to 10KT, release most of their energy well within the blink time, the allowable exposure,  $Q_r^T$ , was determined differently than for larger weapons. This is necessary since  $Q_r^T$  is a function of exposure time, and for low yield weapons, the effective exposure time is relatively short compared to a blink time of 0.25 seconds. The values of  $Q_r^T$  for low yield weapon were selected to correspond to an exposure time of  $2t_{max}$ , where  $t_{max}$  is the time to the second thermal maximum and is given approximately by  $t_{max} = 0.032W^{0.5}$ . Values of  $Q_r^T$  are then obtained from Figure A-4 as previously described.

### EXAMPLE CALCULATION

1. **MISSION:** 100 KT Weapon; Burst Altitude = 2.7 kilofeet; Observer Altitude = 10 kilofeet; night mission (burst observed at night).

$$W = 100 \text{ KT, so that } t_B = 0.25 \text{ seconds.}$$

$$H = 2.7 \text{ KFT}$$

$$A = 10.0 \text{ KFT}$$

$$d_p = 6.5 \text{ mm, so that } f = \frac{F}{d_p} = \frac{17}{6.5} = 2.6$$

From Figure A-3,  $DFB_o = 6.89 \times 10^4 \text{ cm}$

$$\text{and } DFB_H = DFB_o \left[ \sigma^{-1/3} \right]$$

Interpolating from Table A-1,  $\left[ \sigma^{-1/3} \right] = 1.027$  at  $H = 2.7 \text{ KFT}$

$$\text{So that } DFB_H = (6.89 \times 10^4) (1.027) = 7.1 \times 10^4 \text{ cm}$$

From Figure A-1,  $k = 0.22$  at  $W = 100 \text{ KT}$  and  $H = 2.7 \text{ KFT}$ .

Then

$$Q_r = (2) \left[ \frac{a p k W T_e T_x}{4 \pi f^2 (DFB_H)^2} \cdot (10^{12}) \right] T_a$$

$$= (2) \left[ \frac{(0.79)(0.33)(0.22)(100)(0.8)(0.9)(10^{12})}{(4)(3.14)(2.6)^2(7.1 \times 10^4)^2} \right] T_a$$

$$Q_r = 2(9.65)T_a = 19.2T_a$$

$$T_a = \exp \left[ -k_A^{\text{eff}} m \right] \cdot \exp \left[ -k_w^{\text{eff}} w \right]$$

$$m = \frac{(1.4 \times 10^{-3})}{(1.34 \times 10^{-6})} \cdot \frac{[(2.7-10.0)^2 + S^2]^{1/2}}{|2.7-10.0|} \left| \exp(-0.041 \times 10.0) - \exp(-0.041 \times 2.7) \right|$$

$$m = 33.2 \left[ 53.3 + S^2 \right]^{1/2}$$

$$w = \frac{(2.2 \times 10^{-5})}{(5.43 \times 10^{-6})} \cdot \frac{[(2.7-10)^2 + S^2]^{1/2}}{|2.7-10.0|} \left| \exp(-0.1645 \times 10) - \exp(-0.1645 \times 2.7) \right|$$

$$w = 0.250 \left[ 53.3 + S^2 \right]^{1/2}$$

Substituting the expressions for m and w into the expression for  $T_a$ :

$$T_a = \exp \left[ (-6.218 \times 10^{-5})(33.2) \left[ 53.3 + S^2 \right]^{1/2} \right] \exp \left[ (-2.409 \times 10^{-2})(0.250) \left[ 53.3 + S^2 \right]^{1/2} \right]$$

$$T_a = \exp \left[ (-0.00808) \left[ 53.3 + S^2 \right]^{1/2} \right]$$

Substituting this expression for  $T_a$  into the equation for  $Q_r$ :

$$Q_r = 19.2 \exp \left[ (-0.00808) \left[ 53.3 + S^2 \right]^{1/2} \right]$$

Now it merely remains to substitute values into this expression to obtain coordinates to plot  $Q_r$  vs. S. The table below lists a few such values which are in turn plotted in Figure A-7.

<u>Horizontal Range, S</u> (kilofeet)	<u>Retinal Exposure, <math>Q_r</math></u> (cal/cm <sup>2</sup> )
0	18.2
1	18.2
5	18.0
10	17.5
50	12.8
100	8.58
200	3.86
500	0.374
1000	0.00864

To generate a  $Q_r^T$  vs. S curve to intersect with the above  $Q_r$  vs. S curve, we calculate  $d_i$  for various values of S from

$$d_i \text{ (mm)} = \frac{F \times \text{DFB}_H \text{ (cm)} \times 3.28 \times 10^{-5}}{[S^2 + (H-A)^2]^{1/2}}$$

and get  $Q_r^T$  (MEAS) values for each S from Figure A-5.

Values for  $Q_r^T = 1/4 Q_r^T$  (MEAS) for various values of S are listed below and the curve  $Q_r^T$  vs S is shown in Figure A-7.

Horizontal Range, S (kilofeet)	Retinal Image Diam, $d_i$ (mm)	Allowable Retinal Exposure (cal/cm <sup>2</sup> )
0	5.42	.24
1	5.36	.24
5	4.47	.25
10	3.19	.26
50	0.783	.37
100	0.396	.57
200	0.198	1.8
500	0.0792	9.5

The intersection of the two curves is at approximately 260 KFT or 43 nautical miles. This is the required distance,  $S_A$ , and shows that an observer at 10,000 feet altitude could safely venture no closer than 43 nm (horizontal range) to a 100 KT weapon detonated at 2700 feet - AT NIGHT. (In the day time, the pupil would not be as large, thus permitting less energy into the eye. This would allow the observer to approach somewhat closer to the same burst.)

2. MISSION: 1000 KT (1 MT) Weapon; Burst Altitude = 5.0 KFT;

Observer Altitude = 0 KFT; Day Mission (Burst observed during daylight)



$$W = 1000 \text{ KT, so that } t_B = 0.45 \text{ seconds}$$

$$H = 5.0 \text{ KFT}$$

$$A = 0.0 \text{ KFT}$$

$$d_p = 2.5 \text{ mm, so that } f = \frac{17}{2.5} = 6.8$$

$$\text{From Figure A-4, } DFB_o = 1.56 \times 10^5 \text{ cm}$$

and

$$DFB_H = DFB_o \left[ \sigma^{-1/3} \right]$$

$$\text{From Table A-1, } \left[ \sigma^{-1/3} \right] = 1.05 \text{ at } H = 5.0 \text{ KFT}$$

$$\text{So that } DFB_H = (1.56 \times 10^5)(1.05) = 1.64 \times 10^5 \text{ cm}$$

$$\text{From Figure A-2, } k = 0.07 \text{ at } W = 1000 \text{ KT and } H = 5.0 \text{ kft}$$

Then

$$Q_r = (2) \left[ \frac{(0.79)(0.33)(0.07)(1000)(0.8)(0.9)(10^{12})}{(4)(3.14)(6.8)^2(1.64 \times 10^5)^2} \right] T_a$$

$$Q_r = 2(0.841) T_a = 1.68 T_a$$

$$T_a = \exp \left[ -k_A^{\text{eff}} m \right] \exp \left[ -k_w^{\text{eff}} w \right]$$

$$m = \frac{(1.4 \times 10^{-3})}{(1.34 \times 10^{-6})} \cdot \frac{\left[ (5.0-0)^2 + S^2 \right]^{1/2}}{|5.0-0|} \cdot \left| \exp(-0.041 \times 0) - \exp(-0.041 \times 5.0) \right|$$

$$m = 38.9 \left[ 25 + S^2 \right]^{1/2}$$

$$w = \frac{(2.2 \times 10^{-5})}{(5.43 \times 10^{-6})} \cdot \frac{\left[ (5.0-0)^2 + S^2 \right]^{1/2}}{|5.0-0|} \cdot \left| \exp(-0.1645 \times 0) - \exp(-0.1645 \times 5.0) \right|$$

$$w = 0.454 \left[ 25 + S^2 \right]^{1/2}$$

Substituting the expressions for m and w into the expression for  $T_a$ :

$$T_a = \exp \left[ (-6.218 \times 10^{-5})(38.9) \left[ 25 + S^2 \right]^{1/2} \right] \exp \left[ (-2.409 \times 10^{-2})(0.454) \left[ 25 + S^2 \right]^{1/2} \right]$$

$$T_a = \exp \left[ (-0.0134) \left[ 25 + S^2 \right]^{1/2} \right]$$

$$\text{Thus } Q_r = (1.68) \exp \left[ (-0.0134) \left[ 25 + S^2 \right]^{1/2} \right]$$

We again obtain a table as in the previous example by substituting values of S in this expression for  $Q_r$ . The table below lists such values which are plotted in Figure A-8.

<u>Horizontal Range, S</u> <u>(kilofeet)</u>	<u>Retinal Exposure, <math>Q_r</math></u> <u>(cal/cm<sup>2</sup>)</u>
0	1.58
1	1.58
5	1.54
10	1.45
50	0.86
100	0.44
200	0.12
500	0.0014

We again calculate values of  $d_i$  from:

$$d_i(\text{mm}) = \frac{F \text{ DFB}_H(\text{cm}) \times 3.28 \times 10^{-5}}{\left[ S^2 + (H-A)^2 \right]^{1/2}}$$

and refer to Figure A-5 for values of  $Q_r^T$  for each S.

<u>Horizontal Range, S</u> <u>(kilofeet)</u>	<u>Retinal Image Diam., <math>d_i</math></u> <u>(mm)</u>	<u>Allowable Retinal Exposure, <math>Q_r^T</math></u> <u>(cal/cm<sup>2</sup>)</u>
10	7.75	0.39
50	1.82	0.41
100	0.91	0.48
200	0.46	0.80
500	0.18	3.60

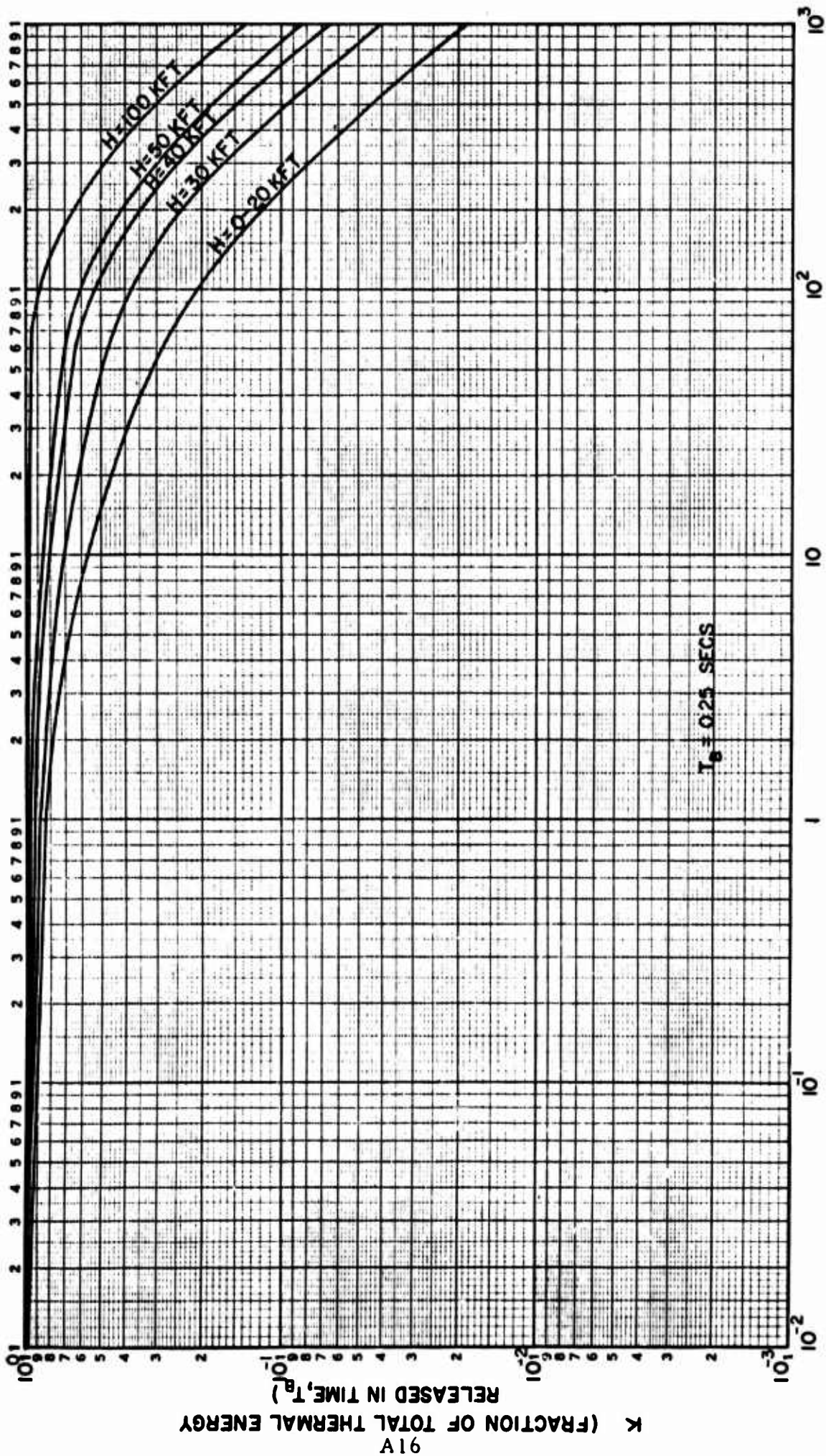
These values are plotted in Figure A-8 to obtain an intersecting curve with the  $Q_r$  vs. S plot. The curves intersect at  $S = 95$  KFT or about 16 nautical miles. For this case, then, an observer at sea level can safely venture no closer than 16 nm (horizontal range) to a 1 MT burst at 5000 feet - IN THE DAYTIME. In this particular example, it is likely that other criteria (radiation, etc.) may prohibit the observer's approaching this close so that the production of retinal burns may not be the limiting factor.

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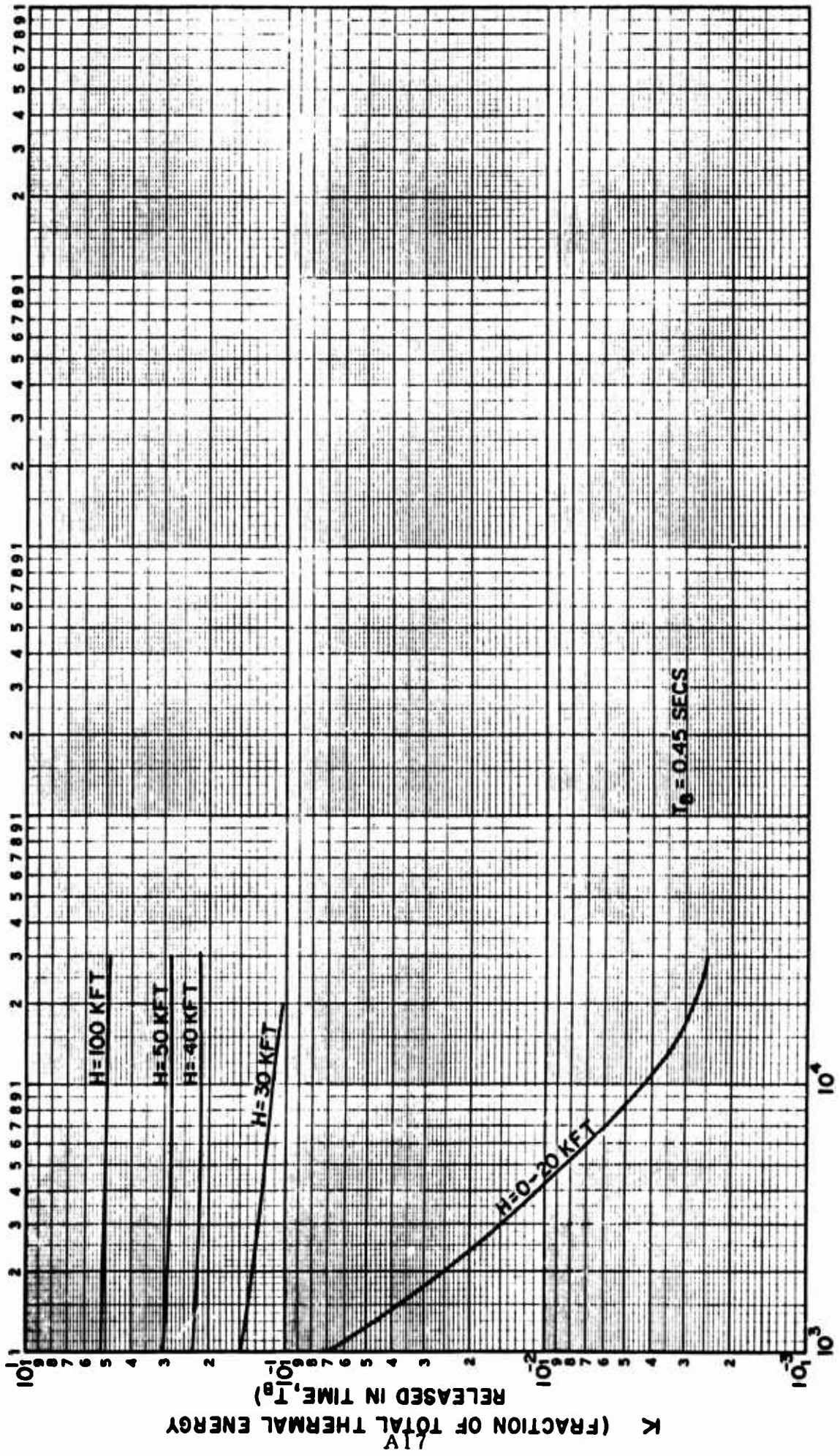
TABLE A-1  
Fireball diameter altitude scaling factors

