Description of document: US Army Edgewood Arsenal report: Unconventional Weapons for the 1970 Battlefield, July 1964

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Source of document: Department of The Army
US Army Research, Development and Engineering Command
Attn: Freedom of Information Act Office
5183 Blackhawk Road
Aberdeen Proving Ground MD 21010-5424

DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND
3071 ABERDEEN BOULEVARD
ABERDEEN PROVING GROUND, MARYLAND 21005-5201

REPLY TO
ATTENTION OF

July 9, 2012

Office of the Chief Counsel

This is the final response to your FOIA request dated January 25, 2005 and received by this office on March 6, 2012, from the Department of Defense Office of Freedom of Information. We assigned your request **RDECOM FOIA Tracking # FA-12-0087**. You requested a copy DTIC Report AD B211633, *Unconventional Weapons for the 1970 Battlefield.*

We determined the records contain information exempt from disclosure pursuant to Title 5 U.S.C. § 552(b)(6) ("Exemption 6"). Exemption 6 and Department of Defense policy protect Army personnel from an unwarranted invasion of personal privacy. We removed the names, phone numbers, and email addresses of personnel who are not general officers, are not division chiefs, who do not normally work with the general public, or who are not federal employees. All redactions made to the enclosed documents were made pursuant to FOIA Exemption 6.

If you find this response to be an adverse action, you may appeal to the Secretary of the Army. General Ann E. Dunwoody, Commanding General, U.S. Army Materiel Command, is the Initial Denial Authority and by position, I have been delegated as an Initial Denial Authority. You should send your appeal to this office, and in turn, we will forward it to the Army General Counsel, the designated Army Freedom of Information Act appellate authority. To meet the deadline for appeal, the appeal letter must be received by this office and forwarded to the Secretary of the Army **within sixty (60) days** of the date of this letter. Please send correspondence to the following address:

Brian A. May
RDECOM, ATTN AMSRD-CCF
4305 Susquehanna Avenue
Room 336
Aberdeen Proving Ground, MD 21010-5001

FOIA processing fees were not assessed. Should you have any questions or concerns regarding the processing of your request, please contact Mr. Brian May at (410) 436-2289 or brian.a.may3.civ@mail.mil.

Sincerely,

DAVID C. DEFRIEZE
Initial Denial Authority, HQ RDECOM

Enclosures

PA 13,261

UNCONVENTIONAL WEAPONS FOR THE
1970 BATTLEFIELD

ARPA Cont. No. 11194

LIMITED TO DOD RESEARCH ONLY

MELPAR INC

A SUBSIDIARY OF WESTINGHOUSE AIR BRAKE COMPANY

3000 ARLINGTON BOULEVARD FALLS CHURCH, VIRGINIA pa 13, 261

CHECKED BY RACIC

[illegible]

UNCONVENTIONAL WEAPONS FOR THE
1970 BATTLEFIELD

ARPA Conf. No. 11194

Melpar, Inc.
3000 Arlington Boulevard
Falls Church, Virginia

July 1964

"This document contains sheets of proprietary data which have been marked with the legend of Armed Forces Procurement Regulations, Paragraph 3-109.

appendices F & G separately for file.

(P443-014 30)

'64

United States Army
EDGEWOOD ARSENAL
Edgewood Arsenal, Maryland 21010

IN REPLY REFER TO:
SMUEA-CM-W11

- 4 DEC 1964

SUBJECT: Melpar, Inc. Report - Unconventional Weapons for the 1970 Battlefield

TO: Director
Advanced Research Projects Agency
Office of the Secretary of Defense
ATTN: Project AGILE (Mr. Edwards)
Washington, D. C.

1. A copy of this report is included as Inclosure 1. It is being sent in response to your telephone request to [redacted] of this Division on 2 December 1964. The report need not be returned.

2. This report resulted from a joint effort by Melpar, Inc. and USA Chemical Research and Development Laboratories, a subordinate element of USA Edgewood Arsenal. We request your consideration of our capabilities if Advanced Research Projects Agency elects to fund for further work in the areas contained in this report.

FOR THE COMMANDER:

[redacted]

1 Incl
as

Directorate of Commodity Management

OSD JUN 29 1966

ARPA Cont. No. 11194

RAC64-2560

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UNCONVENTIONAL BATTLEFIELD WEAPONS

1. INTRODUCTION

Melpar, Inc. has included in the following a summary of its background and capabilities in the area of new and unconventional weapons for the 1970 battlefield. The company has directed a significant portion of its research and development during the last two years in theoretical and experimental investigations related to weapon concepts for design criteria leading to future operational battlefield conditions. The purpose of the various studies has been to bring the advanced state of the art technique to practical utilization for future ground forces weapons. Specific areas of investigations and the scope of recommended future programs are contained in this report.

The breadth of research of Melpar's technical staff which is associated with unconventional battlefield weapons is illustrated in Table 1. The major investigations have included optical, acoustic, biological, plasma, and laser personnel and facilities. Some general informative discussion is given in the immediate following pages to assist in defining the purpose and general results of various facets of the program. In the Appendices more technical reports and data are offered to indicate the depth of some of the individual studies. Within the bounds of known physical principles, several promising weapon concepts worthy of continued research and development study are delineated. They range from the well defined scotomatic glare weapon to the futuristic kugelblitz weapon; in sophistication they can include the subtle alpha rhythm incapacitating weapon and the powerful lethal laser weapon. Such a vista of potentialities indicates a likelihood of significant supplements to the Army's weapons arsenal by 1970.

TABLE I

Melpar R&D Studies Related to Battlefield Weapons

OPTICS	ACOUSTICS	BIOLOGICAL	PLASMA	LASERS
Scotomatic Glare	Ultrasonics	Biological Effects or RF Radiation	Electro Magnetic and Hydromagnetic Interactions	Giant Pulse
High Intensity Light Source	Sonics	Particle Radiation		
Flash Blindness Protection	Psycho-Acoustics			
Modulated Pulsed Light				
Eidetic Visual Memory				

2. MELPAR'S R&D STUDIES RELATED TO BATTLEFIELD WEAPONS

2.1 Optics

2.1.1 Scotomatic Glare

Recent theoretical work has been performed on scotomatic glare under an RAC contract. The study was concerned with dazzling by means of lasers and high intensity light sources. The main substance of the report is provided in Appendix A.

Scotoma, the inability to see the real environment, occurs if the human eye is subjected to intense light energy above the level of approximately 1 lumen-second/ft^2. A disturbing set of positive and negative images is seen after the initial blindness passes. At illuminance-time products of 10 lumen-seconds/ft^2 the visual recovery time is in the range of 7 to 12 seconds.

A large number of graphs on scotomatic glare for both laser and high intensity light sources are presented in Appendix A. The parameters of range and beam divergence are defined for various sources to produce a given illuminance time product and recover time.

The FX-56 xenon flash lamp was found to be among the best of the sources, for it could expose 5200 ft^2 of area with a solid angle of 0.005 steradians at a range of 1000 ft and a recovery time of at least 10 seconds. The FX-56 can be pulsed much faster than 0.1 pps, which would make all human vision blacked in the 5200 ft^2 area at 1000 ft range because the eye requires about 0.1 seconds to blink.

Although lasers are much less efficient than the FX-56, they provide excellent luminescence geometry. For example, a 100 joule output laser will dazzle 1040 ft^2 at a range of 1000 ft with a beam divergence of 0.001 steradians for ideal atmospheric conditions. Eventual improvements in optical pumping will encourage the increased use of lasers for possible weapons applications. A sufficiently large laser array can produce a long visual recovery time at ranges of miles under good atmospheric conditions.

Other devices, such as flash bulbs, mercury arcs, and carbon arcs are also capable of being used as dazzling sources. They are not as efficient as xenon flash lamps, nor do they possess the desirable luminance geometry of lasers.

2.1.2 High Intensity Battlefield Light Sources

2.1.2.1 Microwave Enhanced Sources

A two year program on bright light sources has led to new approaches to high intensity light sources. The program is concerned with the development of microwave pumped high intensity plasma sources with the emission concentrated in a relatively narrow band. The basic principle is microwave enhancement by several orders of magnitude of radiation from the lowest excited state of an atom or the lowest excited electronic state of a molecule.

Where electromagnetic waves are incident upon a conducting medium it is possible to choose the angle of incidence and the orientation of the electric vector with respect to the boundary of the medium so that at least ninety percent is reflected. Thus a high degree of coupling is possible between a plasma and a microwave field.

Experimental and theoretical studies carried out to date indicate that the observed high light output levels combined with very high efficiencies are due at least in part to stimulated emission and that the method can be used to develop microwave pumped vapor lasers with average outputs of the order of 1 kilowatt. Depending on the material used, more than eighty percent of the radiation energy emitted can be concentrated in a band ranging between 40 and 400 Å in width at specified spectral locations. This is to be contrasted with the case of xenon or mercury high intensity lamps where the radiant energy emitted is spread over the entire spectrum extending from the infrared to the ultraviolet. Thus the microwave pumped sources are capable of furnishing the highest output to input ratio per angstrom.

Table II provides an interesting comparison of high intensity xenon arc lamps of power levels similar to the Melpar enhanced source. Since no lamps are available with the same power input as the sodium flame, data are listed for lamps of both higher and lower power.

Because pumping is affected by microwaves, the source can provide CW or pulsed output. Pulse rates of 10 kilocycles or higher can be achieved.

2.1.2.2 Xenon Arc Searchlights

Melpar has participated in a contract for the qualifications of all components for a 12 KW short arc xenon tank searchlight. The searchlight was designed to provide battlefield or general illumination using

TABLE II

Comparison of Melpar Enhanced Light Source With

Two Xenon Arc Lamps

	Melpar Sodium Source	Xenon Arc Lamp	Xenon Arc Lamp
Power Consumption (watts)	4,200	2,200	5,000
Luminous Flux (lumens)	600,000	66,000	200,000
Intensity (candles)	50,000	5,300	21,500
Efficiency (lumens/watt)	140	30	40

either visible or infrared light. The visible light intensity is 75 million candlepower, the infrared 15 million candlepower.

The testing program includes optical, mechanical and electronic evaluation. The optical components must meet rigid specifications to provide the high intensity and accurate beaming of the light. Melpar's facility is capable of measuring the brightness, total lumen output and infrared content of the xenon lamp and possesses a 70 inch diameter aluminum integrating sphere designed for this and higher powered xenon lamps to measure the lumen output. In order to measure the degree of distortion (circle of confusion) and the peak beam candlepower of the reflector Melpar has built a zero-range photometric bench which utilizes a collimating mirror 40" in diameter with a 160" focal length and a modified 60" searchlight base as the holding fixture. This system magnifies the image due to the reflector thus enabling a more critical analysis.

The third optical component requiring critical analyses is the infrared filter. Melpar has designed a unique system with which the transmission of a filter may be determined to a density of seven in the wavelength region of 4000 Å to 12000 Å at any temperature between ambient and 900° F.

2.1.3 Flash Blindness Protection

The aim of this program has been the development of materials that will offer protection against flash blindness. Generally, two types of ophthalmic damage may be considered as a guide to the frequency ranges of light that are to be avoided. The retina may be permanently damaged thermally by intense high-energy light. Light of longer wavelengths may produce a temporary "flash blindness" if the illumination level changes rapidly. Thus, it is necessary to attenuate the visible light as well as the ultraviolet for satisfactory protection.

The search for a system that will respond to a flash by becoming opaque (i.e., acting as a light valve) may be carried out systematically by designing a system on the basis of known photochemical reactions. A first consideration is that of the energies involved in the various chemical reactions and the energy made available to the system by light. With very few exceptions (e.g., photochemical decomposition of chloroform) photochemical changes take place only as the result of energy absorbed by the chemical system. Since any photochemical change involves the breaking of some bond, an estimate may be made of the probability that light of a given wavelength will provide enough energy to break a bond. The usual bond energies are between 50 and 100 Cal/mole.

Calculations show that not much chemical change can be expected from light of wavelength longer than 600 mu. The kinetics of a photochemical reaction are favorable since the life of the excited state is usually about 10^{-8} seconds. However, the mere production of an excited state is not synonymous with chemical change; the molecule may return to its ground state by re-radiation (e.g., fluorescence and resonance radiation) or by intermolecular collision resulting in heat.

The yield of chemical change that can be expected is also a function of the quantum efficiency, and this is another factor in slowing up the reaction. Thus a systematic survey of various photochemical reactions that can lend themselves to the problem must take into consideration, energy, quantum yield, kinetics, absorption characteristics before and after reaction, and reversibility.

Melpar has incorporated the leuco form of methylene blue chloride into agar gels (containing 2-mercaptoethanol) to produce colorless gels capable of remaining in the colorless condition when under normal laboratory lighting conditions and changing to a blue form under brief exposure to a home movie light. The dye sensitized photooxidation is reversible and upon standing under normal illumination, the blue form reverts to the leuco form. Dye gels saturated with N_2 did not undergo conversion to the blue form. It was also noted that the presence of sodium nitrate in the system improved performance. It is tentatively concluded that oxygen is required for the reaction and the sodium nitrate meets this requirement.

Other research carried out in our laboratories has been concerned with the change in spectral properties of fluorescein and naphthol yellow-S resulting from exposure to an intense flash of light. These systems show some promise for the application being considered here.

This work suggests, as a promising approach, the study of the photooxidation of leuco Thiazine dyes in rigid media in the presence of labile peroxides. The yield of the colored form under these conditions (after brief exposure to intense light) may be considerably greater than that for oxygen saturated gels and glasses.

2.1.4 Modulated Pulsed Light

The research studies in modulated pulsed light have been concerned principally with the recognized debilitating effects upon the motor and mental alertness of humans subjected to pulsed light at varying pulse rates, intensity, and spectral energy. Included in the work is the subject matter that falls in the categories of flicker and alpha rhythm.

The energy levels of light in this program were limited to illuminance-time products in the range of 1 to 0.1 lumen-second/ft^2, which is about one order of magnitude of illuminance energy less than that needed for schomatic glare. At these levels strong excitation of the visual sensors occurs with accompanying physiological disturbances. Table III is a summary of the phenomena that arises. The results recorded under under visual disturbance and corollary effects are subjectively catalogued and do not imply a pattern produced by all subjects; rather they are statistical averages that can expect to occur in a significant percentages of cases.

A flicker study at Ream Field Naval Air Station has been reported by L. C. Johnson in 1963. A total of 102 subjects were selected from pillots at the Air Station, which made them a highly selected group with regard to both medical and technical screening and background. The modulated light source was a Grass PS-2 photic stimulator, which can yield a high intensity light up to 1,000,000 candle power of brief duration, 10 µsec. The pattern of flicker was from 2-20 flashes/second in an ascending order with 30 seconds on and 30 seconds off. The pilots were asked to perform mechanically and mentally during the tests. The test group provided the following

TABLE III

Types of Visual Disturbance and Corollary Effects
for Flicker at Varying Pulse Rates

Rate	Visual Disturbance	Corollary Effects
1-3 cps	1) Discrete flashes	
4-6 cps	1) Eye provides irregular counting 2) Field no longer uniform, has moving patches of greater or lesser brightness	1) Unpleasantness 2) Produces headache in many 3) Eyestrain
7-10 cps	1) Irregularity in rate increases or subsides in an erratic fashion 2) Apparent brightness of field is markedly increased 3) The gamma movements, that is, movements of field, become apparent; bright large snow-balls move in field of vision	1) Eyestrain decreases 2) Unpleasantness about same or slightly less
11-14 cps	1) Increased regular flickering field. 2) Apparent brightness loss increase 3) Gamma appearance gives way to a glitter 4) Patches of low saturation color appear 5) Field is moving, seeing windmill movements, scurrying shadows, etc.	1) Flashing is not as unpleasant as lower rates
15-17 cps	1) Field becomes better organized 2) Apparent brightness is greatly enhanced	1) Very unpleasant, glarey or dazzling, headache, dizziness, unreality, nausea
18- cps	1) Field of vision becomes better organized, less apparent move-ment in field, color phenomena diminishes	1) Decreasingly unpleasant

results:

1) Minor to moderate irritation 30 percent

2) Drowsiness or light sleep 21 percent

In regard to drowsiness, in addition to being alert before flicker, the effected 22 pilots were not necessarily aware that they were going to sleep. Those who did realize what was happening indicated they could not prevent it. The EEG clearly showed a state of lowered vigilance in these pilots. These results which have been also suggested by other authors stress not only the problems of vertigo, distraction, nausea, but also drowsiness and hypnotic potentialities.

Melpar has in operation an EEG laboratory with a Sanborn Model 150 rack-mounted, 4 channel recording system equipped with EKG amplifiers. An extremely low noise preamplifier was carefully designed and built using a special operational amplifier. Various types of light sources, such as a 300 watt slide projector equipped with a complete set of spectroscopic-grade color filters, were available. In front of the light source is a variable-speed, motor driven desk light chopping assembly. Discs providing 30% on, 70% off and 50% on, 50% off wer run at stable chopping speeds from approximately 1 cps to 50 cps.

A large wattage neon bulb mounted behind a black screen is employed also. The neon bulb is provided with a polarizing voltage so that it can be kept continually illuminated. Duty cycles from 10% to 90% were obtained with is system. A variable signal source can be provided as the output of a photoformer generator. A wide variety of coarse waveforms can be generated by cutting a mask having the desired shape.

Experiments have been conducted on human subjects and their reactions recorded for a wide variety of laboratory testing conditions. Parameters such as intensity, frequency, duty cycle, color, aperiodic pulsing, and pulsed waveform have been carefully examined. The results of the program confirm the general prognosis shown in Table III, but provide the additional indications that aperiodic pulsing, nonstationary light sources, and varying color strengths can provide increased subject sensitivity.

The phenomena of alpha wave photic stimulation of a subject has been examined carefully by the research teams. Although the EEG records shown the photic driving of the brain response no significant improvement could be noted in the disturbing results on the subject when the periodic pulse shape was matched to his alpha waveform.

2.1.5 Eidetic Visual Memory

An interesting program of research has been concerned with the short-term memory associated with visual information. The eidetic visual memory is meant a memory in which information from a display remains perceptually vivid, i.e., a memory in which the stimulus or its important aspects are preserved such that perceptual decisions and data processing may be performed on essentially the original information. A basic direction pursued in the studies was investigating methods of erasure and confusion which could blank out the short-term memory associated with visual inputs.

In regard to the latter point, specific inquiries were made in a series of investigations. Two forms of erasure were considered; erasure which provides sudden and complete elimination of the information stored in the memory, and erasure which materially affects the length of storage time of information in the memory. Both temporal and spatial factors influencing eidetic decorrelation time. Eidetic decorrelation time is the time interval during which the temporal and spatial order of the stimulus elements is irrelevant in preserving the redundancies existing in the stimulus.

Appendix D describes in further detail some of the pertinent data gathered in this program. As an illustration of the experimental program, a motion picture film was prepared to test the recall of six letter arrays, both in words and random letters, broken into two sets of three letters, with masking times between the two sets of three letters. Between the two partial arrays, one of three types of erasure patterns is presented for a variable duration. The erasure patterns were 1) white screen, 2) black screen, 3) checkerboard random black and white pattern.

Especially worthy of note is the sharp dip evidenced for word performance under checkerboard masking when the delay was increased. Further analysis of the data indicated that this checkerboard masking has the property of causing pre-erasure, for the performance of the second three letters could be made superior by three to one over that of the first three letters. Neither of the other two backgrounds demonstrated pre-erasure.

Another interesting result was obtained with black gackground. While performance for words stayed relatively constant for delay times, the level for letters was enhanced with increasing duration of the masking field. This demonstration of enhancement of information retrieval due to interposing appropriate masking fields has practical connotations.

White background showed improved performance for both letters and words as the duration of the white field increased. However, this increase in performance never results in word performance much above the level achieved without a white mask. Both the curves for black and white masking demonstrate a manipulation of the short-term memory which can be made to exhibit selective enhancement of perception.

2.2 Acoustics

The Electronics Research Laboratory has a research program of national recognition in several fields of acoustics. Consideration has been given to the possibility of interfering with a human's normal coordination pattern and acoustical communication capability by subjecting him to high level acoustical stimuli which would impair his ability to communicate and coordinate his activities due either to psychological or physiological effects.

With regard to psychological impairment, the intent has been to consider the generation in the vicinity of the individual of acoustical stimuli that tend to discoordinate the individual and thus reduce his effectiveness in combat. Two possible methods for achieving this end are offered. The first is to produce sounds which are literally maximumly disconcerting in the sense that they create in the individual discomfort and disorientation which incite the urge to avoid this sound even at the cost of abandonment of his military post. The second pertains to the introduction of sound bursts that are adjusted at a rate that maximumly interferes with speech communication.

An account of previous work in this area by many investigators of note is given by Burris-Meyer and Mallory.[1] They point out that studies performed during World War II served to dispense with the popular myths of the pre-war period concerning the lethal effects of sound and the whistle that could drive a human crazy. However, an important set of sounds called the BJ series was discovered. These sounds produce an effect, called the

1. Harold Burris-Meyer and Vincent Mallory, Psycho-Acoustics, Applied and Misapplied, JASA, Vol. 32, No. 12, December, 1960, p. 1568.

BJ effect, which has the property of inducing nervous tension in the hearer. To illustrate, a square wave has a greater BJ rating on the BJ scale than does a sine wave of the same period. Indeed it was agreed by numerous consultants that BJ sounds gave the listeners the worst possible time per decibel per second exposure. Experiments were conducted using the BJ series which came to the general conclusion that they indeed irritated many individuals but at least certain individuals were able to resist the sound and continue their tasks. It is pointed out that in all of these tests, the sounds were produced at a level equal to the normal comfortable listening level for speech. Further research into such sounds as the BJ series appears to have stopped at the end of World War II. Thus, it does not appear that any information exists on the effects of BJ series sounds at higher than normal listening level, i.e., 60-70 db re. .002 dyne/cm^2.

Turning now to the uses of sound bursts, it is believed possible to interfere effectively with normal speech communications by the propagation of noise or tone bursts at a critical rate. The existence of a critical rate of interference which produces maximum interference with speech communications has been shown. In these experiments, it was demonstrated that the intelligibility of speech can be drastically reduced by switching alternately to the left and right ears of a listener, at a critical rate of alternation. Also it was noted that a corresponding parallel loss of intelligibility occurred when, instead of being switched back and forth between the ears, the speech was interrupted periodically, at the same critical rate. Intelligibility is measured in terms of the mean number of words perceived correctly. It is noted that for interruption rates between 2 and 5 cps the mean intelligibility can be reduced to approximately 20 percent, which makes direct speech communication almost impossible.

It is possible to produce temporary effects on hearing capability. As a result of damage risk studies recently performed by Kryter[1] on the means of assaying the probability of permanent damage to the human ear by long exposure to band limited, high level noise sound fields, a considerable amount of information was generated on the temporary threshold shift of human hearing. In this study the temporary threshold shift measured two minutes after exposure was used as a standard of reference. The hearing loss threshold used required that the subject, 2 minutes after exposure, exhibit an average temporary threshold shift of 10 db or more at 1000 cps or below, or 15 db at 2000 cps, or 20 db at 3000 cps or above. It has been demonstrated experimentally that this is a hearing loss threshold which, if exceeded, begins to produce impairment in the ability of one to communicate by normal speech. The ear is most susceptible to damage in the vicinity of 3 kc, and narrow bands of energy (1/3 octave) inflict more damage potential than broader bands. Noticeable temporary hearing loss can be inflicted at sound levels considerably less than the threshold of pain, and that increase in duration of exposure increases the damage inflicted. Information for the extrapolation of the 2 minute values to values at other times can be analytically defined. For example, a temporary threshold shift of 15 db

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1. Kryter, Carl D., Exposure to Steady-State Noise and Impairment of Hearing, JASA, Vol. 35, 10 October 1963, p. 1515.

measured 2 minutes after exposure decays to a value of 5 db 15 minutes after exposure, or a 35 db measured 2 minutes after exposure decays to a value of 20 db in 15 minutes.

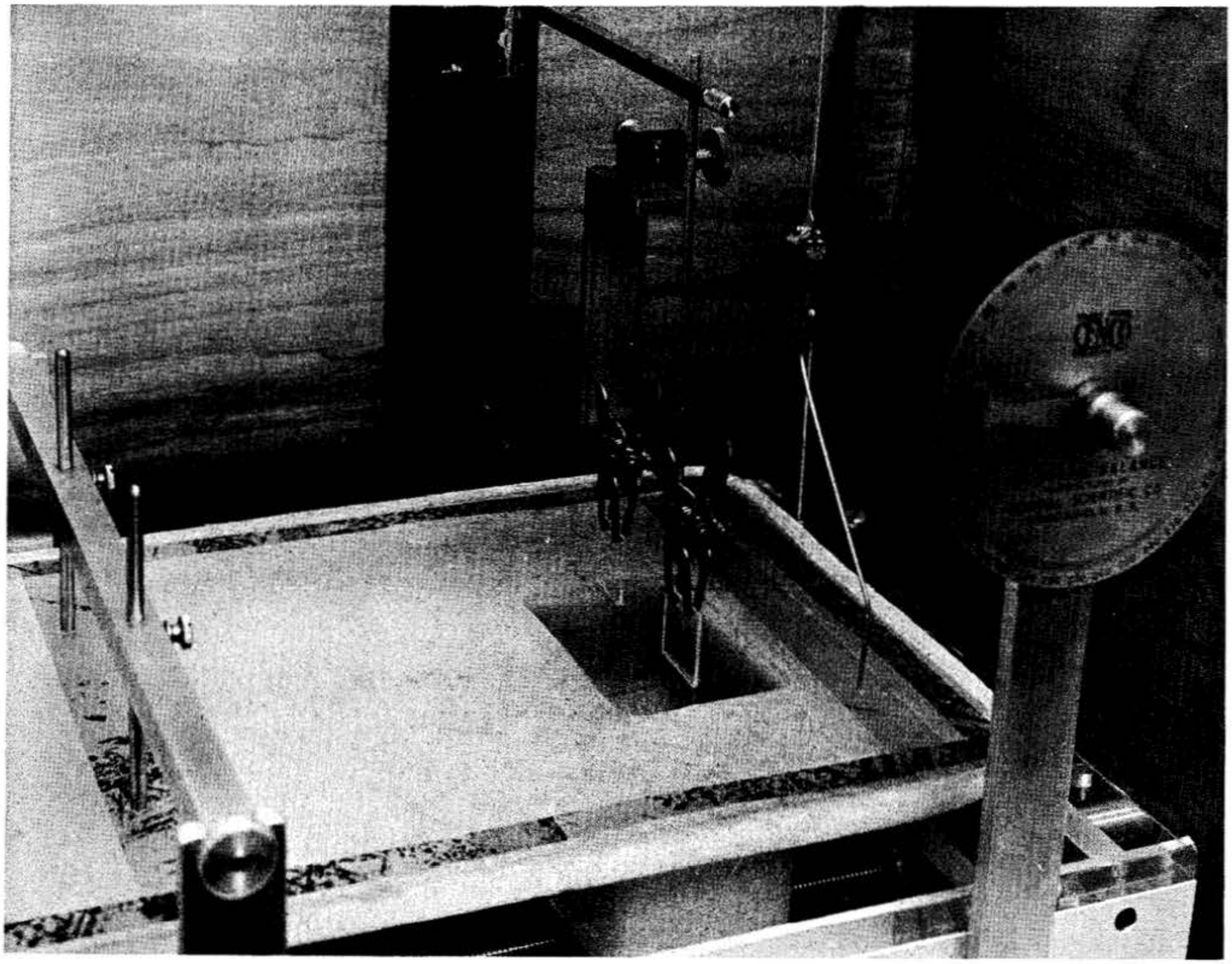
The Acoustics Laboratory has a large soundproof room containing bench space, articulation test area, and a smaller fully-treated announce booth contained therein. This facility is available for full time acoustic research and development work. It is supplied with Sona-graph, listening equipment including high fidelity loudspeakers, headsets, amplifiers, professional tape recording equipment, and the like. In addition, certain specialized tools developed specifically for acoustic research are available.

2.3 Bilogical

2.3.1 Biological Effects of RF Radiation

Melpar has performed on two separate contracts to study the biological effects of RF radiation. A detailed detection and analysis of the biophysical and biochemical effects of irradiating certain macromolecules, such as gamma globulin, with RF energy were pursued. The conclusions indicated that irradiation leads to destruction of the protein. Two different, vitally important proteins underwent irreversible structural alteration.

The additional research program dealt with the determination of the detectable changes which can be wrought on living animals with RF radiation. Of subsidiary interest were organisms such as protozoa, invertebrates, mice, etc. Blood changes in mammals were of particular interest in the laboratory experiments. Efforts are now directed to explain the detailed mechanisms involved in the observed changes for the frequency range of 3 to 16 megacycles.



Languin-Blodgett Dripper Used in Determining Effect of
RF on Macromolecules

2.3.2 Particle Radiation Programs

The radiation laboratory is divided into two parts, one of which is devoted to work with isotopic sources, and the other to work with machine sources. At the present time the latter section is equipped with a 250-kvp, 30-ma X-ray machine. A special aspect of this installation is the adjacent laboratory in which there is installed a very high sensitivity electron-paramagnetic-resonance spectrometer which is arranged so that the magnet can be located in the X-ray beam. This marriage of the X-ray machine and EPR spectrometer allows a search for steady-state free-radical intermediates in specimens during irradiation at elevated temperatures (e.g., in live tissue at 37.5° C), which can be accomplished in few other laboratories in the world. It is planned to augment this capability in the near future with pulsed X-ray equipment to permit studies of radical growth and decay. Liquid-nitrogen and liquid-helium dewars are available for low-temperature research. The X-ray machine can be employed for a variety of other studies, such as the effects of vibration and shock on radiation detector and electronic circuits while operating in a high-intensity radiation field.

Radionuclide sources located in the second section of the radiation chemistry laboratory include a 2000-curie cesium-137 source, a plutonium-beryllium neutron source, and a krypton-85 facility. The cesium source is a self-shielded apparatus which provides gamma dose rates up to 2×10^5 rad hr^{-1} for room temperature irradiations; lower dose rates can be achieved by sample shielding. Specimens up to 7.5 cm in diameter by 7.5 cm high can be exposed. The source is equipped with a timer for precise exposure and to permit automatic termination of long unattended irradiations.

A fast neutron flux of approximately 8×10^6 n $sec^{-1}cm^{-2}$, and a thermal flux of approximately 10^5 n $sec^{-1}cm^{-2}$ are available from the neutron howitzer located in the radiation chemistry laboratory. The howitzer is installed behind a concrete-block wall with deep beam traps so that scattering, albedo, and attenuation experiments can be made safely. Although the available fluxes are low, some activation analyses are possible. The source is most useful for studies of neutron-absorption and -scattering properties of materials, and of low-level, long-term neutron-damage experiments with electronic and biological specimens.

The krypton-85 facility consists of a remotely operated metal vacuum system shielded with approximately 12 tons of lead, which will permit an eventual loading of 100 curies of krypton-85. This is a closed system in which the krypton is pumped cryogenically from a separately shielded permanent storage vessel to a reaction vessel, and returned through a decontamination system to storage. It is designed for kinetic studies of homogeneous gas-phase radiolyses, and for exposure of specimens internally to a homogeneous, high-intensity electron flux such as that encountered in the Van Allen belt. This facility, which is scheduled for completion in late 1964, will be the only known installation in the world capable of research studies with such large quantities of krypton-85.

Research programs currently being pursued by this Branch include studies of water and gas sorption by foods and biological solids, the effects of radio frequency radiation or biological materials, the radiolysis of organic and organometallic compounds, the influence of inert gases on gaseous dosimeters, and the chemical vapor deposition of metal films.

2.4 Plasma Physics

Underlying a class of unconventional weapons, typified by plasmoide and Kugelblitz, is a vast amount of fundamental research in the field of plasma physics. Over the past five years Melpar has endeavored to cover various areas of plasma physics, with a view towards establishing the proper foundation for weapons research, as well as other areas not pertinent to the present discussion.

The research was divided into three groups:

1) Basic plasma physics

2) Coherent generation and amplification

3) Electromagnetic and hydromagnetic interactions

Topics 1 and 3 are of importance here, as both are of significance with regard to Kugelblitz research. In the basic plasma physics were studied recombination and attachment coefficients, elastic and inelastic cross sections, distribution functions, probe theory, ultrapure vacuum techniques and similar topics. In the third area, electromagnetic and hydromagnetic interactions, we have studied breakdown and least maintaining fields, S, P, E and O hydromagnetic waves, microwave diagnostics, the behavior of dense plasmas, rf striations and like subjects.

2.4.1 Ball Lightning

Kugelblitz (ball lightning) is a phenomenon which has been reported for centuries. Although it still lacks positive classification as a real entity, the possibility of illusions associated with linear lightning are not being entirely discounted. From a strictly observational point of view, Kugelblitz is a real phenomenon, although to date it has been given neither an adequate theoretical treatment nor has it been produced in the laboratory.

A number of theories have been proposed, all of which are incomplete to a certain degree. The theory presently in vogue is that of Kapitsa[1], and it has been further considered by some American and Italian investigators. Kapitsa's theory requires the existence of standing electromagnetic waves of wavelength $\lambda = 3.65D$, where D is the diameter of the lightning ball. It turns out that the wavelengths of importance lie between 0.35 and 0.70 meters. This theory permits a reasonable explanation of bead lightning as well, and may be applicable for this case which is spatially in the vicinity of an actual linear stroke channel. Melpar considers that the proper magnitude and spatial distribution of the electromagnetic field for Kugelblitz are not likely to occur as required by this theory.

It is relatively easy to generate something that looks much like a lightning ball, although it may be radically different from the natural item. If, for example, two arms about three inches in diameter and about six inches long, are affixed to a two-liter flask, evacuated (with an ultra pure system) and filled with a rare gas to about 5 to 15 torr, an appropriate excitation circuit will generate a plasma fireball not quite filling the two-liter flask. The appropriate excitation circuits are two helices "climbing up" the two-liter flask a short distance from each arm. It is convenient to use a 20 to 40 mc rf generator capable of delivering up to

1. Doklady Akademi: Nauk USSR, Vol. 101, No. 2, pp. 245-248 (1955).

one kilowatt or more of cw power. Nitrogen may also be used, producing a reddish fireball with appreciable afterglow.

It is significant that these low pressure fireballs exhibit great stability. It may also be significant that they are most stably generated with a mixture of E_{ϕ} and E_Z type fields (fields due to the gradient of the scaler potential are not shielded out). The fireball usually seems to be "fed" by a striation type (beaded) streamer issuing from each arm.

With this well documented experimental laboratory information in hand, Melpar has developed a more useful theory than those dependent upon transient observations of natural phenomena. A more complete expository treatment of calculations to date is contained in Appendix F.

The theory presented is based upon low pressure Kugelblitz, and for this reason is subject to experimentation far more easily than the previous theories. The low pressure concept permits larger plasma fireballs with longer lifetimes. Non-equilibrium ionization can occur far more readily at lower pressures. Thus, it is possible to provide for much larger initial stored energies.