<u>H, kft</u>	<u><math>\sigma^{-1/3}</math></u>	<u>H, kft</u>	<u><math>\sigma^{-1/3}</math></u>	<u>H, kft</u>	<u><math>\sigma^{-1/3}</math></u>
0	1.0000	41	1.6214	81	3.0718
1	1.0098	42	1.6475	82	3.1208
2	1.0198	43	1.6742	83	3.1697
3	1.0300	44	1.7012	84	3.2219
4	1.0403	45	1.7286	85	3.2737
5	1.0509	46	1.7565	86	3.3251
6	1.0616	47	1.7851	87	3.3798
7	1.0725	48	1.8137	88	3.4337
8	1.0835	49	1.8431	89	3.4863
9	1.0948	50	1.8729	90	3.5474
10	1.1062				
		51	1.9030	91	3.6019
11	1.1180	52	1.9337	92	3.6598
12	1.1298	53	1.9650	93	3.7152
13	1.1420	54	1.9968	94	3.7742
14	1.1544	55	2.0291	95	3.8371
15	1.1670	56	2.0617	96	3.8967
16	1.1797	57	2.0953	97	3.9603
17	1.1928	58	2.1292	98	4.0281
18	1.2061	59	2.1631	99	4.0916
19	1.2196	60	2.1985	100	4.1590
20	1.2334				
		61	2.2339		
21	1.2475	62	2.2699		
22	1.2619	63	2.3064		
23	1.2766	64	2.3434		
24	1.2914	65	2.3819		
25	1.3068	66	2.4184		
26	1.3223	67	2.4572		
27	1.3382	68	2.4974		
28	1.3544	69	2.5375		
29	1.3709	70	2.5774		
30	1.3878				
		71	2.6184		
31	1.4050	72	2.6605		
32	1.4226	73	2.7036		
33	1.4405	74	2.7478		
34	1.4589	75	2.7909		
35	1.4777	76	2.8369		
36	1.4969	77	2.8814		
37	1.5206	78	2.9289		
38	1.5452	79	2.9744		
39	1.5702	80	3.0229		
40	1.5955				

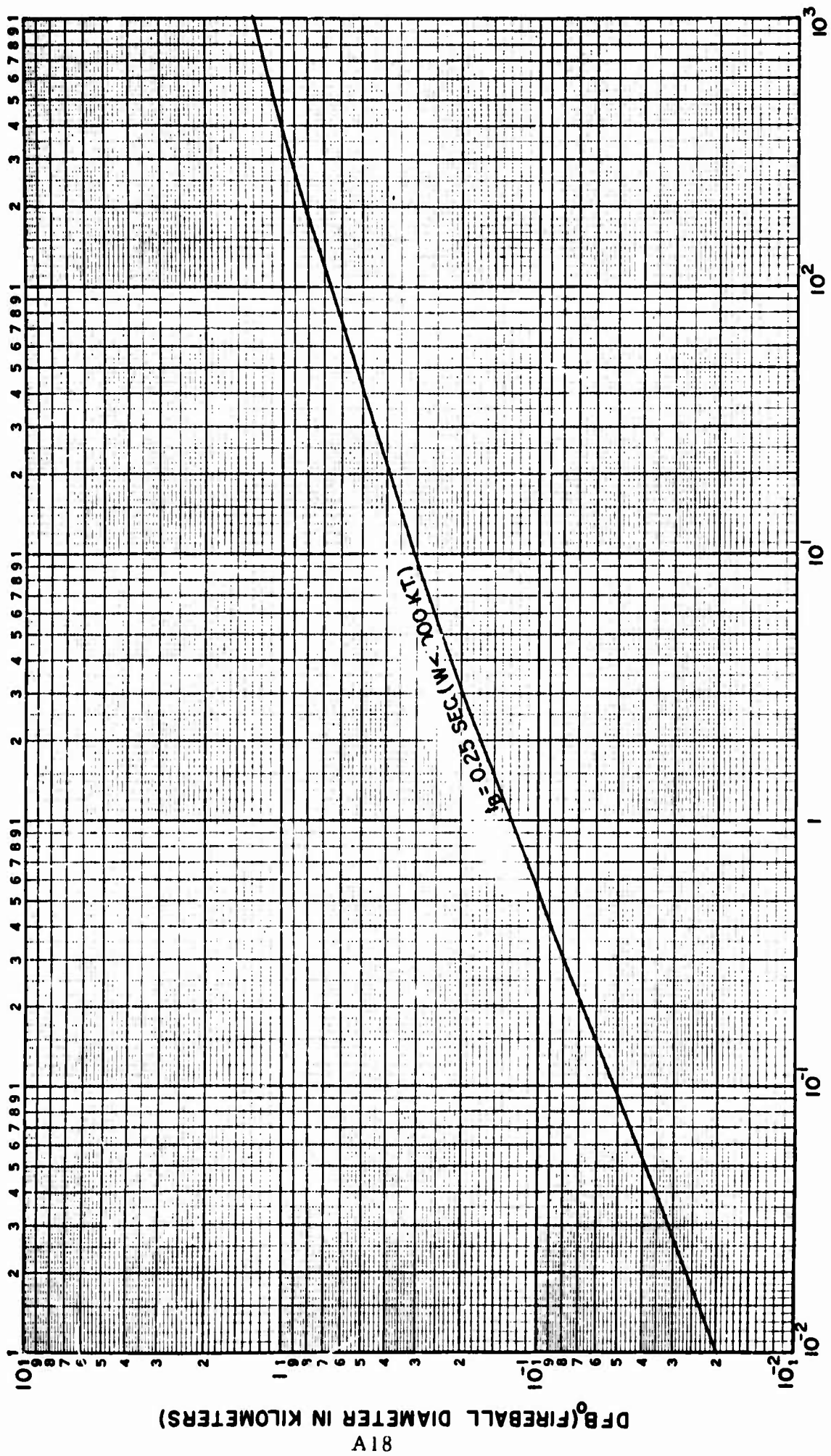


**WEAPON YIELD, W, KILOTONS**

FIGURE A-1. Fraction of total thermal energy released in blink time as a function of yield and burst altitude.



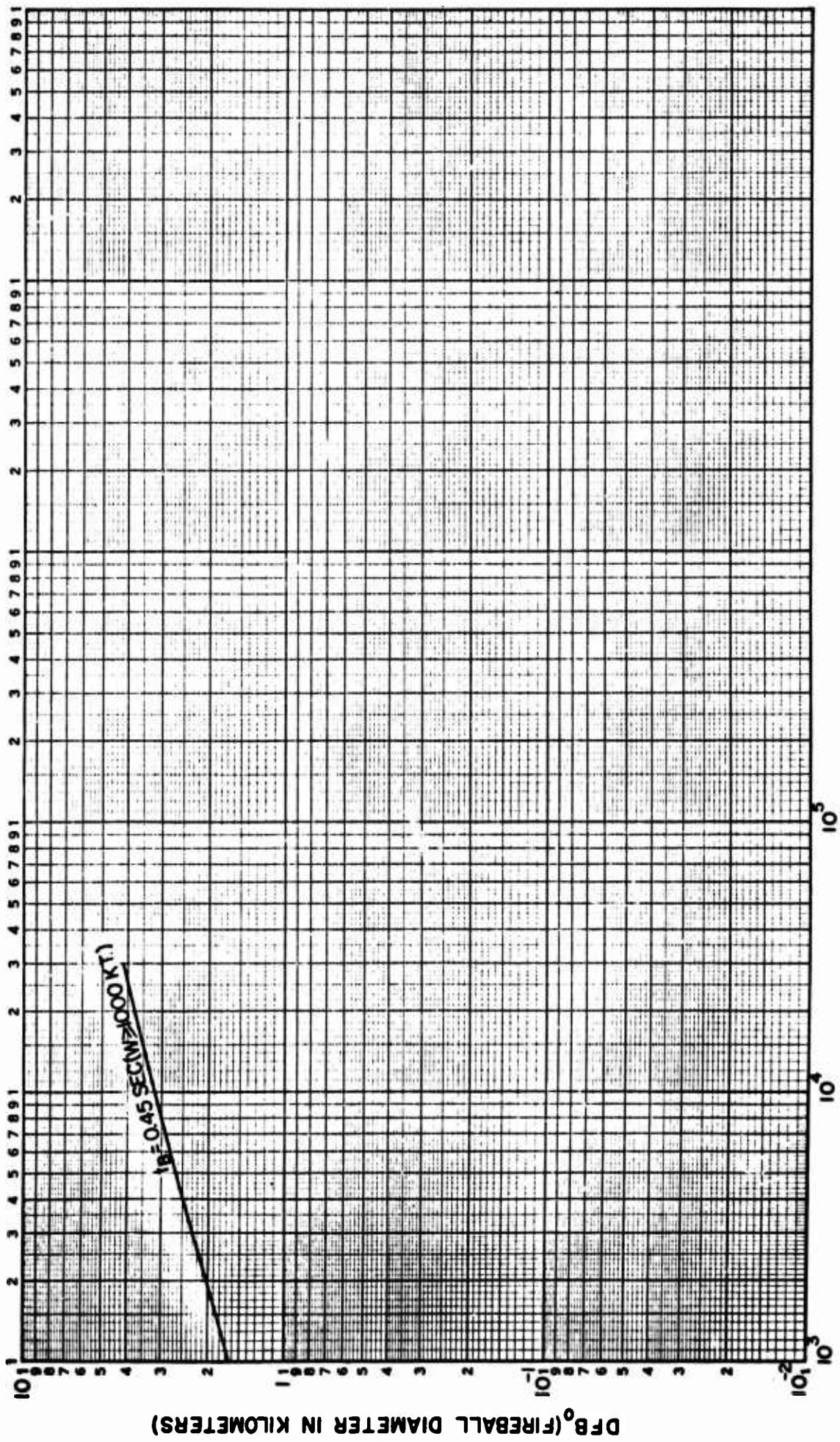
**WEAPON YIELD, W, KILOTONS**  
 FIGURE A-2. Fraction of total thermal energy released in blink time as a function of yield and burst altitude.



**WEAPON YIELD W, KILOTONS**

FIGURE A-3. Fireball diameter as a function of yield at  $T_B = 0.25$  seconds





WEAPON YIELD W, KILOTONS

FIGURE A-4. Fireball diameter as a function of yield at  $T_B = 0.45$  seconds

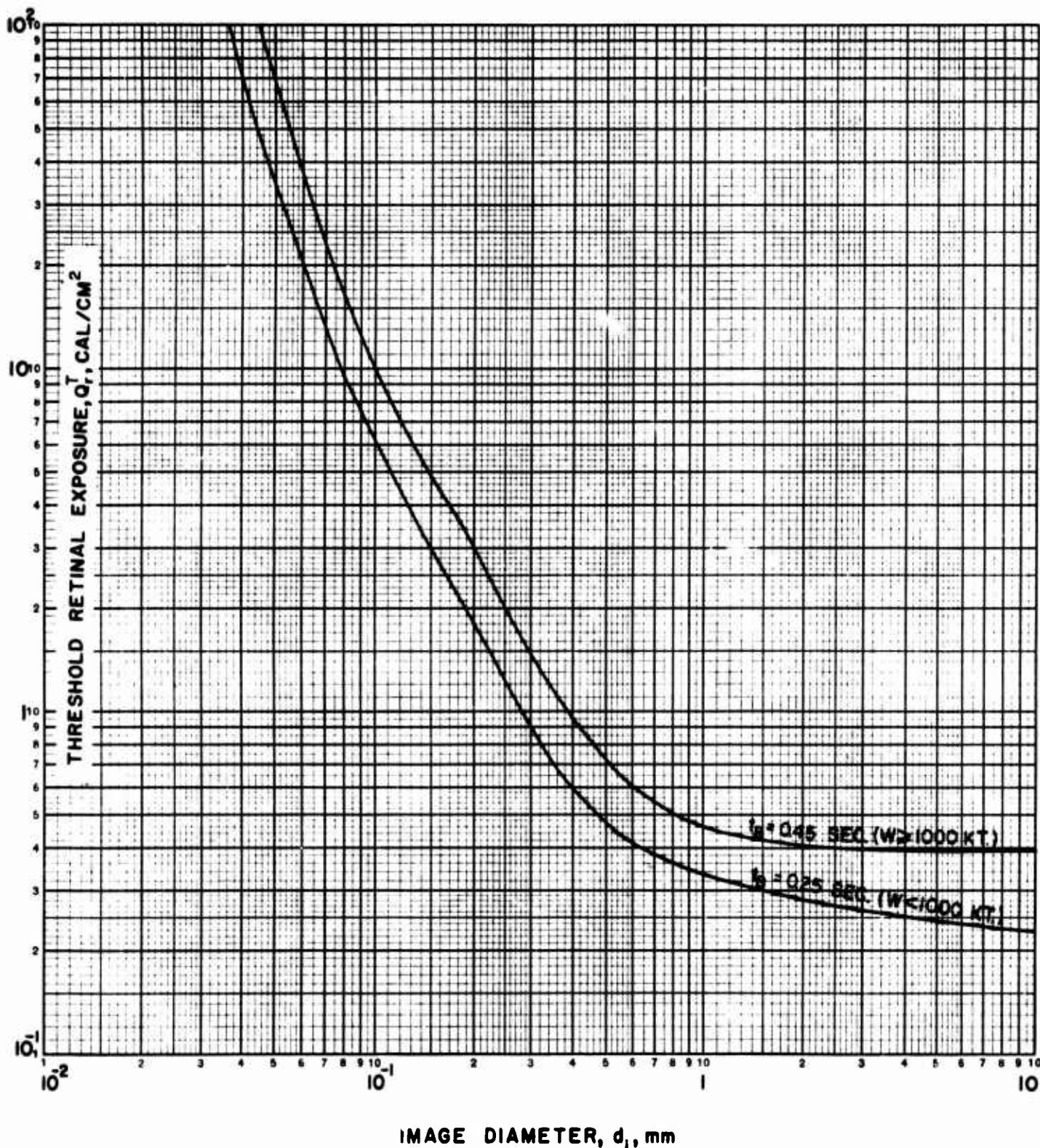


FIGURE A-5. Threshold retinal exposure as a function of image diameter for two blink times