At the present time special properties of large plasma fireballs created by E and H fields are being investigated. Available for the investigations are a large, high speed turbo-molecular pump, ultra pure vacuum system which will be well suited for more advanced investigations. Using this system, and a large exit tank, it is possible to investigate the lifetime of fireballs fed with appropriate streams. Such an experiment, together with adequate photography, will be crucial in indicating the probable validity of the theory. It is doubtful that other companies have the same degree of background experience as a prerequisite for Kugelblitz experimentation.

2.5 Lasers

Melpar through its Research Division has expended considerable effort in the field of laser sources and laser materials during the last three years. The company has developed fixed research and portable gas lasers operating in the visible and infrared portions of the spectrum. Also solid state sources, (pulsed and c.w.), have been developed with special emphasis being placed on materials and on high peak pulse powers as found from Q switched lasers. Some of the more important output properties of these sources have been measured by this group, such as; peak pulse power, total energy, average power, beam divergence, longitudinal mode content, transverse mode structure, and spectral wavelength. Other programs currently active are related to the development of intense coherent infrared sources, light modulation and detection, and application of lasers to military systems.

In solid state laser sources and materials, the company has done extensive experimental work. Spectroscopic measurements have been made on rare earth doped single crystals and glasses and a most recent development was the observation of sharp line fluorescence from rare earth chelates dissolved in organic monomers which were polymerized to solid solution. The latter materials have superior workability and ease of doping as compared to single crystals and glasses and are extremely promising regarding laser applications. Melpar is currently attempting pulse and c.w. operation in these materials.

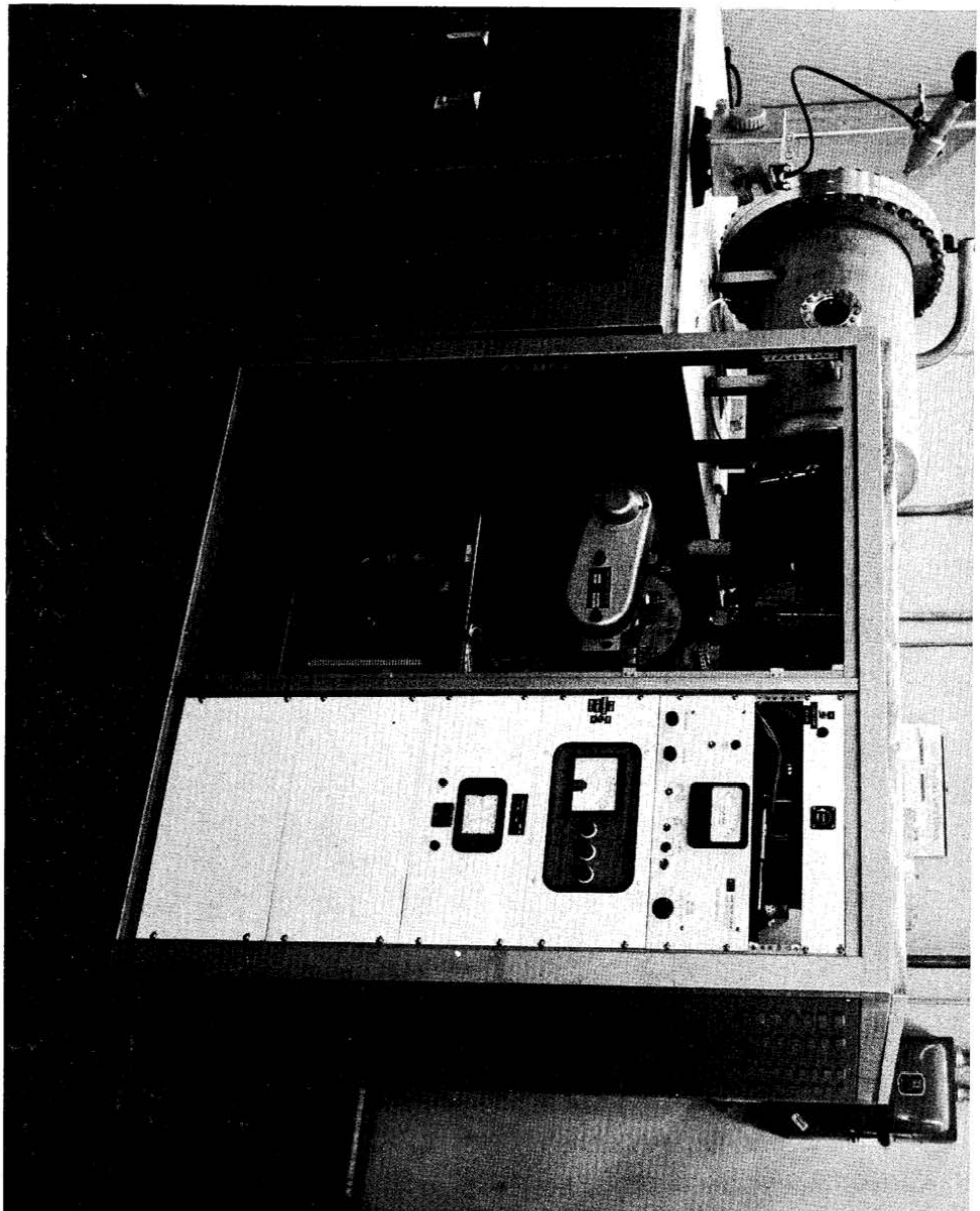
A non-optically pumped light source is presently under development. In this program population inversion is achieved by a combination of microwave-collision pumping of a flame or gaseous discharge. Results to date indicate that this program is developing an intense coherent source of large linewidth.

A giant pulse ruby laser has recently been designed and built. This unit is powered by a moderate size 10,000 joule capacitor bank which energizes an EGG FX-47 xenon flash lamp. The ruby rod is a .615" x 6.25" specimen and delivers normal pulses of nearly 100 joules. With Q spoiling, it is expected that the peak pulse power will lie somewhere in the range of 10-100 megawatts. The Q spoiling technique utilizes a Kappa Scientific Kerr Cell and Glan type of polarizer. The electronics are such that variable delays and pulse shapes are possible.

Experiments are currently under way at Melpar directed towards improved performance characteristics of high energy laser sources. A laser pump research program is investigating types of discharges with various gas mixtures under flash discharge conditions. Light output in the main absorption bands should be optimized per joule of energy dissipated in the lamp. Both short and medium duration discharges are being considered. Improved flash lamp design and circuitry are also involved. In this regard the Melpar proprietary program in high intensity light sources is being studied as use for a potential high efficiency flash lamp for the large ruby lasers.

Switching investigations and development are exploring the problems in fast rise time, high voltage circuitry, the Pockel's cell characteristics, prism characteristics, absorbers. Ruby rod considerations are involved with the system design aspects of large rods, such as 3 cms in diameter or the combination of smaller rods with accompanying optical pumping, switching, and cooling techniques.

Laser scanning or deflection of the optical beam without mechanical movement is of special interest in the program. Deflection by changing the index of refraction of the medium transversed by the laser beam, e.g., by optical pumping or by injection has been given attention. The equipment available for carrying out this work includes ruby crystals with the amount of doping estimated to be necessary to produce a change in refractive index adequate for deflection purposes.



Melpar's Ultrapure Vacuum System Used in Kuzelblitz Research

3. SUGGESTED WEAPONS RESEARCH AREAS

3.1 Kugelblitz Theoretical Study

At this time Melpar would recommend that the possible capabilities of a fireball weapon promote interest in continued development of theory and the initiation of experimental techniques which can produce, eject, and direct fireballs to a target. The research program should provide emphasis upon increasing the energy content of the ball, maximizing the lifetime of the plasma energy, and upon reducing the problems of directing the fireball to a specific target. The research efforts could be expected to require approximately three years to establish the basic principles and techniques for a moderate energy fireball. A demonstration model would then be available to show the effectiveness of the weapon concept.

Following the three years of research and development, with an attendant successful demonstration of all concepts, the program should then extropolate its findings to achieve a very high energy fireball system. A field tactical system could be analyzed on the basis of the known data, and the possible configuration and characteristics of the system for a destructive weapon can be defined for the battlefield conditions.

The inherent potentialities of such a system suggest the importance of establishing research for the possible weapon system that can arise by this approach to assure ourselves a time lead over any potential enemy who may develop such a weapon.

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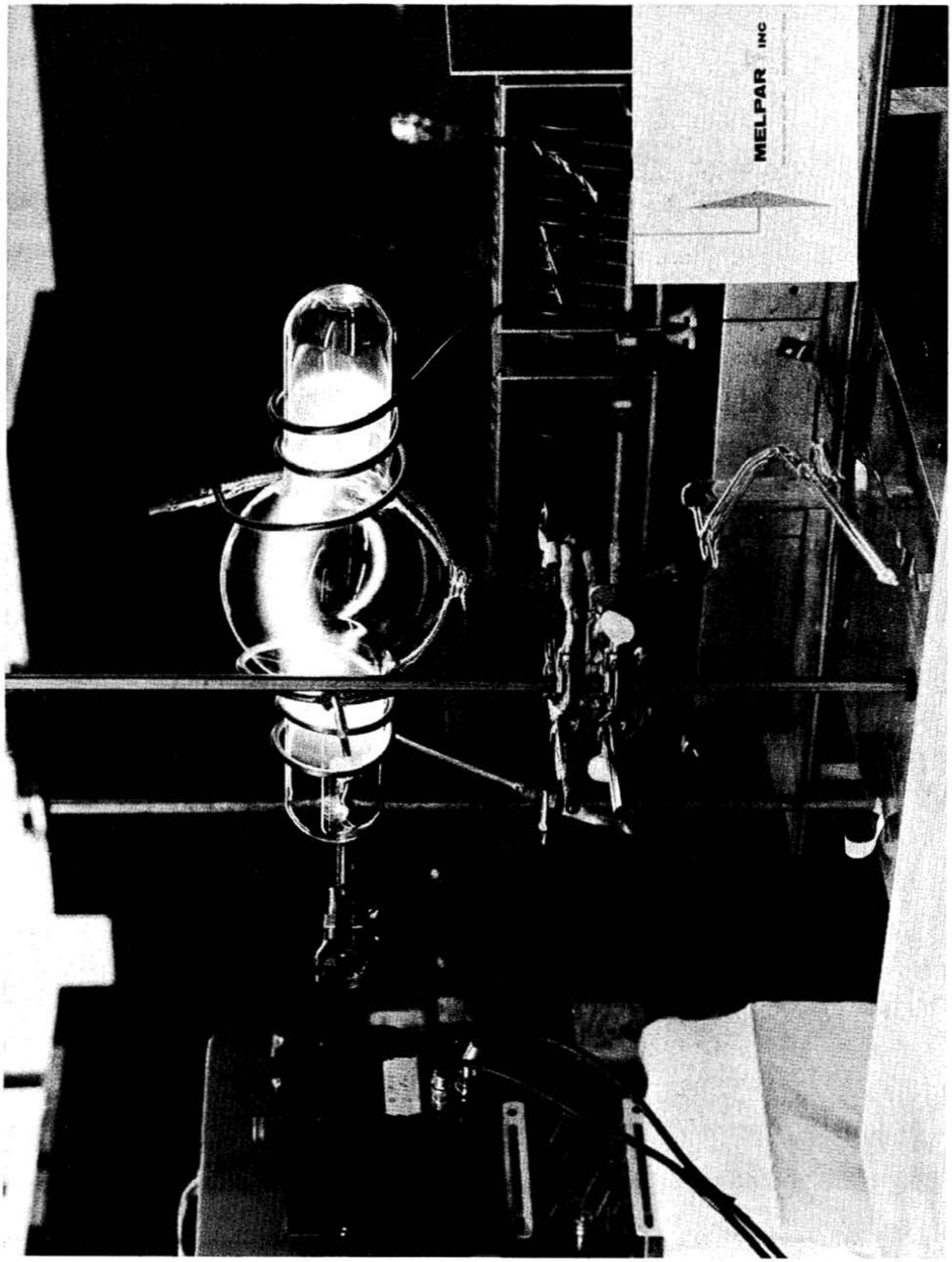

Rope of Stable Plasma in Vacuum

3.2 Visual Excitation

The large quantity of evidence available relating psycho-physiological reactions to modulated light stimuli in the frequency range of 3 to 20 cps, encourages the position of pursuing a research and development program on a tactical visual excitation weapon. The considerable amount of knowledge now available has been obtained primarily under laboratory conditions and with either clinical or non-clinical subjects. The program should be reviewed now from the point of view of battlefield conditions which provide subjects which are tired, sleep-deprived, nervous, low environmental temperatures, possible fear of death, etc. It must be remembered that the sort of fatigue which occurs in battle reduces the stability of the sympathetic nervous system and this influence can cominantly affect his reaction to modulated, pulsed light.

Melpar believes that field and laboratory testing can be carried on in parallel. In the laboratory one should use subjects who are exposed to stresses which can be predicted to occur in the combat field, using drugs to simulate fear responses, sleep-deprivation, extremes of temperature, etc. The visual excitation responses must be analyzed for light intensity, spectrum color, pusle rate, aperiodic pulsing, on-off duty cycle, alternating between two or more light sources differing in time phasing and position, and temporal insertion of optical background masking to affect the short-term memory.

The stimulated responses to be maximized should be measured as objectively as possible. In addition to the visual field-of-view deterioration (such as non-uniformity, moving patches of light, erratic brightness

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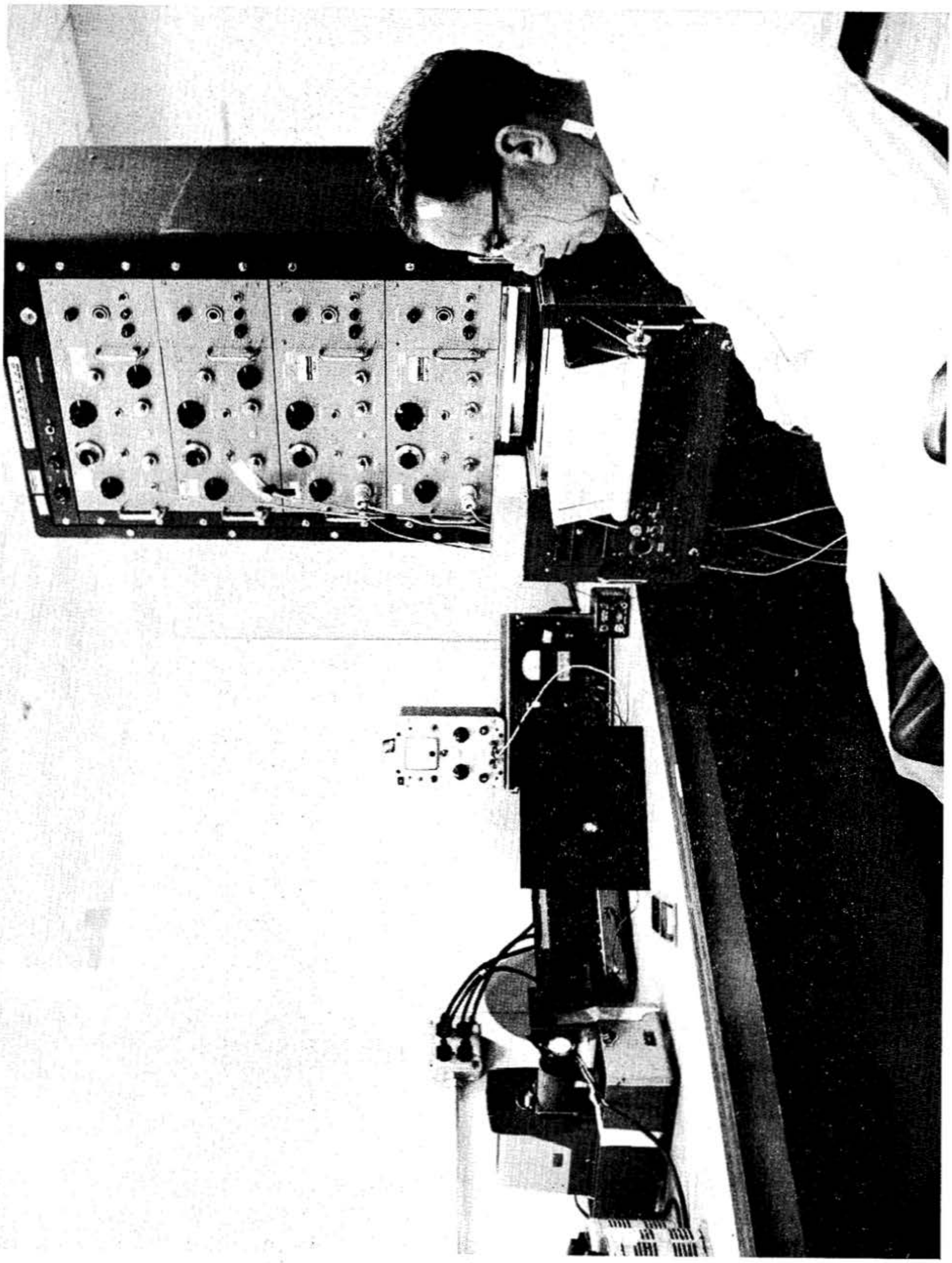

Laboratory Setup for Subject Irradiation in Flash Frequency Experiments of field, glitter, patches of color, radial windmill movements), the study will define the percentages of onslaught of headaches, dizziness, unreality, nausea, and degree of eyestrain. Finally, the field measurements will provide data on the reduced performance in observing targets, firing weapons, maintaining long and short memory functions, and reduction in communication accuracies for various environmental backgrounds.

The results of this program will clearly define the requirements for a tactical weapon. We believe that this system can be combined with the scotomatic, dazzling weapon to produce an important addition to the Army's arsenal.

Available countermeasures point to a type of filter-eyeglass which would attenuate the frequency range of the light source. As the possible light sources will be on the visual range, the filter must effectively reduce the distance and recognition capability of the enemy. The proposed weapon can operate on more than one wavelength, or if it is a broad band source, the enemy cannot plan to remove the optical excitation successfully.

3.3 Scotomatic Glare Weapon

A scotomatic glare weapon should be given serious consideration as a tactical device to provide temporary partial or complete blindness for enemy troops out to distances of several thousand feet during standard atmospheric conditions. Using pulse rates of 1 to 0.1 pps and illuminance time products in the range of 10 lumen-seconds/ft^2 at the target, the eye will not have sufficient visual recovery time to adapt to the real environment.

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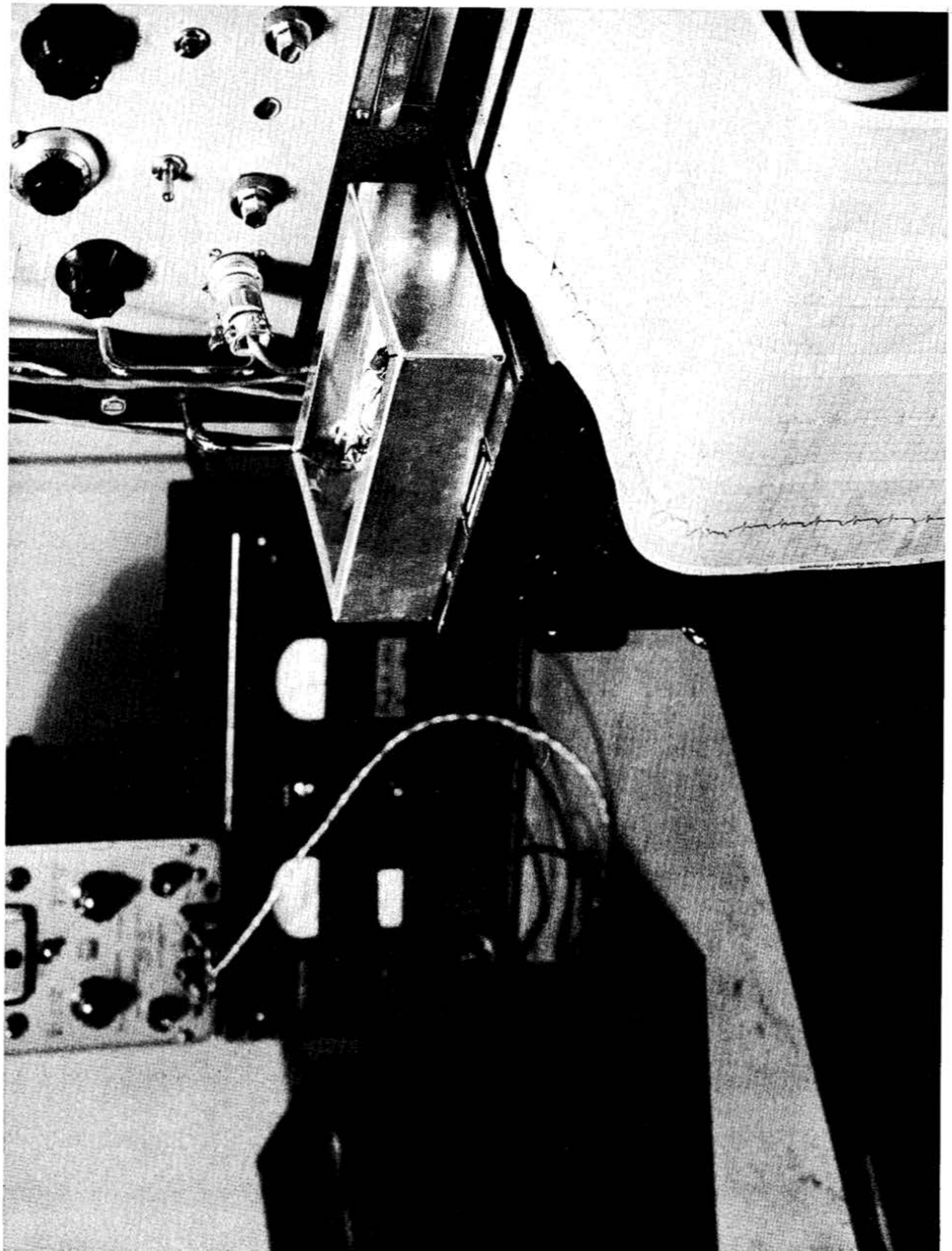

Details of EEG Recorder During Flash Frequency Experiments

Immediate development studies can be applied to the xenon flash lamp system with the FX-56 flash lamp and the modern carbon arc source. The xenon flash lamps require little hardward other than the collecting and collimating optics, a capacitor storage bank plus simple trigger circuitry and a dc charging power supply. A small closed cycle water cooling system could be made an integral part of the vehicle cooling system. A simple mechanical scan can be employed to permit a much larger coverage of the battlefield when pulse rates of 1 pps are employed.

Laser glare systems should be investigated in more detail to define the complexity of hardware that would be required for the 1970's. The present lasers are limited in total energy and pulse rate. Improved pulse rates and increased area coverage can be implemented by multiple laser sources. The main components involved are a dc charging power supply, capacitor storage bank, trigger circuitry, flash lamps, reflector assembly, laser material such as ruby rods, divergent beam optics, and a directional mechanical assembly. The laser system would be considerably more complex and bulky than the xenon flash lamp system, but this approach should not be discontinued because of the other potential applications that can be used with the laser system.

A scotomatic glare weapon can possibly be partially countermeasured by the employment of flash blindness protective goggles. Such goggles will prevent the total blanking out of the visual sensors, but by their own response times and filter characteristics they must reduce the acuity of visual perception.

Scotomatic glare techniques can be employed for both day and night tactical application. The basic limitation of the system must arise from atmospheric attenuation, which increases rapidly under conditions of fog, rain, and snow.

3.4 Lethal Laser Weapon

At great expense and with considerable mobility sacrifice, it is presently possible to build a lethal laser weapon. Upon improving optical pumping and cooling techniques appreciably, the lethal laser weapon can become a more practical reality within the next three years.

Melpar's concern is not solely with devices which produce merely scotoma, nor just non-thermal eye damage. Instead, it appears possible through research to harness huge power densities capable of burning through humans, even when they are protected by normal combat uniforms.

Upon concentrating a small 10 joule output laser into a spot about one millimeter in diameter, a laser beam can burn through one or more razor blades. Certainly, then, energy densities of 1000 joules per square centimeter will produce disastrous effects upon a human. By using an array of 100 joule lasers, it is possible to produce an effective device in the foreseeable future to focus destructive energies at ranges up to 600 yards.

It is necessary to keep field strength along the beam less than about 10^4 volts/cm, to prevent breakdown of the atmosphere.

Thus,

$$Pd \quad \frac{10^{12}}{u_o/E_o} = 2.65 \times 10^9 \ \frac{\text{watts}}{\text{meter}^2} = 2.65 \times 10^5 \ \frac{\text{watts}}{\text{cm}^2} .$$

Using the spiked pulse width of one millisecond, the lasers should be kept down to less than 265 joules output per square centimeter of rod face. For the average large ruby rod, then, each laser of the array should emit only about 500 joules. The laser array can be designed so the beams of the array meet in a common point at the target. For a reasonable figure, such as 10 or 20 lasers, the effect at appreciable ranges under good atmospheric conditions can be extremely potent for destroying human targets.

It is reasonable to expect that overall laser efficiencies will rise to perhaps 10% within the next half decade. It will then be practical to build a much higher output laser array with a prf of at least 1 pps. The charging supply would be mountable on a standard $2\frac{1}{2}$ ton truck.

This possibility is straightforward except for the task of improving overall laser efficiency. There seems little question, however, that if the requisite research is accomplished sufficiently soon, lethal laser weapons might well be extensively employed in the 1970 army.

A major portion of the development program should be concerned with the mechanical and optical focusing of multiple beams to converge at a given range. Methods of optical pumping, switching, and cooling of a multiple laser set requires solution of difficult (but not beyond the state-of-the-art) design problems. A breadboard design involving two to five separate lasers into a package to illustrate the various design features is a program that should be given serious consideration in the near future. From this phase of investigation, a careful assessment can then be given on the potentialities and characteristics of a functional tactical weapon.

3.5 Acoustic Weapon

An acoustic harassment tactical device for battlefield application may become, by a relatively small amount of additional development, an important field weapon. Considerable amounts of primitive evidence are available upon the deployment of various sounds for close tactical situations, but at Melpar it is believed that the present state of acoustical-electronic systems permits a serious evaluation of the design and application of field acoustic generators.

As the initial phase of those studies Melpar would recommend the design and building of an acoustical generator having the following sample characteristics. Two standard searchlight beds would support a 60 KW motor generator set and an 18 KW output, 30° beam, acoustical generator. The transducer-radiator would be approximately 5 ft in diameter. Either pneumatic or electromagnetic devices can be employed. The system would have the capability of producing 120 db level at 1000 ft, 109 db level at 3000 ft, and 104 db level at 5000 ft, for a 3000 cps frequency. Seven minutes duration at this greater range causes temporary hearing debilitation of a degree varying in each individual. These db levels at lesser ranges vary from the threshold of pain to an extremely loud noise causing great distraction and interruption of communication.

The acoustic generator can provide broadband, BJ, square wave, or warbling signals. Further field tests can be performed directly with the equipment to test the validity of distraction, discomfort, nervous tension, and communications under field conditions of stress and weariness.

Effective countermeasures may be principally the use of internal or external ear barriers. Such a countermeasure tends to produce isolation and inability to receive audio communications. The aperiodic application of an acoustic generator harassment can be used to decrease the effectiveness of the enemy at critical periods in tactical battlefield conditions.

The absorption of sound passing through air depends upon the relative humidity percentage. The peak absorptions occur around a 20% relative humidity. As the relative humidity increases the coefficient decreases. Since the major loss is in square law spreading with only a minor loss in absorption, one can conclude that the acoustic weapon is responsive to almost all possible atmospheric conditions, which makes it an excellent alternate to an optical scotomatic weapon.

3.6 Concentrated Energy Transmission for Field Conflagration

A multiple laser system offers significant possibilities for providing a tactical complement for the standard flame thrower. The flame thrower as used now provides a means for ejecting combustible fuel which can fill contained volumes and ignite material not in the direct line of sight. Limitations occur in the short ranges involved and the fact that the fuel must traverse the range between the source and target in a form easily noted by the enemy.

A high energy focussed laser system can deliver energy to a specified target at long ranges, and without the usual easily detected plume of the flame thrower. Melpar believes that a continued research program should be pursued which defines precisely the burning capability of a focussed laser beam on various types of combustible materials, such as leaves, grass, trees, wood, clothing, etc. Inherent in these studies would be the means of optimizing the buriing destruction of the targets. This would include the time-energy relationship, that is, should a high energy, short time pulse be used or a lower energy, longer time pulse be used? In addition, the wavelengths that are permitted by the atmospheric windows should be examined for maximizing the burning capabilities. Laboratory experimental measurements can complete the major portion of the needed data.

In conclusion, we wish to point out the close tactical relationship that the laser system for complimenting the flame thrower can be combined readily with the scotomatic glare weapon and the visual flicker weapon. Mounted upon a single carrier, such as a truck or tank, the high energy laser system can be precisely focussed on a distant set of targets to destroy or confuse by fires, or change to the mode of scotomatic glare by the de-focussing and scanning an area at a low pulse rate, or combine the scotomatic glare operation with the higher pulse rate, low energy, flicker mode to provide disruption effects upon enemy troops on the battlefield.

4. PERSONNEL

4.1 Company Personnel

Melpar has available a skilled group of scientists who are well qualified in the physical and biological sciences. They have established a reputation, both in their own careers and for the Company, of being able to grasp a problem, outline its solution, and proceed to successfully complete assigned projects on time and within funding limits.

It is anticipated that this proposed program for weapons development, utilizing the most advanced applicable sciences of our era, will be under the direction of [redacted] whose professional biography is on the next page. He will have as his principal investigators three doctoral researchers: [redacted] whose professional biographies follow those of [redacted].

Melpar is fortunate to have a number of senior Army Officers, now retired, who can bring to this proposed study a combination of military and scientific training and insight which will be invaluable in outlining the final weapons' design criteria. These men are [redacted] whose combined military and industrial experience adds up to over 100 years. Their professional biographies are also attached.

In addition to the above, biographies of several other personnel are included. They are now available in the Company for assignment to this proposed program when their skills are required.

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4.2 Outside Consultants

The biographies of two Melpar Consultants, [redacted] are included. [redacted]

These distinguished scientists will be freely consulted in the pursuance of Melpar's proposed program for new, advanced weapons for the 1970 battlefield. [redacted]

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5. BIBLIOGRAPHY

Laser Weapons

AD-327 464 Some Aspects of Optical Masers for Tactical Use (U), Army Signal Research and Development Lab., Ft. Monmouth, N. J., September 1961

AD-329 676L Laser Design Concepts Studies (U), Electro-Optical Systems, Inc., Pasadena, Calif., 29 April 1962

AD-342 115 Test Laser Source (U), Westinghouse Electric Corp., Baltimore, Md., 19 July 1963

AD-340 837L A Preliminary Assessment of the Feasibility of Application of a Laser Weapon Against Certain Soft Targets (U), Research Analysis Corp., Bethesda, Md., June 1963

Particle Weapons

AD-331 442 Investigation of Electrostatic Projectors (U), Armour Research Foundation, Chicago, Ill., August 1962

AD-337 642 Linear Accelerator Research (U), General Electric Co., Schenectady, N. Y., 21 June 1963

AD-334 870 Beam Parameters and the Choice Between Protons and Electrons (U), Illinois U., Urbana, Ill., 1963

Radiation Weapons

AD-316 668 Radiation Weapon Antenna (U), Systems Labs., Corp., Los Angeles, Calif., 2 February 1960

AD-326 515 Radiation Weapon Antenna Investigation (U), Electronic Specialty Co., Los Angeles, Calif., 1 June 1961

AD-339 115 Microwave Energy Transfer Mechanisms (U), General Dynamics/Convair, San Diego, Calif., 20 June 1961

AD-327 057 Antenna Focusing System Study (U), Sperry Gyroscope Co., Great Neck, N. Y., September 1961

AD-328 999 Antenna Focusing System Study (U), Sperry Gyroscope Co., Great Neck, N. Y., December 1961

AD-289 135 Advanced Electronic Systems (U) General Dynamics/Convair, San Diego, Calif., 1961

AD-329 115 Radiation Weapon Antenna Investigation (U), Electronic Specialty Co., Los Angeles, Calif., 18 January 1962

AD-330 022 Antenna Focusing System Study (U), Sperry Gyroscope Co., Great Neck, N. Y., March 1962

AD-331 249 Radiation Weapon Antenna Investigation (U), Electronic Specialty Co., Los Angeles, Calif., 10 April 1962

AD-310 741L Laser Design Concepts Study (U), Maser Optics, Inc., Boston, Mass., 30 April 1962

AD-331 200 Investigation of Optics for a Radiation Weapon System (U), Westinghouse Electric Corp., Baltimore, Md., 1 May 1962

AD-291 466 Investigation of Optics for a Radiation Weapon System, Volume III (U), Westinghouse Electric Corp., Baltimore, Md., 1 August 1962

AD-343 486 Radiation Weapons Analysis Study Group (U), Report no. 3, New York U. Coll. of Engineering, N. Y., September 1962

AD-333 247 Feasibility Studies for Electromagnetic Radiation Weapon (U), Rome Air Development Center, Griffiss Air Force Base, N. Y., November 1962

Ion Beam Weapons

AD-338 355 Ion Beam Weapon, Volume I, Synthesis (U), General Electric Co., Santa Barbara, Calif., June 1962

AD-338 354 Ion Beam Weapon, Volume II, Summaries of Major Problem Areas (U), General Electric Co., Santa Barbara, Calif., June 1962

AD-338 353 Ion Beam Weapon, Supplement 1, Ion Sources (U) General Electric Co., Santa Barbara, Calif., June 1963

AD-338 380 Ion Beam Weapon, Supplement 2, High Voltage (U), Technical Military Planning Operation, General Electric Company, Santa Barbara, Calif., June 1963

AD-338 376 Ion Beam Weapon, Supplement 3, Accelerator Beam Dynamics (U), Technical Military Planning Operations, General Electric Company, Santa Barbara, Calif., June 1963

AD-338 379 Ion Beam Weapon, Supplement 5, Beam Neutralization (U), Technical Military Planning Operation, General Electric Co., Santa Barbara, Calif., June 1963

AD-338 378 Ion Beam Weapon, Supplement 6, Target Detection (U), Technical Military Planning Operation, General Electric Co., Santa Barbara, Calif., June 1963

AD-338 387 Ion Beam Weapon, Supplement 7, Beam Aiming and Deflection (U), Technical Military Planning Operation, General Electric Co., Santa Barbara, Calif., June 1963

AD-338 386 Ion Beam Weapon, Supplement 9, Attitude Control of Ion Beam Projector (U), Technical Military Planning Operation, General Electric Company, Santa Barbara, Calif., June 1963

AD-338 431 Ion Beam Weapon, Supplement 11, Position Control of Inner Electrode (U), Technical Military Planning Operation, General Electric Co., Santa Barbara, Calif., June 1963

Plasmoid Weapons

AD-327 173 Investigation of Pulsed-Train Plasmoid Weapons (U), Aerojet-General Corp., Downey, Calif., October 1961

AD-327 174 Investigation of Pulsed-Train Plasmoid Weapons (U), Aerojet-General Corp., Downey, Calif., October 1961

AD-328 413 Investigation of the Generation and Projection of High-Energy Spherical Plasmoids (U), Raytheon Co., Wayland, Mass., March 1962

AD-328 414 Investigation of the Generation and Projection of High-Energy Spherical Plasmoids (U), Raytheon Co., Wayland, Mass., March 1962

BIBLIOGRAPHY (Continued)

Non Nuclear Weapons

AD-334 348 Non-Nuclear Weapons Compatibility and Employment (U), Falcon Research and Development Co., Denver, Colo., February 1963

AD-341 715 Subtle Lethal Mechanisms for Non-Nuclear Anti-Missile Warheads (U), Hughes Research Labs., Malibu, Calif., May 1963

AD-341 657 Subtle Lethal Mechanisms for Non-Nuclear Anti-Missile Warheads (U), Hughes Research Labs., Malibu, Calif., July 1963

Defense Against Exotic Kill Weapons

AD-340 145 Defense Against Exotic Kill Mechanisms (U), Northrop Space Labs., Hawthorne, Calif., August 1963

Other

"Toward a New Weapon-System Analysis," Berman, E. G., Rand Number P1493, 1958.

"Weapons Systems Costs," DDC Report Bibliography ARB-10,000; refs from 1957-1962.

"Electromagnetic Radiation Effects on Personnel," Letter ATSWB-W 000.9g from Hqs. Combat Development Section USCONARC, Ft. Monroe, Virginia to the Surgeon General, Department of the Army, Washington, D.C., 1961.

"Psychophysiological Reactions to Novel Stimuli: Measurement, Adaptation, and Relationship of Psychological and Physiological Variables in the Normal Human," Annals of the New York Academy of Sciences, Vol. 79, Art. 3, pages 43-107, Dykman, Roscoe A., Reese, William G., Galbrecht, Charles R. Thomasson, Peggy J., 1959.

Proceedings of Tri-Service Conference on Biological Hazards of Microwave Radiation, Air Research and Development Command, Hdqs. Project No. 57-13, Contract AF 18(600)-1180, The George Washington University, Washington, D.C.

"New Living Tissue Radiation Effects Being Investigated," Electronic News, March 23, 1960.

"Analysis of Experimental Radiation Effects Data "Final Report of Edgerton, Germeshausen Grier, Inc. to Fort Monmouth, New Jersey, 1962.

"Menace of the Silent Noise," CEC/Recordings, p. 19, Fall Issue 1959.

"Electronic Components for Ground Equipment," R&D Project Card, DD Form 613-1, Project No. 5578, 29 Jan. 1960.

"Tulane Studies on the Effects of Flickering Light on Human Subjects,: Bach, L. M. N., Sperry, C. J., Jr., and Ray, J. T., ERDL Tulane Symposium on Flicker (Bach, L. M. N., Ed.) Dept. of Physiology, Tulane Univ. School of Medicine, April 1957.

"A Variety of Familial Light Sensitive Epilepsy," Daly, D., Siekert, R. G., and Burke, E. C., EEG Clin. Neurophysio., Vol. 11, p. 141, 1959.

"Photic Activation and Photoconvulsive Response in a Non-Epileptic Subject," Davidoff, R. A., and Johnson, L.C., Neurology. In Press.

"Psychophysiology and Motivation," Lindsley, D. B., Nebraska Symposium on Motivation, p. 44, (Jones, R., Ed), Lincoln, Neb., Univ. of Neb. Press, 1957.

"The Clinical and Theoretical Importance of EEG Rhythms Corresponding to States of Lowered Vigilance," Roth, B., EEG Clin. Neurophysical., Vol. 13, p. 395, 1961.

"Pattern, Stability, and Correlates of Photic Electroencephalographic Activation," Ulett, G. A., and Johnson, L. C., J. Nerv. Ment. Dist., Vol. 126, p. 153, 1958.

6. FACILITIES

6.1 Melpar, Inc.

Melpar, Inc., a subsidiary of Westinghouse Air Brake Company, is engaged in research, development, and production of electronic, electromechanical and chemical systems and components. Important programs have been undertaken in reconnaissance, simulation and training, data handling, radar, communications, antennas, special test and analysis equipment, countermeasures, detection and identification, the physical sciences, and space and missile electronics. Experience in these areas has resulted in a completely integrated industrial facility capable of (a) efficiently executing all phases of electronic systems development from analysis and research to engineering and production, (b) performing basic and applied research in the fields of electronics, chemistry, physics, solid-state physics, physical electronics, chemical warfare, and life sciences, and (c) manufacturing equipments and components that range in size from subminiature components to the largest flight simulators.

Since its establishment in 1945, Melpar has become the largest industrial organization in the Washington, D. C. area. Sales during 1963 amounted to approximately $65 million. About 748,000 square feet of floor space is available in Melpar plants in northern Virginia (near Washington, D.C.) and Oklahoma City, Oklahoma. Subsidiaries of Melpar include Television Associates of Indiana; Melpar West Virginia Corp. with plants in Fairmont and Beckley, West Virginia; and the Microwave Physics Corp. of Garland, Texas. Corporation executive offices are located at Melpar's main plant in Falls Church, Virginia near Washington,

D. C. (See figure 1.)

Melpar employs about 3000 persons. Approximately 800 are professional scientific and engineering personnel, e.g., chemists, physicists, mathematicians, aerodynamicists, mechanical engineers, electronic engineers, production engineers, and field service engineers.

Melpar consists of several operational groups supported by administrative and service groups as described below. (See figure 2.)

Operational Groups

Engineering

This operational group, reporting to the Vice President for Engineering, consists of the Electronics Division, the Aerospace Division, the Special Products Division, the Technical Services Division, and the Technical Staff.

Electronics Division: The Electronics Division is primarily concerned with the study, design, development, and fabrication of prototype electronic and electromechanical devices. It is composed of four departments: Communications, Computer, Intelligence, and Reconnaissance/Radar.

Aerospace Division: This division, established in 1961, offers systems analysis, engineering and integration, as well as design and fabrication of payloads for space vehicles and probes. The Aerospace Division is functionally organized into three departments: Systems Analysis, Vehicle, and Payload.

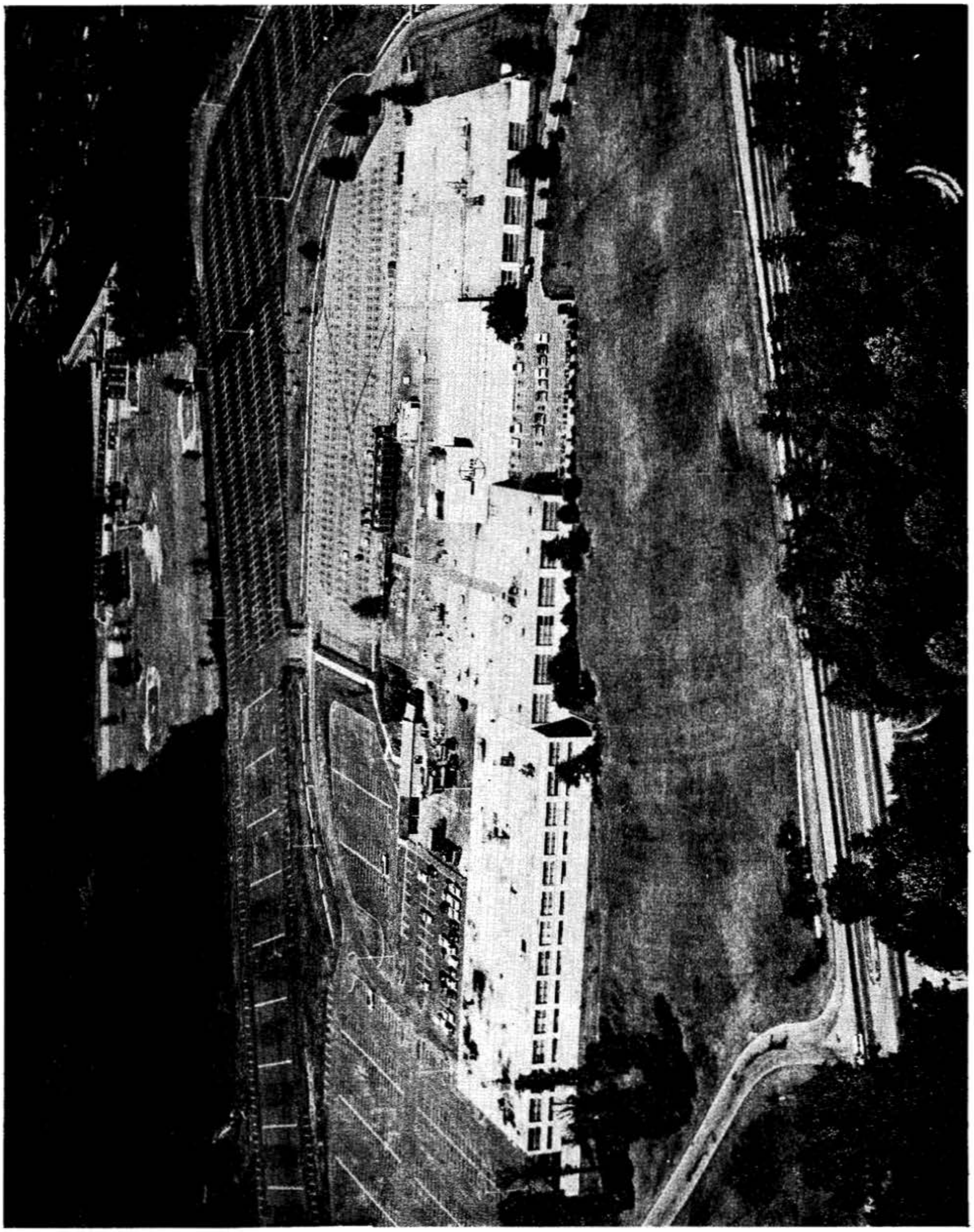

Figure 1. Melpar, Inc., Falls Church, Virginia

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Special Products Division: The Special Products Division was established in 1959 to bring Melpar's materials, services, and products to the commercial electronics market. Drawing on Melpar's experience in electronic research and development, the Special Products Division has produced a varied line of products and services which have many applications throughout the electronics industry.

Products now being marketed include frequency standards (now used in many space probes), photoelectric devices, dielectric materials (Melfoam), ceramic adhesives (Melbond), casting resins (Melpak), insulating varnishes (Melvar), silicone rubber coatings (Melcoat), and marking compounds (Mel-Ink).

Through market and product analysis, and application and engineering studies, the Division conducts a continuing program of expansion of existing product lines and introduction of new products.

Technical Services Division: This division consists of the Publications, Drafting, and Field Service Departments. Publication and Drafting services are provided to other divisions and departments within the Company as well as to various Government agencies. The Field Service Department provides engineers and technicians, on a contract basis, to Government agencies. The services of these field service personnel may be utilized anywhere in the world.

Research Division

The Research Division, reporting to the Vice President for Research, conducts basic and applied research in electronics, chemistry, physics, solid-state physics, physical electronics, chemical warfare, and life sciences. Extensive contractual experience has been combined with large, independently sponsored programs in each area to produce fully equipped, fully staffed laboratories. Major contract efforts in materials development and testing, chemical warfare agent detection, miniaturized thin-film electronic circuits, and biological studies have been performed. It engages also in tasks concerned with toxicological-metabolic studies, space sciences, plasma physics, and biological-chemical satellite observation equipment.

Manufacturing Division

The Manufacturing Division fabricates Melpar-developed electronic and electromechanical equipment, ranging from missile fuzes to airborne and ground-based reconnaissance systems. The Manufacturing Division consists of six subdivisions: the Manufacturing Shops, the Model and Tool Shops, Manufacturing Control, Wiring and Assembly, Manufacturing Engineering, and Shipping. This division reports to the Vice President for Manufacturing.

For more than two years, under contracts from Autonetics, a division of North American Aviation, Inc., Melpar has been engaged in the production of ultrahigh-reliability printed circuit board assemblies and modules for the U.S. Air Force Minuteman ICBM electronics system. This production was integrated into a separate manufacturing activity -- the Minuteman Division has unique facilities located in northern Virginia and Oklahoma City, Oklahoma, which are not readily available elsewhere in industry. Its services and know-how are available to all groups within Melpar.

Supporting Organizations

Melpar's research, design, and development programs receive direct support from organizations which report directly to the Vice President and General Manager. A brief description of Contract Management and Engineering Services is presented below along with a description of Melpar's Reliability and Quality Control Directorate, Security Directorate, and Administration Directorate.

Contract Management

The major functions of this operational support group are: Contract Administration, Purchasing, and Program Management. These functions are supported by the Production Control Department. Major corporate staff functions also report to the Vice President for Contract Management including the House Counsel, the Budget Coordinator, and the Central Controls office.

Contract Administration: This directorate, reporting to the Vice President of Contract Management, processes correspondence concerning invitations to bid and transmits proposals and cost estimates to procuring agencies; it negotiates contracts following acceptance of proposals, reviews and analyzes proposed contracts, notifies operating units of contract assignment, and prepares settlement proposals upon contract completion. The contract administrators work closely with program personnel and with service organizations to ensure compliance with all provisions of the contracts. The Directorate also furnishes other departments with interpretations of contractual clauses as they relate to the various aspects of a program. Each contract administrator has the responsibility to constantly survey the financial and delivery status of each contract and to see that every attempt is made to comply with the terms of the contract. When required, he ensures that timely notifications are forwarded to the customer to inform him of any program problems or of changes required therein.

Program Management: Since 1961 Melpar has utilized the Program Management concept. Good program management is considered the key to successful job completion. A Program Manager is assigned responsibility for each individual contract within the Engineering and Manufacturing Divisions. The manager's principal responsibility is to: control the program, establish a work plan and schedule, make task assignments to participating groups, establish budgets, monitor subcontracts, and ascertain that all contractual obligations are met. With authority to cut across interdivisional lines, he continuously compares all work programs against the original work plan. At the first indication of difficulty -- engineering, manufacturing, scheduling, or budgetary -- he initiates corrective action and alerts Top Management of impending difficulty. The Program Manager is Melpar's direct customer liaison man. He is authorized to speak directly for Top Management on all matters pertaining to job progress within the scope of the contract. Contractual matters dealing with changes in such requirements as deliveries or funds are handled through Contract Administration. Melpar's organization affords every contract proper management attention through the role of the Program Manager.

To assist the Program Manager in the performance of his duties, one or more (depending on the nature and size of the project) assistants, Program Coordinators are assigned particular areas of responsibility by the Program Manager.

Production Control: The Production Control group is charged with the responsibility of planning and scheduling of the manufacturing effort, the acquisition of all components and materials, and the movement of these into appropriate operations at scheduled intervals. Working closely with the development engineers, planners derive gross requirements from drawings, parts lists, and bills of materials generated in the engineering laboratories. They then prepare requisitions for the procurement of purchased items and work orders for fabrication and assembly work in Melpar shops. The IBM 1410 data processing system is used for inventory control. Summary inventory tabulations are prepared daily.

Central Controls: Among the services provided by the Central Controls group are schedule and cost reporting (PERT), cost estimating, preplanning for customer coordination conferences, and coordination of proposals and small spares programs. This group also has responsibility for budgeting overhead expenses, which includes proposal preparation efforts and Company-sponsored research projects. In addition, the group provides executive management with a monthly report pertaining to performance of operational groups, schedule, and fiscal data.

Purchasing: The Purchasing Directorate is comprised of Open Market and Subcontract Sections, supported by a Price/Value/Cost Analysis Section. A separate purchasing section, physically located in the Minuteman Division, supports that division's procurement effort. All of these sections report to the Director of Purchasing.

Purchasing policies, records, and reports are based upon the Armed Services Procurement Regulations, Air Force Procurement Regulations, Air Force Procurement Instructions, Navy Procurement Directives, and Army Procurement Procedures. To be utilized as a Melpar supplier, a vendor must first meet the criteria established by Melpar's Vendor Reliability Program. This program is designed to ensure that our sources of supply are reliable in terms of delivery, financial responsibility, and quality of product. Quality of product acceptability of the vendor is determined by on-site surveys when required in the interests of the Government and/or Melpar. The Director of Purchasing determines, from the procurement aspect only, when on-site surveys or resurveys are required and when the necessary data can be obtained by correspondence. When on-site surveys are required, he also determines the Company functions to be represented on the survey teams; he monitors the conduct of the survey, notifies accepted vendors by letter, and advises them that the general levels of workmanship set forth in applicable Melpar standards must be maintained. Melpar supports the Government Small Business Program and attempts to place orders in labor surplus or "depressed" areas.

The Director of Purchasing reports to the Vice President for Contract Management.

Engineering Services

This operational support group, reporting to the Vice President for Engineering Services, analyzes the Company's present and potential capabilities to meet known and anticipated defense needs. He makes recommendations as to new fields for product development, performs market analyses and forecasts, maintains customer relationships with the Department of Defense, and reviews and coordinates technical presentations required by new business efforts.

Finance

Finance, directed by the Vice President and Treasurer, is responsible for general ledger accounting, cost accounting, payroll and timekeeping, accounts payable, budgetary control, accounting, accounts receivable, and supporting statements and reports. It also develops financial plans, forecasts, and policies, and prepares financial statements, reports, and tax returns for the Company.

Reliability and Quality Control

Management has provided, through a directorate organization, an effective system of total reliability and quality control. The Director of Reliability and Quality Control is responsible to the Vice President and General Manager and has the necessary authority to enforce required decisions. Through the reliability, quality engineering, purchased material control, measurement standards laboratory, test, inspection, and administration functions of this organization, all elements of Melpar contracts receive the direct attention required. The quality control and the reliability system is established in accordance with Department of Defense Specifications MIL-Q-9858, MIL-R-26484(A) (USAF), USAF Bulletin NR-515, and USAF Bulletin NR-520. The quality control system provides for statistical quality control techniques, product quality ratings, parts failure analysis, inspection and test equipment control, nonconforming material control, information feedback, and other pertinent data.

The Melpar Reliability and Quality Control Directorate is staffed with experienced personnel including engineers, technicians, inspectors, and support personnel. It provides continuous attention to the requirements of reliability and quality. Because the Directorate is organizationally independent from other operating groups, it is in a desirable position to make objective evaluations and to guarantee the generation of quality products on a timely and economical basis.

Administration

This directorate is responsible for internal administration and control as well as for providing special administration services to the corporation. Reporting to the Vice President and General Manager, the directorate consists of five functional organizational groups: Data-Processing Systems and Operations, Management Analysis, Office Services, Personnel, and Plant Engineering.

Security

Security, a directorate independent of other Melpar support functions, reports directly to the Vice President and General Manager and is under the security cognizance of the Inspector of Naval Material, Baltimore, Maryland.

The Security Directorate is responsible for obtaining Company personnel and visitor security clearances and for the control of classified documents and mail summaries.

The Security Guard, headed by the Captain of the Guard, polices all unlocked entrances to the various Melpar buildings, is stationed in restricted areas, and patrols within the buildings. The Guard, maintained 24 hours a day, is supplemented by electrical detection devices.

Classified material is controlled by a receipt system; couriers and drivers who carry classified material conform with the regulations set forth by the Department of Defense Industrial Security Manual and Melpar's Procedures Manual.

Resident Air Force Officer

Melpar has at its main building a resident Air Force representative who, under the interservices agreement, has cognizance of all phases of contract management and who audits for all the military services. This contractual office, headed by [redacted], includes for management branches: Contract Administration Branch, Production Branch, Industrial Property Branch, and Quality Control Branch. The personnel complement includes a resident auditor [redacted], who has complete audit responsibility for all military contracts at Melpar.

The address of the Air Force Representatives at Melpar is:

Melpar Air Force Contract Management Office
Philadelphia Air Force Contract Management District
Eastern Contract Management District
3000 Arlington Boulevard
Falls Church, Virginia

Melpar Subsidiaries

Television Associates of Indiana, Inc. (TAI)

In 1961, Television Associates, Inc. was merged with its subsidiary, Television Associates of Indiana, Michigan City, Indiana and became a subsidiary of Melpar.

This subsidiary is well established nationally and internationally in telecommunications engineering. Currently, TAI is expanding its operation for providing technical assistance to underdeveloped countries as well as operating and providing maintenance and training for telecommunication systems.

TAI has contracts with the Agency for International Development to provide systems engineering for point-to-point microwave communication networks in Pakistan, Turkey, Iran, Laos, Vietnam, and Thailand. This engineering work involves site surveys, specification preparation, installation supervision, system test and operation, and the training of customer personnel. In addition to foreign operations, TAI is engaged in aerialterrain surveys for highways, pipelines, and microwave links for numerous customers in the United States.

Melpar West Virginia Corporation

The Melpar West Virginia Corporation, a wholly owned subsidiary, was established in 1963 to provide additional production capabilities for electromechanical equipment. It operates two plants, one in Fairmont, West Virginia, the other in Beckley, West Virginia.

Microwave Physics Corporation

The Microwave Physics Corporation of Garland, Texas, became a subsidiary of Melpar in 1962. The Corporation designs and manufactures microwave components and subsystems for companies engaged in both commercial and military electronics.

6.2 Applicable Research Division Facilities

The detailed organizational and physical facilities described herein are considered of special importance to the performance of the proposed prime contract for Unconventional Weapons.

Research Division

The Research Division, reporting to the Vice President for Research, conducts basic and applied research in electronics, chemistry, physics, solid-state physics, physical electronics, chemical and biological warfare, and life sciences. Extensive contractual experience has been combined with large, independently sponsored programs in each area to produce fully equipped, fully staffed laboratories. Major contract efforts in materials development and testing, chemical and biological warfare agent detection, miniaturized thin-film electronic circuits, and life sciences studies have been performed. It engages also in tasks concerned with toxicologicalmetabolic studies, space sciences, plasma physics, and biological-chemical satellite observation equipment.

The Research facilities are modern and extensive. Completely instrumented laboratories exist for research in all areas of classical and contemporary sciences. Representative of the range and versatility of the Division's facilities are the Chemistry, Life Sciences, Physics, and Materials Laboratories.

Electronics-Physics Research Center

The Electronics-Physics Research Center is engaged in pure and applied research in an extensive program associated with the present and future needs of electronic systems.

The Electronics Research Laboratory is nationally known for its successes in speech bandwidth compression systems. In addition, research is in progress on scatter propagation at vhf via ionospheric perturbations; the propagation of waves through media characterized by a homogeneous but random distribution of refractive index; the development of a high-efficiency optical voice communication system; and signal analyses employing pattern recognition techniques.

The Applied Science Laboratory performs applied research in electronic systems, electronic components and circuits, and electronic applications to geosciences. Novel detection systems responsive to the requirements of the military encompass the fields of seismics, acoustics, infrared, and electro-magnetic radiations. Bright light sources of extremely high efficiency produced by using microwave pumping with a plasma jet are particularly interesting. Also, the laboratory has an excellent materials evaluation section which performs precision electrical, thermal, and mechanical measurements.

The Physics Section is pursuing research and development in waves in gaseous and solid-state plasmas, improved gas lasers including the generation of new wavelengths, and other special plasma phenomena. The group is investigating new device concepts originated at Melpar, such as the beatron, the plasma beam dielectric amplifier, and the plasma scanner.

The Materials Laboratory has the following major areas of interest. Metallurgical research and engineering includes basic physical metallurgy, materials selection and fabrication, high-strength-high-pressure materials, cryogenic applications. Plastics and ceramics are being rigorously studied for fabrication and application. In addition, the optical areas include photometry, spectral measurements, image converters, filters, infrared and ultraviolet detectors.

The Physical Electronics Section provides major efforts in the research and development of techniques for the vacuum deposition of metal, semiconductor, and dielectric thin films; and secondly, the study of the electrical, optical, and mechanical properties of the films singly and in combination with other films. A large activity is involved in the development and production of techniques for fabrication of active and passive thin-film components as integrated thin-film functional circuits.

Physics Section

The Physics Section is pursuing research and development in the following areas:

a. Plasma Physics:

(1) Waves in gaseous and solid state plasmas: This current investigation deals primarily with the area of growing waves in plasmas. Both theoretical and experimental work has been performed in the microwave frequency range with hopes of ultimately generating millimeter wavelengths. From this work new concepts have evolved in working backwards towards millimeter waves from the infrared region.

(2) Gas Lasers: Development on this area centers on increased power output from gas lasers and on the generation of new wavelengths. Also time and spatial coherences (frequency stability) are topics of investigation. Little effort is being expended in the area of modulation techniques.

(3) Other Plasma Phenomena: Re-entry plasma studies have been conducted in the past using a radio frequency generated plasma to simulate the actual heating conditions. Fundamental breakdown studies at radio frequencies have also been performed and are a current topic of investigation. Considerable vacuum equipment and r-f plasma generators are available for any fundamental studies in this broad area. The section will not be engaged in magneto hydrodynamics plasma or ion propulsion, thermo-nuclear plasmas, or other fields beyond the scope of the present capabilities and facilities.

b. Electron, Ion and Neutral Beam Ballistics:

(1) Design of special purpose electron guns.

(2) Interaction of electrons and/or ions with neutral beams.

(3) Special (not high energy) electron ballistic problems.

c. Plasma, Vacuum, and Solid State Devices:

Examples are the Behtron, Plasma-Beam-Dielectric Amplifier, Plasma Resonance Scanner, etc.

Electronics Research Laboratory

The Electronics Research Laboratory is pursuing research and development in the following areas:

a. Speech Bandwidth Compression: Research and development leading to speech bandwidth compression systems capable of communicating speech at an information rate and bandwidth reduction of 40 times and possessing the quality and articulation of good telephone communications.

b. Pattern Recognition: Research and development of mathematical pattern recognition techniques that utilize the formation of a matched filter based on a pattern memory developed during a learning program and the recognition of unknown events in terms of the set of memorized patterns. The techniques developed utilize the expression of patterns in the form of vectors in an n-dimensional space and the computation of distribution functions of such vectors. The method has successfully been applied to automated word recognition and speaker recognition and to events characterized by certain infrasonic and underwater sound signature. The technique developed is applicable to virtually any pattern recognition problem.

c. Ionospheric Physics: Research into the scatter propagation at VHF frequencies via ionospheric perturbations.

d. Communications Theory: Research and study into the propagation of waves through media characterized by a homogeneous but random distribution of refractive index.

e. Optical Communications:

(1) Development of a high efficiency optical voice communication utilizing the transmission of zero-axis crossings by means of a GaAs injection laser. (Model for demonstration has already been perfected).

(2) Development and operation of a high-power pulse laser retro communication link to the S-66 satellite for general optical communications studies and particularly for studies of the variability of optical path attenuation over the link to and from the S-66 satellite.

Materials Laboratory

The Materials Laboratory is concerned with the testing and application of various materials (plastics, metals, ceramics, etc.) in situations to determine whether the material is suitable for use in the area for which it is being considered. The Laboratory is made up of: the Materials Applications Branch, Metallurgy, Ultra High Pressure, and Ceramics. Discussions of these groups follow.

Materials Application Branch

Materials Applications at Melpar brings about the timely union of modern materials technology with modern materials engineering know-how. All major fields of materials technology are brought to bear on the solutions of materials applications problems and all types of materials are considered--from plastics to ceramics. For re-entry applications, ingenious antenna designs have been developed which incorporate combinations of ceramics, plastics, plastic foams and refractory metal materials.

Plastic foams are used also to protect delicate components and electronic assemblies exposed to extreme vibration. Melpar's Materials Applications has mastered the plastic foam technique and can properly select and use plastic foam materials which will provide optimum dielectric, heat resistance, dampening and mechanical properties best suited for a specific engineering design.

In the area of packaging, current emphasis is being given to the packaging of high reliability microcircuitry for use in the hyper-environments encountered in space exploration. Packages for both thin film and solid-state circuitry are being developed and will be put into use shortly. Already, Melpar has established a unique capability for packaging radiation detection devices. Specifically designed to detect ultraviolet, gamma and X-ray radiation, these devices are being used throughout the world for upper atmosphere radiation studies and space exploration.

Metallurgy

The Metals Group attacks a wide variety of metallurgical problems; from the investigations of metals failure to the development of unique methods for metals joining. Complete facilities are available for diffusion studies, grain boundary migration, solid state transformations and dislocations, and precipitation studies. The facilities include:

1. Complete Automet grinding and polishing equipment for specimen preparation of materials ranging from lead to sapphire.

2. Bench microscopes for micro and macro examination.

3. Completely equipped Bausch and Lomb Research Metallograph.

4. Kentron Microhardness Tester.

High temperature space-age materials: refractory metals, intermetallics, and specialized alloys can be studied in controlled environments such as vacuum, inert gases, and reducing atmospheres. Current programs involve the development of techniques for brazing, sintering, diffusion bonding, and recrystallization of refractory metals.

Augmenting conventional metallographic equipment, are a 2 high - 4 high rolling mill and a swaging machine for determining the fabricability of experimental alloys.

Ultra High Pressure

Ultra High Pressure is an exciting new materials research tool at Melpar. Pressures up to 100 kilobars (1,500,000 psi) are being used to discover and understand many of the mysteries of solid state processes, phase equilibria, chemical reactions, mineral formations and inner earth geology. Husky high pressure equipment essential for the formation of many synthetic mineral structures together with unique high pressure devices used in infrared, visible, and X-ray studies of materials under pressure for the extended range of Melpar's high pressure research. Both diamonds and emeralds have been synthesized at Melpar using high pressure techniques. Silicate mineral synthesis at high pressure optics has led to the development of techniques which permit direct observation at room temperature of the high pressure crystals forms of: ice, benzene, carbon tetrachloride, ethyl alcohol and other organic and inorganic materials.

Ceramics

Melpar's Ceramic Materials Group is well versed in most areas of high temperature technology. This capability includes the synthesis of new or special high temperature materials, fabrication techniques, firing techniques and characterization of ceramic materials and products.

The growth of single crystals of highly refractory materials by induction plasma fusion and the Vernuli technique is also included in this capability.

A prime example of our experience in high temperature materials synthesis is our work in rare earth compounds including oxides, carbides, borides, mitrides and silicides. Several new materials have been synthesised using solid state techniques at elevated temperatures. These have in turn been characterized by X-ray and other techniques, and have been fabricated into sintered compacts. Various physical properties have been determined from these compacts.

All types of refractory inorganic materials can be fabricated into finished parts at Melpar by all the usual ceramic fabrication techniques. This includes slip casting, extrusion, isostatic compaction and pressing as well as flame and plasma spraying, hot pressing and others. Most of the rare earth borides and carbides fabricated at Melpar are made by hot pressing. Studies are continuously being made on the fabrication and sintering of all types of ceramic materials. These include specialized materials for electronic and nuclear application as well as general high temperature applications.

Considerable research and development by the ceramic group resulted in the capability to produce a wide variety of light weight ceramic materials. These foams have found usage as light weight dielectrics, insulating brick, catalyst carriers, nose cap materials, etc.

The capability of this group covers the gamut of materials and processes from the more conventional ceramics for every day usage to the highly specialized materials and the sometimes unusual fabrication techniques required for space age applications.

Applied Science Laboratory

This laboratory is engaged in applied research in technological areas as implied by the titles of its four sections: Detection Systems Section, Evaluation Section, Opto-Electronics Section, and the Electronics Section. Descriptions of these groups and their responsibilities follow.

Detection Systems Section

The objective of Detection System Research is to conduct experiments and build breadboards to establish the feasibility of novel detection ideas responsive to the requirements of the military. These detection ideas encompass the fields of seismics, acoustics and electromagnetic radiations.

As a result of Detection System Research, several operational detectors have been developed. Following is a list and brief description of some of the devices.

Seismic Personnel Intrusion Detector: This is a small, rugged, passive device which detects and analyzes the seismic disturbances created by personnel footsteps. A standard unit, model M1-4, is suitable for detecting the presence of humans at distances up to 20 meters. The device is resistant to false triggering from natural sources, and has an output circuit which can operate many alarms directly. Designed for all weather usage, the unit can be completely buried in the ground. Self contained penlight batteries in the 18 cubic inch device supply power for 10 days of continuous operation.

Seismic Vehicle Intrusion Detector: This is a small, passive device which detects, analyzes and responds to seismic disturbances created by moving vehicles. This system is very resistant to false signals from personnel and natural disturbances, and responds to heavy vehicles at distances out to 200 yards. Since heavy vehicles generally create a larger disturbance than light vehicles, some degree of vehicle discrimination can be accomplished by adjusting the system sensitivity. The vehicle detector contains two "D" cells which supply power for 30 days continuous operation. The unit is completely encapsulated so that it can be operated while buried.

Infrared Vehicle Detectors: Both active and passive infrared vehicle detectors have been developed through detection research. The classified nature of these devices prohibits a detailed discussion of their operational characteristics. However, one unclassified area of interest is in light choppers. In conjunction with the active system, Melpar developed a small inexpensive, stable light-chopper. Total power requirement for the unit is approximately 100 milliwatts.

Gunshot Detector: Melpar has developed a gunshot detector which can be used in an environment of very high sound level such as encountered on helicopters and fixed wing aircraft. This is an ultrasonic device which operates at approximately 40 kc, and responds to the shock wave produced by the bullet or muzzle blast. Since the wavelength of operation is short, a single detector can be made very directional, and several detectors can be used in an array to give hemispheric coverage with good directional resolution.

Evaluations Section

The Evaluations Section of the Applied Sciences Laboratory is primarily concerned with the evaluation of material characteristics. The basic measurements performed by the staff include dielectric constant and loss over a wide frequency range, volume resistivity of both conductors and insulators, thermal expansion, thermal conductivity, specific heat, emissivity, and mechanical properties such as tensile, flexural, and compressive strength. These are all conducted at elevated temperatures up to 3000°F and some are carried out at temperatures as low as that of liquid nitrogen.

These measurements are conducted as a fixed price service for several dozen private companies. In addition, the same types of measurements are conducted for Government agencies such as the Air Force or NASA.

The Evaluations Section has developed a competence in instrumentation which has resulted in the design of equipment that can be sold commercially, for example the X-band dielectrometer. The ability of the staff to design special purpose heating equipment has been used as a support function to other departments in Melpar performing contracts. Both the JPL chromatograph and the current Apollo effort have drawn upon the talents of this group.

Currently the Section is providing a survey type effort for the Research Technology Division on the use of nonmetallic inorganic refractory materials as an elevated temperature radome.

Opto-Electronics Section

The objectives of this section are given following:

a. To develop a cw bright light source of extremely high efficiency by using microwave pumping in conjunction with a plasma jet. The light emitted is concentrated in a relatively narrow band, from 50 to 300 Å wide. So far, bright light sources have been made to operate in the yellow, the green, the red, and the blue. It is possible to develop a source anywhere in the visible or infrared. This source will emit in all directions. Efficiencies obtained in preliminary experiments have been 150 lumens/watt. They should be doubled with better design of the microwave cavity. Brightness levels obtained have been of the order of 2 million foot-lamberts. These sources can also be pulsed at kc rates and are particularly suitable for coding.

b. To develop a high intensity vapor laser to operate on the same principle as the solid state ruby laser with pumping to be carried out by microwaves. Average output power should be 1 kw with peak pulses in the multimegawatt range. No cooling would be required and operating wavelengths would be in the long side of 5600 Å.

c. To develop a means for coherent coupling of laser beams. This will be done by using one laser beam to influence a medium such as a plasma, a dielectric or vacuum, and have the medium in turn effect another laser beam.