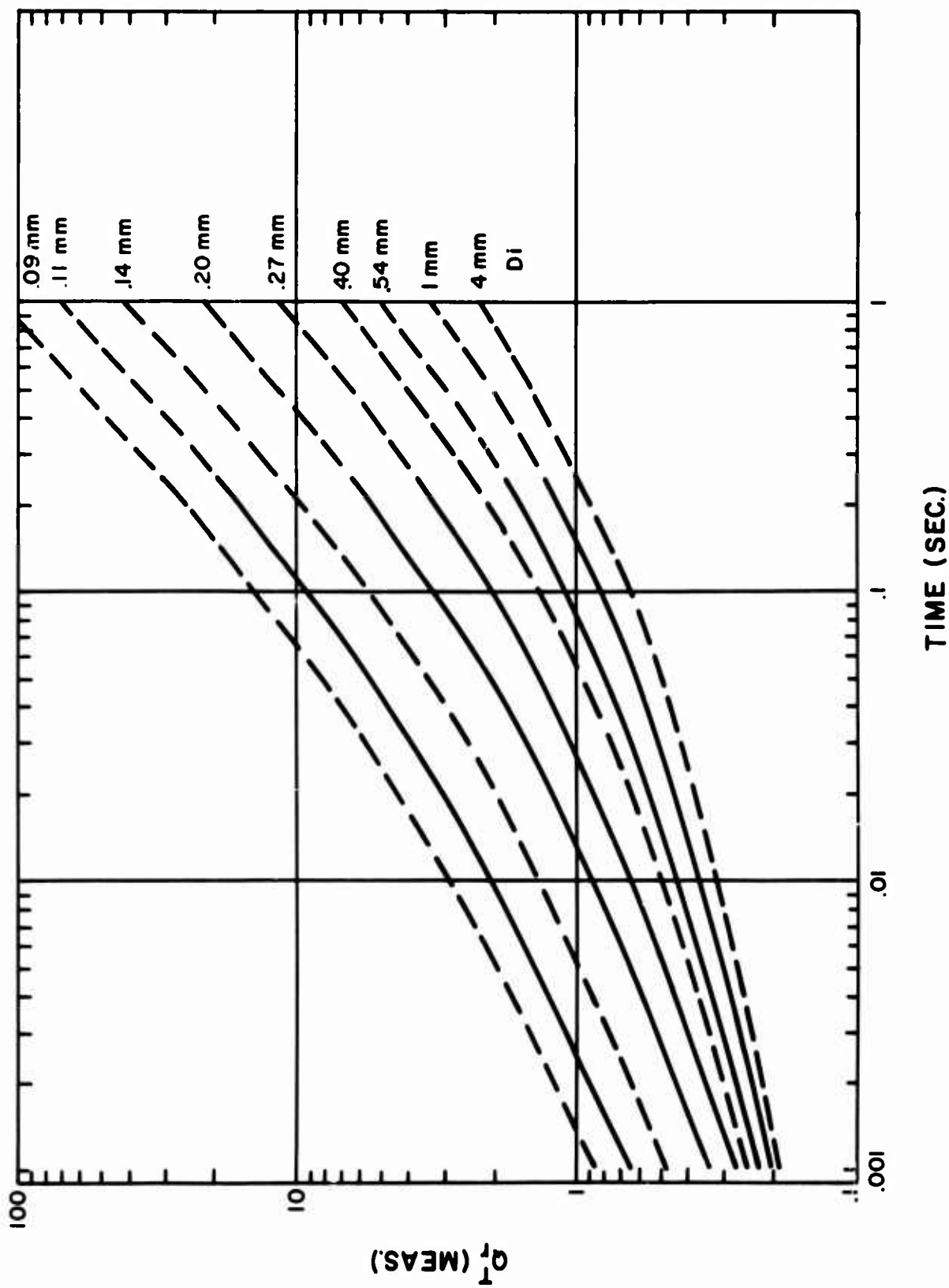


FIGURE A-6.  $Q_r^T$  (MEAS) as a function of exposure time and image diameter.

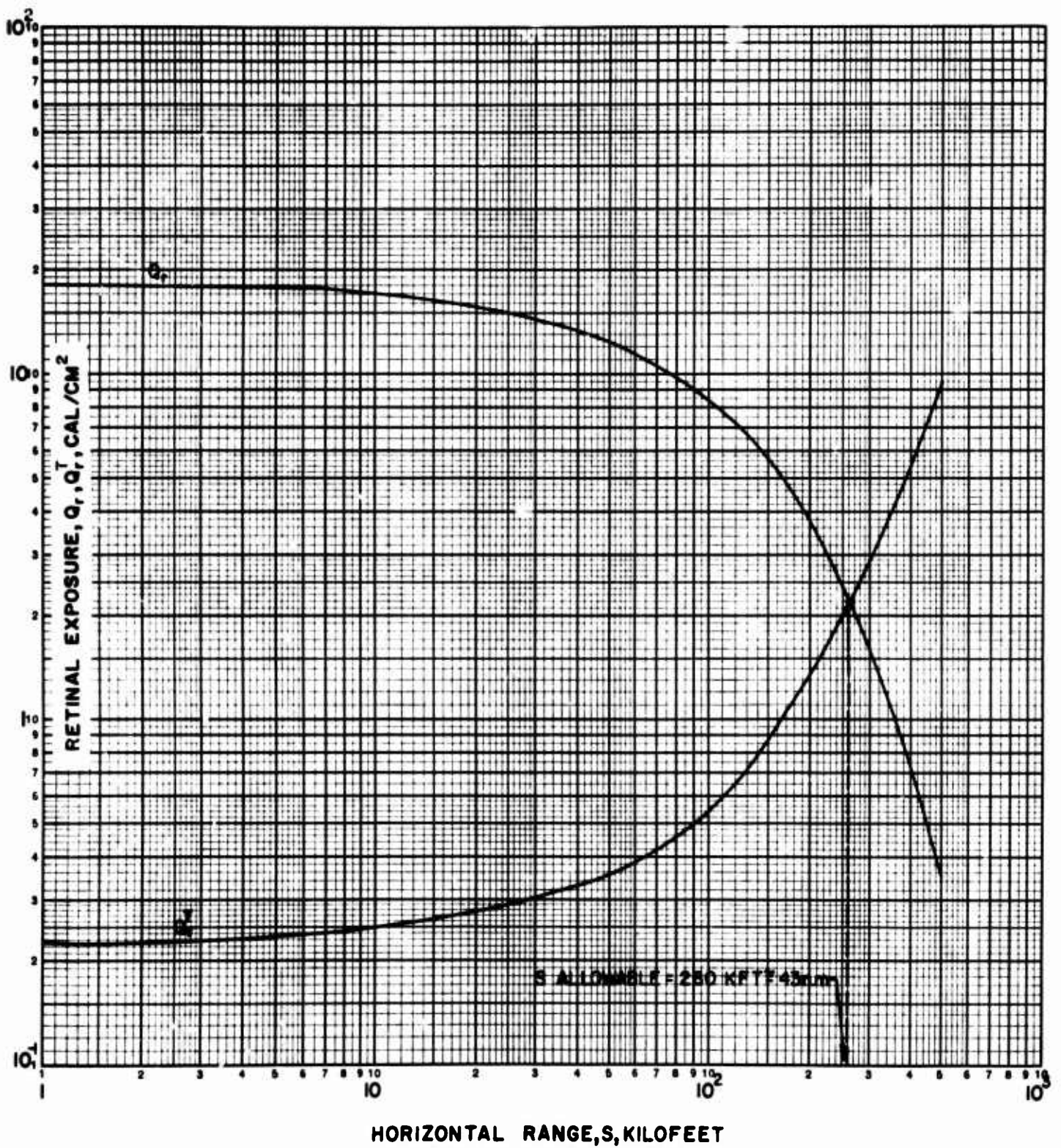


FIGURE A-7. Determination of safe separation distance

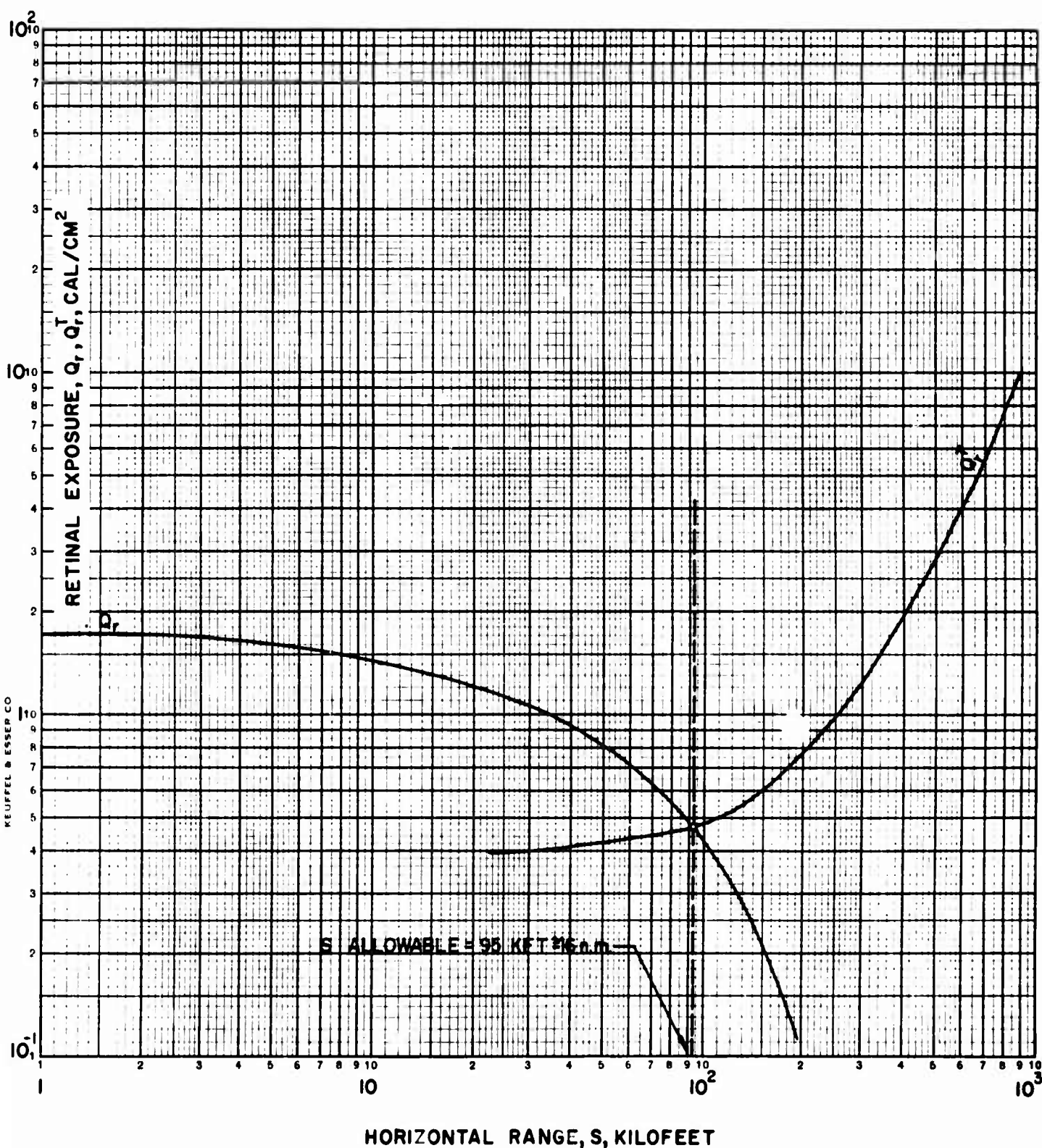


FIGURE A-8. Determination of safe separation distance

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APPENDIX B

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FLASHBLINDNESS CALCULATIONS

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## APPENDIX B - FLASHBLINDNESS CALCULATIONS

The problem of determining the degree of flashblindness, or the time required to recover a specified visual acuity after exposure to a high-luminance source, is inherently more complicated than the problem of determining the occurrence or non-occurrence of a retinal burn of significant dimensions. The additional complexity arises because the diffusely scattered light cannot be ignored in the determination of flashblindness--as it was in the case of retinal burns. Three factors influence the calculation of an acceptable separation distance--image size, image exposure, and extra-image exposure. Richey<sup>(B-1)</sup>, in examining the effect of image size on flashblindness, viewed a standard altimeter at a distance of 30 inches--average eye-to-instrument distance in fighter aircraft--following exposure to centrally fixated flashes of bright light. He reported no difficulty in reading the altimeter when the afterimages subtended visual angles of  $3^{\circ}$  or less (image diameters of 0.9mm or less) even when individual numbers, when fixated directly, could not be identified through the afterimages. In view of these results, a focused image on the fovea less than about 1.0 millimeter in diameter has been considered to have no significant effect on a pilot's ability to extract useful information from his instruments, at least for instruments similar to the altimeter. However, depending upon the magnitude of the exposure, afterimages larger than 1.0mm can interfere with visual acuity. The maximum allowable exposure,  $E_r^A$ , is based on the recovery, within 10 seconds, of a visual acuity of 20/120. For night situations, instrument luminance was taken to be 0.07 millilamberts<sup>(B-2)</sup>. For day exposures, an average instrument luminance of

20 millilamberts <sup>(B-3)</sup> was used.

According to Miller <sup>(B-4)</sup>, the corresponding foveal exposures,  $E_r^M$ , that correspond to a 10 second recovery time are  $1.0 \times 10^6$  troland-seconds for the night condition and  $2.5 \times 10^7$  troland-seconds for the day situation.

As in the calculation of retinal burns, safety factors have been introduced to account for variations between individuals. The "allowable" value,  $E_r^A$ , is obtained by reducing  $E_r^M$ , the measured value, by a factor of 2, i. e.  $E_r^A = E_r^M/2$ .

In addition, the calculated luminous exposure,  $E_r$  (CALC), has been arbitrarily increased by a factor of 2 to allow for inaccuracies which may have been introduced by the model used. Thus, the "safe-sided" value is obtained from the equation  $E_r = 2E_r$  (CALC).

The many variables of the problem and the state-of-the-art concerning the calculation of luminous exposure suggest the use of a "worst-case" philosophy in dealing with flashblindness. Since the maximum exposure will occur within the retinal area covered by the image, and since central vision is of primary concern, the worst case consists of direct foveal viewing of the fireball--i. e. an image of the fireball centered in or upon the fovea.

In view of the significance of image size, the following criteria have been introduced:

- a) If the image diameter is greater than or equal to one millimeter, the foveal exposure will be determined by the imaged or focused energy.



- b) If the image diameter is less than one millimeter, the foveal exposure will be determined by the extra-image or scattered energy.

In each case, the horizontal distance of nearest approach is determined by the condition  $E_r = E_r^A$ .

The first step in determining the "allowable" distance is the calculation of the horizontal distance ( $S_1$ ) at which the image diameter at assumed blink time is 1 millimeter. As in the case for retinal burns, blink time is assumed to be 0.25 seconds for weapon yields less than one megaton and 0.45 seconds for yields of one megaton or larger. The retinal exposure in the image,  $E_r^i$ , at distance  $S_1$  is then calculated:

- a) If  $E_r^i(S_1) < E_r^A$ ,  $E_r^i$  is calculated as a function of decreasing distance (S) until  $E_r^i(S) = E_r^A$ . The horizontal distance (S) at which  $E_r^i(S) = E_r^A$  is taken to be the nearest allowable approach distance.
- b) If  $E_r^i(S_1) = E_r^A$ ,  $S_1$  is the "allowable" distance.
- c) If  $E_r^i(S_1) > E_r^A$ , the extra-image exposure,  $E_r^x$ , becomes of concern. The value  $E_r^x$  is then calculated as a function of increasing distance (S), using the model developed by Vos (B-5)(B-6), until  $E_r^x(S) = E_r^A$ . Since  $E_r^x$  is a function of position on the retina relative to the center of the image, it was necessary to select an appropriate retinal position for the calculation of  $E_r^x$ . This position was selected to correspond to the edge of a one millimeter image, i. e. approximately

1.5° degrees from the direction defining the center of the image.  
(By the conventions adopted, the direction defining the center of  
the image is also the direction of fixation.)

This selection insures a recovery of 20/120 acuity, within 10 seconds,  
in the fovea adjacent to, but outside of a one millimeter diameter area--  
regardless of the circumstances of the exposure. On the basis of Richey's<sup>(B-1)</sup>  
experience, this will permit extraction of useful information from most  
aircraft instruments within 10 seconds.

#### Calculation Methods

##### A. Exposure due to direct image radiation

The concepts and equations used in calculating flashblindness in  
the direct image are essentially the same as those used in  
calculating retinal burns. However, the luminous exposure in  
the direct image is of interest only when the image diameter is  
equal to or greater than one millimeter. In this case, the calculation  
of luminous exposure is carried out as described in Appendix A,  
with  $E_r$  (troland-seconds) obtained from  $Q_r$  (cal/cm<sup>2</sup>) using the  
relationship

$$E_r^i \text{ (troland-secs)} = \frac{680 \times 10^4 (F)^2 \bar{R} Q_r \text{ (watt-sec/cm}^2\text{)}}{T_e} \quad (1)$$
$$= 1.54 \times 10^9 Q_r \text{ (cal/cm}^2\text{)}$$

where:

$F$  = effective focal length of eye in mm (17mm).