Electronics Section

This section is engaged in applied research in the following electronically oriented areas: Electronic systems, electronic components and circuits, electronic applications to geosciences, and pattern recognition and data handling.

In electronic systems, investigations have been conducted in topics associated with electronic warfare research, including ECM susceptibility of compressed pulse radar and digital communications systems, and ECCM Techniques in FM voice Communications. The group has prepared proposals in the areas of Hazard Monitoring Systems for NASA KSFC, and a special-purpose Hydrogen Hazards Detection and Monitoring System. Areas of principal interest are: electronic countermeasures and counter-countermeasures, reconnaissance, surveillance, communication, radar, intelligence, and hazard monitoring and evaluation systems.

The Electronic Components and Circuits group is working on the conception and application of new circuitry techniques. Its specialty is the microminiaturization of analog and digital electronic systems such as analog-digital converters, vocoders, and the electronics for the Apollo Gas Chromatograph, which is presently being developed. Other studies, proposals, and developments include electronic instrumentation systems for gathering and processing data of meteorological and biological origin.

The Geosciences group has developed a new, toroidal sensor for magnetotelluric investigations. This device is presently gathering data which will be evaluated and used as the basis for proposals concerning telluric currents, geomagnetism, earth and lunar crust structure, and ocean conductivity at enormous depths. The group is interested in seismic studies, including the development of new sensors such as an electron-beam seismometer, and an interferometer accelerometer. Work is in progress on a study of plasma-sheath electromagnetic radiators and reflectors.

The Pattern Recognition and Data Handling group has worked on a device called DIMUS which was the application of a particular signal processing technique to the outputs of large arrays of seismometers. Hardware was simulated on a general purpose computer. Programming assistance was provided to the General Electric Co. in the simulation of an attack by various agents on selected targets. Other studies have been conducted toward the development of abstract descriptor functions for pattern recognition, BW/CW Threat Analysis, and Reference Coding in Information Retrieval Systems.

Physical Electronics Laboratory

The major efforts of the Physical Electronics Laboratory are (1) research and development of techniques for vacuum deposition of metal, semiconductor, and dielectric thin films; (2) study of the electrical, optical, and mechanical properties of the films singly, and in combination with other films; and (3) the development and production of techniques for fabrication of active and passive thin-film components as an integrated thin-film functional circuit .

The Materials Research Branch is engaged in the formation and study of the properties of dielectric, semiconducting, and metal films. The main efforts are directed towards the successful development of thin-film capacitors and resistors capable of operation at 500°C, the fabrication of a high-impedance thin-film voltage source, study the radiation-resistant properties of thin films to radiation fields of space environments, and study of the semiconducting properties of intermetallic compounds. Further objectives are to incorporate the properties of the thin film as integral parts of thin-film circuits. The optical properties of the films were studied as a function thickness and disposition parameter .

The Micro-devices Research Branch is concerned with the formation of single and multi-layered films in order to form active electronic devices. The electronic properties of microcrystals found in films, as well as metal-dielectric and metal-semiconductor interfaces, are being studied. Areas of research currently being undertaken include: nucleation on similar and dissimilar substrates, grain growth in thin films, vacuum doping of thin films, thin layer semiconductor formation, multilayer structures (tunneling, hot electron devices), and effects of surface states. The surface studies have led to the development of a thin-film field effect device; crystallite growth studies have led to the deposition of tunnel diode crystallites; layer formation and doping studies have led to point contacts, alloy, and grown diodes. The microdevices so formed will be integrated with passive thin-film circuit components.

The Molecular Circuits Branch has the task to design and develop vacuum equipment and deposit thin-film circuits. Several circuits have been designed and fabricated. These circuits, both hybrid and completely thin film, are adaptable to most low-power analog or digital applications. The capability for fabrication of thin-film circuits is developed from a wide range of materials and geometrical configurations. The primary result has been the design and development of a production plant for thin-film circuits.

At present the plant is partially automatic; by the end of the year it will be completely automated. The system has advantages of high versatility, short set-up time, high operating temperatures, provision for large numbers of masks and sources (or film materials), high yield, and a capability for processing large quantities of circuits in a single evacuation. Two units are in operation and a third is ready for assembly in the Manufacturing Division. A pilot run for hybrid circuits containing several 3% resistors and several soldered-on bulk components has been initiated. It is expected that the plant will be available for sale or lease in the near future.

APPENDIX A

DAZZLING BY LASERS AND HIGH INTENSITY LIGHT SOURCES

ABSTRACT

The potentialities of lasers and high intensity light source have been investigated for the production of dazzling and scotomatic glare. It is found that high intensity light sources are to be preferred, both for luminance-time product and for efficiency.

Using the basic physiological data from the sources mentioned in the report, together with the luminance-time capabilities of the various light sources, a number of graphs have been drawn exhibiting the relative glare capabilities of lasers and high intensity light sources.

Xenon flash lamps are shown to be the preferred type of source, followed by High Intensity Carbon Arcs and Photo Flash Bulbs. A typical large xenon flash lamp (the FX-56) has a useful output of about 50,000 lumen-seconds. This enables an area of 5200 ft^2 to be exposed at a range of over 1000 ft., with indefinitely long recovery time when flashing at the rate of only once every few seconds. It is feasible to flash this lamp at rates in excess of 1 p.p.s.

Lasers are shown to be relatively poor sources for the present application, even when invoking considerable system complexity. It is shown to be feasible to build a stacked blinking laser array which will cover an area of over 100 ft^2 with indefinitely long recovery time. However, the system

complexity, especially the laser head array, is quite great, and the performance can be easily surpassed by simple divergent beam, high intensity light source systems.

1. THE NATURE OF THE STUDY

We have investigated the potentialities of coherent and incoherent sources of luminance (lasers and high intensity light sources, respectively) for field use in producing dazzling and scotomatic glare. The basic physiological data utilized has been that compiled by Metcalf and Horn[1] and Miller and Fry[2].

Our study is sharply divided into two classes, those of Lasers and High Intensity Light Sources. Although coherency in itself has not been shown to have any physiological effect bearing upon glare, it is convenient to treat lasers separately in order to demonstrate their fundamental limitations and advantages most clearly.

Our laser studies are confined solely to the ruby laser, which is the only practical source of intense, visible coherent radiation presently available. Several types of high intensity light sources, on the other hand, are available, a number of the most practical receiving consideration in this report. In neither the case of the laser nor the high intensity light source have we discussed the fundamental principles of light generation, as such treatments are not believed to be germane to the present study. What we do discuss in each case are the practical considerations having a direct bearing upon glare

1. "Visual Recovery Times From High-Intensity Flashes of Light," by Robert D. Metcalf, Capt. USAF(MSC) and Richard E. Horn OD (WADC Technical Report 58-232. ASTIA Document No. AD 205543.

2. "Visual Recovery from Brief Exposures to Very High Luminance Levels," by Norma D. Miller andGlenn A. Fry (Contract No. XF 33(657)-9229, USAF School of Aerospace Medicine, Aerospace Medical Division (AFSC), Brooks AFB, Texas).

systems, presenting the data in the form of easily interpretable graphs.

Our discussion is conservative throughout, centering around equipment and components which exist or can be designed and constructed at the present time. For example, we discuss "high" prf systems of only 0.1 joule per pulse output, mentioning the possibility of constructing equipment extending to 1 joule per pulse. In the present literature, on the other hand, systems of 1 p.p.s. extending up to 50 joules/pulse are mentioned; as we believe such a system to be impractical for immediate field use, we have given this more liberal estimate no consideration. Our approach is similar in other areas treated in this report.

The basic physiological data of importance can be summed up in two graphs. Figure 1 shows illuminance-energy ($\frac{\text{lumen-seconds}}{\text{ft}^2}$) versus visual recovery time (seconds) according the studies of Metcalf and Horn (op.cit.). The other aspect of importance is the demonstration of the importance of illuminance-energy instead of illuminance itself. The approximate validity of this concept is shown in Figure 2, after the work of Miller and Fry (op. cit.). It is unfortunate that they have used luminance-energy (rather than illuminance-energy), although this has no bearing upon showing the importance of exposure time.

A common ground for comparison of the various sources was

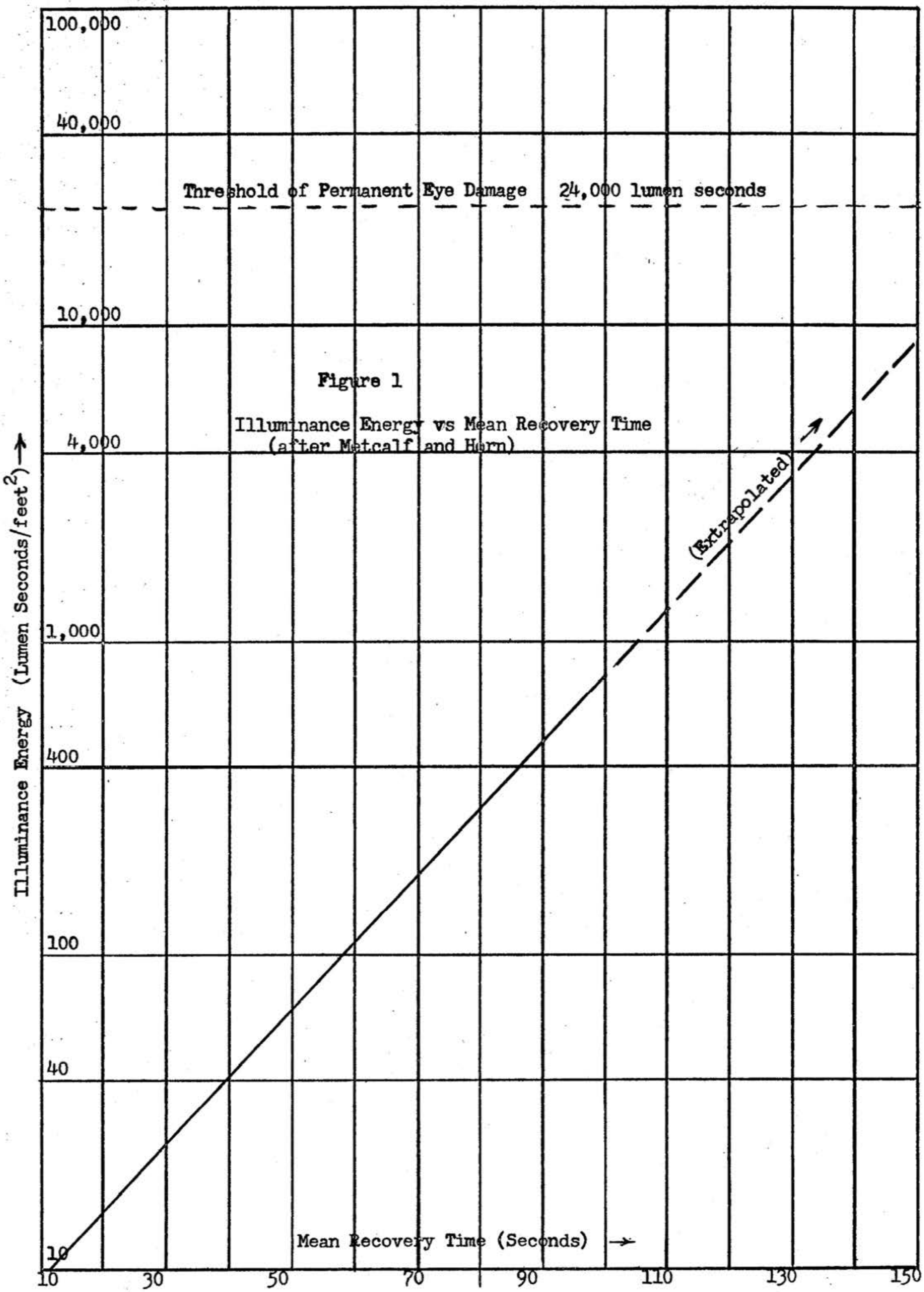


Figure 1

Illuminance Energy vs Mean Recovery Time
(after Metcalf and Horn)

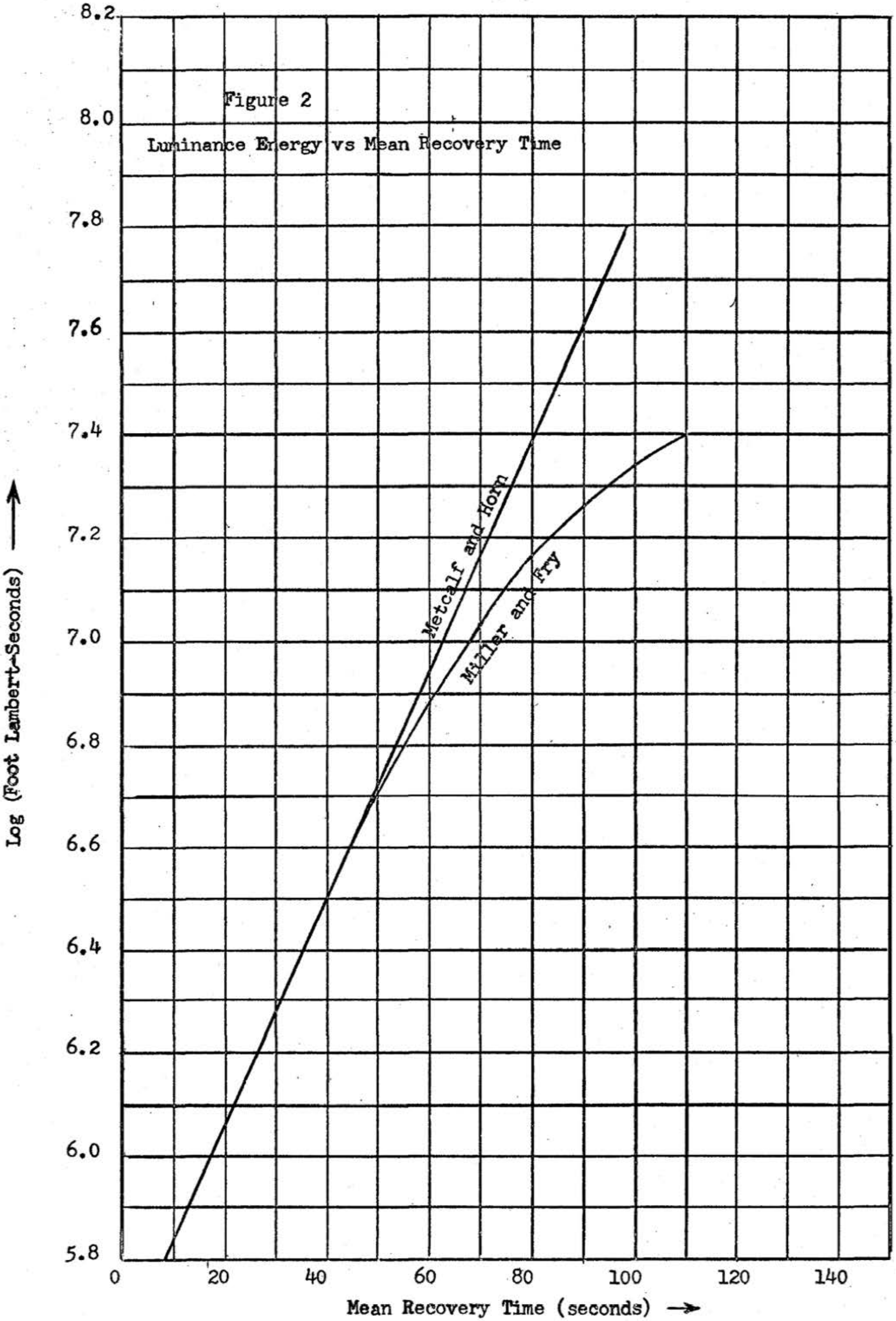


Figure 2
Luminance Energy vs Mean Recovery Time
Metcalf and Horn
Miller and Fry
8.2
8.0
7.8
7.6
7.4
7.2
7.0
6.8
6.6
6.4
6.2
6.0
5.8
Log (Foot Lambert-Seconds)
0
20
40
60
80
100
120
140
Mean Recovery Time (seconds)

founded upon the following considerations:

The illuminance-energy ($\frac{\ell\,dt}{A}$), at a target can be considered to be the amount of energy per square foot that will affect the eye and arrive during a time dt. Consider now a light source emitting in all directions. A certain fraction of this energy, k, can be collimated into a beam of some sort. For the ruby laser this fraction will be 1.0. For the extended noncoherent sources the fraction was set at 0.25, based upon figures published by G.E. for mounting of an AH6 lamp in a 25 inch searchlight. This collimated light radiates into a solid angle $d\Omega$, so that at a distance R it illuminated an exposed area $R^2\,d\Omega$.

Thus, $\frac{k\ell\,dt}{R^2\,d\Omega}$ is the illuminance energy for a given source.

Next, the curve shown in Figure 1 was expressed as the analytic function

$$i = 10^{0.02126t+.771},$$

where i is the illuminance energy needed to dazzle for a time, t .

These two terms were equated to form the algebraic expression that was used to generate the various curves

$$i = \frac{k\ell\,dt}{R^2 d\Omega}$$

Solving for $d\Omega$ tells us how well the beam must be collimated in order to dazzle a specified time for various ranges. This information is plotted in figures, 3,4,5,9,10, 11,13,14,16,17.

Some idea of the practical limitation to optical collimation can be ascertained from the performance of 60" carbon arc search lights. These devices yield a beam from a 5/8" extended arc that is collimated to 4.7×10^{-4} steradian.

Alternately, one can solve for $R^2 d\Omega$ and calculate the possible area of coverage as a function of the mean recovery time, (dazzle time). This information is plotted in figures 6, 12, 15 and 18.

For continuously operating sources the effective duration time was considered to be 0.1 second (the eye blink response time). Any battle field system would probably use some sort of shutter system with a duty time of this magnitude.

We divide our laser investigation into studies of a simple divergent beam system and scanning and stacked blinking arrays. It is easy to show that the divergent system must be rather high power, that the scanning system possesses essentially no advantages and that a properly constructed stacked blinking array can be extremely effective using an ensemble of low power laser rods. Appropriate graphs display all of the important conclusions in units which are compatible with the high intensity light source data.

In the case of high intensity light sources we present a variety of sources including flashbulbs, xenon flash tubes, high pressure mercury vapor sources and carbon arcs. In presenting their luminance-energy figures we have been very conservative, which means that optimum optical collector and collimation design will enable the values we have quoted to be exceeded, in some cases appreciably. On the other hand, no sophisticated systems are discussed, as involved systems are better used with the improved luminance geometry of lasers. Thus, we present our conclusions (in the form of several graphs) for a simple divergent beam system but for a number of different sources. Comparison of these graphs with those prepared for the laser show the general superiority of the high intensity light source. Nevertheless, on a per lumen-second basis the laser is to be preferred, and its use should not be discounted for certain situations.

In addition to what amounts to a series of photometric analyses, we give some data on the actual hardware which can be used immediately. Although we have not considered it necessary to present the most minute details, we do give information on general sizes and power requirements, in addition to discussing critical components such as capacitors, flash tubes, etc. The short period of time available for the study has prohibited the inclusion of detailed typical system configurations and the like.

Finally, we present our conclusions in which we give comparisons, recommendations, possible extensions of physiological effects and future system capabilities. We believe that this short study has definitely exposed the main points of interest, and that the conclusions obtained are valid and conservative. Further work is required for any detailed system recommendations, but the graphs presented allow an immediate determination of the present glare system potentialities of lasers and high intensity light sources.

2. LASERS AS GLARE SOURCES

2.1 Introduction

There are no really high power cw lasers, nor even high power pulsed lasers with pulse lengths approaching the blink time of the eye (~ 0.1 second). As a result, lasers suffer from the deficiency of inadequate luminance time, although their inherently high luminance causes this deficiency to be relatively minor.

At the present time all lasers of sufficiently high power to be of interest employ optical pumping. The conversion of electrical power into total light output is efficiently performed by modern laser flash lamps. Unfortunately, however, only a small fraction of this light is matched to the absorption bands of the laser material, resulting in a very small efficiency for overall conversion of prime electrical power to coherent radiation. For normal ruby laser operation the overall efficiency varies from one-half to one percent, and it is not greater than about one-tenth of a percent for giant pulse operation.

A laser does transform a rather poor luminance geometry (either a straight or coiled flash lamp) into "good" luminance geometry. This enables beams of literally any desired geometry to be formed, to be varied, to be scanned, to be stacked, etc. In addition, it allows (under good atmospheric conditions) the transport of high illuminance ($\frac{\text{lumens}}{\text{ft}^2}$) to extreme ranges. It also allows field strengths to be developed (under certain conditions) which cause catastrophic, non-thermal eye damage, although this fact is incidental to the subject of present interest.

It has been indicated that pulse recurrence rates of from 1 to 4 p.p.s. should be considered. Lasers have been built to operate up to 1. p.p.s., although several problems arise:

(1) Capacitor bank lifetime.

(2) Flashtube lifetime.

(3) Laser rod cooling.

(4) Reduced peak output.

The capacitors must be severely derated, the flashtubes must be operated much below their peak capability and must be cooled, the laser rod must be cooled to the maximum extent possible and really high energy output per pulse (tens of joules and above) must be sacrificed.

We consider first the straightforward divergent cone laser system configuration, assuming a one millisecond pulse and standard ($\sim$ 0.1 p.p.s.) and high ($\sim$5 p.p.s.) pulse recurrence rates. For the "standard" system it is possible to utilize rather high energy per pulse ($\sim$10-100 joules), while the "high" prf system must be reduced to the order of 0.1 joule per pulse. The pertinent data are presented in the form of several curves which allow quick evaluation a given set of conditions.

Next, we consider scanned and blinking stacked systems which may be of some tactical value. In the absence of a precise knowledge of the necessary and/or desired conditions, we have attempted to include a sufficiently wide range of parameters to allow adequate evaluation. Again, we present the data in the form of several curves which are believed to be conveniently arranged.

Finally, we discuss some of the mundane, but important, hardware problems involved. Basic information on special components, prime power requirements and sizes are included.

2.2 Divergent Cone Laser Systems

Luminous flux (in lumens) is given by the standard relation

$$F = \sum_{\lambda = 3800\,\text{Å}}^{7700\,\text{Å}} P_\lambda K_\lambda ,$$

where K_λ is 680 times tabulated photopic luminosites and P_λ is power in watts per 50 Å band of wavelengths. In integral terms this may be written as

$$F = \int_{\lambda_1}^{\lambda_2} P(\lambda) k(\lambda) d\lambda :$$

for a laser

$$P(\lambda) \cong P_0 \,\delta(\lambda - \lambda_0), \text{ so that } F = P(\lambda_0)K(\lambda_0) = P_0K(\lambda_0) \;.$$

It would be more precise to utilize Lorentzian line shapes for the laser spectrum, but $K(\lambda)$ is a slowly varying function and it would be a trivial refinement.

The normal laser produced a spiked spectrum of several hundred microseconds duration, Melpar's standard large (6" by 5/8" rod) ruby system producing a total pulse duration of very close to one millisecond. Although Melpar's laser generates an energy approaching 100 joules per pulse, the average large "standard" system may be reasonably assigned a value of 10 joules per pulse. As previously stated, "high" prf systems are presently limited to the order of 0.1 joule per pulse.

With sufficient accuracy for the present purpose, we assign a pulse power of 10^4 watts for the "standard" prf system and 10^2 watts for the "high" prf system. For an operating wavelength of 6943 Å, $K(\lambda_0) = 104 \frac{\text{lumens}}{\text{watt}}$, giving a total pulse flux output of 1.04×10^6 lumens for the standard system and 1.04×10^4 lumens for the high prf system. As lasers are not perfectly diffuse emitters, it is well to express the source luminance in candles per square centimeter, rather than in lamberts. For an emission of F lumens, a rod area of A square centimeters and a beam of solid angle Ω , the source strength in candles per square centimeter is

$$B = \frac{F}{A\Omega} ,$$

neglecting refinements such as mode structure which are relatively unimportant for glare systems.

We assign, then, a total luminous pulse flux output of 10^6 lumens (10^3 lumen-seconds) for the standard laser and 10^4 lumens (10 lumen-seconds) for the high prf laser. It is not really necessary to establish values for the source luminance (in candles per square centimeter or in lamberts), as we use the data given in reference (1). However, we will insert some information on effective source luminance (for given divergence angles) in terms of candles per square centimeter.

According to Metcalf and Horn (op.cit.), the minimum illumination at the eye which is of interest (to give 7-12 seconds recovery time) is 100 lumens/ft^2 for a 0.1 second pulse. As the work of Miller and Fry (op.cit.) shows energy impinging upon the eye to be the important factor, a figure of 10 lumen-seconds/ft^2 is the minimum illuminance energy of interest. Obviously, then, the standard laser beam must not be spread over an area in excess of 100 ft^2, and the high prf laser beam must be restricted to 1 ft^2 area. Clearly, even the standard laser is only marginally acceptable, if our estimate of the desired area coverage is proper.

Metcalf and Horn's estimate of the threshold of retinal damage is 24,000 lumen-seconds/ft^2. This estimate agrees within a factor of about two with the minimum for microhistochemical permanent damage as given by the Surgeon General's Office. We shall, as a result, use the figure of 24,000 lumen-second/ft^2 as the marginal value for retinal damage.

As it is evident that a 10 joule laser is of only marginal use, we have also considered the use of a 100 joule laser. Although it involves a larger power supply, it is still practical to consider a prf of 0.1 p.p.s. The area covered can now be increased to 1000 ft^2 for minimum useful recovery time.

Figure 3 shows a 100 joule laser with solid angle plotted versus range, with recovery time as a parameter. Figures 4 and 5 respectively, show similar plots for 10 and 1 joule lasers. So far we have only considered single rod, simple divergent beam systems. In order to provide nearly any desired degree of scotomatic glare, a variable cone angle must be used; as is evident from figure 6 the useful exposure area suffers when increased glare levels are demanded, but this may be necessary as the tactical situation demands.

Figure 7 shows the range for retinal damage plotted versus cone angle, with laser pulse luminous flux as a parameter. It

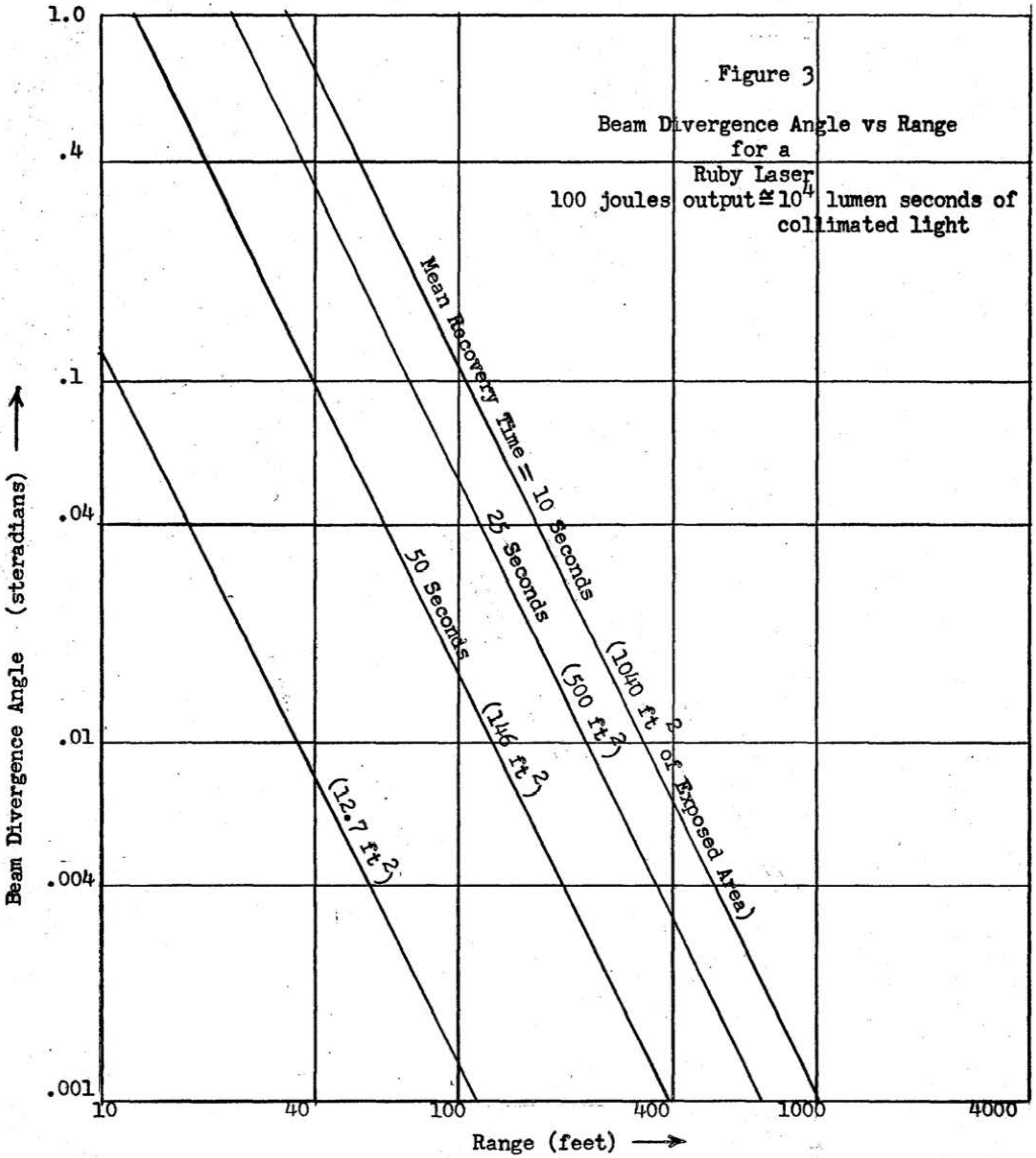


Figure 3
Beam Divergence Angle vs Range
for a
Ruby Laser
100 joules output ≅ 10^4 lumen seconds of
collimated light
Mean Recovery Time = 10 Seconds
(1040 ft^2 of Exposed Area)
25 Seconds
(500 ft^2)
50 Seconds
(146 ft^2)
(12.7 ft^2)
Beam Divergence Angle (steradians)
1.0
.4
.1
.04
.01
.004
.001
10
40
100
400
1000
4000
Range (feet)

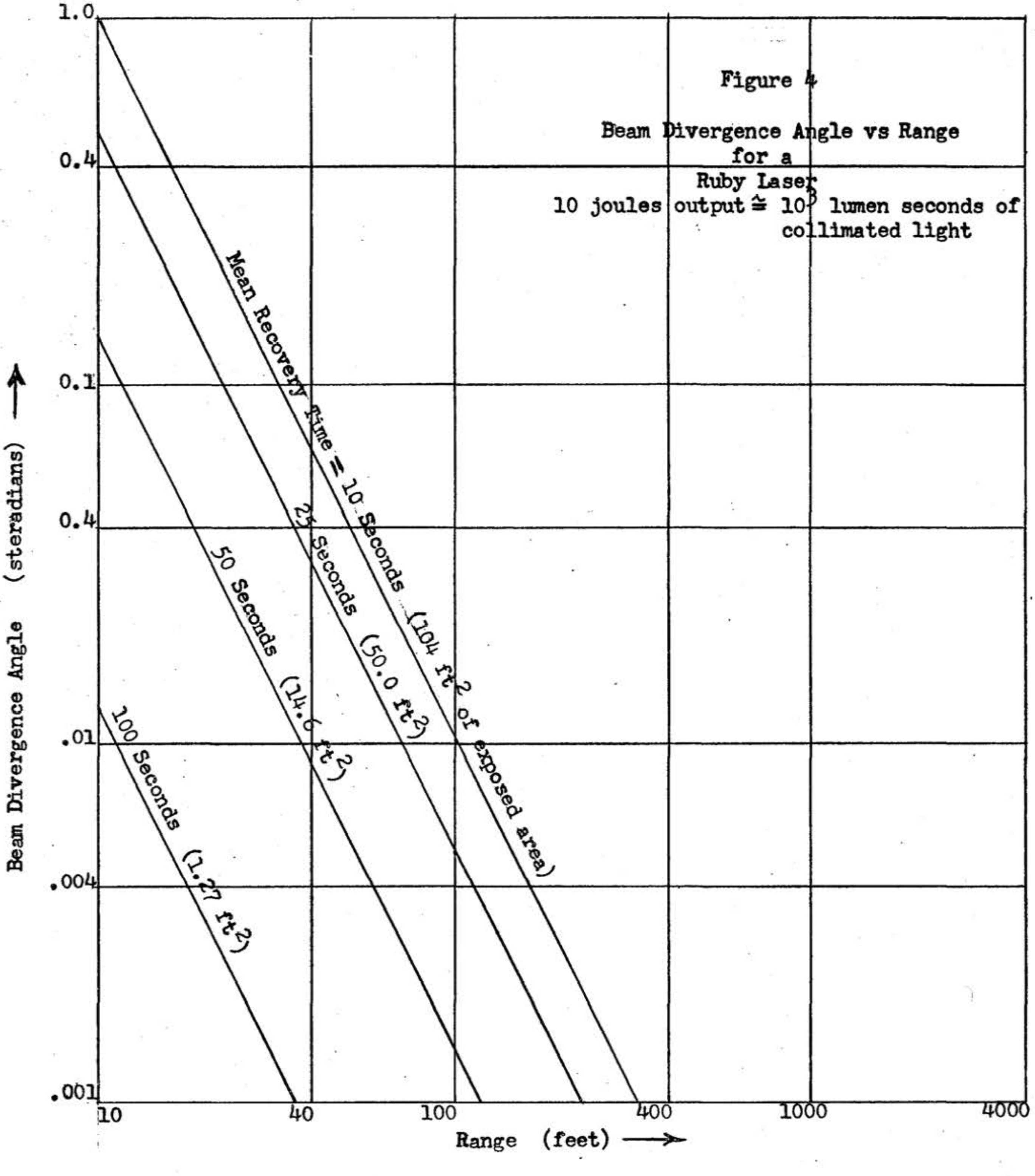


Figure 4
Beam Divergence Angle vs Range
for a
Ruby Laser
10 joules output ≅ 10[3] lumen seconds of
collimated light
Mean Recovery Time = 10 Seconds (104 ft2 of exposed area)
25 Seconds (50.0 ft2)
50 Seconds (14.6 ft2)
100 Seconds (1.27 ft2)
1.0
0.4
0.1
0.4
.01
.004
.001
10
40
100
400
1000
4000
Range (feet)
Beam Divergence Angle (steradians)

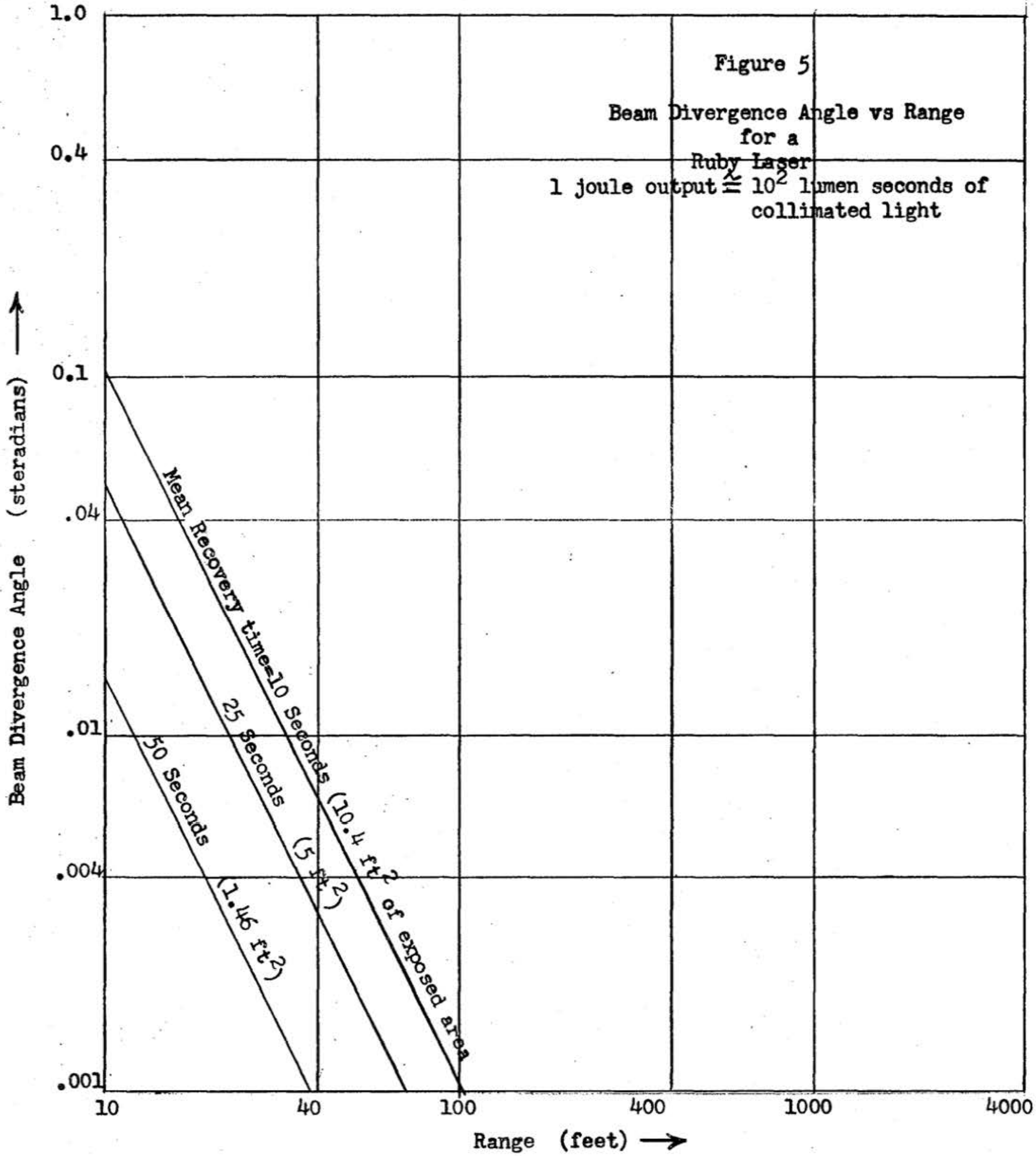


Figure 5
Beam Divergence Angle vs Range
for a
Ruby Laser
1 joule output ≅ 10² lumen seconds of
collimated light
1.0
0.4
0.1
.04
.01
.004
.001
10
40
100
400
1000
4000
Beam Divergence Angle (steradians)
Range (feet)
Mean Recovery time=10 Seconds (10.4 ft² of exposed area
25 Seconds (5 ft²)
50 Seconds (1.46 ft²)

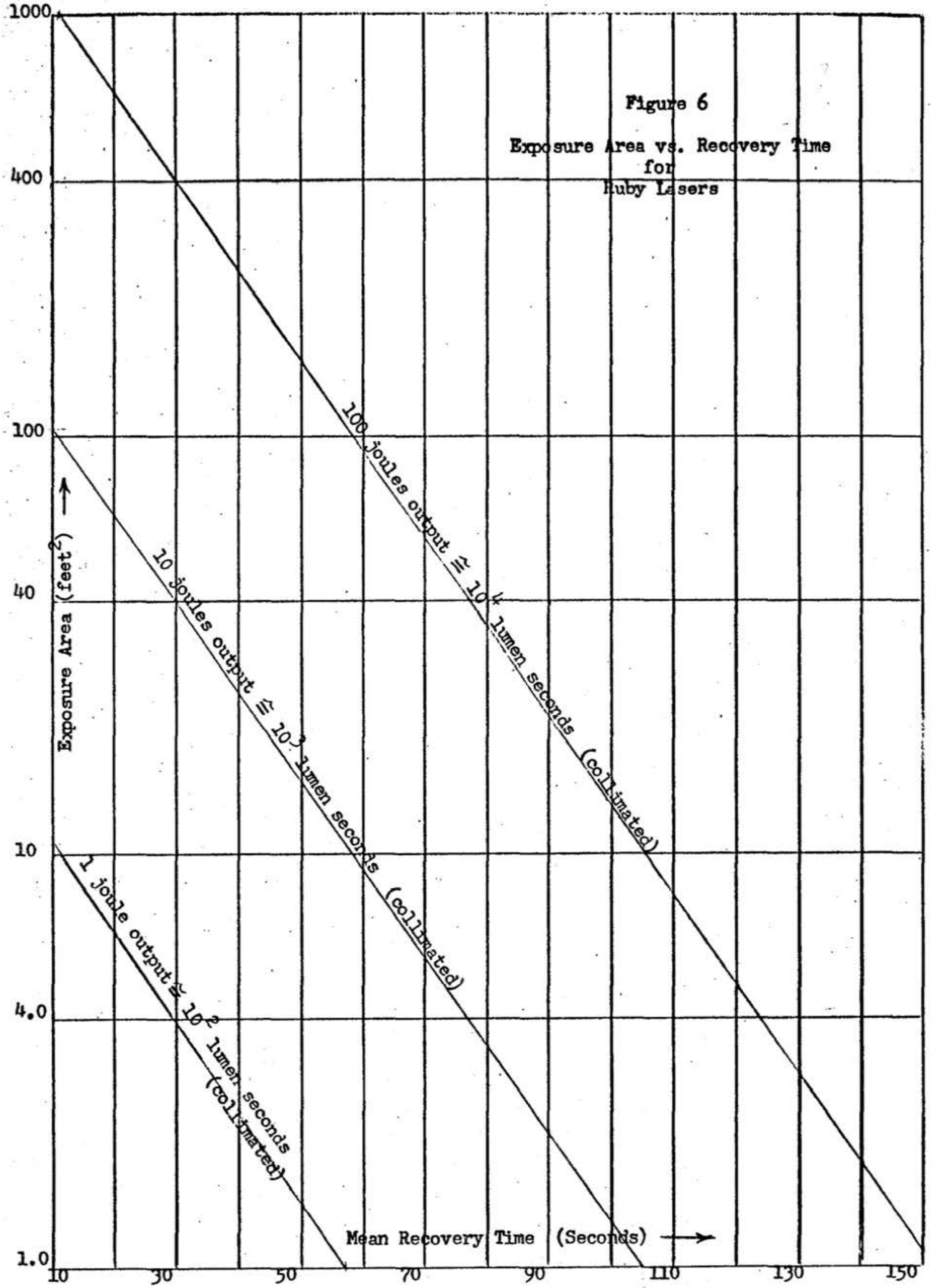
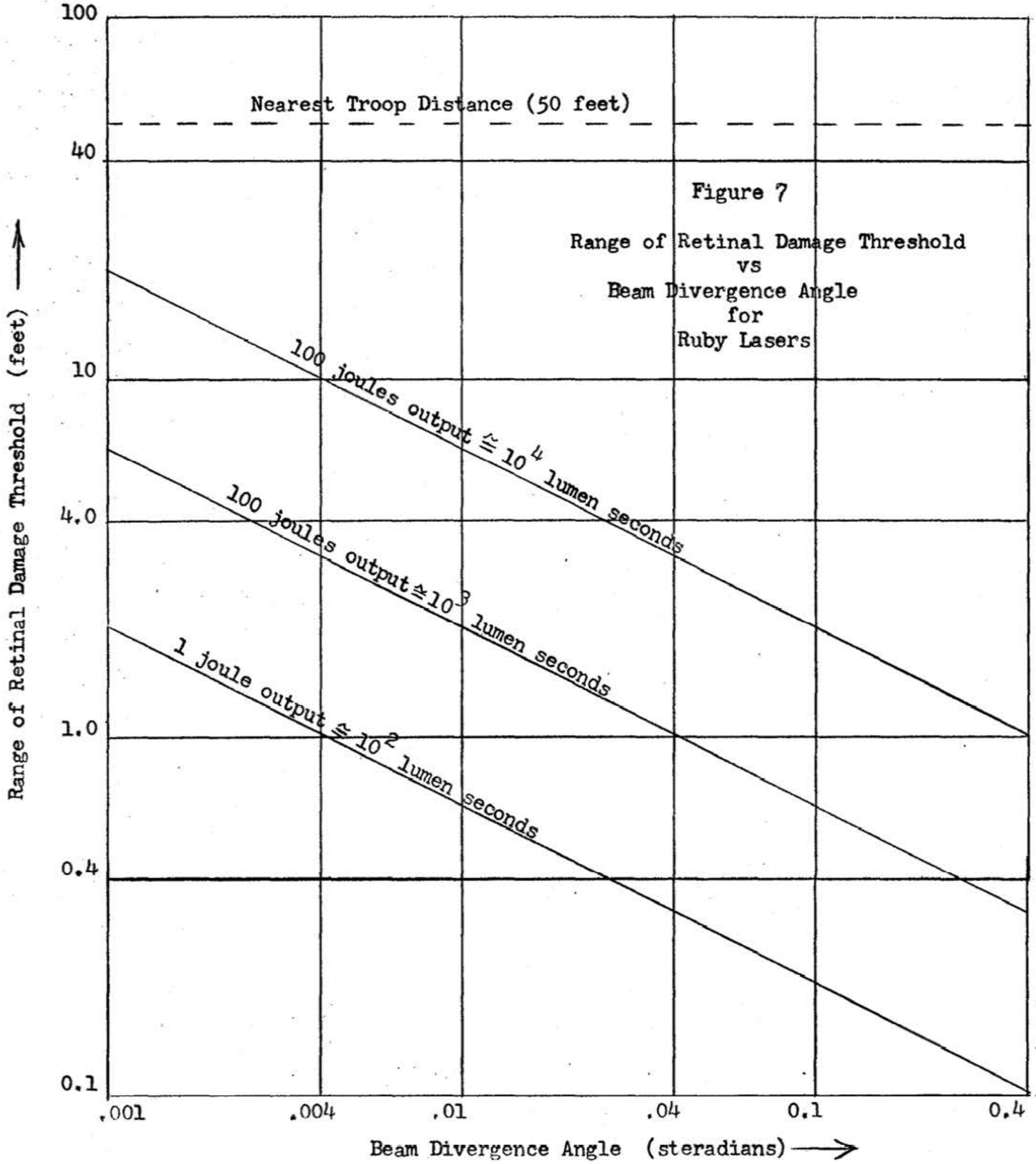


Figure 6
Exposure Area vs. Recovery Time
for
Ruby Lasers
1000
400
100
40
10
4.0
1.0
Exposure Area (feet²) →
100 joules output ≅ 10⁴ lumen seconds (collimated)
10 joules output ≅ 10³ lumen seconds (collimated)
1 joule output ≅ 10² lumen seconds (collimated)
Mean Recovery Time (Seconds) →
10
30
50
70
90
110
130
150


Nearest Troop Distance (50 feet)
Figure 7
Range of Retinal Damage Threshold
vs
Beam Divergence Angle
for
Ruby Lasers
100 joules output ≅ 10^4 lumen seconds
100 joules output ≐ 10^3 lumen seconds
1 joule output ≅ 10^2 lumen seconds
100
40
10
4.0
1.0
0.4
0.1
.001
.004
.01
.04
0.1
0.4
Range of Retinal Damage Threshold (feet)
Beam Divergence Angle (steradians)

is considered that 50 ft is a safe inner range, so that all cone angles resulting in a greater retinal damage range are not to be allowed.

2.3 Scanning and Stacked Blinking Systems

The smaller the cone angle the greater the recovery time for a given range, together with the fact that recovery time becomes a less sensitive function of range. Clearly, then, it would be advantageous to consider systems capable of greater concentration. The scanning system would be ideal if recovery time were only a function of peak illuminance, rather than the product of illuminance and time. Nevertheless, some advantages may accrue, and the subject is worth a short elementary treatment.

For a circular beam of linear cone angle θ, the peak illuminance is

$$\frac{F}{\frac{\pi}{4} R^2 \theta^2} ,$$

where R is the range and F is the peak luminous flux out of the laser. To cover a given area by simple flooding at a certain range requires a flood angle

$$\theta_D = F \Big/ \frac{\pi}{4} R^2 \dot{F}_p ,$$

where $\dot{F}_p$ is the necessary peak illuminance. Obviously, scan must take place within a pulse duration. The new divergence angle, θ_{DN}, is to be $\ll \theta_D$, otherwise there is no advantage to even consider. Let the scan angular velocity be ω, resulting in a linear scan velocity $V = R\omega$; with a spot size of linear dimensions $L = R\ \theta_{DN}$, the dwell time on a point target will be $\tau_D = \frac{\theta_{DN}}{\omega}$, so that the illuminance-time product will be

$$\frac{F}{\pi/4\ R^2 \theta_{DN} \omega} .$$

As the "old" illuminance-time product was

$$\frac{F \tau}{\frac{\pi}{4} R^2 \theta_D^{\ 2}} ,$$

where τ is the laser pulse width, the ratio of scan glare energy to divergent beam glare energy will be

$$\rho = \frac{\theta_D^{\ 2}}{\omega \tau \theta_{DN}} ;$$

it remains to establish the value of $\omega\tau$, as $\frac{\theta_D}{\theta_{DN}} \gg 1$ by definition.

Assuming a square scan raster, there will be n^2 scan spots within a divergent beam spot size of $R\theta_D$, if $\frac{\theta_D}{\theta_{DN}} = n$. It will take a time equal to $\tau_S = \frac{n^2\,\theta_{DN}}{\omega}$ to cover this entire raster; this time may be set equal to a laser pulse width, so that $\omega = \frac{n^2\,\theta_{DN}}{\tau}$. Thus,

$$\rho = \frac{{\theta_D}^2}{n^2\,{\theta_{DN}}^2} = 1, \text{ as } \frac{\theta_D}{\theta_{DN}} = n \;;$$

it is apparent, as a result, that no advantage is to be gained by using a scanning system. Actually, the area covered by $n^2\,R\,\theta_{DN} > R\,\theta_D$, so that a slight advantage is obtained in exposure area. In general, the complexities of a scan system would not warrant its use for such a slight exposure area increase. In those cases wherein actual field effect eye damage is to be considered at appreciable range, however, the scanning system would offer great advantages; such a system lies beyond the scope of interest of the present study.

Consider a system of n laser rods producing beams which overlap at some critical distance. A high prf system (for prf $<$ 10 p.p.s.) ordinarily offers little if any advantage, as the eye blinks shut between the n and n+1 pulses. In a stacked blinking system, however, advantage can be taken of a high prf system. The illuminance-time factor is increased by a factor of n when using a stacked system, and each rod can be fired 5 times a second. By sequential firing the entire pattern can be blinked in 0.2 second. With an increase to 2 n rods, still covering the same area, the entire pattern can be blinked in 0.1 second, prohibiting neighboring troops from using eye blink protection.

The great advantage of a 2 n rod system, then, is that an array of reasonable size laser rods can essentially, insofar as the eye is concerned, continuously flood a given area with high illuminance. It is feasible to build a 5 p.p.s. 2 n rod system, with n being an integer dependent upon single rod peak pulse luminance. The present difficulty, unfortunately, is that n would have to be a very large number to illuminate a really effective area. This is due to the small luminous flux output of present "high" prf systems. It may be feasible in the near future to pulse a rod at 5 p.p.s. which delivers an output of 1 joule. In this case n can be some reasonable number - such as 10; a 20 rod array is not unreasonable.

Assuming that the eye will be exposed to continuous flooding whenever open, it will always suffer a 7-12 second recovery time when exposed to 100 lumens/ft^2. Thus, the recovery time may be made <u>indefinitely long</u> with only moderate dazzling glare illuminance. For this reason, it is well to merely plot a curve of effective area versus n, with laser output as a parameter; such a curve appears in Figure 8. It should be noted that this has been a very conservative discussion, and the stacked blinking system may actually be used with good results under conditions of appreciably weaker illuminance than is normally regarded as useful!

2.4 Laser Hardware

As we are only considering ruby laser systems, the hardware is rather standard. The main components involved are the following:

1. A dc charging power supply.
2. A capacitor storage bank.
3. Trigger Circuitry.
4. One or more xenon flash lamps.
5. A reflector assembly (usually elliptical) containing one or more flash lamps and a ruby rod.
6. A ruby rod.
7. Divergent beam optics.
8. A laser head directional mechanical assembly.

Neglecting items (7) and (8), some idea of the hardware may be obtained for a "high" prf system by examining a unit designed by Maser Optics. This unit pulses at 1 p.p.s. with an output of from 0.5 to 0.75 joules/pulse, using water cooling for the flash lamp. The laser rod weighs 4 pounds, and the

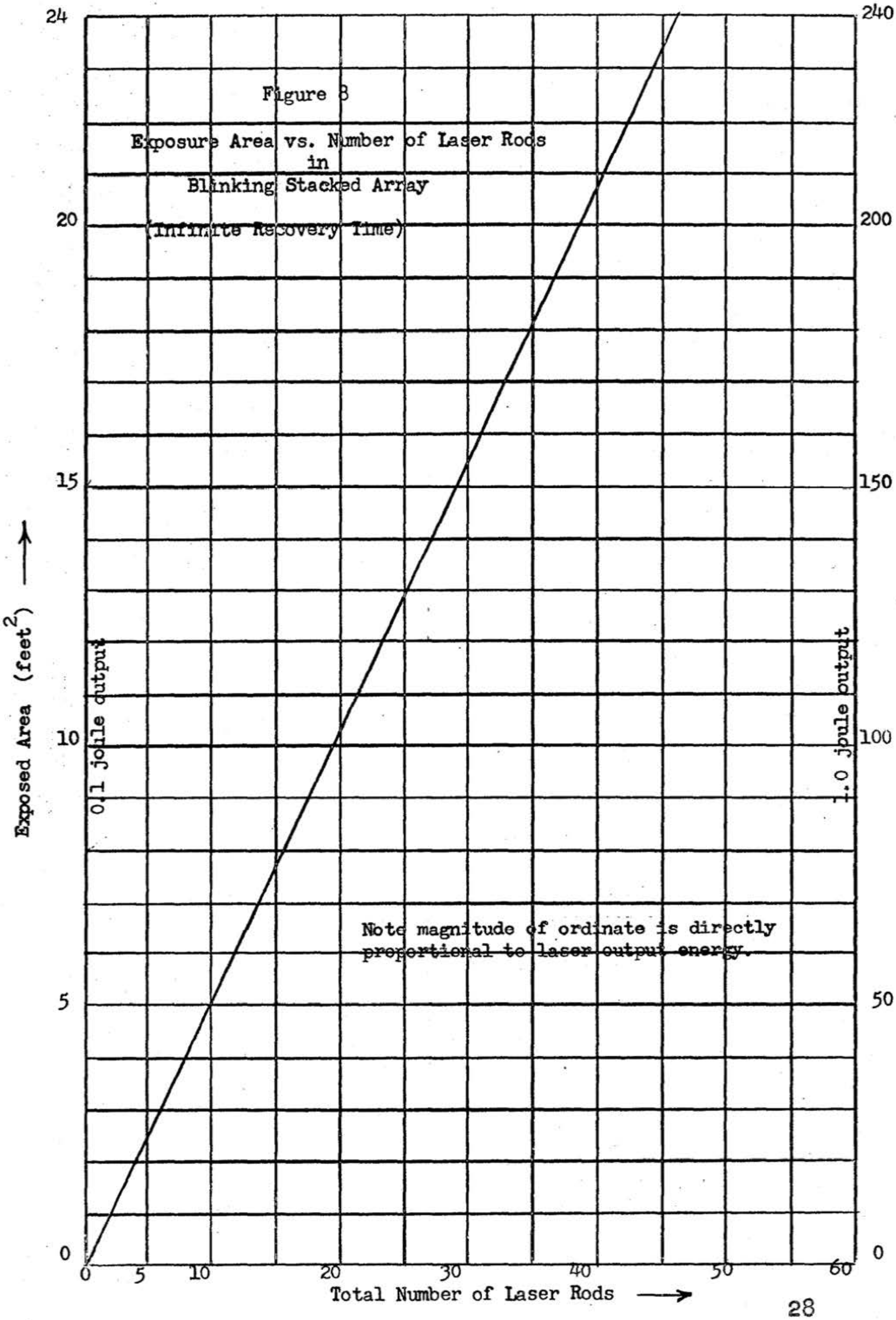


Figure 8
Exposure Area vs. Number of Laser Rods
in
Blinking Stacked Array
(Infinite Recovery Time)
Note magnitude of ordinate is directly proportional to laser output energy.
Exposed Area (feet^2)
0.1 joule output
1.0 joule output
Total Number of Laser Rods
0
5
10
15
20
24
0
50
100
150
200
240
0
5
10
20
30
40
50
60

power supply plus capacitors, trigger circuitry, etc. weighs about 150 pounds. The capacitor bank is derated from 800 to 600 joules, and the flash lamp has a life of 10^4 flashes.

For more bulky standard systems, a good idea of the hardware may be obtained by examining Melpar's large solid state laser. This unit is mounted in (and on) a single large relay rack, using an elliptical reflector with a standard FX-47 flash lamp and a 6" by 5/8" ruby rod. The storage bank uses 18 capacitors rated at 4 KV at 100 microfarads. Each capacitor weighs 60 pounds and occupies a space of 935 cubic inches. The dc power supply used is a small unit delivering up to 3 KV at a maximum average power of 1.5 KW. Various small relays, a small trigger power supply, etc. are negligible in size and weight compared to the capacitor bank or even the charging power supply. The unit normally delivers about 40 joules output, although this is without cooling of any kind. With cooling and maximum use of the capacitor storage bank it can deliver nearly 150 joules output; the unit is not presently arranged to operate in this fashion.

Divergent beam optics occupies negligible space, and no collection or collimation optics is needed. A directional laser head assembly would involve some design work, but the additional weight, size and power requirements would be negligible relative to the remainder of the system.

Scanning systems have been shown to possess little advantage, while blinking stacked systems are of value. Nevertheless, the compound laser head assembly would be very complex, although the weight and size would be appreciably less than 2n times the values for a single rod system. It is impossible at this time to give any close estimates of size and weight for a stacked blinking system.

Although this has been a brief description of the laser hardware required, it should be sufficient information for present use. Scaling the Maser Optics unit allows a determination of the magnitude of the hardware presently required for a given application.

3. HIGH INTENSITY LIGHT GLARE SOURCES

3.1 Introduction

Actually, incoherent light sources are, in general, less amenable to straightforward design procedures than is a laser (given an appropriate flash lamp for optical pumping). However, high intensity light source have been built for a number of years, and very efficient designs have evolved. A wide variety of continuous and pulsed sources are available, and we have chosen representatives of the more important classes.

There are some types of very high luminance flash tubes which we have not discussed in the text. Among these are the Wilson tube and the Fischer tube. The former is a low pressure nitrogen, external electrode tube, while the latter is a high pressure steel flash lamp with an end-on window. The Wilson tube generates much of its power in the ultra-violet, in addition to having a pulse width of less than a microsecond. The Fischer tube has a pulse length in the tens of nanoseconds region, yielding a very low luminance energy. Thus, even though the luminance of these sources is very high (even for the Wilson tube), the luminance-time product is too low to be of interest. For various reasons, usually a low luminance-time product, we have neglected a number of sources which are useful for other applications.

We only consider simple divergent beam systems, although it is possible to use stacked blinking arrays. In general the luminance-time product of these incoherent sources is so high that a single source, simple divergent beam system provides all the capability desired. In analyzing these simple sources it is indeed amazing that they have not been widely used in battle-field situations, as it appears that their capability for an optical incapacitating function is extremely high.

Specifically, we consider xenon flash tubes, photo-flash bulbs, carbon arcs and high pressure mercury arcs. The latter two are continuous sources, although it is considered that a maximum of one-tenth of a second illuminance time should be used in the calculations - due to the blink response of the eye. Both the xenon flash tubes and the photo flash bulbs are directly rated in lumen-seconds.

We consider first the xenon flash tube, especially as developed by Edgerton, Germeshausen and Grier, Inc. These are the most efficient high intensity sources extant, and, in addition, their luminance-time products are extremely high. Considered from the present application viewpoint, this type of source is to be preferred over all other - including lasers of the present generation.

Next, we consider photo flash bulbs. Although this type of source seems extremely primitive, and it suffers from an inherently "one-shot" lifetime, a device employing an automatic feed and this type of source might be very convenient for certain tactical situations. At any rate, we believe that such a source should be considered for the sake of completeness.

The U. S. Army already has a potent optical incapacitating weapon in the form of its 800 million candle searchlight. The general category of carbon arcs represents an important class of high intensity light sources. Although not as efficient as the xenon source, the carbon arc is easily handled and repaired, and its luminance geometry is good. We consider this type of source worthy of some mention.

Then, we consider briefly the high pressure mercury arc. This type of source has reasonable efficiency and life, together with a good luminance-time capability. It should be of value for field use under some conditions.

We give the important conclusions concerning all of these sources in a series of easily read graphs. They are plotted as for the laser divergent beam case, so that direct comparison is readily made. Finally, we give the important hardware information for these sources, although, as for the laser, we do not consider it necessary, in such a study, to go into great detail.

3.2 The Xenon Flash Tube Source

Only flash tubes of $1\frac{1}{2}$" arc length and longer are of sufficient luminance-time rating to merit consideration. We consider the FX-33 ($1\frac{1}{2}$" arc), the FX-52 (3" arc) and the FX-56 (6" arc). The latter two lamps are normally used for laser pumping, and by using forced air or water cooling their average power ratings are 600 and 5000 watts respectively. The FX-33 is not designed for high average power, and it is rated at only 10 watts average power. The ratings for the various lamps are 2000 lumen-seconds (FX-33), 25,000 lumen-seconds (FX-52) and 200,000 lumen-seconds (FX-56). A very conservative collector and collimation design allows more than 25% of this luminance energy to be used, but 25% was chosen as a feasible figure. As the luminance geometry is not as good as for the carbon arc case, an estimated lower collimation limit of 10^{-3} steradians solid angle has been used in our calculations. The conversion efficiency of these lamps averages about 40 lumens/watt, which is an efficiency not equaled by any other high intensity source.

When used with the maximum average input powers previously mentioned, these lamps have a flash number lifetimes of 10,000 flashes for the FX-33, 5000 for the FX-52 and 7500 for the FX-56. With due precaution for average power, these lamps may be flashed up to several times per second.

The conclusions pertinent to these lamps for a simple divergent beam, single lamp source are shown in Figures 9-12. The performance is so good that we have not regarded it necessary

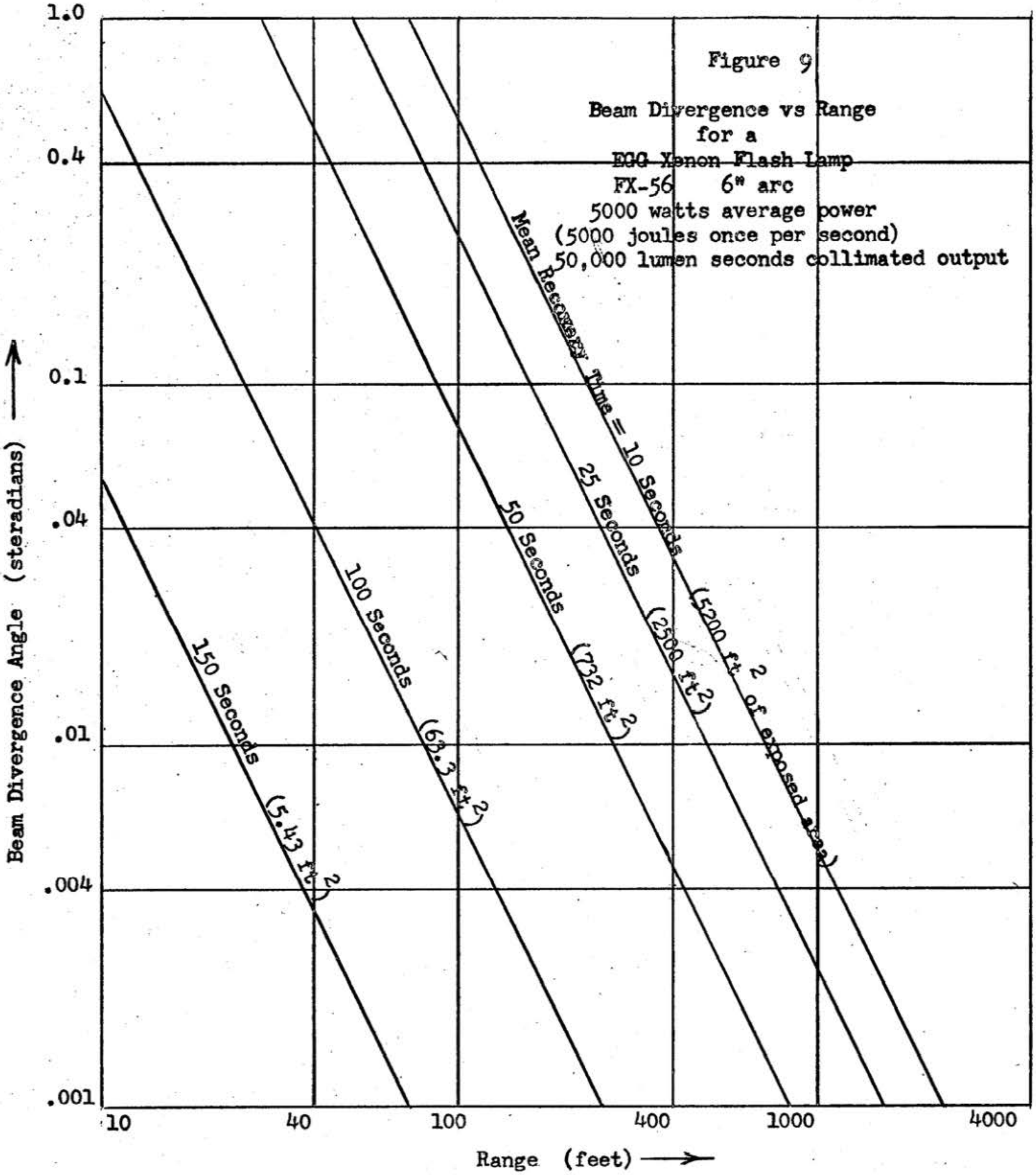


Figure 9
Beam Divergence vs Range
for a
EGG Xenon Flash Lamp
FX-56 6" arc
5000 watts average power
(5000 joules once per second)
50,000 lumen seconds collimated output
Mean Recovery Time = 10 Seconds (5200 ft 2 of exposed area)
25 Seconds (2500 ft2)
50 Seconds (732 ft2)
100 Seconds (63.3 ft2)
150 Seconds (5.43 ft 2)
1.0
0.4
0.1
.04
.01
.004
.001
Beam Divergence Angle (steradians)
10
40
100
400
1000
4000
Range (feet)

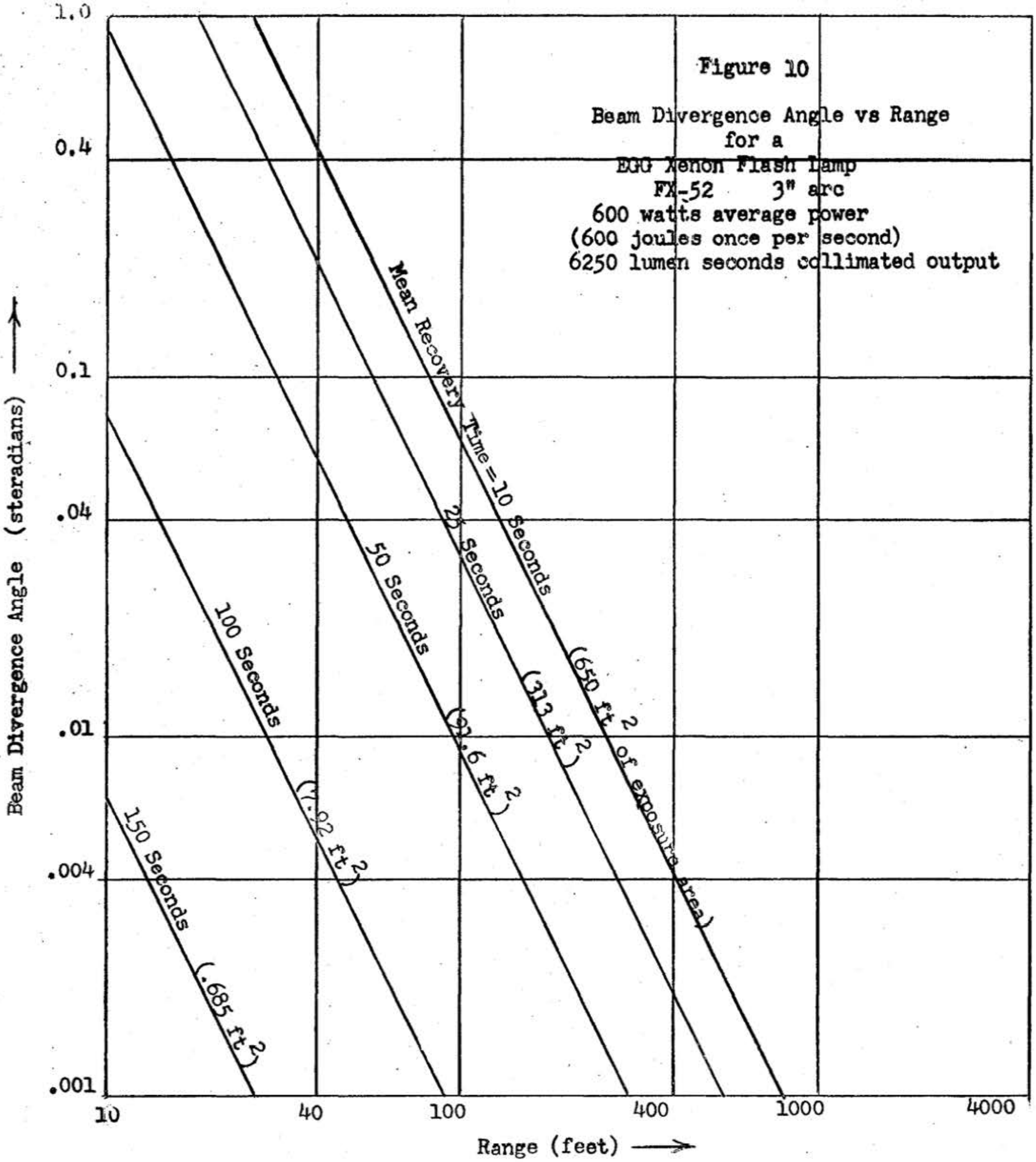


Figure 10

Beam Divergence Angle vs Range
for a
EGG Xenon Flash Lamp
FX-52 3" arc
600 watts average power
(600 joules once per second)
6250 lumen seconds collimated output