$T_e$  = average transmission of the clear media of the eye (0.8).

$$\bar{R} = \frac{\int_0^{\infty} V(\lambda) N(\lambda) d(\lambda)}{\int_0^{\infty} N(\lambda) d(\lambda)} = 0.15$$

$V(\lambda)$  = relative photopic luminous efficiency

$N(\lambda)$  = spectral radiance of the fireball in watts/cm<sup>2</sup>-steradian-m $\mu$

$\lambda$  = wavelength of incident radiation in m $\mu$

**B. Exposure resulting from scattered radiation**

Calculation of the extra-image exposure, adapted from the model developed by Vos<sup>(B-5)(B-6)</sup>, is based on the following assumptions:

- 1) With respect to the diffusely scattered light, the fireball is considered to be a point source.
- 2) The luminous exposure resulting from the scattered light depends upon the amount of radiant energy entering the eye, hence, varies inversely with the square of the distance between source and observer.
- 3) The extra-image exposure at a particular position on the retina depends upon the distance of the retinal position in question from the center of the geometrical image of the fireball.

4. Three components of indirect light are responsible for extra-image exposure:

- a) Intra-ocular scattering ( $E_{Io}^x$ ).
- b) Scattering of light by the atmosphere ( $E_{At}^x$ ).
- c) Diffusely reflected light from the earth's surface (ground or water) and clouds ( $E_{Cl}^x$ ).

The contributions of these three components in troland-seconds, adapted from those described by Vos, are:

	<u>Day</u>	<u>Night</u>
$E_{Io}^x$ (CALC) =	$\frac{110 c^2 E_c}{D^2 a^2}$	$\frac{675 c^2 E_c}{D^2 a^2}$
$E_{At}^x$ (CALC) =	$\frac{40 c^2 E_c}{D^2 a}$	$\frac{240 c^2 E_c}{D^2 a}$
$E_{Cl}^x$ (CALC) =	$\frac{2 c^2 E_c}{D^2}$	$\frac{13 c^2 E_c}{D^2}$

Combining these three expressions into one, and correcting for atmospheric transmission yields

$$E_r^x(\text{CALC}) = \frac{c^2}{D^2} T_a(D) \cdot T_e \cdot T_x \left( \frac{110}{a^2} + \frac{40}{a} + 2 \right) E_c$$

Day

$$E_r^x(\text{CALC}) = \frac{c^2}{D^2} T_a(D) \cdot T_e \cdot T_x \left( \frac{675}{a^2} + \frac{240}{a} + 13 \right) E_c \quad (2)$$

Night

where:

$$c = 4920 W^{0.33} \text{ feet}$$

W = yield in kilotons

$T_e = 0.8$  = average transmission of clear media of the eye (assumed 5800° K black-body spectrum).

$T_x = 0.9$  = maximum transmission of aircraft canopy or windows.

The expression for c is an empirical expression derived by Vos to describe a critical distance of approach and serves here only as a reference distance in extrapolating to other distances.

D = slant range from the fireball to the observer, in feet.

$E_r^x$  (CALC) = extra-image exposure in troland-seconds.

$E_c$  = integrated illumination in lux-seconds at c, the critical distance.

$T_a(D)$  = average transmission of the atmosphere for the slant range D.

$\alpha$  = distance of the retinal position from the center of the geometrical image of the fireball at which the extra-image exposure is being calculated.

The integrated illumination,  $E_c$ , at the critical distance, can be determined from the integrated luminance of the fireball from

$$E_c = \frac{1}{c^2} \int_0^{t_b} \pi B(t) R^2(t) dt, \quad (3)$$

with  $c = 1500 W^{0.33}$  meters and  $t_b =$  blink time. (4)

Combining equations (3) and (4),

$$E_c = 4.5 \times 10^{-7} W^{-0.67} \int_0^{t_b} \pi B(t) R^2(t) dt. \quad (5)$$

Since,  $t = t_s W^{0.5}$  and  $dt = dt_s W^{0.5}$ ,

$$\int_0^{t_b} \pi B(t) R^2(t) dt = W^{1.3} \int_0^{t_b W^{-0.5}} \pi \rho^2(t_s) B(t_s) dt_s. \quad (6)$$

$$\therefore E_c = 4.5 \times 10^{-7} W^{0.63} \int_0^{t_b W^{-0.5}} \pi \rho^2(t_s) B(t_s) dt_s \quad (7)$$

where

$R(t_s) =$  radius of the fireball, meters

$B(t_s) =$  luminance of fireball

$W =$  yield in kilotons

$t_s = t W^{-0.5} =$  scaled time

$\rho = R W^{-0.4} =$  scaled fireball radius

The quantity  $\int_0^{t_b W^{-0.5}} \pi \rho^2(t_s) B(t_s) dt_s$ , corresponding to blink times of 0.25 and 0.45 seconds, can be obtained from Figures B-1 and B-2, and  $E_c$  can then be determined using equation (7).

The value of  $F_c$ , used in equation 2, with  $\alpha = 1.5^\circ$ , gives

$E_r^x(\text{CALC})$ .  $E_r^x$  is obtained from  $E_r^x = 2E_r^x(\text{CALC})$  and the distance at which  $E_r^x = E_r^A$  defines the allowable distance of nearest approach.

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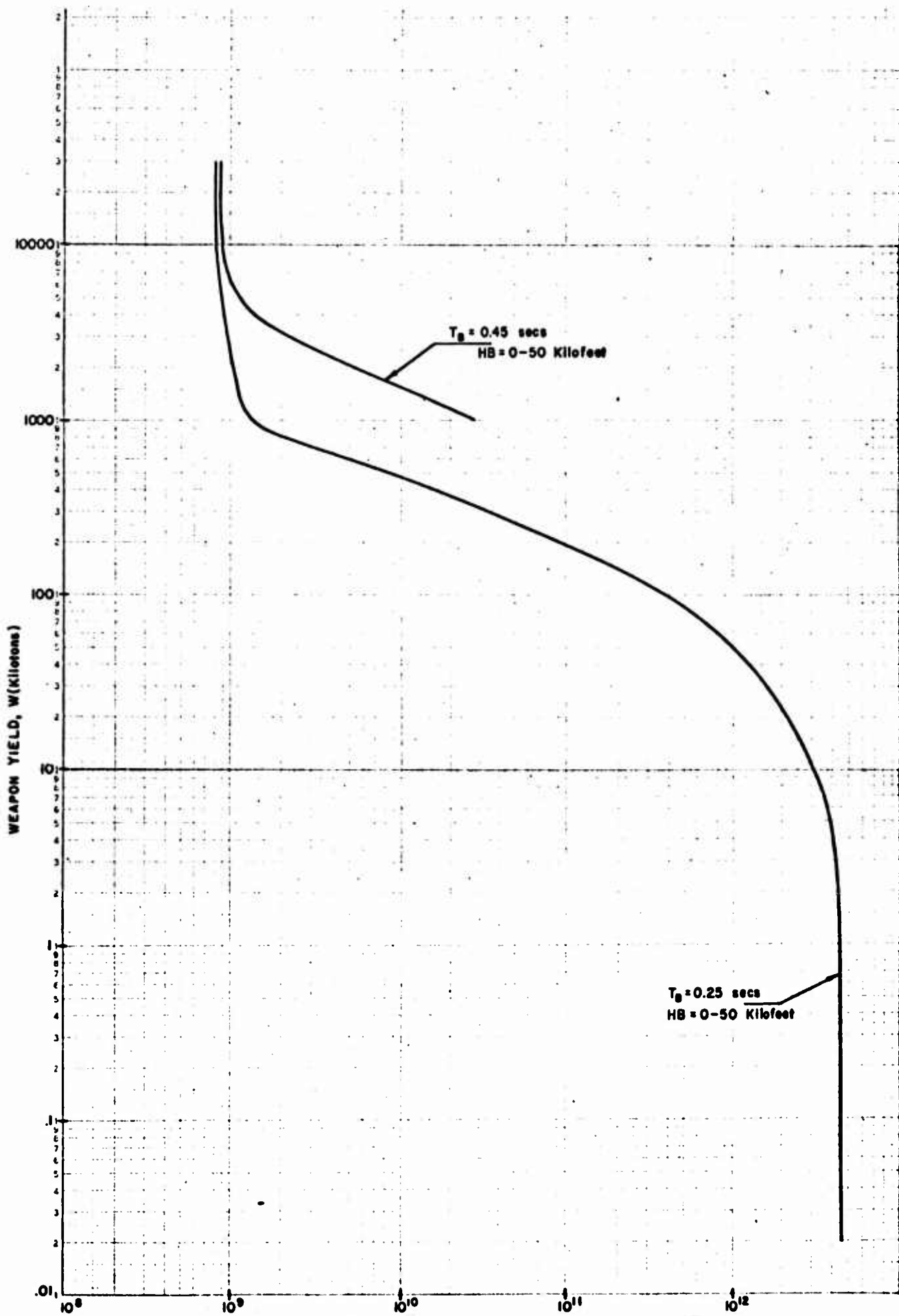


FIGURE B-1. Yield vs. luminous intensity

$$\int_0^{T_0} \frac{W^{-0.5}}{\pi \rho^2 r(t)} S(t) dt \quad (\text{cd-sec})(\text{LUMINOUS INTENSITY})$$

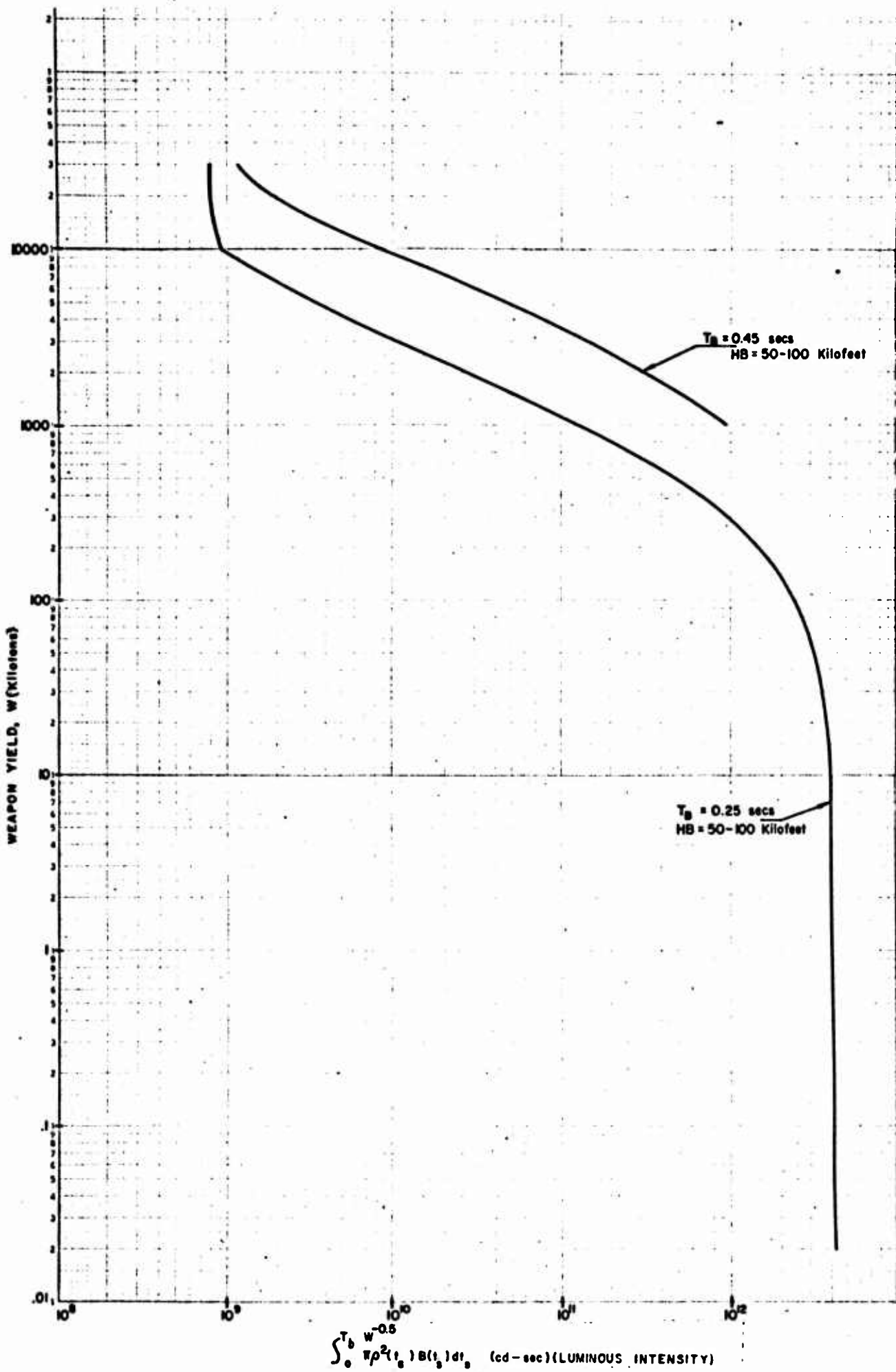


FIGURE B-2. Yield vs. luminous intensity

APPENDIX C

RETINAL BURN AND FLASHBLINDNESS COMPUTER PROGRAMS

## APPENDIX C

### RETINAL BURN AND FLASHBLINDNESS COMPUTER PROGRAMS

The major distinctions between the computer programs which determine retinal burn and flashblindness safe separation distances are (1) the formulation of the retinal exposure functions, and (2) the logic for choosing the safe separation distances based on these functions.

The formulation of the retinal exposure function, QREC, in the retinal burn program is based on direct image exposure and is not limited by image diameter. The flashblindness program bases safe separation distances on QREC or extra-image exposure, ETOT, and depends upon image diameter as set forth in Appendix B.

The basic structure of the burn and flashblindness programs is similar except for output format and the definition of safe separation solutions. Two subroutines appear in both programs; subroutine AIR computes relative temperature, pressure and density at any altitude up to 100 kilofeet, and subroutine TRANS, which uses subroutine AIR, computes the atmospheric transmission for a given slant path.

#### Retinal Burn Program

The retinal burn program is listed, except for system control cards, and card sequence numbers are referred to in the description which follows.

The atmospheric transmission subroutines are contained on cards MASS 001

to TRAN 009 and the input parameter symbolic names used in these subroutines are defined in the program symbol table.

The main, or calling, routine begins on card BURN 001 with format and specification statements. The program begins execution by reading an initial card containing various atmospheric and transmission constants. The next card read by the program at BURN 038 defines the problem situation in terms of weapon yield, fraction of the thermal energy given off before blink time, the detonation altitude, blink time, etc.

The program proceeds by determining the fireball diameter, DFB, and the retinal exposure near the fireball, QF. (Later, retinal exposure with a transmission coefficient, T, will be referred to as QREC.) The next step is to insure the existence of a safe separation envelope so that future iterations will be valid. This is accomplished by examination of the ratio, QRAT, the ratio of the safe allowable exposure to the safe received exposure on card BURN 064. If the ratio is less than 1.0 envelope coordinates are generated, otherwise the program comments accordingly and cycles to begin another situation.

The first step in generating an envelope is to establish the minimum envelope altitude, AMIN, and the maximum envelope altitude, AMAX. These two altitudes are determined in order to facilitate the selection of a satisfactory altitude interval, DELTA, with which to increment observer altitude from the lowest to the highest altitude on the envelope. This process assures that the envelope will be well defined by a sufficient number of solutions.

The determination of AMIN and AMAX is unique only because horizontal range does not apply. The selection of AMIN, AMAX, and DELTA is performed on cards BURN 070 through BURN 122.

Referring to both the program listing and the flowchart in Figure C-1, the mechanics of iterating toward a solution at each discreet observer altitude is illustrated.

The mechanics of iterating to a solution is comparable to the convergence of the  $Q_r$  and  $Q_r^T$  curves as explained in Appendix A. The procedure for obtaining these two curves is also outlined in Appendix A.

#### Flashblindness Program

The flashblindness logic is similar to the retinal burn logic until direct image and extra image exposures are calculated. These quantities are calculated at a distance from the fireball such that the image diameter is equal to one millimeter at that distance. From then on, the logic follows the path as illustrated in Figure C-2 and explained in detail in Appendix B. The envelopes generated are similar in appearance to retinal burn envelopes, but the safe separation distances for flashblindness are generally much greater.