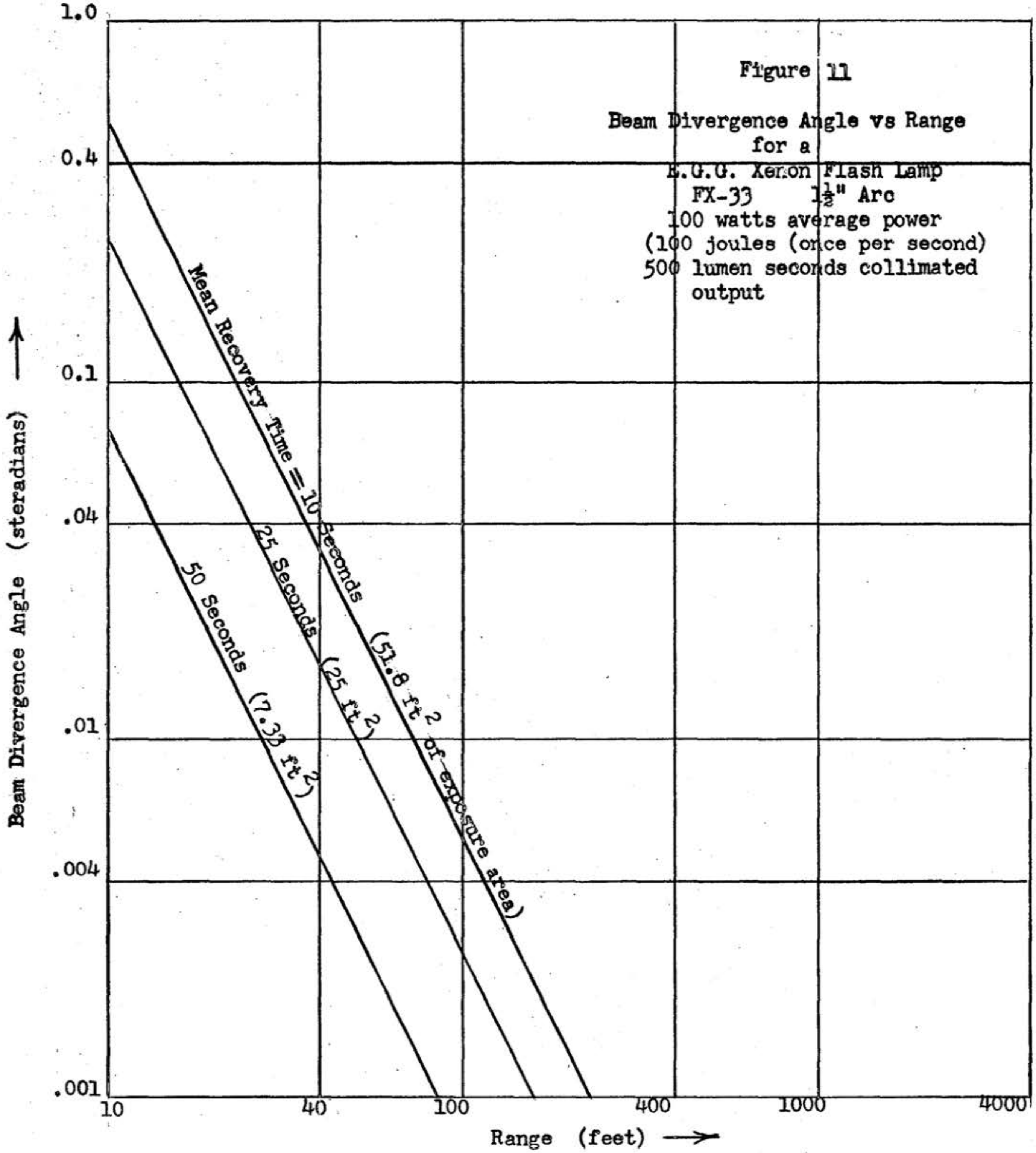


Figure 11
Beam Divergence Angle vs Range
for a
E.G.G. Xenon Flash Lamp
FX-33 1½" Arc
100 watts average power
(100 joules (once per second)
500 lumen seconds collimated
output
Mean Recovery Time = 10 Seconds (51.8 ft² of exposure area)
25 Seconds (25 ft²)
50 Seconds (7.33 ft²)
1.0
0.4
0.1
.04
.01
.004
.001
10
40
100
400
1000
4000
Beam Divergence Angle (steradians) →
Range (feet) →

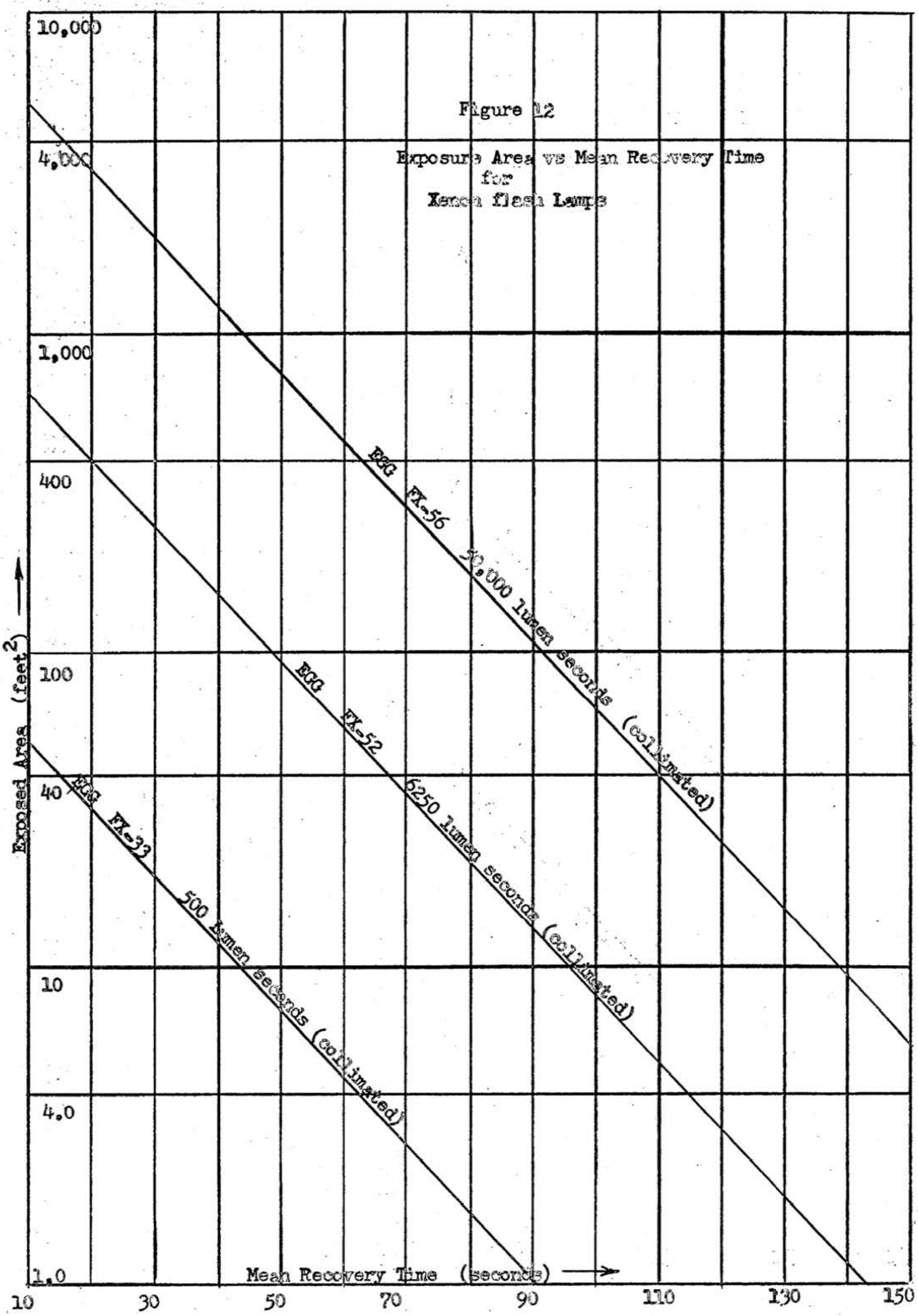


Figure 12
Exposure Area vs Mean Recovery Time
for
Xenon flash Lamps
10,000
4,000
1,000
400
100
40
10
4.0
1.0
Exposed Area (feet^2)
Mean Recovery Time (seconds)
10
30
50
70
90
110
130
150
EGG FX-56 50,000 lumen seconds (collimated)
EGG FX-52 6250 lumen seconds (collimated)
EGG FX-33 500 lumen seconds (collimated)

to discuss stacked blinking systems or the like. The high prf capabilities of these lamps makes it feasible, however, to produce significant dazzle at extreme ranges (for appreciable exposure area) by utilizing a blinking system.

Although somewhat less impressive than the 800 million candle searchlight, a consideration of the respective hardware requirements quickly shows the general advantages of the xenon flash tube. The appreciable exposure area for lengthy recovery time, demonstrated in the above mentioned graphs, shows the significant capabilities of the xenon flash tubes. Comparison with the laser sources quickly demonstrates the advantages of using the flash lamps themselves, rather than using them as optical pumping sources!

3.3 Photo Flash Tube Sources

The seemingly innocuous photo flash bulb possesses appreciable capability as a glare source. Despite its "one-shot" nature, a simple feed mechanism can be designed to utilize this expendable item at a rate sufficient to cause indefinitely long recovery time under proper conditions. We consider two flash bulbs, the common #5 and the large PH 50-1.

The #5 photo flash bulb is rated at 21,000 lumen-seconds, while the PH 50-1 has a rating of 100,000 lumen-seconds. The luminance geometry is such that we again assume a 25% collection and collimation efficiency.

The curves appropriate to these sources appear in Figures 13-15. The PH 50-1 in particular obviously has tremendous dazzling capability, and even the lowly #5 exceeds the capabilities of a laser of significant power output.

3.4 The Carbon Arc Source

The carbon arc is a rather ancient high intensity source, but one still worthy of consideration. The efficiency of a carbon arc approaches 20 lumens/watt, or about one-half that of a typical xenon flash tube. The arc itself, however, is rather small, even for a high intensity source, and the luminance geometry is very good. It is not difficult, by good design, to obtain a minimum solid angle of less than $5x10^{-4}$ steradians. While this scarcely compares favorably with a laser, it is among the best in the realm of incoherent sources.

Merely because it is a potent source and a standard piece of military hardware (for many years), we consider the 800 million candle searchlight used by the U. S. Army. The collimated solid angle of this device is $4.7x10^{-4}$ steradians yielding a luminous flux output of $3.76x10^{5}$ lumens. It is possible to spoil the collimation, of course, and obtain larger divergence angles.

The conclusions appropriate to this 60" searchlight appear in Figures 16 and 18. This device clearly possesses significant glare capability.

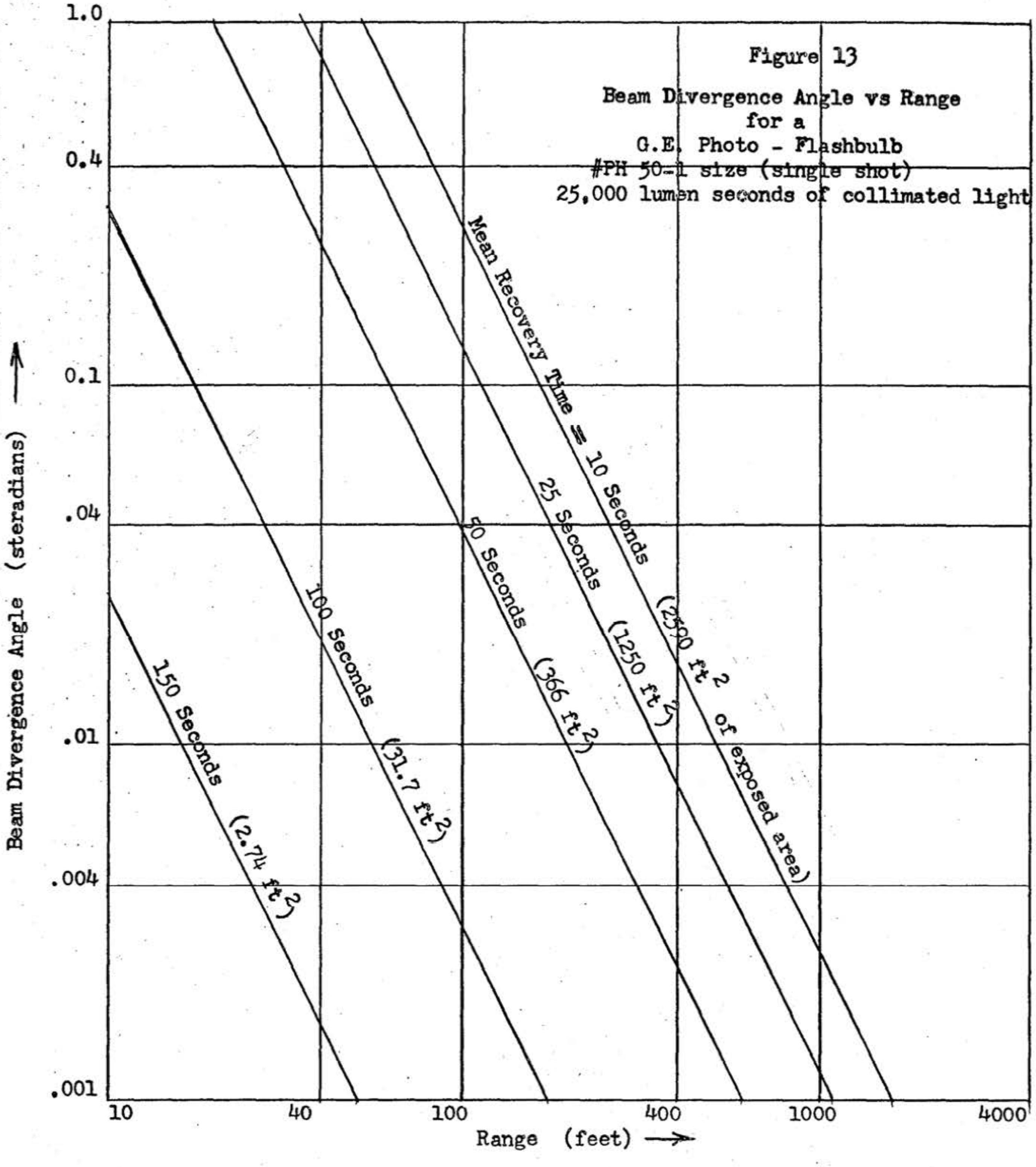


Figure 13
Beam Divergence Angle vs Range
for a
G.E. Photo - Flashbulb
#PH 50-1 size (single shot)
25,000 lumen seconds of collimated light
Mean Recovery Time = 10 Seconds (2590 ft 2 of exposed area)
25 Seconds (1250 ft²)
50 Seconds (366 ft²)
100 Seconds (31.7 ft²)
150 Seconds (2.74 ft²)
1.0
0.4
0.1
.04
.01
.004
.001
Beam Divergence Angle (steradians)
10
40
100
400
1000
4000
Range (feet)

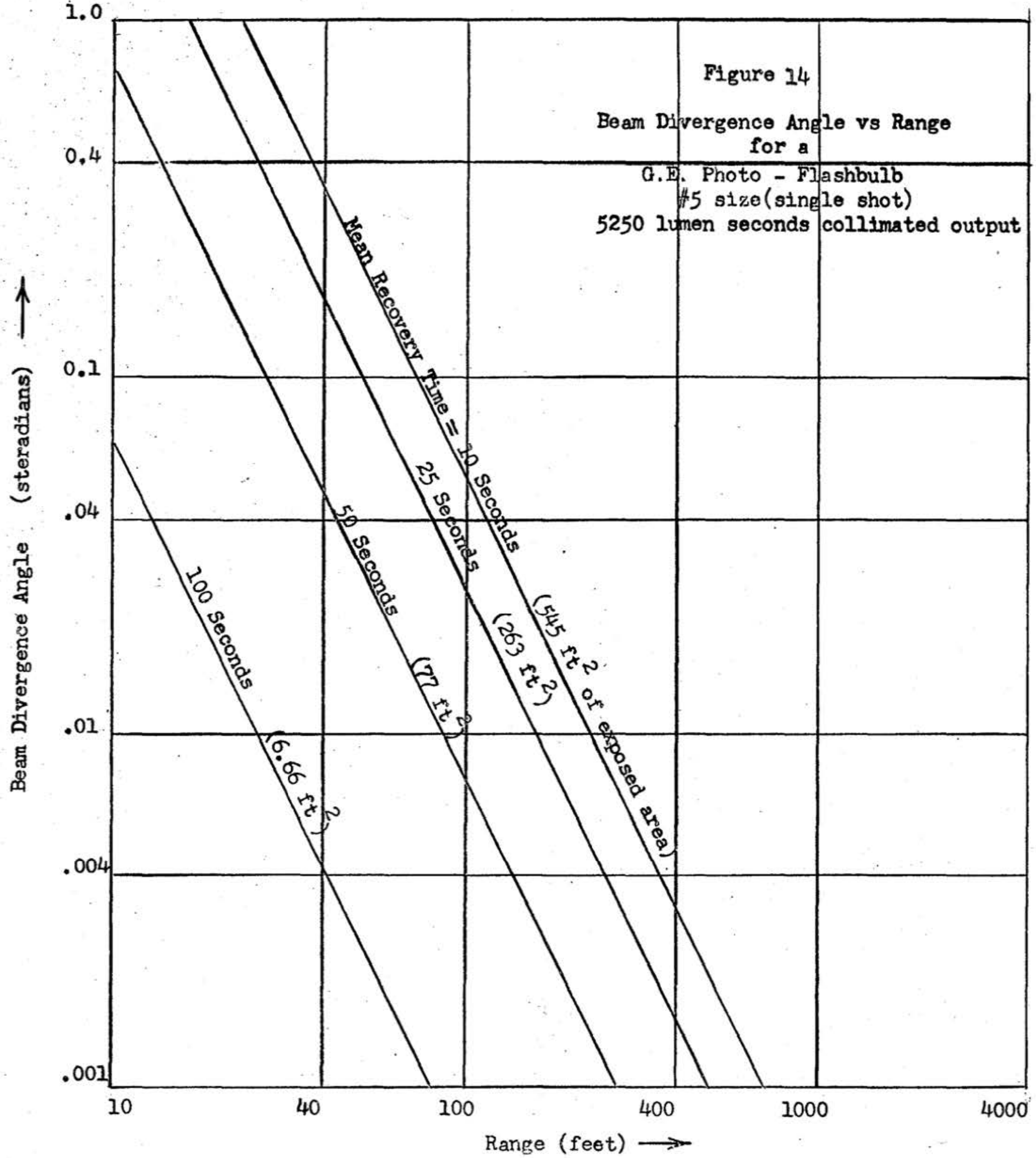


Figure 14
Beam Divergence Angle vs Range
for a
G.E. Photo - Flashbulb
#5 size(single shot)
5250 lumen seconds collimated output
Mean Recovery Time = 10 Seconds
(545 ft² of exposed area)
25 Seconds
(263 ft²)
50 Seconds
(77 ft²)
100 Seconds
(6.66 ft²)
1.0
0.4
0.1
.04
.01
.004
.001
Beam Divergence Angle (steradians) →
10
40
100
400
1000
4000
Range (feet) →

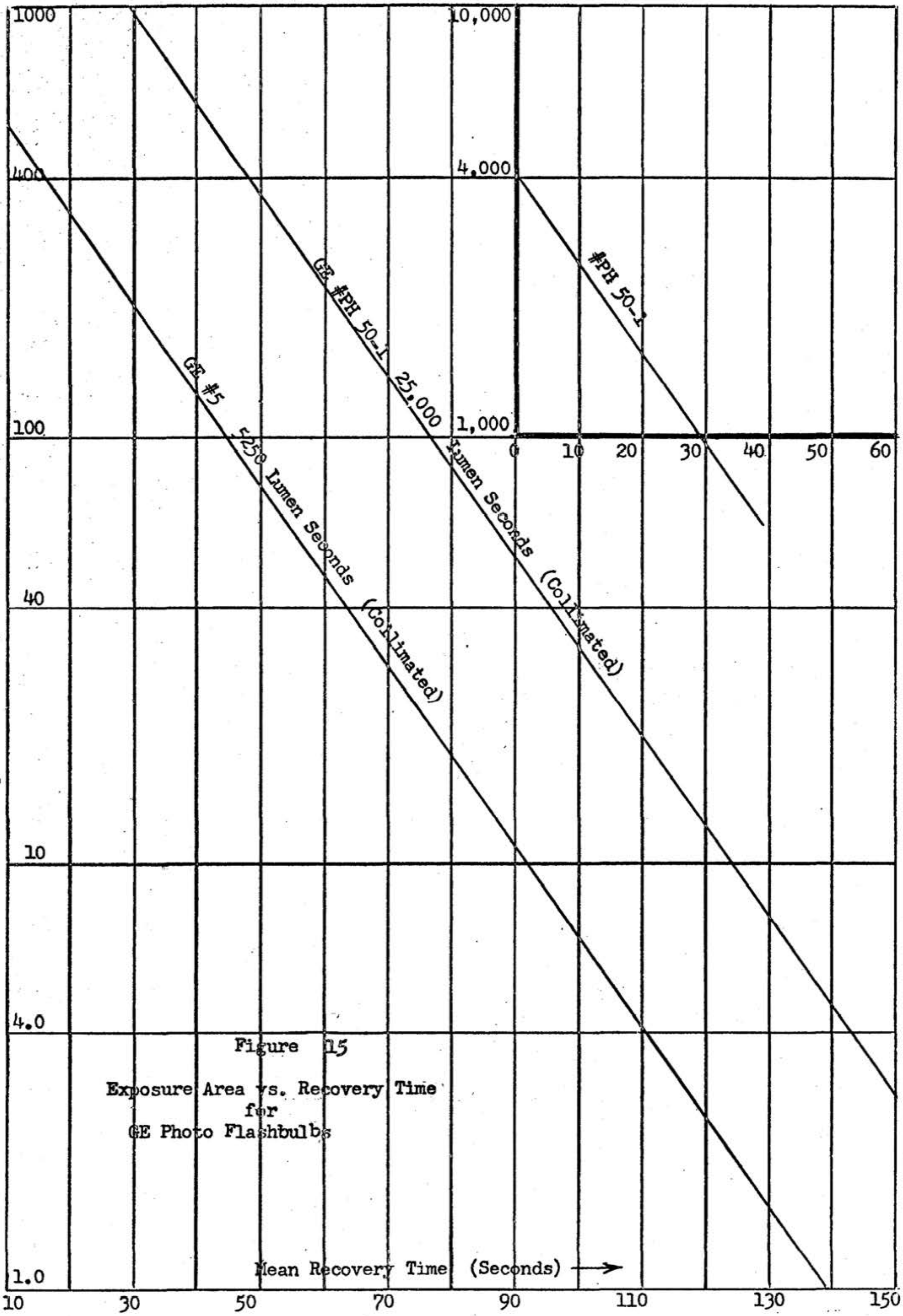


Figure 15

Exposure Area vs. Recovery Time for GE Photo Flashbulbs

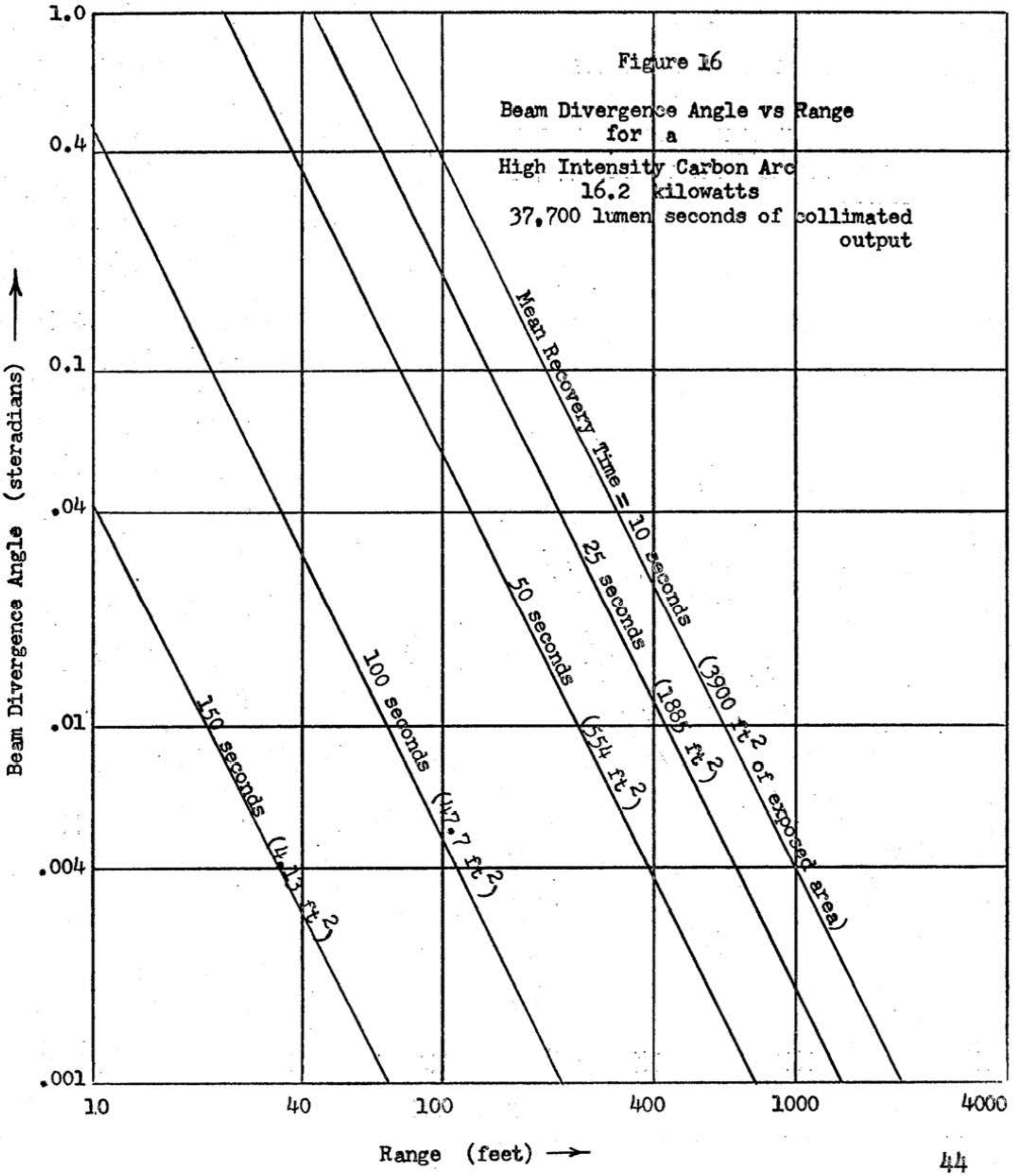


Figure 16

Beam Divergence Angle vs Range for a High Intensity Carbon Arc 16.2 kilowatts 37,700 lumen seconds of collimated output

In addition to the relative ease with which new compact carbon arcs may be designed and built, there exists a standard 70 million candle searchlight for aircraft. We have not considered this much less bulky device here, but its output is of the order of 3.5×10^4 lumens and would be another very acceptable glare source.

3.5 The Mercury Arc Source

Another continuous source is that of the high pressure mercury arc. This device operates at 110 atmospheres with a lifetime of about 75 hours, The G.E. AH6 lamp has been used with 24" mirrors to produce a 3×10^7 candle source giving an output of 65,000 lumens. It is necessary to use water cooling for this source.

Again using a 0.1 second effective source time, or a luminance-time product of 6500 lumen-seconds, the appropriate glare capabilities are presented in Figures 17 and 18.

The high pressure mercury vapor arc in general uses a short arc and has good luminance geometry. It is also a "clean" easily handled source of good field utilization potentiality. A number of other high pressure mercury arc lamps exist, but the AH6 is typical of the largest available commercial units.

3.6 Hardware

The xenon flash lamps require little hardware other than the collecting and collimating optics, a capacitor storage bank

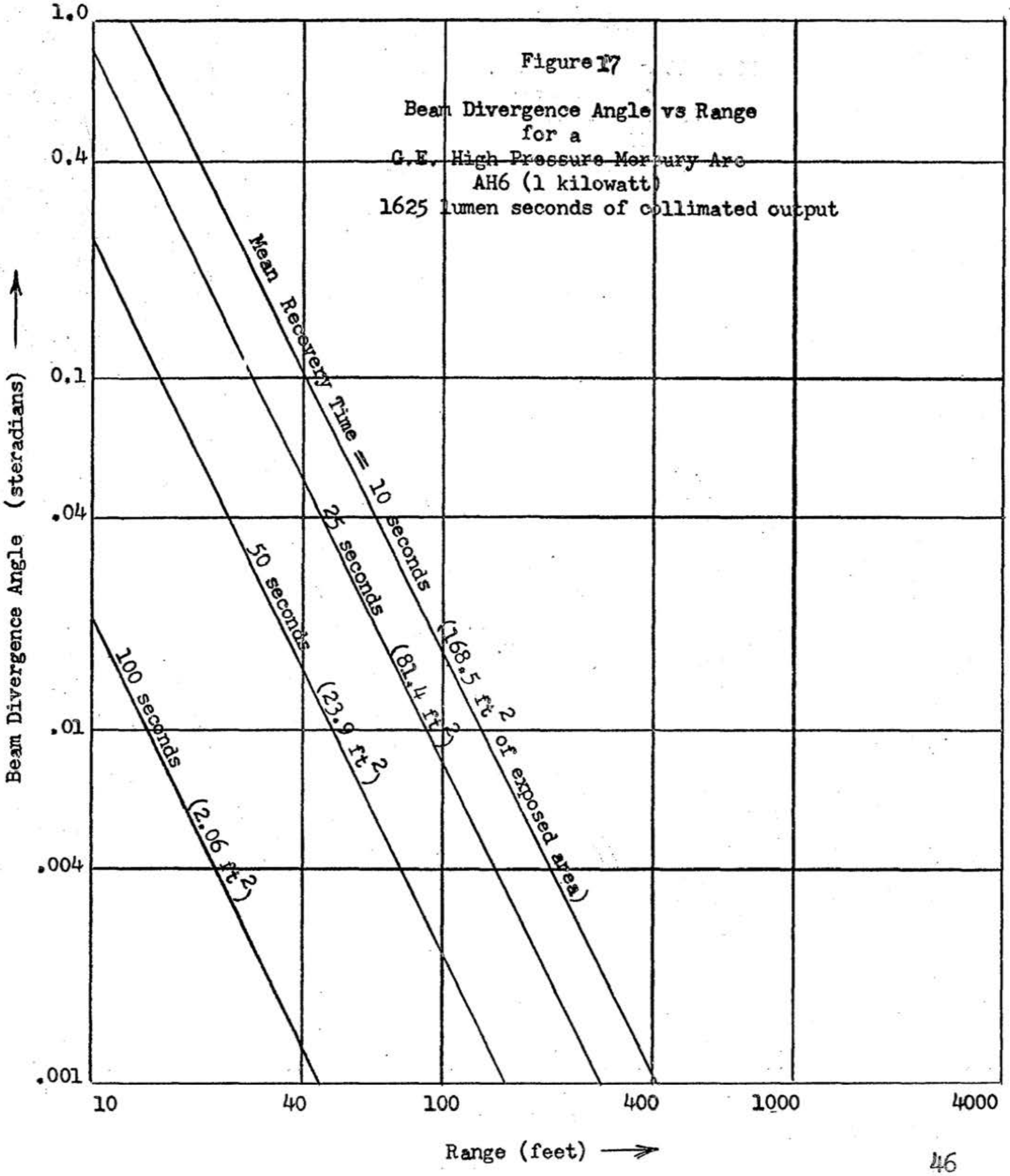


Figure 17
Beam Divergence Angle vs Range
for a
G.E. High Pressure Mercury Arc
AH6 (1 kilowatt)
1625 lumen seconds of collimated output
Mean Recovery Time = 10 seconds (168.5 ft2 of exposed area)
25 seconds (81.4 ft2)
50 seconds (23.9 ft2)
100 seconds (2.06 ft2)
1.0
0.4
0.1
.04
.01
.004
.001
10
40
100
400
1000
4000
Beam Divergence Angle (steradians)
Range (feet)

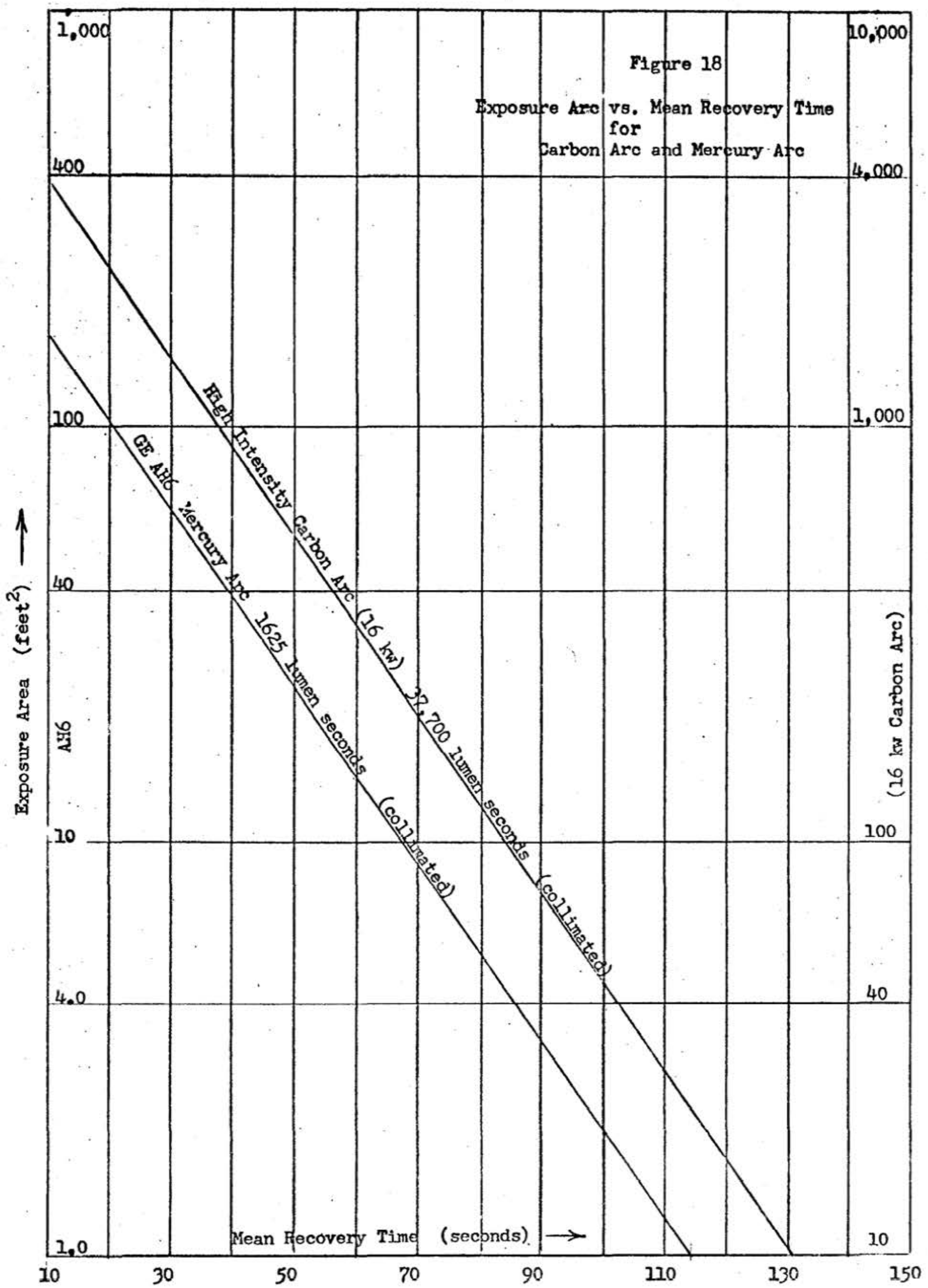


Figure 18

Exposure Arc vs. Mean Recovery Time
for
Carbon Arc and Mercury Arc

plus simple trigger circuitry and a dc charging power supply. The capacitor storage banks have been discussed in the section on laser hardware, while trigger circuitry (including a trigger transformer) occupies very little space and consumes only a small amount of auxiliary power. The dc charging power supply has also been discussed in the section on laser hardware. For the high average powers a small closed cycle water cooling system is recommended; the cooling system could be made on integral part of the vehicle cooling system.