PROGRAM SYMBOL TABLE

<u>PROGRAM SYMBOL</u>	<u>SYMBOL USED BY</u>	<u>UNITS</u>	<u>DESCRIPTION</u>
AK	both	$\frac{\text{cm}^2}{\text{gm}}$	Effective narrow beam extinction coefficient of air.
WK	both	$\frac{\text{cm}^2}{\text{gm}}$	Effective narrow beam extinction coefficient of water.
DWO	both	$\frac{\text{gm}}{\text{cm}^3}$	Sea level moisture content.
WL	burn	km	Moisture lapse rate.
WL	flash	kft <sup>-1</sup>	Moisture lapse rate.
TX	both	pure	Transmission factors of all filters combined.
TE	both	pure	Transmission of the eye.
ABAR	both	pure	Thermal energy in visible region of the spectrum.
P	both	pure	Energy given off as thermal energy.
W	both	KT	Yield of weapon.
PERY	burn	pure	Energy given off within blink time.
HB	both	kft	Height of burst.
TB	both	sec	Blink time.
TS	both	sec	Time scaled.
F	both	pure	F stop of the eye.
FL	burn	cm	Focal length of the eye.
FQA	burn	pure	Safety factors applied to the allowed retinal exposures.
FEA	flash	pure	
FQR	burn	pure	Safety factors applied to the received retinal exposures.
FER	flash	pure	

<u>PROGRAM SYMBOL</u>	<u>SYMBOL USED BY</u>	<u>UNITS</u>	<u>DESCRIPTION</u>
EALLOW	flash	troland-sec	Allowable retinal exposure (Not safe sided).
PRIMEK	flash	I(cd-sec)	Luminous intensity.
ALPHA	flash	deg	Angular direction from center of the image to the point on the retina at which specified recovery time is desired.
PHB	both	pure	Pressure at burst height normalized to sea level.
THB	both	pure	Temperature at burst height normalized to sea level.
DHB	both	pure	Density at burst height normalized to sea level.
WSCL	both	pure	Relative yield as scaled by density at burst height.
TSF	both	pure	Scaled time.
FB(2, 11)	both	pure	Array containing relative fireball size behavior with respect to scaled time.
DFB	both	feet	Fireball diameter.
DFBM	both	cm	Fireball diameter.
A	both	feet	Altitude.
AMIN	both	feet	Altitude of bottom of safe separation envelope.
AMINI	both	feet	Altitude of bottom of safe separation envelope rounded off to nearest thousand feet.
AMAX	both	feet	Altitude of top of safe separation envelope.



<u>PROGRAM SYMBOL</u>	<u>SYMBOL USED BY</u>	<u>UNITS</u>	<u>DESCRIPTION</u>
AMAXI	both	feet	Altitude of top of safe separation envelope rounded off to nearest thousand feet.
DELTA	both	feet	The incremental altitude.
HR	both	feet	Horizontal range.
HRMILE	both	naut. mile	Horizontal range.
T	both	pure	Atmospheric transmission between burst and observer.
DIM	both	mm	Image diameter.
LAST	both	pure	Number of increments to go from AMINI to AMAXI.
ILAT	both	pure	Counts increments.
CRITD	flash	feet	Critical distance.
EMAX	flash		Intermediate result.
TERM	flash		Intermediate result.
ETOTA	flash		Intermediate result.
QRET	flash	troland-sec	Direct image retinal exposure (safe sided)
ETOT	flash	troland-sec	Extra-image retinal exposure. (safe sided)
DS	flash	feet	Slant range.
ABHR	flash		Intermediate result.
QF	burn	$\frac{\text{cal}}{\text{cm}^2}$	Retinal exposure not modified by transmission.

<u>PROGRAM SYMBOL</u>	<u>SYMBOL USED BY</u>	<u>UNITS</u>	<u>DESCRIPTION</u>
QREC	bcth	$\frac{\text{cal}}{\text{cm}^2}$	Retinal exposure (Not safe sided).
QA	burn	$\frac{\text{cal}}{\text{cm}^2}$	Allowable retinal exposure (Not safe sided).
QRAT	burn	pure	$(QA * FQA) / (QREC * FQR)$ .
DELTAHR	burn	feet	An increment used in the iteration.

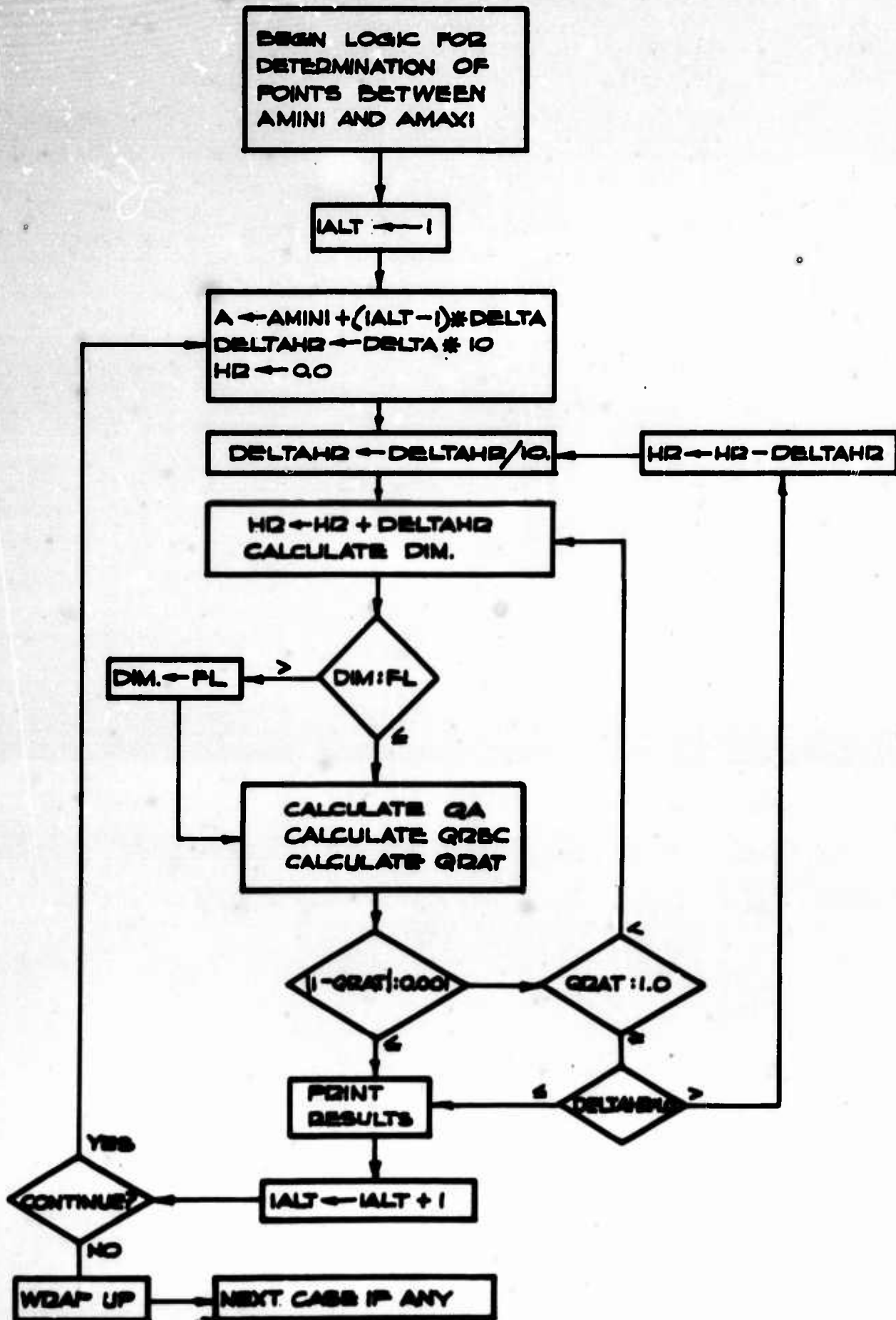


FIGURE C-1. Retinal burn flow diagram.

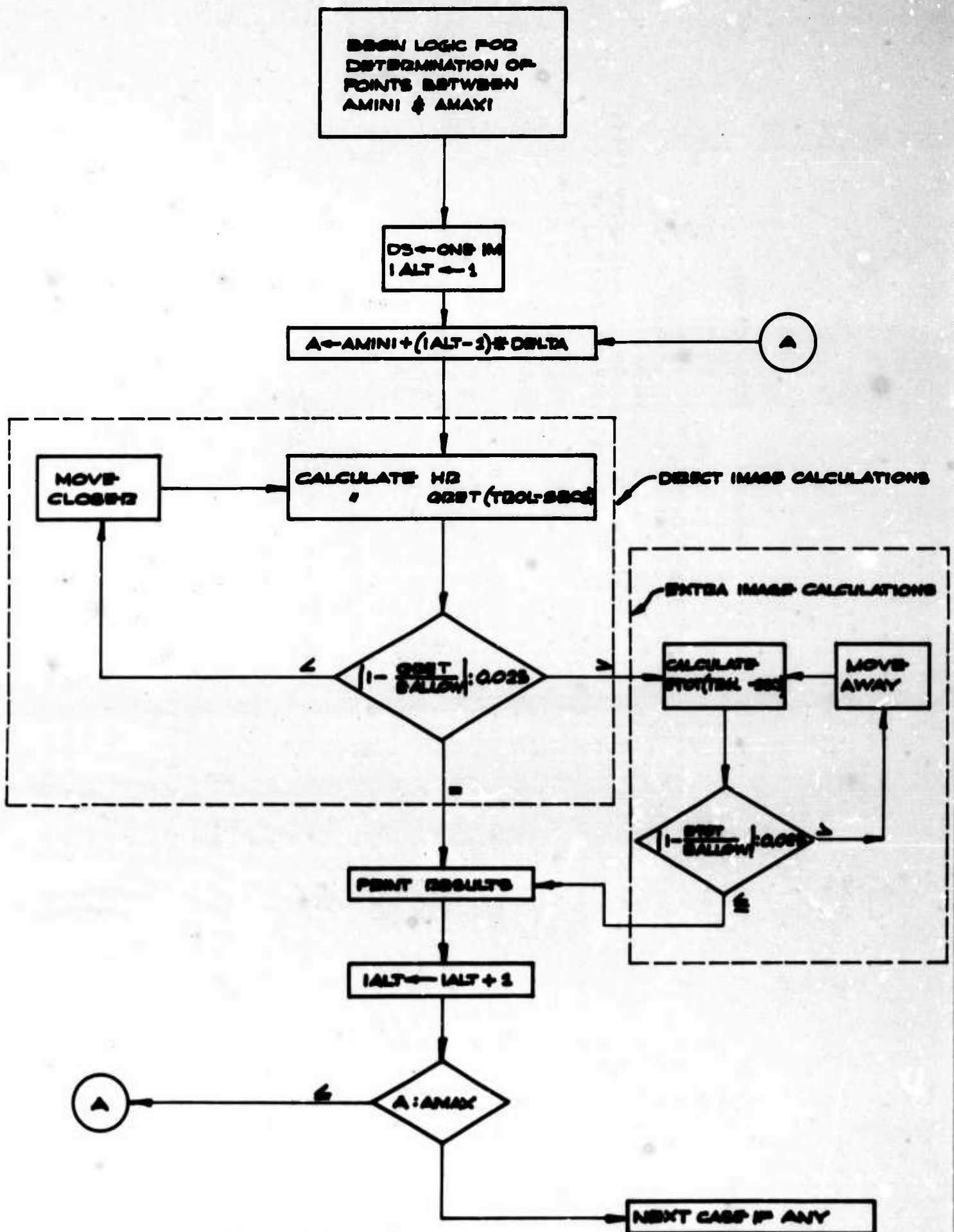


FIGURE C-2. Flashblindness flow diagram.

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JOB          C,0,37777
DUMP         A,1000,37777
DUMP         F,1000,37777
IBIT        44
ALTAC       MAGTAPE,LIB
EYE SAFE   BURN
SUBROUTINE  RWMASS(AMRM,AIRM,A2RM,SRM,DRM,AORM,GAMRM,
WORM,WXRM,WMRM)$
EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
(A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
(D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
(A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
(DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
(A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
COMMON BITS,SP,DP,A3,R1,R2,CM1,
D,D1,R0,R02,SG,
A3D,R1D,R2D,CM1D,
DD,D1D,R0D,R02D,SGD,
A33D,DDD,R11D,TD,
S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WMS
DIMENSION BITS( 35),SP(9),DP(26),
A3D(2),R1D(2),R2D(2),CM1D(2),
DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
A33D(2),DDD(2),R11D(2),TD(2)$
TABLEDEF ONED(2),TWOD(2)$
A1=AIRM,A2=A2RM,S=SRM,W0=WORM,WX=WXRMS
IG=3,L=2$
R1=RE+A1,R2=RE+A2,A3=A1-A2,ALF=S/RES
CALL COSM1(CM1,ALF)$
CALL AMDP(SP ,A3D ,0,4,1,1,1)$
CALL AMDP(A3D ,A3D ,3,A33D)$
CALL AMDP(TWOD,R1D ,3,TD )$
CALL AMDP(TD ,R2D ,3,TD )$
CALL AMDP(TD ,CM1D,3,TD )$
CALL AMDP(A33D,TD ,2,DDD )$
CALL AMDP(DDD ,DD ,5 )$
CALL AMDP(R1D ,CM1D,3,TD )$
CALL AMDP(TD ,A3D ,1,TD )$
CALL AMDP(TD ,DD ,4,SGD )$
CALL AMDP(R2D ,R2D ,3,R11D)$
CALL AMDP(SGD ,SGD ,3,TD )$
RWM 001
RWM 002
RWM 003
RWM 004
RWM 005
RWM 006
RWM 007
RWM 008
RWM 009
RWM 010
RWM 011
RWM 012
RWM 013
RWM 014
RWM 015
RWM 016
RWM 017
RWM 018
RWM 019
RWM 020
RWM 021
RWM 022
RWM 023
RWM 024
RWM 025
RWM 026
RWM 027
RWM 028
RWM 029
RWM 030
RWM 031
RWM 032
RWM 033
RWM 034
RWM 035
ABS
I