Photo flash bulb hardware is literally that employed by photographers plus two important refinements. An automatic feed and ejection mechanism must be designed to utilize flash bulbs at a sufficient rate to maintain dazzling. Also, a collector and collimation system must be designed, the nature of the optics being similar to those required for the xenon flash lamps.

The large searchlight may be used as an example of carbon arc hardware. The searchlight plus carrier weighs 2950 pounds and occupies a volume of about 140 cubic feet. The power supply with carrier weighs about 5800 pounds and occupies a space of about 288 cubic feet. Obviously this is a very bulky device, but the majority of the weight and volume used is occupied by the carrier equipment - not the searchlight or power supply. The aircraft searchlight would provide a more realistic example, but details are not immediately available to us.

The mercury arc hardware consists of a power supply, a starting circuit, collection and collimation optics and a water cooling system (involving a 1/6 H.P. motor). The size of the power supply can be judged from the lumens output plus a knowledge that the mercury arc efficiency is about equal to that of the carbon arc. Thus, a prime power supply larger than the xenon flash lamp is required, but no capacitor storage system is used.

We realize that our discussion of the hardware has been very meagre, but there has been little time to engage in a search for details. The general nature of the hardware involved should be apparent, however, and really detailed information should be relatively unimportant at this stage of the glare source study.

4. CONCLUSIONS

It is evident from our photometric analyses that high intensity light sources are much better glare sources than are present generation ruby lasers. We conclude that the glare systems which can be presently constructed should be arranged in the following preferred order:

1. Xenon Flash Lamps.
2. High Intensity Carbon Arcs (with rotating shutters).
3. Photo Flash Bulbs (with automatic feed mechanism).
4. High Pressure Mercury Arc (with rotating shutters).
5. Stacked Blinking Laser Systems.
6. Single Rod Divergent Beam Laser Systems.

We recommend the xenon flash lamp system with the FX-56 flash lamp for a system of tremendous glare capability which can be designed and constructed immediately. It is also possible to design a really modern carbon arc source which would be reliable, easy to use and especially easy to maintain under field conditions; the glare capability would approach that of a good xenon flash lamp system.

For the future lasers should not be discounted. As non-optical pumping methods are developed, laser materials with absorption bands matched to specially designed flash lamps evolve and injection type lasers are further developed, it may well be that lasers (with their excellent luminous geometry) could become the preferred type of glare source.

It is evident that Miller and Fry have not succeeded in demonstrating the full validity of the luminance-time product theory, nor that infra-red effects can be neglected. With an intense infrared source (such as the gallium arsenide injection laser), near infrared <u>can</u> excite visual response. Similarly, fluorescence of the eyeball due to ultraviolet indicates that this form of "non-luminous" radiant flux may also have some glare significance. More detailed and extensive visual recovery time studies are needed to provide the basic d ta for a complete evaluation of dazzling and scotomatic glare.

In considering an optical incapacitating weapon, some attention should also be paid to excitation of the eye by waveforms approximating the α rhythm. By utilizing lower dazzling levels and special modulation waveforms, the disturbance may be quite pronounced over exposure areas and at ranges at which high dazzling levels (and consequently long recovery times) are impractical.

Within the limits inherent in the basic physiological data, the information presented in this report is valid and reasonably complete. Further work could be done on specific system details, as well as in presenting an array of other possible sources. However, we are confident that the most useful sources have been investigated and that the general conclusions are correct and sufficient for an initial evaluation of the problem.

APPENDIX B

REVIEW OF RESEARCH ON BRIGHT LIGHT SOURCES

REVIEW OF RESEARCH ON BRIGHT LIGHT SOURCES

BRIEF STATEMENT OF RESULTS

a. Sodium Seeded Flame

An oxyhydrogen flame impregnated with sodium was subjected to the action of a microwave field at 2.45 kmc and 1 kw output power. When the orientation of the electric vector was such as to permit the field to penetrate inside the flame and give rise to about 25% coupling, the brightness of the flame was enhanced by a factor of 130 to a value close to 2 million foot-Lamberts. This enhancement was very definitely a function of the initial (i.e., unenhanced) flame brightness. The higher the initial brightness, i.e., the higher the amount of sodium added to the flame, the higher the degree of enhancement, starting with about 10 at relatively low levels of sodium seeding. Judging by the spectrograms, more than 75% of the output energy was concentrated in the region of the sodium D-lines. The input thermal power of the oxyhydrogen torch was computed, from the amount of hydrogen used, to be 2.2 kw.

b. Light Source Using Barium

Hydrated barium chloride in an evacuated tube was subjected to the action of the same microwave field as was the sodium flame. The observed brightness of the source was about 50,000 foot-Lamberts concentrated in the range between 5050 and 5350 Å. Anhydrous barium chloride gave a higher overall brightness. However, some of the emission was in the red as well as in the ultraviolet. (The brightness measuring device did not record the uv output.)

c. Sources in Other Spectrographic Regions

A potassium seeded red flame exhibited marked enhancement under microwave action. Also an exceptionally bright source in the "actinic" blue region was obtained by placing copper chloride in an evacuated tube into the microwave field.

Description of the Experiments

a. Work with Flames

The microwave field was produced by a Raytheon 707 OK magnetron operating at 60 cycles. Microwave generation occurs only during a portion of the positive cycle when the voltage applied exceeds 6000 V. The field was produced in a waveguide 4.3" in dimensions. The waveguide arrangement was designed to make certain that microwave generation was dominantly in the TE_{10} mode even in the presence of the flame. Two holes were drilled on opposite sides of the eaveguide to permit passage of the flame in a direction perpendicular to the electric vector in the TE_{10} mode. (Thus the flame was directed along the longer dimension of the waveguide cross section.) A schematic of the arrangement is shown in Figure T-1. The waveguide had an open end and microwaves not absorbed by the flame were reflected at the end so that a standing wave pattern was formed inside the waveguide. Tuning mechanisms located on either side of the holes in the waveguide made it possible to adjust the length of the resonant cavity. The position of the flame, therefore, did not have to be changed to obtain optimum enhancement as was shown by using a sliding waveguide section.

The spectral intensity distribution in the vicinity of the sodium lines was recorded using a monochromator. Some difficulty was experienced

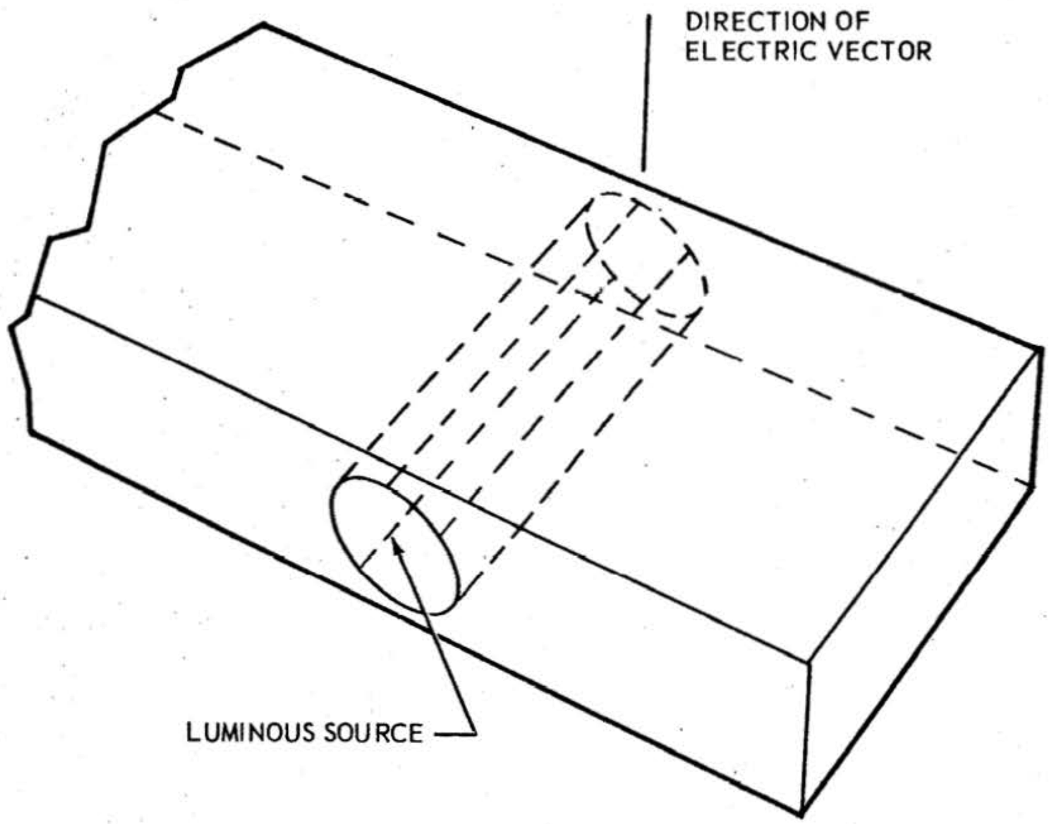


Figure T-1. Relation of Geometry of Source and Direction of Electrical Vector in using this equipment because in spite of careful shielding, the microwave field appeared to affect the monochromator electronics. However, the final results obtained are believed to be basically correct. It was found that the intensity of the sodium lines was increased by only a factor of 10. However, the spreading of the lines was very pronounced, the range of strong intensity extending over about 50 Angstroms. (The spacing between D-lines under normal conditions is 6 Angstroms.) In actual appearance, the sodium doublet was replaced by a triplet. This is shown in Figure T-2. While precise measurements were not made, the total area under this spectral distribution curve, i.e., the integrated intensity was some 100 times higher than in the absence of microwaves. It is to be noted that broadening of the sodium lines by hydrogen was already noticed by R. W. Wood in 1900.[1]

The dependence of enhancement on plasma density can be deduced from Figures T-3 and T-4. The oscilloscope trace of the enhanced light output in Figure T-2 was taken 15 seconds after ignition. Each horizontal division represents 5 milliseconds, the vertical (intensity) scale is arbitrary. The enhancement is synchronized with the 60 cycle magnetron pulsing. With the arrangement used, the NaCl is slowly blown out through the open tube ends. The three curves, a, b, and c, of Figure T-4 show oscilloscope traces of the light output at successive stages of depletion, 3, 5, and 7 minutes after ignition, respectively, on the same scale as Figure T-3.

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1. R. W. Wood, Physical Optics, 3rd edition, p. 528 (Macmillan).

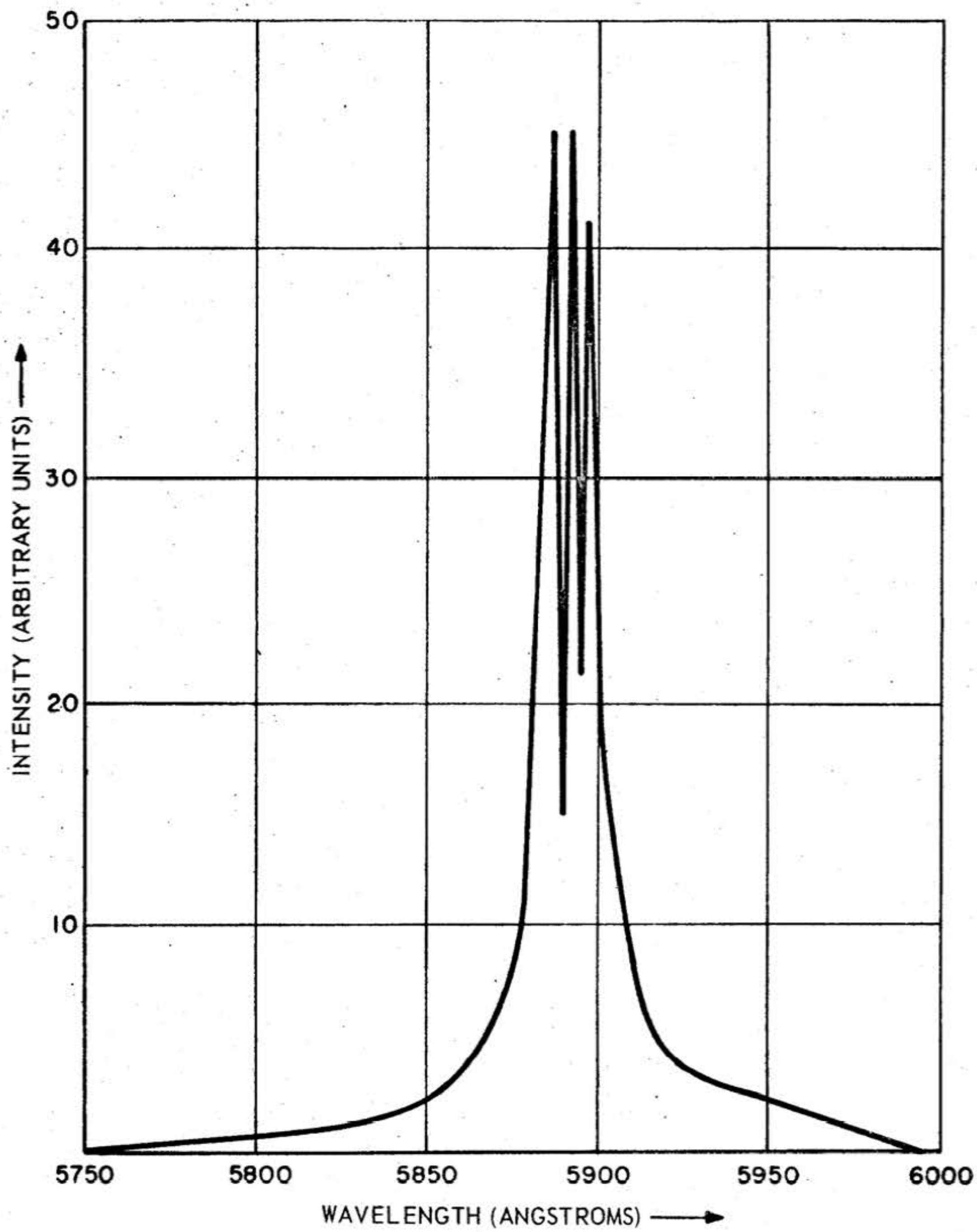

Figure T-2. Monochromater of Sodium D Lines Under Microwave Excitation

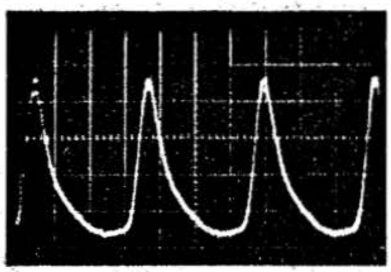

Figure T-3. Oscilloscope Trace of Enhanced Sodium Light

Figure T-4. Oscilloscope Trace of Enhanced Sodium Light as Sodium Content is Depleted

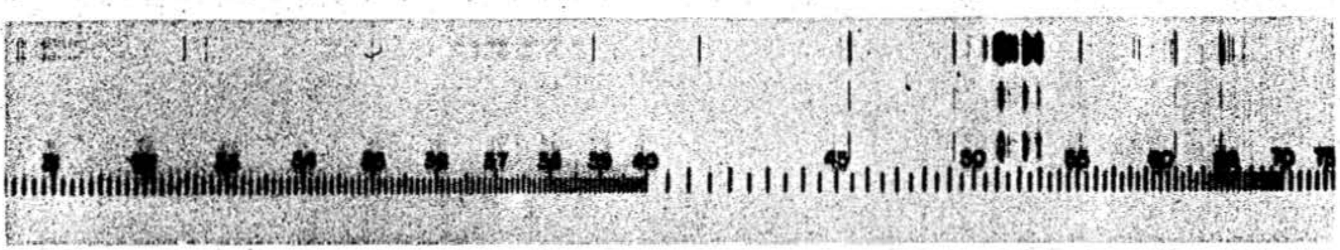

Figure T-5. Barium Chloride Spectrum

b. Experiments with Salts in Evacuated Tubes

A number of experiments were conducted to study the effect of microwaves acting as the sole source of power. Barium chloride (and in one instance copper chloride) was placed in a quartz tube, 1" in diameter and 4" long, i. e., the same type of tube that was used as an envelope in the flame experiments. The tube was closed off at one end and connected at the other through stopcocks to a conventional vacuum system so it could be pumped out. Provision was also made for admitting foreign gases, such as argon or water vapor. When the tube was placed in the microwave field with the same orientation as in the flame experiments, very intense green light was generated. Brightness readings were of the order of 100,000 foot-Lamberts under stable conditions and could be peaked to an appreciably higher figure for short periods of time. Spectrograms taken with a Hilger-Watts prism spectrometer showed that the luminescence was due primarily to the BaCl green band system in the range from 5050 to 5350 Å. The band system is due to a $^2\pi - ^2\Sigma_{11}$ transition from the lowest excited state to the ground state. When barium chloride is used in the form $BaCl_2 2H_2O$, other band systems of the BaCl molecule appear with negligible intensities. (See Figure T-5.) If the salt is used in its anhydrous form, the other systems (which involve an excited state) become much more intense. The light emitted, while intense, is no longer bright green. The addition of a small amount of water vapor to the discharge tube at this stage restores the bright green color of the source. Apparently the water vapor not only quenches the uv and red BaCl bands but acts to transfer more energy to the $^2\pi$ state with resulting intensification of the green bands.

c. Experiments on Combining dc Discharge with Microwave Excitation

A number of electrode designs were used which would not interfere with the penetration of the microwave field into the plasma. The voltage and current values used were in the range required for an arc discharge. However, when the dc discharge was combined with the microwave field no enhancement was observed beyond a slight intensification due to the addition of power.

Discussion of Data

a. Introductory Remarks

In order to be able to interpret the brightness data obtained, it is necessary to correlate them with power values. This is done by means of the following standard formulas:

If L is the luminous flux in lumens, A the area of the source in cm^2, B the brightness in foot-Lamberts, C the candle power of the source, then

$$\frac{L}{4\pi A} \quad 929\pi = B, \quad L/4\pi = C \tag{1}$$

The emitting area of the source constituted by the 4.3 quartz cylinder of 1" diameter containing the flame inside the waveguide is about $75cm^2$.

b. Evaluation of Results for Sodium Flame

Since the value obtained for B was 2×10^6 ft-L, Eq. (1) gives

L = 600,000 lumens, C = 50,000 candles.

If the total power input of 4 kW is taken into account, the efficiency is 150 lumens/watt. However, if we allow for the fact that the coupling between the microwave field and the flame is only 25% and with proper design can be made 90%, then the effective power input is only about 2.7 kW. The efficiency of the energy transformations is therefore as high as 220 lumens/watt.

It is of interest to compare these values with those of high intensity xenon arc lamps of similar power input, such as the Hanovia Compact Arc Lamps. Such a comparison is presented in Table 1. Since no lamps are available with the same power input as our sodium flame, data are listed for lamps of both higher and lower power.

One can note from this table that in these preliminary experiments in which a rudimentary sodium flame is used, we have already exceeded by a sizeable factor the luminous output of a xenon arc lamp of comparable power and have exceeded the efficiency by a factor of about 2.

c. Evaluation of Data Obtained for Barium Source

As mentioned previously, in this case we deal solely with microwave excitation not with microwave enhancement. The figure of 100,000 ft-L, which were observed, corresponds (according to Eq. (1) to 30,000 lumens. This efficiency is low but could be improved by a factor close to x 4 if the present 25% utilization of microwave power were replaced by 90% through a suitable redesign of the microwave cavity. It is to be noted, however, that even the present low efficiency still gives presumably the brightest known steady-state or regularly pulsed source in the green.

TABLE I

Comparison of Melpar Enhanced Light Source With

Two Xenon Arc Lamps

	Melpar Sodium Source	Xenon Arc Lamp	Xenon Arc Lamp
Power Consumption (watts)	4,200	2,200	5,000
Luminous Flux (lumens)	600,000	66,000	200,000
Intensity (candles)	50,000	5,300	21,500
Efficiency (lumens/watt)	140	30	40

Theoretical Interpretation

While the data are obviously still incomplete so that no rigorous theory can be formulated, a number of facts stand out which permit to state at least a working hypothesis. The following points appear to be of prime importance:

Tremendous enhancement of flame brightness under microwave action.

Lack of appreciable enhancement when the flame source is replaced by dc discharge.

Relatively low efficiency of light output produced solely by microwave excitation.

In order to be able to interpret them, we have first to specify the essential difference between a flame and an arc discharge. In a flame, the electrons and other constituents, such as atoms, molecules, and ions, are nearly in thermal equilibrium, i.e., they are at nearly the same temperature. In an arc discharge, on the other hand, the electron temperature is high, that of the other constituents is low. The effect of the microwaves is to raise the temperature of the electrons in the plasma, i.e., to impart high energies to them. From the data obtained we may therefore conclude that the population of low lying excited states increases at a particularly high rate when high energy electrons collide with high energy atoms. There is also the possibility that the same thing holds when the electrons recombine with high energy ions.

The high degree of enhancement under microwave action also suggests the possibility of the emission of stimulated radiation. Since this occurs for flames but not for an arc discharge, we would conclude that the atoms or molecules must be at a high temperature for this effect to occur. It is possible that higher frequency transitions do occur but are immediately reabsorbed and thus serve to pump the low lying excited states.

APPENDIX C

MODULATED LIGHT STUDIES

MODULATED LIGHT STUDIES

From a large collection of experimental data taken in the EEG Laboratory on the optical stimulation by modulated, pulsed light, the following set of charts illustrate the type of outputs which are obtained. The results shown are taken from the data obtained on one subject for change in duty cycle, change in pulse rate from 5cps to 40cps, intensity variation from 30% to 100%, and red vs. green light. The top trace in each figure is the EEG response showing frequency and amplitude. The lower trace gives the frequency and amplitude variation of the light source.

To be noted are sudden sharp responses that arise in the EEG pattern when certain optical stimulation has a high sensitivity on the subject. This indicates a set of parameters for which the subject is likely to be most dehabilitated by dizziness, nausea, and similar effects.

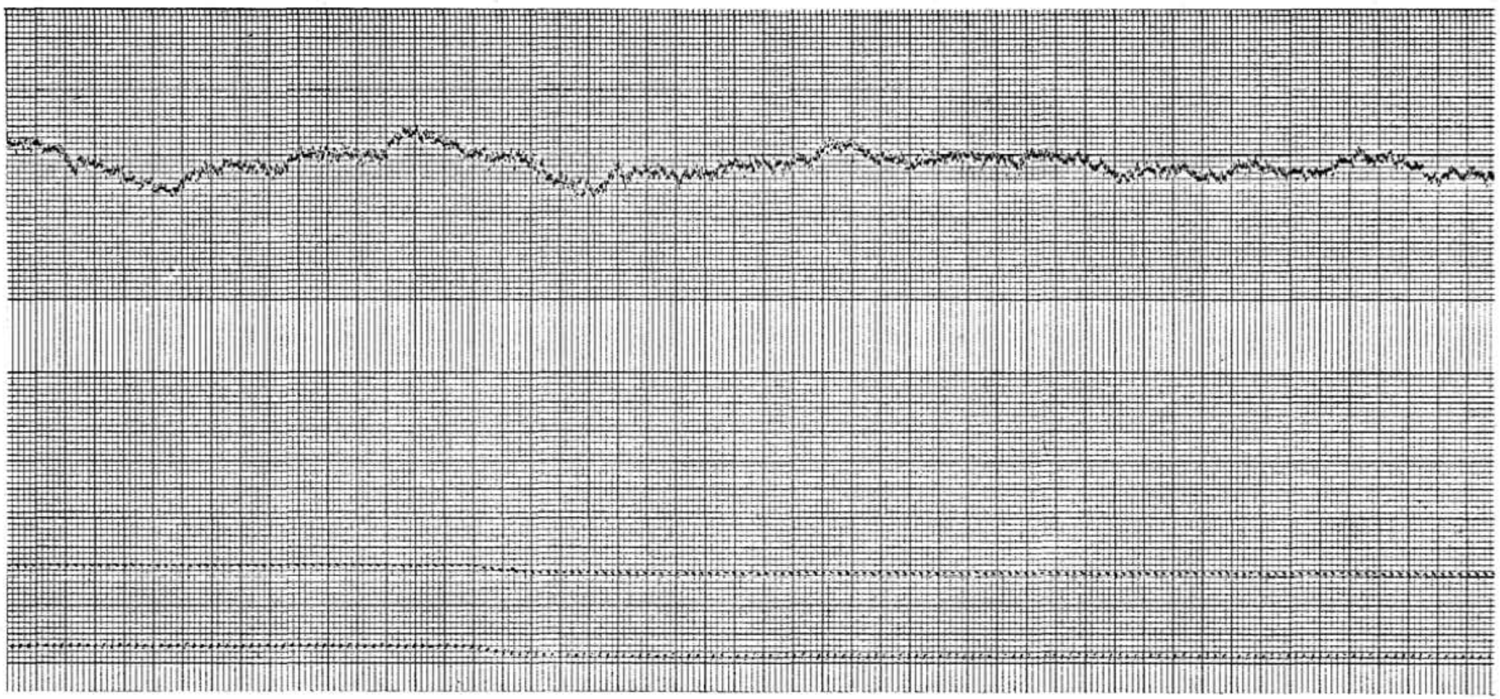

Figure 1. White Light Max Intensity Changed Duty Cycle from 30% to 50%. Paper Speed 25 mm/Sec. PRF - 10 cps Sens. 10 μv/cm

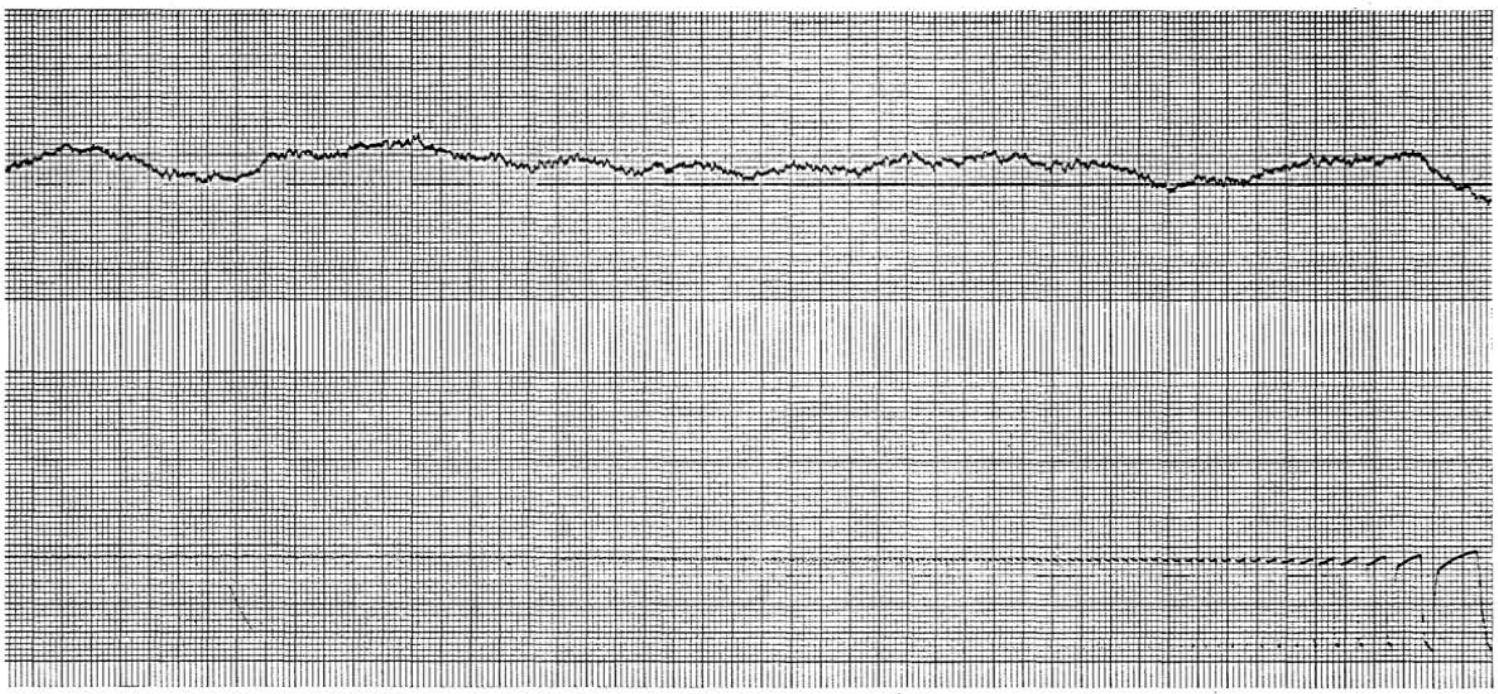

Figure 2. White Light Max. Intensity . PRF Varied from Approx. 5 cps to 40. Duty Cycle 30%
Paper Speed 25 mm/Sec. Sens. 10 μv/cm

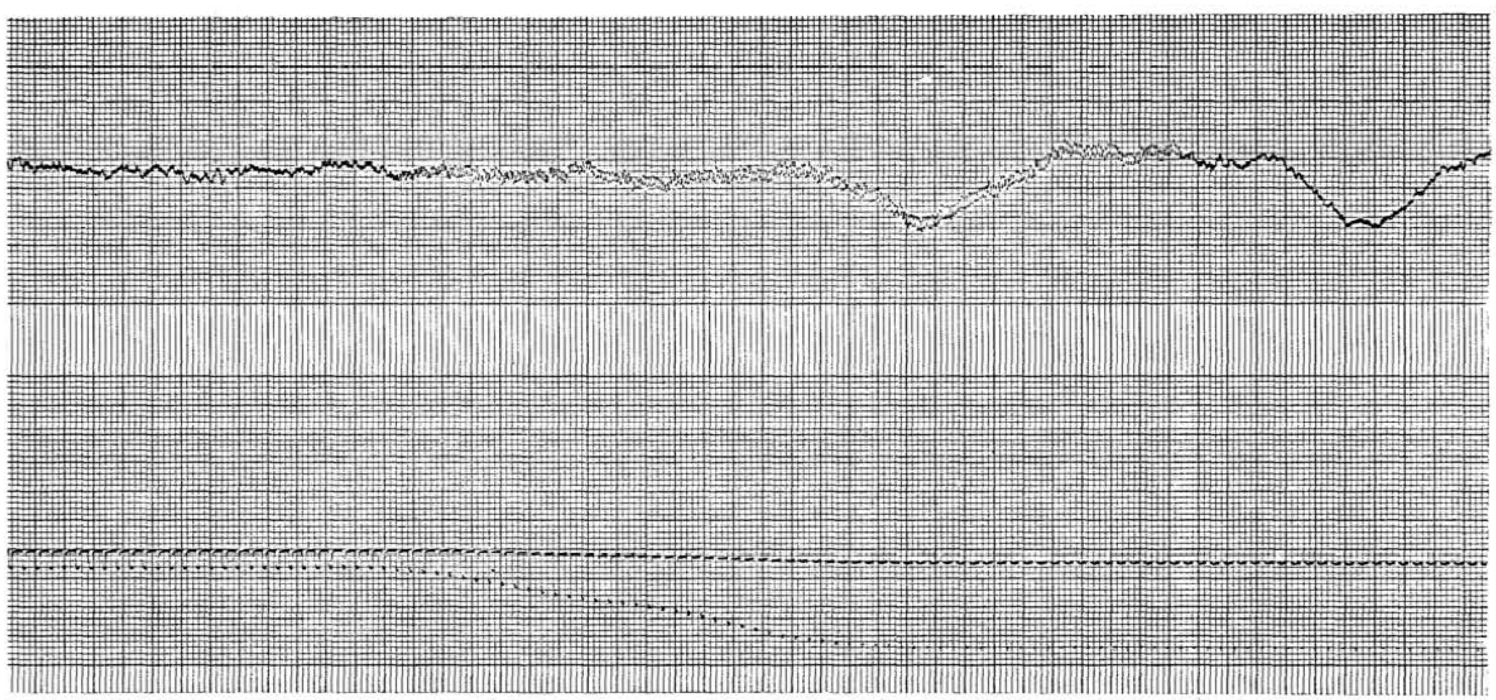

Figure 3. White Light Intensity Changed from 100% to 30%. Paper Speed 25 mm/Sec.
PRF Approx. 10cps. Duty Cycle 30% Sens 10 μv/cm

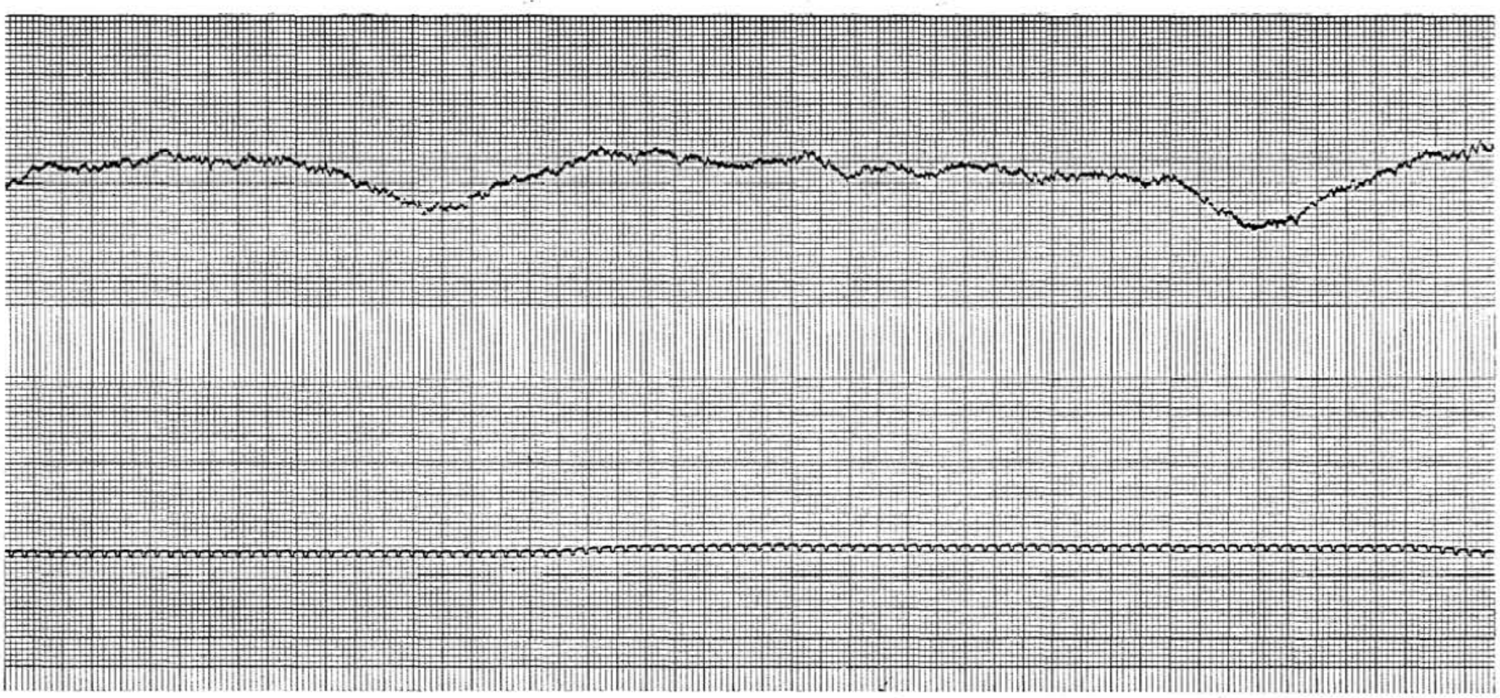

Figure 4. Paper Speed 25 mm/Sec. Color Changed to Green. PRF Approx. 10 cps. Duty Cycle 30%
Light Intensity 100%. Sens. 10 μV/cm

Figure 5. Red Light. Paper Speed 25 mm/Sec. PRF 10 cps Duty ~ 30%. Sens 10 μv/cm

APPENDIX D

EIDETIC VISUAL MEMORY

EIDETIC VISUAL MEMORY

INTRODUCTION

Questions concerning the span of immediate memory in sensory information intake have been the subject of many papers in the psychological literature. In addition to describing the properties of so-called immediate or long-term memory, psychophysical and physiological experimentation over the past 50 to 100 years has strongly hinted at the existence of a short-term visual memory. Evidence of some elementary forms of short-term memory is found in the work of Kuffler[1] describing the ON and OFF responses of the mammalian retina -- where the amplitude of a stimulus, recently withdrawn, is "remembered" in the nature of post-exposure neural discharges. The common visual afterimage is another manifestation of short-term memory evident in certain visual information intake tasks. In particular, it is believed that this common afterimage gives rise to the difficulty in computing the information rates from short-term psychophysical experiments, since very often the afterimage has the effect of elongating the "effective" stimulus duration from which information may be retrieved.[2] The importance in understanding the operation of short-term visual memory as the major contributor to the difference in information intake between experiments which measure the span of immediate memory and the enormous assumed information intake in normal visual experiences cannot be overestimated. Recent work done by Averbach and Sperling[3], and Averback and Coriell[4], has clearly demonstrated the role of short-term visual memory in the processing of information from English letter displays. The quantitative data provided by these researches has indicated that a high capacity buffer storage exists in the retrieval of information from letter arrays; and that this buffer storage is capable of extremely rapid readin and readout with storage time (believed to be a function of the stimulus material) of the order of significant fractions of a second. Massa[5] in 1961 demonstrated that short-term memory plays a similar role in the perception of geometric patterns. From this work, it was concluded that the short-term memory associated with patterns is at least partially eidetic; i.e., provides for information retrieval almost unaffected by the redundancies present (or not present) in patterned stimulus material. In addition to demonstrating the capacity and storage time of short-term visual memory, the work described above has also demonstrated that this memory is susceptible to erasure and confusion.