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RWM 036		CALL AMDP(ONED,TD ,2,TD )\$
RWM 037		CALL AMDP(R11D,TD ,3,R02D)\$
RWM 038		CALL AMDP(R02D,R0D ,5 )\$
RWM 039		IF(A2)GTE(A1), GO TO A1M\$
RWM 040		CALL AMDP(R1D ,R1D ,3,R11D)\$
RWM 041		CALL AMDP(R11D,R02D,2,TD )\$
RWM 042		CALL AMDP(TD ,D1D ,5 )\$
RWM 043		CALL AMDP(DD ,SP ,9,5,1,5)\$
RWM 044		A0=R0-RE'D2=D1-D'D2A=ABSF(D2)'AM=0.'WM=0.5
RWM 045		GAM=57.2957795*ASINF(SG)\$
RWM 046		IF(D2)GT(-.0001),GO TO A3M\$
RWM 047		IF(A0)GT(0.0 ) , GO TO A2M\$
RWM 048		IG=-3.'AM=PINF.'WM=PINF' GO TO X1M\$
RWM 049		AM=2.'*AMSIMP(SUM,0.,D2A,AXRHO)\$
RWM 050		IF(W0)E(0.),GO TO A3M\$
RWM 051		WM=2.'*AMSIMP(SUM,0.,D2A,AWRHO)\$
RWM 052		AM=AM+AMSIMP(SUM,D2A,D1,AXRH0)\$
RWM 053		IF(W0)E(0.),GO TO A5M\$
RWM 054		WM=WM+AMSIMP(SUM,D2A,D1,AWRHO)\$
RWM 055		WM=1E5*WMS
RWM 056		AM =.997391859E5*AMS
RWM 057		AMRM=AM'DRM=D'AORM=AO'GAMRM=GAM'WMRM=WMS
RWM 058		RETURNS
RWM 059		STARTTACS
RWM 060		O/2\$
RWM 061		D/1\$
RWM 062		O/2\$
RWM 063		D/2\$
RWM 064		F/6371.221\$
RWM 065		35/1135.11/1147\$
RWM 066		C/HLT,1'C/HLT,XRHO,WRHOS
RWM 067		C/HLT,1'C/HLT,WRHO,WRHOS
RWM 068		SYMBOUT AO'A1'A2'A3'S'D'D1'D2'RE'R02'ALF'GAM'AM'L'IG'WO'WX'WMS
RWM 069		REFOUT XRHO,XRHO,WRHO,WRHOS
RWM 070		ENDTAC \$
RWM 071		ENDS

```

XRH 001 SUBROUTINE XRHO(X) $
XRH 002 EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
XRH 003 (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
XRH 004 (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
XRH 005 (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
XRH 006 (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
XRH 007 (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
XRH 008 COMMON BITS,SP,DP,A3,R1,R0,CM1,
XRH 009 D,D1,R0,R02,SG,
XRH 010 A3D,R1D,R2D,CM1D,
XRH 011 DD,D1D,R0D,R02D,SGD,
XRH 012 A33D,DDD,R11D,TD,
XRH 013 S,A0,A1,A2,D2,ALF,GAM,AM,L,IG$
XRH 014 DIMENSION BITS( 35),SP(9),DP(26),
XRH 015 A3D(2),R1D(2),R2D(2),CM1D(2),
XRH 016 DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
XRH 017 A33D(2),DDD(2),R11D(2),TD(2)$
XRH 018 TABLEDEF HL(22)$
XRH 019 H=SQRTF(R02+X*X)-RES
XRH 020 IF(H)GTE(0.),GO TO AORHOS
XRH 021 IF(H)LTE(-.0005),GO TO X2RHOS
XRH 022 H=0.$
XRH 023 L=L-1,K=0$
XRH 024 AORHO IF(H-HL(L))A2RHO,A5RHO,A4RHO $
XRH 025 AIRHO IF(K)X2RHO,A3RHO,A5RHO $
XRH 026 A2RHO L=L-1, IF(L)X2RHO,X2RHO,A1RHOS
XRH 027 A3RHO L=L+1,K=1,GO TO AIRHO $
XRH 028 A4RHO GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
XRH 029 22,23),L $
XRH 030 L=2$
XRH 031 X=1.225 E-3*(1.-2.2518827E-2* H )** 4.2359, GO TO X1RHO $
XRH 032 X=3.6392E-4/EXPF(.15692 *(H-11.019)) , GO TO X1RHO $
XRH 033 X=8.8035E-5/(1.+4.577983 E-3*(H-20.063))**35.167 , GO TO X1RHO $
XRH 034 X=1.3225E-5/(1.+1.2098404E-2*(H-32.162))**13.201 , GO TO X1RHO $
XRH 035 X=1.4275E-6/EXPF(.12426 *(H-47.35 )) , GO TO X1RHO $
XRH 036 X=7.5943E-7*(1.-7.258821 E-3*(H-52.429))**16.081 , GO TO X1RHO $
XRH 037 X=2.5109E-7*(1.-1.5485454E-2*(H-61.591))** 7.5408, GO TO X1RHO $
XRH 038 X=2.001 E-8/EXPF(.18414 *(H-79.994)) , GO TO X1RHO $
XRH 039 X=3.170 E-9/(1.+1.6606698E-2*(H-90. ))**12.012 , GO TO X1RHO $
XRH 040 X=4.974E-10/(1.+2.3736055E-2*(H-100. ))** 7.612 , GO TO X1RHO $
XRH 041 X=9.829E-11/(1.+3.8365624E-2*(H-110. ))** 4.2955, GO TO X1RHO $
XRH 042 X=2.436E-11/(1.+5.5455428E-2*(H-120. ))** 2.6389, GO TO X1RHO $

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XRH 043	14	X=1.836E-12/(1.+1.5614428E-2*(H-150.	)** 3.1713	GO TO X1RHO \$
XRH 044	15	X=1.159E-12/(1.+9.003737 E-3*(H-160.	)** 4.249	GO TO X1RHO \$
XRH 045	16	X=8.036E-13/(1.+5.782018 E-3*(H-170.	)** 5.6179	GO TO X1RHO \$
XRH 046	17	X=4.347E-13/(1.+3.701921 E-3*(H-190.	)** 7.4016	GO TO X1RHO \$
XRH 047	18	X=1.564E-13/(1.+2.579563 E-3*(H-230.	)** 8.8731	GO TO X1RHO \$
XRH 048	19	X=3.585E-14/(1.+1.802638 E-3*(H-300.	)**10.302	GO TO X1RHO \$
XRH 049	20	X=6.498E-15/(1.+1.203342 E-3*(H-400.	)**12.465	GO TO X1RHO \$
XRH 050	21	X=1.577E-15/(1.+7.022907 E-4*(H-500.	)**18.032	GO TO X1RHO \$
XRH 051	22	X=4.640E-16/(1.+4.246039 E-4*(H-600.	)**26.546	GO TO X1RHO \$
XRH 052	23	GO TO 22 \$		
XRH 053	X1RHO	RETURN \$		
XRH 054	TX2RHO	JMP 1SUBERR\$		
XRH 055		STARTTACS		
XRH 056	LHRHO	TJML XRHO.XRHO-1\$		
XRH 057		TAM HS		
XRH 058		JMP A6RHOS		
XRH 059	CHL	F/0\$		
XRH 060		F/11.019\$		
XRH 061		F/27.063\$		
XRH 062		F/32.162\$		
XRH 063		F/47.35\$		
XRH 064		F/52.429\$		
XRH 065		F/61.591\$		
XRH 066		F/79.994\$		
XRH 067		F/90\$		
XRH 068		F/100\$		
XRH 069		F/110\$		
XRH 070		F/120\$		
XRH 071		F/150\$		
XRH 072		F/160\$		
XRH 073		F/170\$		
XRH 074		F/190\$		
XRH 075		F/230\$		
XRH 076		F/300\$		
XRH 077		F/400\$		
XRH 078		F/500\$		
XRH 079		F/600\$		
XRH 080		F/1E6\$		
XRH 081	C	SYMBOL HL\$		
XRH 082		SYMBOL HRHO.HRHOS		
XRH 083		SAME HRHO.HRHO.HRHOS		
XRH 084		REFOUT COMMON.RES		
XRH 085		ENDTAC \$		
XRH 086		END\$		



```

001 SUBROUTINE WRHO(X) $
002 EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
003 (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
004 (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
005 (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
006 (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
007 (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
008 COMMON BITS,SP,DP,A3,R1,R2,CM1,
009 D,D1,R0,R02,SG,
010 A3D,R1D,R2D,CM1D,
011 DD,D1D,R0D,R02D,SGD,
012 A33D,DDD,R11D,TD,
013 S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WMS
014 DIMENSION BITS( 35),SP(9),DP(26),
015 A3D(2),R1D(2),R2D(2),CM1D(2),
016 DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
017 A33D(2),DDD(2),R11D(2),TD(2)$
018 H=SQRTF(R02+X*X)-RES
019 IF(H)GTE(0.),GO TO A0WRHOS
020 IF(H)LTE(-.0005),GO TO X2WRHOS
021 H=0.$
022 A0WRHO X=W0/EXPF( WX*H)$
023 X1WRHO RETURN $
024 TX2WRHO JMP 1SUBERRS
025 T REFOUT COMMON.RES
026 WRH ENDS$

```

COS	STARTTAC	NAME	SYMBOL	SYMBOL	SYMBOL
COS 001	\$				
COS 002	COSM1\$				
COS 003	COSM1\$				
COS 004	LCOSM1	TJM	X\$	COSM1\$	
COS 005		TQM	A\$		
COS 006		TDM	A2\$		
COS 007		FMMRS	A2\$		
COS 008		TMD	F/1\$		
COS 009		TDM	P\$		
COS 010		TMD	F/0\$		
COS 011		TDM	C\$		
COS 012		TMD	F/2\$		
COS 013		TDM	D\$		
COS 014		TDM	E\$		
COS 015		TDM	F\$		
COS 016		TMD	1/1T19\$		
COS 017		DORMS	J\$		
COS 018		JMP	I\$		
COS 019	H	TMA	F/1\$		
COS 020		FAMS	E\$		
COS 021		TDQ	\$		
COS 022		FMMRS	F\$		
COS 023		TMA	F/1\$		
COS 024		FAMS	E\$		
COS 025		TDQ	\$		
COS 026		FMMRS	F\$		
COS 027	I	TMQ	A2\$		
COS 028		FMMRS	P\$		
COS 029		FDA	F\$		
COS 030		TQM	B\$		
COS 031		NOP	\$		
COS 032	LJ	FCSM	B\$		
COS 033		FAMS	C\$		
COS 034		TMD	D\$		
COS 035		JAED	K\$		
COS 036		TAM	D\$		
COS 037		TMA	1/1T19\$		
COS 038		AWCS	J\$		
COS 039		JMP	H\$		
COS 040	K	TMA	F/0\$		
COS 041		TMQ	C\$		
COS 042		JAGQF	X-1\$		



AIR 001	SUBROUTINE AIR(H,P,T,DA) \$
AIR 002	HKM=H*3.048E-4 \$
AIR 003	IF(HKM) GT (25.) GO TO 20 \$
AIR 004	IF(HKM) GT (11.) GO TO 10 \$
AIR 005	T=288.16-6.5*HKM \$
AIR 006	P=1033.2*(T/288.16)**5.2561 \$
AIR 007	DA=1.225E-3*(T/288.16)**4.2561 \$
AIR 008	GO TO 30 \$
AIR 009	T=216.66 \$
AIR 010	C=EXPF(0.15769*(11.-HKM)) \$
AIR 011	P=C*231.47 \$
AIR 012	DA=C*3.648E-4 \$
AIR 013	GO TO 30 \$
AIR 014	T=216.66+3.*(HKM-25.) \$
AIR 015	P=25.772*(216.66/T)**11.3882 \$
AIR 016	DA=4.0639E-5*(216.66/T)**12.3882 \$
AIR 017	T=T/288.16 \$
AIR 018	P=P/1033.2 \$
AIR 019	DA=DA/1.225E-3 \$
AIR 020	RETURN \$
AIR 021	END \$

TRAN001  
TRAN002  
TRAN003  
TRAN004  
TRAN005  
TRAN006  
TRAN007  
TRAN008  
TRAN009

10

SUBROUTINE TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) \$  
HBKM=HB\*3.048E-4 \$  
AKM=A\*3.048E-4 \$  
HRKM=HR\*3.048E-4 \$  
IF(HRKM) E (0.0),HRKM=3.048E-4 \$  
CALL RWMASS(AM,HBKM,AKM,HRKM,SR,AO,GAM,DWO,WL,WM) \$  
T=EXPF(-AK\*AM-WK\*WM) \$  
RETURN \$  
END \$

```

BURN001 1000 FORMAT(8F10.0) $
BURN002 1200 FORMAT(7F10.0,2F5.0) $
BURN003 1300 FORMAT(1H1) $
BURN004 1400 FORMAT(//////42X,35HNO RETINAL BURN ENVELOPE EXISTS FOR/
BURN005 42X,16HTHIS SITUATION -//
BURN006 42X,16HYIELD = ,1PE11.4/
BURN007 42X,16HBURST HEIGHT = ,E11.4/
BURN008 42X,16HPERCENT YIELD = ,E11.4/
BURN009 42X,16HBLINK TIME = ,E11.4,7H DURING, A7,7HMISSION/
BURN010 42X,16HGA FACTOR = ,E11.4/
BURN011 42X,16HQR FACTOR = ,E11.4) $
BURN012 FORMAT(/40X,7HW = 1PE11.4,4X,7HAK = E11.4/
BURN013 40X,7HHB = E11.4,4X,7HWK = E11.4/
BURN014 40X,7HDFB = E11.4,4X,7HDWO = E11.4/
BURN015 40X,7HPERY = E11.4,4X,7HWL = E11.4/
BURN016 40X,7HTB = E11.4,4X,7HTX = E11.4/
BURN017 40X,7HTS = E11.4,4X,7HTE = E11.4/
BURN018 40X,7HTSF = E11.4,4X,7HABAR = E11.4/
BURN019 40X,7HF = E11.4,4X,7HP = E11.4/
BURN020 40X,7HFL = E11.4,4X,7HFGA = E11.4/
BURN021 62X,7HFQR = E11.4) $
BURN022 1600 FORMAT(35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET/
BURN023 61X,7HQA = E11.4/
BURN024 61X,7HQREC = E11.4/
BURN025 61X,7HDIM1 = E11.4) $
BURN026 1700 FORMAT(35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET/
BURN027 61X,7HQA = E11.4/
BURN028 61X,7HQREC = E11.4/
BURN029 61X,7HDIM2 = E11.4) $
BURN030 1800 FORMAT(/35X,21HLET DELTA ALTITUDE = 1PE11.4,5H FEET////19X,
BURN031 75HALTITUDE H RANGE H RANGE Q ALLOWABLE Q RECEIVE
BURN032 D IMAGE DIAM/21X,4HFEET,7X,6HN MILE,9X,3H FT,37X,2HMM) $
BURN033 1900 FORMAT(18X,1PE11.4,2X,5(E11.4,2X)) $
BURN034 TABLEDEF FB(2,11) $
BURN035 T TMD F/1.E-2$
BURN036 T TDM AMSIMP.AMSIMP+3$
BURN037 READ 1000,AK,WK,DWO,WL, TX,TE,ABAR,P $
BURN038 CARD READ 1200,W,PERY,HB,TB,TS,F,FL,FQA,FOR $
BURN039 IF(W) E (0.0),GO TO EXIT $
BURN040 PRINT 1300 $
BURN041 CALL AIR(HB,PHB,THB,DHB) $
BURN042 WSCL=0.032*(DHB*W)*#0.5 $

```

```

BURN043 IF(TB) E (0.0),TB=(TS-0.0025)*WSCL,GO TO 10 $
BURN044 IF(TS) E (0.0),TS=0.0025+TB/WSCL,GO TO 10 $
BURN045 IF(TB) GT ((TS-0.0025)*WSCL),TB=(TS-0.0025)*WSCL,GO TO 10 $
BURN046 TS=.0025+TB/WSCL $
BURN047 TSF=.032*TS $
BURN048 IF(TS) GTE (FB(1,11)),DF=FB(2,11),GO TO 40 $
BURN049 IF(TS) LT (FB(1,1)),I=2,GO TO 30 $
BURN050 DO 20 I=2,11 $
BURN051 IF(TS) LT (FB(1,1)),GO TO 30 $
BURN052 CONTINUE $
BURN053 DF=FB(2,I-1)+LOGF(TS/FB(1,I-1))*(FB(2,I)-FB(2,I-1))/
BURN054 LOGF(FB(1,I)/FB(1,I-1)) $
BURN055 DFB=360.0*DF $
BURN056 DFB=DFB**0.4*(1./DHB)**0.333 $
BURN057 DFBM=30.48*DFB $
BURN058 QF=7.95775E10*ABAR*P*PERY**TE*TX/(F*F*DFBM*DFBM) $
BURN059 HR=1.0 $
BURN060 A=HB-1.0 $
BURN061 T=1.0 $
BURN062 QREC=QF*T $
BURN063 QA=10.**(0.192*LOG10F((TB*1000.)*1.605)-.766) $
BURN064 QRAT=(FQA*QA)/(FQR*QREC) $
BURN065 IF(QRAT) LT (1.0),GO TO TOWN $
BURN066 IF(F) GT (5.0),TITLE(1)=DAY $
BURN067 IF(F) LT (5.0),TITLE(1)=NIGHT $
BURN068 PRINT 1400,W,HB,PERY,TB,TITLE(1),FQA,FQR $
BURN069 GO TO CARD $
BURN070 HR=0.0,QA=0.0,QREC=0.0,DIM=0.0 $
BURN071 PRINT 1500,W,AK,HB,WK,DFB,DWO,PERY,WL,TB,IX,TS,TE,TSF,ABAR,F,P,
BURN072 FL,FQA,FQR $
BURN073 A=0.0 $
BURN074 IF(HB) LTE (1000.),AMIN=0.0,GO TO 80 $
BURN075 A=HB'DELTA=10000. $
BURN076 DELTA=DELTA/10. $
BURN077 A=A-DELTA $
BURN078 IF(A) LTE (0.0),AMIN=0.0,GO TO 80 $ ARE WE AT SEA LEVEL
BURN079 DIM=FL*DFB/(HB-A) $
BURN080 IF(DIM) GT (FL),DIM=FL $
BURN081 QA=10.**(0.044/(DIM+.02)+.19)*LOG10F((TB*1000.)*1.605)
BURN082 (-.079/(DIM+.12)+1.61)+.06/DIM -.77) $
BURN083 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
BURN084 QREC=QF*T $

```

CHECK TO INSURE THAT AN INTER-SECTION DOES EXIST

DETERMINE ALTITUDE OF BOTTOM

ARE WE AT SEA LEVEL

TOWN

```

BURN085  GRAT=(FQA*QA)/(FQR*QREC) $
BURN086  IF(ABSF(1.-QRAT)) LTE (.001),GO TO 70 $
BURN087  IF(QRAT) LT (1.0),GO TO 60 $
BURN088  IF(DELTA) LTE (.01*A),GO TO 70 $
BURN089  A=A+DELTA $
BURN090  GO TO 50 $
BURN091  AMIN=A $
BURN092  PRINT 1600,A,QA,QREC,DIM $
BURN093  A=HB'DELTA=100000. $
BURN094  DELTA=DELTA/10. $
BURN095  A=A+DELTA $
BURN096  IF(A) GTE (100000.),A=100000. $
BURN097  IF(A-HB) E (0.0),GO TO 110 $
BURN098  DIM=FL*DFB/(A-HB) $
BURN099  IF(DIM) GT (FL),DIM=FL $
BURN100  QA=10.**((.044/(DIM+.02)+.19)*LOG10F((TB*1000.))**
BURN101  (-.079/(DIM+.12)+1.61))+.06/DIM -.77) $
BURN102  CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
BURN103  QREC=QF*T $
BURN104  GRAT=(FQA*QA)/(FQR*QREC) $
BURN105  IF(A) E (100000.),GO TO 110 $
BURN106  IF(ABSF(1.-QRAT)) LTE (.001),GO TO 110 $
BURN107  IF(QRAT) LT (1.0),GO TO 100 $
BURN108  IF(DELTA) LTE (.01*A),GO TO 110 $
BURN109  A=A-DELTA $
BURN110  GO TO 90 $
BURN111  AMAX=A $
BURN112  PRINT 1700,AMAX,QA,QREC,DIM $
BURN113  AMAXI=1000.*INTF(AMAX/1000.) $
BURN114  AMINI=1000.*INTF((AMIN+999.)/1000.) $
BURN115  IF(AMAXI-AMINI) GT (40000.),DELTA=5000.'GO TO 120 $
BURN116  IF(AMAXI-AMINI) GT (20000.),DELTA=2000.'GO TO 120 $
BURN117  IF(AMAXI-AMINI) GT (10000.),DELTA=1000.'GO TO 120 $
BURN118  IF(AMAXI-AMINI) GT ( 4000.),DELTA= 500.'GO TO 120 $
BURN119  IF(AMAXI-AMINI) GT ( 2000.),DELTA= 200.'GO TO 120 $
BURN120  DELTA=100. $
BURN121  AMINI=INTF(AMINI/DELTA)*DELTA $
BURN122  LAST=(AMAXI-AMINI)/DELTA+1.0 $
BURN123  PRINT 1800,DELTA $
BURN124  HR=0.0 $
BURN125  DO 160 IALT=1,LAST $
BURN126  A=AMINI+(IALT-1)*DELTA'DELTAHR=DELTA*10. $

```

HAVE WE CONVERGED  
ARE WE INSIDE  
ARE WE WITHIN 1 PCT

DETERMINE ALTITUDE OF TOP

CHECK MODEL LIMIT

CHECK MODEL LIMIT  
HAVE WE CONVERGED  
ARE WE INSIDE  
ARE WE WITHIN 1 PCT

SET UP A  
DELTA ALT  
FROM MIN TO  
MAX ALT

BOTTOM ALTITUDE TO NEAREST KFT  
NUMBER DELTA ALTS TO REACH TOP

DELTAHR=DELTA\*10. \$



BURN127	130	DELTAHR=DELTAHR/10. \$	
BURN128	140	HR=HR+DELTAHR \$	
BURN129		DIM=FL*DFB/SQRTF((A-HB)**2+HR**2) \$	
BURN130		IF(DIM) GT (FL),DIM=FL \$	
BURN131		QA=10.**((.044/(DIM+.02))+.19)*LOG10F((TB*1000.))**	
BURN132		(-.079/(DIM+.12)+1.61))+.06/DIM -.77) \$	
BURN133		CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) \$	
BURN134		QREC=QF*T \$	
BURN135		QRAT=(FQA*QA)/(FQR*QREC) \$	
BURN136		IF(ABSF(1.-QRAT)) LTE (.001),GO TO 150 \$	HAVE WE CONVERGED
BURN137		IF(QRAT) LT (1.0),GO TO 140 \$	ARE WE INSIDE
BURN138		IF(DELTAHR) LTE (.01*HR),GO TO 150 \$	ARE WE WITHIN 1 PCT
BURN139		HR=HR-DELTAHR \$	
BURN140		GO TO 130 \$	
BURN141	150	HRMILE=HR/6080. \$	
BURN142		PRINT 1900,A,HRMILE,HR,QA,QREC,DIM \$	
BURN143	160	CONTINUE \$	
BURN144		GO TO CARD \$	
BURN145	EXIT	STOP \$	
BURN146	TFB	F/.001\$	
BURN147	T	F/.1\$	
BURN148	T	F/.002\$	
BURN149	T	F/.135\$	
BURN150	T	F/.0045\$	
BURN151	T	F/.19\$	
BURN152	T	F/.01\$	
BURN153	T	F/.265\$	
BURN154	T	F/.02\$	
BURN155	T	F/.345\$	
BURN156	T	F/.05\$	
BURN157	T	F/.4675\$	
BURN158	T	F/.15\$	
BURN159	T	F/.65\$	
BURN160	T	F/1.0\$	
BURN161	T	F/1.0\$	
BURN162	T	F/2.0\$	
BURN163	T	F/1.09\$	
BURN164	T	F/4.0\$	
BURN165	T	F/1.165\$	
BURN166	T	F/8.0\$	
BURN167	T	F/1.2\$	
BURN168	TDAY	W/ DAY \$	
BURN169	TNIGHT	W/ NIGHT \$	
BURN170		END \$	
BURN171		ABS 2,EYE SAFE BURN,GO	

```

-----
JOB          C,0,37777
DUMP        A,1000,37777
DUMP        F,1000,37777
IBIT        44
ALTAC       MAGTAPE,LIB
EYE SAFE   FLASH
SUBROUTINE RWMASS(AMRM,A1RM,A2RM,SRM,DRM,AORM,GAMRM,
WORM,WXRM,WMRM)$
EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
(A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
(D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
(A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
(DD,DP(9)),(D1D,DP(11)),(RCD,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
(A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
COMMON BITS,SP,DP,A3,R1,R2,CM1,
D,D1,R0,R02,SG,
A3D,R1D,R2D,CM1D,
DD,D1D,R0D,R02D,SGD,
A33D,DDD,R11D,TD,
S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WMS
DIMENSION BITS( 35),SP(9),DP(26),
A3D(2),R1D(2),R2D(2),CM1D(2),
DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
A33D(2),DDD(2),R11D(2),TD(2)$
TABLEDEF ONED(2),TWOD(2)$
A1=A1RM,A2=A2RM,S=SRM,W0=WORM,WX=WXRMS
IG=3,L=2$
R1=RE+A1,R2=RE+A2,A3=A1-A2,ALF=S/RE$
CALL COSM1(CM1,ALF)$
CALL AMDP(SP ,A3D ,0,4,1,1,1)$
CALL AMDP(A3D ,A3D ,3,A33D)$
CALL AMDP(TWOD,R1D ,3,TD )$
CALL AMDP(TD ,R2D ,3,TD )$
CALL AMDP(TD ,CM1D,3,TD )$
CALL AMDP(A33D,TD ,2,DDD )$
CALL AMDP(DDD ,DD ,5 )$
CALL AMDP(R1D ,CM1D,3,TD )$
CALL AMDP(TD ,A3D ,1,TD )$
CALL AMDP(TD ,DD ,4,SGD )$
CALL AMDP(R2D ,R2D ,3,R11D)$
CALL AMDP(SGD ,SGD ,3,TD )$
RWM 001
RWM 002
RWM 003
RWM 004
RWM 005
RWM 006
RWM 007
RWM 008
RWM 009
RWM 010
RWM 011
RWM 012
RWM 013
RWM 014
RWM 015
RWM 016
RWM 017
RWM 018
RWM 019
RWM 020
RWM 021
RWM 022
RWM 023
RWM 024
RWM 025
RWM 026
RWM 027
RWM 028
RWM 029
RWM 030
RWM 031
RWM 032
RWM 033
RWM 034
RWM 035
ABS
I

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RWM 036		CALL AMDP(ONED,TD ,2,TD )\$
RWM 037		CALL AMDP(R11D,TD ,3,R02D)\$
RWM 038		CALL AMDP(R02D,ROD ,5 )\$
RWM 039		IF(A2)GTE(A1), GO TO A1M\$
RWM 040		CALL AMDP(R1D ,R1D ,3,R11D)\$
RWM 041	A1M	CALL AMDP(R11D,R02D,2,TD )\$
RWM 042		CALL AMDP(TD ,D1D ,5 )\$
RWM 043		CALL AMDP(DD ,SP ,9,5,1,5)\$
RWM 044		A0=R0-RE'D2=D1-D'D2A=ABSF(D2)'AM=0.'WM=0.0.\$
RWM 045		GAM=57.2957795*ASINF(SG)\$
RWM 046		IF(D2)GT(-.0001),GO TO A3M\$
RWM 047		IF(A0)GT(0.0 ), GO TO A2M\$
RWM 048		IG=-3.'AM=PINF.'WM=PINF.' GO TO X1M\$
RWM 049	A2M	AM=2.*AMSIMP(SUM,0.,D2A,AXRHO)\$
RWM 050		IF(W0)E(0.),GO TO A3M\$
RWM 051	A3M	WM=2.*AMSIMP(SUM,0.,D2A,AWRHO)\$
RWM 052		AM=AM+AMSIMP(SUM,D2A,D1,AXRHO)\$
RWM 053		IF(W0)E(0.),GO TO A5M\$
RWM 054		WM=WM+AMSIMP(SUM,D2A,D1,AWRHO)\$
RWM 055		WM=1E5*WMS
RWM 056	A5M	AM =.997391859E5*AMS
RWM 057		AMRM=AM'DRM=D'AORM=A0.'GAMRM=GAM.'WMRM=WMS
RWM 058	X1M	RETURNS
RWM 059		STARTTACS
RWM 060	CONED	O/2\$
RWM 061		D/1\$
RWM 062	CTWOD	O/2\$
RWM 063		D/2\$
RWM 064	CRE	F/6371.221\$
RWM 065	CPINF	35/1135.11/1147\$
RWM 066	AXRHO	C/HLT,1'C/HLT,XRHO.XRHOS
RWM 067	AWRHO	C/HLT,1'C/HLT,WRHO.WRHOS
RWM 068	C	SYBOUT A0'A1'A2'A3'S'D1'D2'RE'R02'ALF'GAM'AM'L'IG'WO'WX'WMS
RWM 069		REFOUT XRHO.XRHO'WRHO.WRHOS
RWM 070		ENDTAC S
RWM 071		ENDS

```

XRH 001 SUBROUTINE XRHO(X) $
XRH 002 EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
XRH 003 (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
XRH 004 (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
XRH 005 (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
XRH 006 (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
XRH 007 (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
XRH 008 COMMON BITS,SP,DP,A3,R1,R2,CM1,
XRH 009 D,D1,R0,R02,SG,
XRH 010 A3D,R1D,R2D,CM1D,
XRH 011 DD,D1D,R0D,R02D,SGD,
XRH 012 A33D,DDD,R11D,TD,
XRH 013 S,A0,A1,A2,D2,ALF,GAM,AM,L,IG$
XRH 014 DIMENSION BITS( 35),SP(9),DP(26),
XRH 015 A3D(2),R1D(2),R2D(2),CM1D(2),
XRH 016 DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
XRH 017 A33D(2),DDD(2),R11D(2),TD(2)$
XRH 018 TABLEDEF HL(22)$
XRH 019 H=SQRTF(R02+X*X)-RES
XRH 020 IF(H)GTE(0.),GO TO AORHOS
XRH 021 IF(H)LTE(-.0005),GO TO X2RHOS
XRH 022 H=0.$
XRH 023 L=L-1,K=0$
XRH 024 AORHO IF(H-HL(L))A2RHO,A5RHO,A4RHO $
XRH 025 A1RHO IF(K)X2RHO,A3RHO,A5RHC $
XRH 026 A2RHO L=L-1, IF(L)X2RHO,X2RHO,A1RHOS
XRH 027 A3RHO L=L+1,K=1,GO TO A1RHO $
XRH 028 A4RHO GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
XRH 029 22,23),L $
XRH 030 L=25
XRH 031 X=1.225 E-3*(1.-2.2518827E-2* H )** 4.2559, GO TO X1RHO $
XRH 032 X=3.6392E-4/EXPF(.15692 *(H-11.019)) , GO TO X1RHO $
XRH 033 X=8.8035E-5/(1.+4.577983 E-3*(H-20.063))**35.167 , GO TO X1RHO $
XRH 034 X=1.3225E-5/(1.+1.2098404E-2*(H-32.162))**13.201 , GO TO X1RHO $
XRH 035 X=1.4275E-6/EXPF(.12426 *(H-47.35 )) , GO TO X1RHO $
XRH 036 X=7.5943E-7*(1.-7.258821 E-3*(H-52.429))**16.081 , GO TO X1RHO $
XRH 037 X=2.5109E-7*(1.-1.5485454E-2*(H-61.591))** 7.5408, GO TO X1RHO $
XRH 038 X=2.001 E-8/EXPF(.18414 *(H-79.994)) , GO TO X1RHO $
XRH 039 X=3.170 E-9/(1.+1.6606698E-2*(H-90. ))**12.012 , GO TO X1RHO $
XRH 040 X=4.974E-10/(1.+2.3736055E-2*(H-100. ))** 7.612 , GO TO X1RHO $
XRH 041 X=9.829E-11/(1.+3.8365624E-2*(H-110. ))** 4.2955, GO TO X1RHC $
XRH 042 X=2.436E-11/(1.+5.5455428E-2*(H-120. ))** 2.6389, GO TO X1RHO $
XRH 043 X=1.836E-12/(1.+1.5614428E-2*(H-150. ))** 3.1713, GO TO X1RHO $

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WRH 001 SUBROUTINE WRHO(X) $
WRH 002 EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
WRH 003 (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
WRH 004 (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
WRH 005 (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
WRH 006 (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
WRH 007 (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
WRH 008 COMMON BITS,SP,DP,A3,R1,R2,CM1,
WRH 009 D,D1,R0,R02,SG,
WRH 010 A3D,R1D,R2D,CM1D,
WRH 011 DD,D1D,R0D,R02D,SGD,
WRH 012 A33D,DDD,R11D,TD,
WRH 013 S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WMS
WRH 014 DIMENSION BITS( 35),SP(9),DP(26),
WRH 015 A3D(2),R1D(2),R2D(2),CM1D(2),
WRH 016 DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
WRH 017 A33D(2),DDD(2),R11D(2),TD(2)$
WRH 018 H=SQRTF(R02+X*X)-RES
WRH 019 IF(H)GTE(0.),GO TO ADWRHOS
WRH 020 IF(H)LTE(-.0005),GO TO X2WRHOS
WRH 021 H=0.$
WRH 022 A0WRHO X=W0/EXPF( WX*H)$
WRH 023 X1WRHO RETURN $
WRH 024 TX2WRHO JMP 1SUBERR$
WRH 025 T REFOUT COMMON.RES
WRH 026 ENDS

```

COS	STARTTAC	NAME	SYMBOL	SYMBOL
COS 001	\$			
COS 002	COSM1\$			
COS 003	COSM1.COSM1\$			
COS 004	XS	TJM		LCOSM1
COS 005	AS	TQM		
COS 006	A2\$	TDM		
COS 007	A2\$	FMMRS		
COS 008	F/1\$	TMD		
COS 009	P\$	TDM		
COS 010	F/0\$	TMD		
COS 011	C\$	TDM		
COS 012	F/2\$	TMD		
COS 013	D\$	TDM		
COS 014	E\$	TDM		
COS 015	F\$	TDM		
COS 016	1/1T19\$	TMD		
COS 017	JS	DORMS		
COS 018	IS	JMP		
COS 019	F/1\$	TMA		H
COS 020	E\$	FAMS		
COS 021	\$	TDQ		
COS 022	F\$	FMMRS		
COS 023	F/1\$	TMA		
COS 024	E\$	FAMS		
COS 025	\$	TDQ		
COS 026	F\$	FMMRS		
COS 027	A2\$	TMQ		I
COS 028	P\$	FMMRS		
COS 029	F\$	FDA		
COS 030	B\$	TQM		
COS 031	\$	NOP		
COS 032	B\$	FCSM		LJ
COS 033	C\$	FAMS		
COS 034	D\$	TMD		
COS 035	K\$	JAED		
COS 036	D\$	TAM		
COS 037	1/1T19\$	TMA		
COS 038	JS	AWCS		
COS 039	H\$	JMP		
COS 040	F/0\$	TMA		K
COS 041	C\$	TMQ		
COS 042	X-1\$	JAGQF		





AIR 001	SUBROUTINE AIR(H,P,T,DA) \$
AIR 002	HKM=H*3.048E-4 \$
AIR 003	IF(HKM) GT (25.) GO TO 20 \$
AIR 004	IF(HKM) GT (11.) GO TO 10 \$
AIR 005	T=288.16-6.5*HKM \$
AIR 006	P=1033.2*(T/288.16)**5.2561 \$
AIR 007	DA=1.225E-3*(T/288.16)**4.2561 \$
AIR 008	GO TO 30 \$
AIR 009	T=216.66 \$
AIR 010	C=EXP(0.15769*(11.-HKM)) \$
AIR 011	P=C*231.47 \$
AIR 012	DA=C*3.648E-4 \$
AIR 013	GO TO 30 \$
AIR 014	T=216.66+3.*(HKM-25.) \$
AIR 015	P=25.772*(216.66/T)**11.3882 \$
AIR 016	DA=4.0639E-5*(216.66/T)**12.3882 \$
AIR 017	T=T/288.16 \$
AIR 018	P=P/1033.2 \$
AIR 019	DA=DA/1.225E-3 \$
AIR 020	RETURN \$
AIR 021	END \$

TRN 001	SUBROUTINE TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) \$
TRN 002	HBKM=HB#3.048E-4 \$
TRN 003	AKM=A#3.048E-4 \$
TRN 004	HRKM=HR#3.048E-4 \$
TRN 005	IF(HRKM) E (0.0),HRKM=3.048E-4 \$
TRN 006	CALL RWMASS(AM,HBKM,AKM,HRKM,SR,AO,GAM,DWO,WL,WM) \$
TRN 007	IF(AO)LTE(0.0),GO TO 20 \$
TRN 008	T=EXPF(-AK*AM-WK*WM) \$
TRN 009	RETURN \$
TRN 010	END \$

10  
20

CHECK EARTH INTERSECTION

```

FLS 001 1000 FORMAT(8F10.0) $
FLS 002 1100 FORMAT(3A8,7X,I1,11X,F6.0,9X,F5.0) $
FLS 003 1200 FORMAT(2F8.0,2E8.0,4F5.0,2F9.0,2F5.0) $
FLS 004 1300 FORMAT(1H1) $
FLS 005 1400 FORMAT(//////42X,37HNO FLASHBLINDNESS ENVELOPE EXISTS FOR/
FLS 006 42X,16HTHIS SITUATION -//
FLS 007 42X,16HYIELD = ,1PE11.4/
FLS 008 42X,16HBURST HEIGHT = ,E11.4/
FLS 009 42X,16HPERCENT YIELD = ,E11.4/
FLS 010 42X,16HBLINK TIME = ,E11.4,7H DURING,A7,7HMISSION/
FLS 011 42X,16HEA FACTOR = ,E11.4/
FLS 012 42X,16HER FACTOR = ,E11.4) $
FLS 013 1500 FORMAT(/40X,7HW = 1PE11.4,4X,7HAK = E11.4,5X,5HFLASH,
FLS 014 /40X,7HHB = ,E11.4,4X,7HWK = ,E11.4,5X,9HBLINDNESS,
FLS 015 /40X,7HDFB = ,E11.4,4X,7HDWO = ,E11.4,5X,8HENVELOPE,
FLS 016 /40X,7HTB = ,E11.4,4X,7HWL = ,E11.4,
FLS 017 /40X,7HTS = ,E11.4,4X,7HTX = ,E11.4,
FLS 018 /40X,7HTSF = ,E11.4,4X,7HTE = ,E11.4,
FLS 019 /40X,7HF = ,E11.4,4X,7HFEA = ,E11.4,
FLS 020 /62X,
FLS 021 1600 FORMAT(/35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET
FLS 022 /61X,9HEALLOW = E11.4
FLS 023 /61X,9HETOT = E11.4
FLS 024 /61X,7HDIM1 = E11.4) $
FLS 025 1601 FORMAT(/35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET
FLS 026 /61X,9HEALLOW = E11.4
FLS 027 /61X,9HRET = E11.4
FLS 028 /61X,7HDIM1 = E11.4) $
FLS 029 1700 FORMAT(/35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET
FLS 030 /61X,9HEALLOW = E11.4
FLS 031 /61X,9HETOT = E11.4
FLS 032 /61X,7HDIM2 = E11.4) $
FLS 033 1701 FORMAT(/35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET
FLS 034 /61X,9HEALLOW = E11.4
FLS 035 /61X,9HRET = E11.4
FLS 036 /61X,7HDIM2 = E11.4) $
FLS 037 1800 FORMAT(/35X,21HLET DELTA ALTITUDE = 1PE11.4,5H FEET////19X,
FLS 038 82HALTITUDE H RANGE H RANGE E ALLOWABLE E RECEIVE
FLS 039 D IMAGE DIAM TRANS/21X,4HFEET,7X,6HN MILE,9X,3H FT,37X,2HMM)$
FLS 040 FORMAT(18X,1PE11.4,2X,6(E11.4,2X)) $
FLS 041 TABLEDEF FB(2,11),SYMB1(10),SYMB2(10),ORD(2),AB(4),LINE1(2) $
FLS 042 READ 1000,AK,WK,DWO,WL, TX,TE $

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FLS 043 T      TMD      F/1.E-2$
FLS 044 T      TDM      AMSIMP.AMSIMP+3$
FLS 045 CARD   READ 1200,W,HB,EALLOW,PRIMEK,ALPHA,TB,F,ABAR,P,PERY,FFA,FER $
FLS 046        TS=0.0 $
FLS 047        IF(W) E (0.0),GO TO EXIT $
FLS 048        CALL AMRUPT$
FLS 049 T      JMP      M/4$
FLS 050        PRINT 1300 $
FLS 051        CALL AIR(HB,PHB,PHB,THB,DHB) $
FLS 052        WSCL=0.032*(DHB*W)**0.5 $
FLS 053        IF(TB) E (0.0),TB=(TS-0.0025)*WSCL,GO TO 10 $
FLS 054        IF(TS) E (0.0),TS=0.0025+TB/WSCL,GO TO 10 $
FLS 055        IF(TB) GT ((TS-.0025)*WSCL),TB=(TS-.0025)*WSCL,GO TO 10 $
FLS 056        TS=.0025+TB/WSCL $
FLS 057 10     TSF=.032*TS $
FLS 058        IF(TS) GTE (FB(1,1)),DF=FB(2,11),GO TO 40 $
FLS 059        IF(TS) LT (FB(1,1)),I=2,GO TO 30 $
FLS 060        DO 20 I=2,11 $
FLS 061        IF(TS) LT (FB(1,I)),GO TO 30 $
FLS 062        CONTINUE $
FLS 063 30     DF=FB(2,I-1)+LOGF(TS/FB(1,I-1))*(FB(2,I)-FB(2,I-1))/
FLS 064        LOGF(FB(1,I)/FB(1,I-1)) $
FLS 065 40     DFB=360.0*DF $
FLS 066        DFB=DFB**0.4*(1./DHB)**0.333 $
FLS 067        DFBM=30.48*DFB $
FLS 068        PRINT 1500,W,AK,HB,WK,DFB,DWO,TB,WL,TS,TX,TSF,TE,F,FEA,FER $
FLS 069        EALLOW=EALLOW*FEA $
FLS 070        QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*DFBM*DFBM) $
FLS 071        QRET=1.23E9*QREC/TE*FER $
FLS 072        IF(QRET) GTE (EALLOW),GO TO 710 $
FLS 073        PRINT 1400,W,HB,PERY,TB,FEA,FER $
FLS 074        GO TO CARD $
FLS 075 710    CRITD=4920.*W**0.3333 $
FLS 076        EMAX=4.5E-7*PRIMEK*W**0.63 $
FLS 077        IF(F)GT(3.0),TERM=FER*EMAX*(110./ALPHA**2+40./ALPHA+2.) $
FLS 078        IF(F)LT(3.0),TERM=FER*EMAX*(675./ALPHA**2+240./ALPHA+13.) $
FLS 079        TE=TERM*TE*TX $
FLS 080        DS=(17.*DFB)/1.0 $
FLS 081        A=HB-DS $
FLS 082        IF(A)LTE(0.0),A=1.0 $
FLS 083        HR=0.0 $
FLS 084 720    CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $

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085 QRET=QRET*T $
086 IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 740 $
087 IF(QRET)LT(EALLOW),A=A+300.,GO TO 720 $
088 ETOT=TERM*(CRITD**2/DS**2)*T $
089 IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 700 $
090 IF(ETOT)LT(EALLOW),GO TO 700 $
091 DS=DS+300. $
092 A=HB-DS $
093 IF(A)LT(0.0),A=1.0,GO TO 700 $
094 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
095 GO TO 730 $
096 AMIN=A $
097 IF(HB-A)E(0.0),DIM=17.0,GO TO 701 $
098 DIM=17.*DFB/(HB-A) $
099 PRINT 1600,AMIN,EALLOW,ETOT,DIM $
100 GO TO 750 $
101 AMIN=A $
102 IF(HB-A)E(0.0),DIM=17.0,GO TO 702 $
103 DIM=17.*DFB/(HB-A) $
104 PRINT 1601,AMIN,EALLOW,QRET,DIM $
105 GO TO 750 $
106 DS=(17.*DFB)/1.0 $
107 A=HB+DS $
108 IF(A)GTE(100000.),A=100000. $
109 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
110 QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
111 QRET=1.23E9*QREC/TE*FER*T $
112 IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 790 $
113 IF(QRET)LT(EALLOW),DS=DS-300.,A=HB+DS,GO TO 770 $
114 ETOT=TERM*(CRITD**2/DS**2)*T $
115 IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 780 $
116 IF(ETOT)LT(EALLOW),GO TO 780 $
117 DS=DS+300. $
118 A=HB+DS $
119 IF(A)GT(100000.),A=100000.,GO TO 780 $
120 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
121 GO TO 760 $
122 AMAX=A $
123 IF(HB-A)E(0.0),DIM=17.0,GO TO 781 $
124 DIM=17.*DFB/(A-HB) $
125 PRINT 1700,AMAX,EALLOW,ETOT,DIM $
126 GO TO 800 $
730
700
701
740
702
750
770
760
780
781

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790 FLS 127 AMAX=A $
FLS 128 IF(HB-A)E(0.0),DIM=17.0*GO TO 782. $
FLS 129 DIM=17.*DFB/(A-HB) $
782 FLS 130 PRINT 1701,AMAX,EALLOW,QRET,DIM $
FLS 131 GO TO 800 $
800 FLS 132 AMAXI=1000.*INTF(AMAX/1000.) $
FLS 133 AMINI=1000.*INTF((AMIN+999.)/1000.) $
FLS 134 IF(AMAXI-AMINI) GT (40000.),DELTA=5000. GO TO 120 $ SET UP A
FLS 135 IF(AMAXI-AMINI) GT (20000.),DELTA=2000. GO TO 120 $ DELTA ALT
FLS 136 IF(AMAXI-AMINI) GT (10000.),DELTA=1000. GO TO 120 $ FROM MIN TO
FLS 137 IF(AMAXI-AMINI) GT ( 4000.),DELTA= 500. GO TO 120 $ MAX ALT
FLS 138 IF(AMAXI-AMINI) GT ( 2000.),DELTA= 200. GO TO 120 $
FLS 139 DELTA=100. $
120 FLS 140 AMINI=INTF(AMINI/DELTA)*DELTA $ BOTTOM ALTITUDE TO NEAREST KFT
FLS 141 LAST=(AMAXI-AMINI)/DELTA+1.0 $ NUMBER DELTA ALTS TO REACH TOP
FLS 142 PRINT 1800,DELTA $
FLS 143 DS=(17.*DFB)/1.0 $
FLS 144 DO 860 IALT=1, LAST $
FLS 145 DELD=1000. $
FLS 146 IF(W)LTE(10.),DELD=250. $
810 FLS 147 A=AMINI+(IALT-1)*DELTA $
FLS 148 ABHR=ABSF(DS**2-(HB-A)**2) $
FLS 149 HR=SQRTF(ABHR) $
FLS 150 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
FLS 151 IF(IG)E(-3),QRET=0.0*GO TO 840 $ CHECK EARTH INTERSECTION
FLS 152 QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
FLS 153 QRET=1.23E9*QREC/TE*FER*T $
FLS 154 IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 840 $
FLS 155 IF(QRET)LT(EALLOW),GO TO 850 $
880 FLS 156 ETOT=TERM*(CRITD**2/DS**2)*T $
FLS 157 IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 870 $
FLS 158 IF(ETOT)LT(EALLOW),GO TO 870 $
FLS 159 DS=DS+DELD $
FLS 160 ABHR=ABSF(DS**2-(HB-A)**2) $
FLS 161 HR=SQRTF(ABHR) $
FLS 162 CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
FLS 163 IF(IG)E(-3),ETOT=0.0*GO TO 870 $ CHECK EARTH INTERSECTION
FLS 164 GO TO 880 $
870 FLS 165 DIM=17.*DFB/SQRTF(HR**2+(HB-A)**2) $
FLS 166 HRMILE=HR/6080. $
FLS 167 PRINT 1900,A,HRMILE,HR,EALLOW,ETOT,DIM,T $
FLS 168 GO TO 860 $

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FLS 169 DIM=17.*DFB/SQRTF(HR**2+(HB-A)**2) $
FLS 170 HRMILE=HR/6080. $
FLS 171 PRINT 1900,A,HRMILE,HR,EALLOW,QRET,DIM $
FLS 172 GO TO 860 $
FLS 173 DS=DS-DELD $
FLS 174 GO TO 810 $
FLS 175 CONTINUE $
FLS 176 GO TO CARD $
FLS 177 CALL RSYS $
FLS 178 JMP IOHTAB.RUNALLS
FLS 179 JMP M/4$
FLS 180 TFB F/.001$
FLS 181 T F/.1$
FLS 182 T F/.002$
FLS 183 T F/.135$
FLS 184 T F/.0045$
FLS 185 T F/.19$
FLS 186 T F/.01$
FLS 187 T F/.265$
FLS 188 T F/.02$
FLS 189 T F/.345$
FLS 190 T F/.05$
FLS 191 T F/.4675$
FLS 192 T F/.15$
FLS 193 T F/.65$
FLS 194 T F/1.0$
FLS 195 T F/1.0$
FLS 196 T F/2.0$
FLS 197 T F/1.09$
FLS 198 T F/4.0$
FLS 199 T F/1.165$
FLS 200 T F/8.0$
FLS 201 F/1.2$
FLS 202 END $
FLS 203 ABS 2.EYE SAFE FLASH.GO

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UNCLASSIFIED  
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author) Technology Incorporated Life Sciences Division 8531 N. New Braunfels Ave. San Antonio, Texas 78217	2a. REPORT SECURITY CLASSIFICATION <b>Unclassified</b>
	2b. GROUP

3 REPORT TITLE  
**NUCLEAR FLASH EYE EFFECTS TECHNICAL REPORT FOR MILITARY PLANNERS**

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)  
**Final Report**

5 AUTHOR(S) (Last name, first name, initial)  
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6. REPORT DATE <b>February 1967</b>	7a. TOTAL NO. OF PAGES <b>223</b>	7b. NO. OF REFS <b>Thirteen</b>
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8a. CONTRACT OR GRANT NO. <b>AF 41(609)-2900</b> b. PROJECT NO. <b>Task No. 630103</b> c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) <b>None</b>
	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES  
**Distribution of this Document is Unlimited**

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY <b>USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas</b>
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13. ABSTRACT  
**This report is intended to be used as an aid to military mission planners in determining allowable proximity to a nuclear fireball from the standpoints of permanent retinal injury and the temporary effects of flashblindness. Pertinent physical and physiological phenomena are discussed in moderate detail; the nucleus of the work being a family of curves which indicate acceptable separation distances for the prevention of retinal burns and flashblindness. Detailed instructions for approximating acceptable separation distances using a slide rule are included as an appendix.**