TECHNICAL CONSIDERATIONS

The Meaning of Eidetic Memory

The notion of memory associated with visual information intake is not difficult to comprehend. A very general definition of memory would concern itself with what may be stored or remembered from a visual display and how long this information storage persists. In this proposal, we are concerned with a very specific notion of visual memory. First, we are restricting our attention to short-term memory, i.e., memory which is probably based upon physiological aspects of the visual process and not upon higher integrative action in the cortex or brain of the individual involved. We are not going to emphasize those aspects of a person's prior "history" which influence his ability to perceive information from a visual stimulus. Rather, we are concerned with the past -- where the past may often entail little more than a fraction of a second -- and the role of this time period on perception of visual information. Furthermore, we are concerned with something we call an eidetic memory. The word "eidetic" essentially means vivid. We use a somewhat more specialized definition or connotation to the term "eidetic." By an eidetic memory we mean a memory in which information from a display remains perceptually vivid; i.e., a memory in which the stimulus or its important aspects are preserved such that perceptual decisions and data processing may be performed on essentially the original information. We may further expand on the notion of an eidetic short-term visual memory with the simple statement that we are concerned with how temporal and spatial factors of the visual field in the immediate past influence perception at the present time.

Some of the salient features of this eidetic visual memory are outlined below.

a. Storage Time

Averbach and Sperling[3], in demonstrating the existence of a high capacity short-term visual memory associated with the perception of letters from letter arrays, noted that memory effects existed over periods of time of the order of one quarter of a second. Massa[5], in studying the role of short-term memory on spatial patterns, found that considerable influence of the past continues to exist in pattern recognition problems up to about one eighth of a second. In neither instance was any work done to determine the effect of the quantity of stored information on storage time. From these two research studies, we conclude that short-term memory effects of the order of significant fractions of a second are probably the storage intervals of interest in our study of eidetic visual memory.

b. Erasure and Confusion

Despite the fact that Averbach and Sperling found the short-term visual memory associated with letter displays to be capable of rapid readin and readout, it was determined that this memory was susceptible, to a very great extent, to erasure and confusion by the introduction of extraneous information into the visual display. In particular, it was found that certain spatial patterns interposed in the information display sequence are effective in causing erasure and blanking of this memory. This points strongly to the fact that the memory is eidetic, i.e., that it depends upon the exact stimulus correlates. We, here at Melpar, in later work involving letter displays and studies of short-term memory using motion picture test techniques have discovered that there is a pre- and post-erasure aspect to this memory confusion. In fact, by interposing appropriate masking fields, this memory may be manipulated to a very great extent. More will be said about this point later.

c. Selective Readout

Of great interest in understanding of short-term visual memory is the question of selective readout. Can the subject influence, through some overt action -- his ability to read pre-selected elements of the display -- and more important, can the display designer produce conditions which enhance readout of certain specified elements from the display while masking other elements in the display? Very little work has been done in the past on this particular point. Set and expectancy have not been considered. Neither have questions of selective masking of individual information elements. A portion of the experimental program proposed later deals with this phase of investigation.

The question of selective readout has even wider implications. The role of short-term storage in long-duration information intake tasks is not understood at all. In fact, no conclusive demonstration that this memory is involved in normal perceptual tasks has been offered. We propose to perform some experiments using the motion picture technique to demonstrate the extent to which short-term storage is involved in information intake tasks requiring the correlation of stimulus elements displaced in time over several seconds.

d. Spatial Extent of Short-Term Memory Influence

Massa, using patterns which extend well beyond the foveal angle, has found significant differences from results presented in the literature with respect to short-furation exposure information transmission. In general, the spatial extent of the stimulus (or dispersion of the picture elements) has not been considered as a parameter in memory experiments. Furthermore, the place where this memory exists (physiologically), i.e., at the fovea or the periphery (or a combination of foveal and peripheral position on the retina) has not been determined. From the point of view of enhancing our knowledge of the physiology of vision, the portion of the retina responsible for vivid memory should be determined.

e. Role of Stimulus Intensity on Memory Performance

Averbach and Sperling have indicated that the short-term memory, which was the subject of their measurements, may not be different from the normal continuing afterimage associated with intense visual displays. Massa found that reduction of the stimulus intensity to the point where no apparent afterimage exists does not seriously modify the role of memory in enhancing the information retrieval from certain displays. The extent to which short-term memory is merely lodged in the chemical and/or electrical time constants of the retinal neural system should be determined. The time constants over which memory is effective, i.e., significant fractions of a second, appear to be considerably longer than those normally encountered in the chemical and electrical behavior which has been measured to date.

f. Interaction of Eye Motion

When considering measurements of memory from information displays considerably larger than the extent of foveal vision, one must become concerned with the interaction of eye motion. It has been observed in many of our experiments with the motion picture technique that dips in performance often occur for certain critical exposure durations. These dips are not recorded in experiments which cite information retrieval from smaller displays. Measurements made by Massa, relative to the extent of eye motion in certain perceptual tasks involving extremely short displays, have indicated that in many instances the interaction of eye motion and information retrieval is most pronounced. Questions regarding whether or not the fovea is blanked during eye motion have not as yet been resolved. Certainly, experiments regarding the role of eye motion in memory will help to resolve these and other physiological problems associated with the role of eye motion in perception.

The paragraphs above have outlined some of the features of visual memory which concern us at this time. During the course of Melpar's company-sponsored program which has dealt with problems of eidetic visual memory, we have found it convenient to consider many aspects of memory in terms of a single variable which is relatively easily measured from various types of displays. We call this variable the eidetic decorrelation time associated with memory for any specific stimulus type. Briefly, eidetic decorrelation (correlation) time and its dependance upon the detailed stimulus parameters combines storage capacity, storage time and erasure properties in a single variable. For instance, a very simple definition of eidetic decorrelation time might be as follows: Eidetic decorrelation time is the time interval during which the temporal and spatial order of the stimulus elements is irrelevant in preserving the redundancies which exist in the stimulus. By this definition, we imply that the short-term visual memory is capable of effectively summing elements of the display which appear separated in time -- as well as spatially separated -- and still, from this summation, we can retrieve and take advantage of the redundancies present in the stimulus material. It has been found from some relatively simple measurements we have made, that the concept of an eidetic decorrelation time may also be extended to include the effects of certain forms of erasure. In fact, some very startling results of the dependence of eidetic decorrelation time on the mode of erasure or confusion used in a given experiment have been recorded.

In summation, the eidetic visual memory, which we are considering in this proposal, is influenced by many factors of the stimulus presentation. It is characterized by a time duration over which it can store information while preserving the redundancies present in that information -- it can be erased and confused by the insertion of appropriate erasure fields in the stimulus display -- it can, through the use of special erasure and confusion devices, exhibit selective readout of information -- it has associated with it both a spatial extent and an area of occurrence on the retina, i.e., peripheral or foveal -- it may be strongly related to stimulus intensity much in the same manner as a common afterimage is -- and it may be wholly dependent upon aspects of eye motion which can be introduced by control of the spatial extent of the stimulus. In addition, there are some very interesting variables related to eidetic visual memory which incorporate many of these features in relatively simple measurements.

Measurement Techniques

Our work on the measurement of short-term memory in vision has drawn extensively upon the use of a motion picture testing technique. In our company-sponsored program, we have made two such motion pictures, to date. Our motion picture display provides for a wide variety of pre- and post-exposure fields and permits extensive temporal variations of the stimulus. Furthermore, it guarantees continuous adjustment of the size of the display, and to a certain extent, of the intensity of the display. In addition, the ease of experimentation implied by recording an entire experiment, including instructions, in a single reel of film is a significant timesaving factor where extensive amounts of data are required to establish statistical validity.

This motion picture tehcnique has one additional advantage. Relatively complicated experiments may be performed with extremely small attendant cost; i.e., we can build some extremely complicated displays without extensive electronic apparatus, and we can achieve complete and consistent time control of these displays without the use of highly accurate timing mechanisms.

To demonstrate some of the properties of the eidetic visual memory as we understand it at the outset of this proposed program, we shall describe two of the films which we have made, and the experimental results from these films. All of the film work discussed has been done with 16-millimeter sound films. The experimental portions of the two particular films cited in this writing were in black and white, but full facilities exist at the Applied Science Laboratory for the design and production of color films. In fact, the technical (or test) portions of the two films considered were imbedded in 16-millimeter color/sound educational information footage intended for display and testing at high school or college science classes. The non-technical material incorporated with these films (produced at Melpar expense) is intended to provide our subjects with some information about the known facts concerning the physiology and psychophysics of vision, and to acquaint them with current research problems in this area.

The first film concerned with the properties of eidetic visual memory consisted of a series of six-letter arrays. There were two classes of these arrays; one class was composed entirely of six-letter words -- the other class with sets of six random letters. The arrays were projected on the screen for short intervals of time varying in duration from one to ten frames (1/24th to 10/24th's of a second). The subjects were asked, following each display, to write down in any order, as many of the letters they remembered for each of the 140 trials included in the film. The purpose for making this particular film was to determine the base levels of performance for non-redundant stimulus material (random letters), and highly redundant stimulus material (words). The results of this experiment, summarized in Figure 1, indicate that an exposure duration of 2 frames accentuates the difference between performance with letters and performance with words.

The second film in the series uses the information gained from Figure 1 as a starting point. We are interested in investigating if the performance measured for words may be deteriorated, or if the performance measured for random letters can be enhanced by a suitable scheme of spatial and temporal separation of stimulus material, and the interposition of masking fields. Film Number 2, therefore, consists of six-letter arrays which are broken up into two three-letter arrays. Spatial position is preserved; i.e., if the two three-letter partial arrays are superposed, the original six-letter array would result. Each partial array is presented for the optimum duration found in Film Number 1 (2 frames). Between the

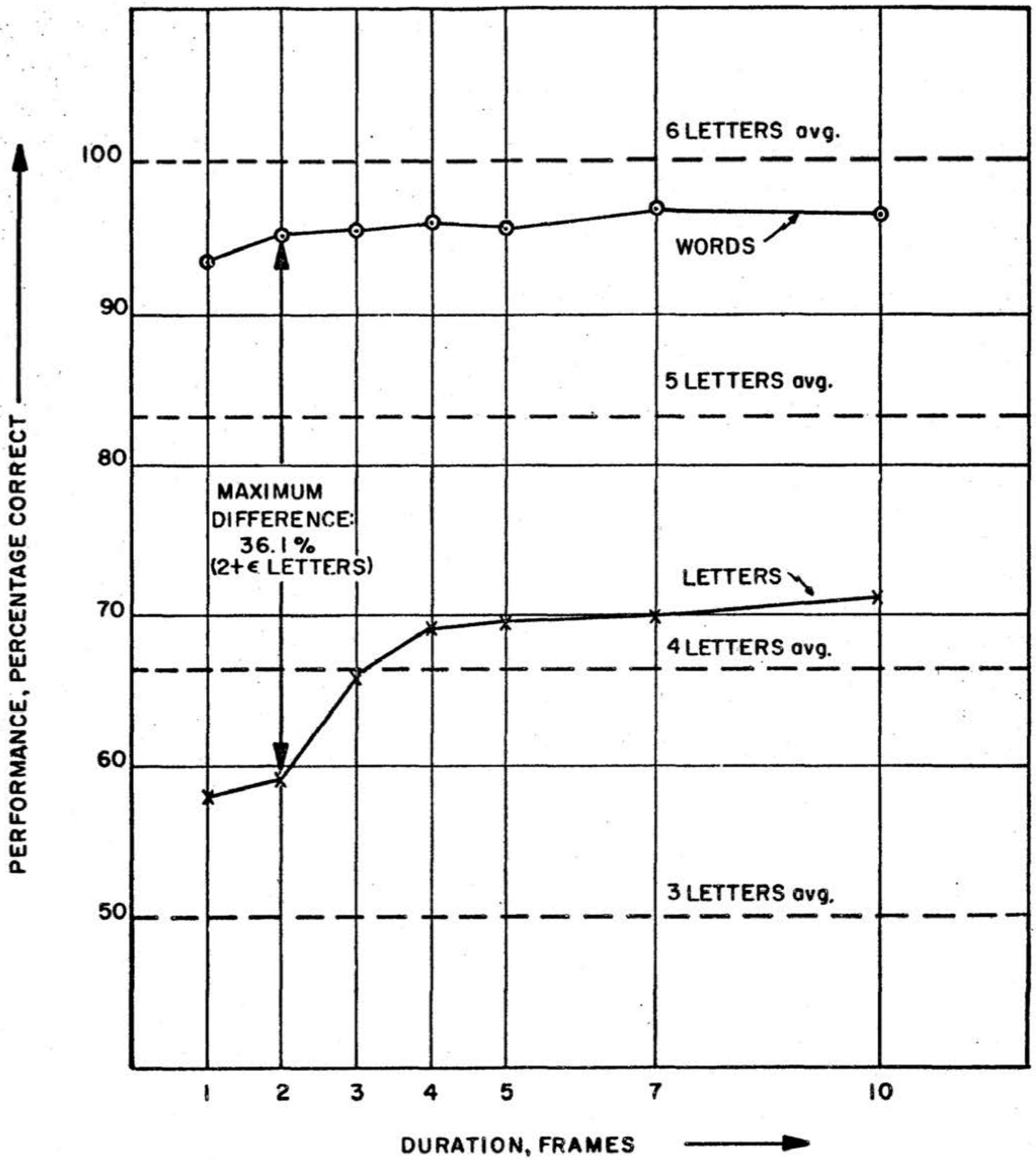

Figure 1. Film No. 1 Results: (15 subjects) Percentage Correct vs. Duration

two partial arrays, one of three types of "noise" or erasure patterns is presented for a variable duration. The noise patterns are classified as:

1. White - (white screen)
2. Black - (black screen)
3. Gray - (checkerboard pattern with half the squares, picked at random, filled in black)

As before, the subject's task is to record, in any order, as many as possible of the six letters he sees during each exposure. A typical exposure sequence is shown in Figure 2. The results of a pilot film are shown in Figure 3a, b, and c. These graphs plot performance versus delay for each type of noise for both word and random arrays. In these plots, all spatial combinations have been averaged together. A total of 12 subjects were tested. Some interesting inferences may be drawn from the results of this experiment. Especially worthy of note is the sharp dip evidenced for word performance under gray-noise masking when delay (duration of the masking field) is increased beyond one frame (Figure 3c). This behavior indicates that if the duration of the masking field is short enough, this field has no effect on the perceptual redundancies in the stimulus; in other words, a delay of one frame is within the eidetic decorrelation time. Further analysis of the data indicated that this gray-noise mask has the property of causing pre-erasure. The performance for the second three letters was superior to that of the first three letters, by a factor of about three to one. Neither of the other noise types demonstrated pre-erasure.

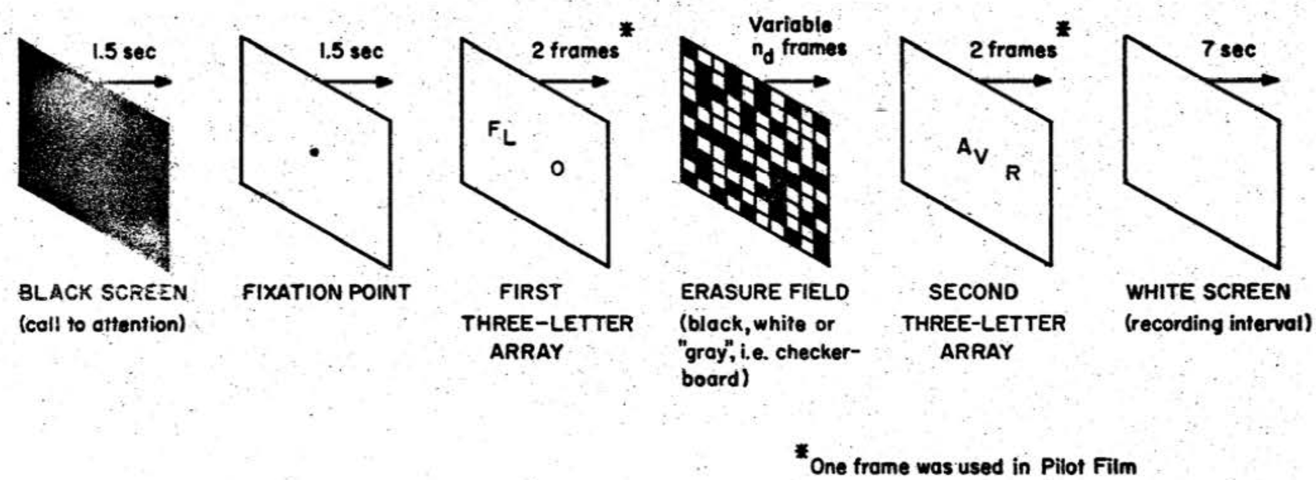

Figure 2. Typical Exposure Sequence for Film No. 2 (shown for word "FLAVOR")

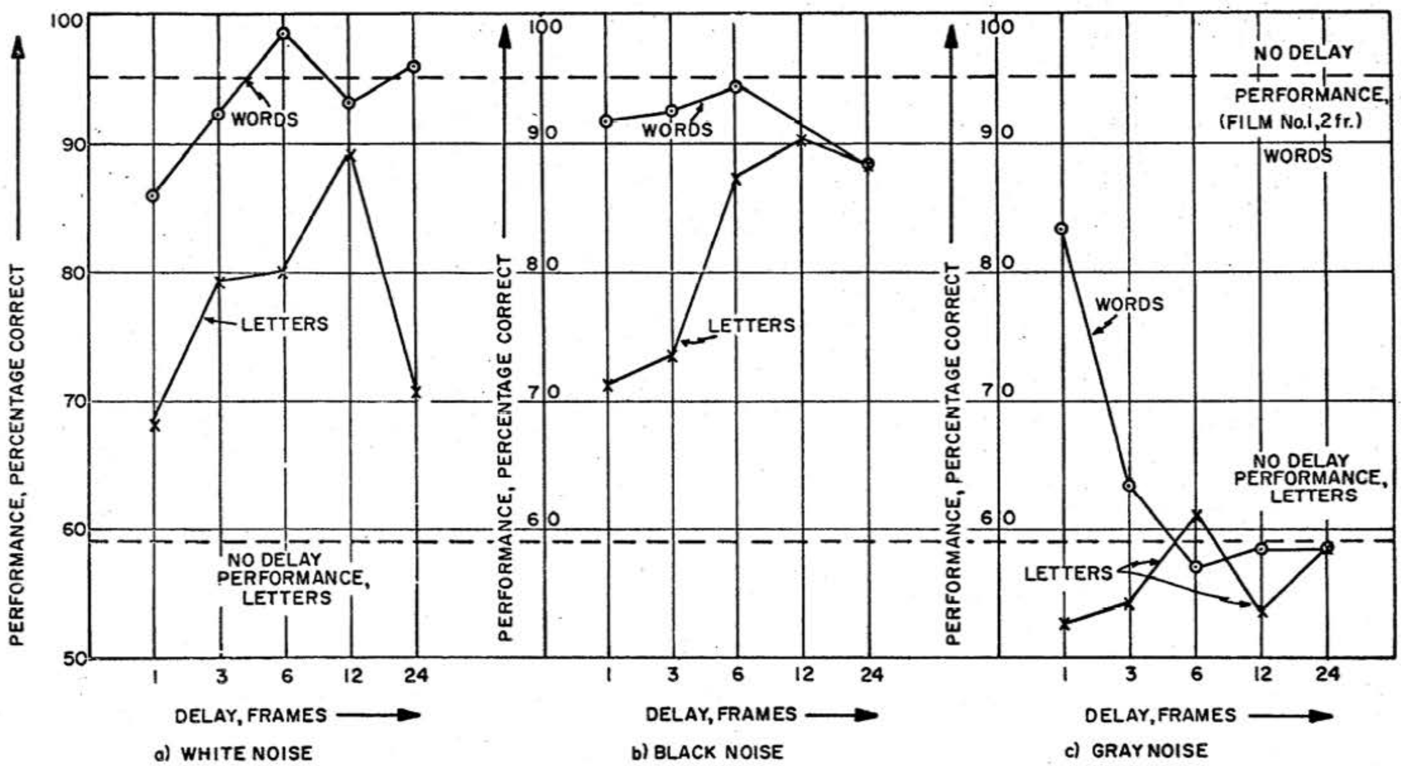

Figure 3. Film No. 2 Results: Performance vs. Frames of Delay

Another interesting result is shown in the graph for black noise (Figure 3b). Note that while performance for words stays relatively constant, the level for letters is enhanced with increasing duration of the masking field—apparently peaking at 12 frames (1/2 second) of delay. This demonstration of enhancement of information retrieval due to interposing appropriate masking fields -- which modify the short-term memory readin and readout -- has very interesting practical connotations.

The behavior recorded with white noise is also quite interesting. Generally speaking, performance for both letters and words is increased as the duration of the white noise field is increased. However, this increase in performance never results in word performance much above the value achieved without the use of the white field at all. Again, letter performance is enhanced. Curiously enough, this enhancement peaks again at 12 frames of delay. Both the curves for black and white noise demonstrate a manipulation of the short-term memory which can be made to exhibit selective enhancement of perception -- selective in the sense that we may create redundancies or take advantage of, at will, existing redundancies in the stimulus material. Though the data taken to date is insufficient to warrant firm quantitative conclusions, white erasure fields appear to cause post-erasure. The significance of the results presented above cannot be fully assessed at this time. They are presented to demonstrate that there are many aspects of even such a mundane display as a six-letter array, which are not yet understood. Furthermore, they demonstrate our ability to interfere with, in a variety of ways, the normal perceptual processes which take place during and after short-duration displays. This ability to manipulate is an intriguing one -- both from the point of view of its practical application, and from the point of view of making a contribution to the understanding of the way in which memory works. It should be noted that in all of these instances 24 frames, or 1 second, is the maximum time considered. Furthermore, most of the interesting things appear to have been over by this time. Thus again, we see some support for the notion of a separate and somewhat independent visual process called the short-term eidetic memory.

In all instances of our company-sponsored film work, data reduction has been performed using the Recomp II computer, programmed to permit extensive data processing with minimum difficulty and cost. The particular film, Film Number 2, in our reference above will be made into a much longer version incorporating many more exposures under many different experimental conditions. This film will be shown, as part of our company-sponsored program, to from 100 to 300 subjects, and the results incorporated to achieve higher statistical reliability in the measurements described above. We regard the data presented in this proposal as the starting point of a further quantitative measurement program concerning the nature of short-term visual memory -- using this data solely to support our contention that there are many interesting aspects of stimulus displays which are indicative of relatively complicated physiological and perceptual processes, and that these aspects are manifested in short-term visual memory. Further this data supports the hypothesis that there is associated with this short-term memory a significant variable which we choose to call eidetic decorrelation (correlation) time, and that through measurement of this time for a wide variety of conditions, we may be in a position to state accurately the nature of the short-term visual memory and its physiological implications.

REFERENCES

1. Kuffler, S. W., "Discharge Patterns and Functional Organization of the Mammalian Retina", Journal of Neurophysiology 16 (1953).

2. Sperling, G. A., "The Information Available in Brief Visual Presentations," Psychological Monograph 74 (1960).

3. Averbach, E. and Sperling, G., "Short Term Storage of Information in Vision", Proceedings -- Fourth London Symposium on Information Theory (1961).

4. Averbach, E. and Coriell, A. S., "Short-Term Memory in Vision", Bell System Technical Journal 40 (309-328) 1961.

5. Massa, R. J., "An Investigation of Human Visual Information Transmission" Ph.D. Thesis, M.I.T. 1961.

APPENDIX E

ESTIMATES FOR HIGH SOUND FIELD LEVELS

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The following comments are directed to the generation of high sound field levels. It is well known that the threshold of pain is usually assumed to be 120 db above the 0 db reference level of .0002 dynes/cm^2. Attainment of this level would not produce any permanent physical damage but it would induce temporary hearing loss and would also deliver speech interference pulses and BJ series sounds with great effectiveness. The equivalent sound pressure level for 120 db is determined as follows:

$$120\text{db} = 20 \log_{10} \frac{P_1}{P_2} \qquad (1)$$

where $P_2 = .0002 \text{ dynes/cm}^2$

$$\log_{10} \frac{P_1}{P_2} = 6 = \log_{10} \frac{P_1}{.0002}$$

$$P_1 = 200 \text{ dynes/cm}^2$$

The maximum sound pressure level that can be sustained in air without cavitation is the equivalent of the atmospheric pressure of 14.7 b/in^2. The conversion to dynes/cm^2 is

$$\frac{14.7 \text{ b}}{\text{in}^2} \times \frac{445\ 000 \text{ dynes}}{\text{b}} \times \frac{\text{in}^2}{6.4516 \text{ cm}^2} \qquad 10^6 \text{ dynes/cm}^2$$

or 194 db above .0002 dynes/cm^2

This is the maximum sound level that can be attained at the sound projector.

We now calculate the power level at a source which will produce a sound intensity level equal to the threshold of pain at a range of 1000 feet. The transmission of plane wave of sound in air is expressed by the relation

$$I = I_o e^{-mx} \qquad (2)$$

where I = sound intensity at point x

I_o = sound intensity at reference point

m = absorption coefficient (per cm)

x = distance from reference to point x (cm)

Assuming a frequency of 3000 cps, the absorption coefficient for 80% relative humidity is .00005/cm*. This produces an atmospheric attenuation of 0.64 db/1000 feet, a number relatively negligible in our considerations here.

The intensity in ergs/sec/cm^2 of a plane wave is

$$I = \frac{P^2}{\rho c} \tag{3}$$

where P = Pressure (dynes/cm^2)

c = Velocity of sound in cm/sec

ρ = Density of medium in gms/cm^3

Substituting

$$I_{120db} = \frac{(200)^2}{41.4} \quad \begin{aligned} &= 9.66 \times 10^2 \text{ ergs/sec/cm}^2 \\ &= 9.66 \times 10^{-5} \text{ watts/cm}^2 \end{aligned}$$

and

$$I_{194db} = \frac{(10^6)^2}{41.4} \quad \begin{aligned} &= 2.42 \times 10^{10} \text{ ergs/sec/cm}^2 \\ &= 2.42 \times 10^3 \text{ watts/cm}^2 \end{aligned}$$

Consider now the sound field produced by an acoustical radiator having a beam spread of 30° (± 15°). At a distance of 1000 feet the area covered by sound is

$$A = \pi R^2$$

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* Olson, H.F., Elements of Acoustical Engineering, Second Edition, p. 429.

where $R = 1000 \tan 15^{o} = 258.8'$ $A = 3.14\ (2.588)^2 \times 10^4 = 21.1 \times 10^4 ft^2 =$

$1.96 \times 10^8\ cm^2$

Assuming absorption losses are negligible and the threshold of pain is to be attained, a radiated acoustic power of

$$P = \frac{9.66 \times 10^{-5} \text{ watts} \times 1.96 \times 10^8 \text{ cm}^2}{\text{cm}^2} = 18.9 \times 10^3 \text{ watts}$$

is required of the source. If the source is not to cavitate, the power level at the source must not exceed 194 db re. to .0002 dyne/cm^2 (i.e., 10^6 dynes/cm^2 or 2.42×10^3 watts/cm^2); hence, the aperature of the radiator must be at least 18.9×10^3 watts/w.42 x 10^3 watts/cm^2 8 cm^2. This is a reasonable size aperature to be expected of a piston source driver unit.

This discussion serves to illustrate that a sound field equal to the threshold of pain can be attained at a range of 1000 feet using a source of 64 kilowatts input power to a 30% efficient radiator. It is noted that such a radiator would require a relatively large power supply; but not so large as to be beyond the current state of the art. A drop in power level by 10 db would still deliver a 110 db sound level at the range of 1000 feet that would be very effective in creating the desired disturbing effects. This would require a power source of 6.4 kilowatts, a unit that could be transported on a small vehicle such as a jeep.

APPENDIX H

HIGH POWER RUBY LASER SYSTEMS

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Introduction to Ruby Techniques

A vast amount of work, both theoretical and experimental, has been done on the chromium doped aluminum oxide lattice structure. It is no accident, then, that the ruby laser has been so highly developed, although it is not necessarily the ultimate type for high power, by any means. Nevertheless, the ruby laser has been subjected to such an array of experiments and ruby rod technology has been so refined that the immediate design of a super power laser system practically demands the use of a ruby.

This appendix discusses standard giant pulse techniques, which represented the first breakthrough toward the evolution of a super power system. Such a scheme allows power in the hundred megawatt region to be generated, but, with such a scheme alone, it would be difficult to go into the 10^9 watt region of power output. The full transmission mode (or "pulsed transmission mode" as first described in an open publication by Vuylsteke), on the other hand, allows peak powers which will probably eventually go above 10^{11} watts to be generated.

The standard giant pulse technique could be of value when used in conjunction with a ruby laser amplifier. For that reason, a brief description of amplification techniques is given. Although it is true that we generally prefer the full transmission mode scheme, we recognize that the use of an amplifier is desirable in certain situations. For example, using the basic excitation switching at low powers causes much less trouble with Pockel's cells, etc.

To achieve any significant increase in efficiency in a ruby laser system, the flash lamp must be markedly improved. Improvement by means of gas mixtures, type of discharge and fluorescent cooling are discussed. The first two are probably absolutely necessary to the improvement for efficiency; the use of a fluorescent coolant may or may not prove to be feasible. In any event, one percent efficiency will not be achieved without appreciable improvement in laser pumping.

Cooling is necessary to increase efficiency, as well as to allow a reasonable prf at these high energies and peak powers. We give this some consideration in this proposal. Along with cooling we desire to match the light into the ruby rod by means of appropriate coatings or sleeves. The use of sleeves will also allow more efficient cooling to take place, so the subjects are somewhat related.

Finally, in this section, a super power ruby laser development program is outlined. The problems are difficult; however Melpar's long and diverse experience in plasma physics, laser development (starting before the advent of the first laser), applied optics and electronics indicate that the goals are feasible.

Standard Giant Pulse Techniques

Since the suggestion of generating "giant" laser pulses by controlling the regenerative feedback by R. W. Hellwarth[1], a number of approaches have been practically demonstrated.

[1] R. W. Hellwarth "Advances in Quantum Electronics" p. 334, Columbia University Press (1961).

Electro-optical switching was the first approach used, and for highest output powers coupled with ease of modification for optimum performance it remains the best method to consider for obtaining the desired laser characteristics. Only basic components were used by McClung and Hellwarth[1] in demonstrating this approach. With their apparatus one can achieve the desired end by either of the following two methods. First, one must note that the fluorescent radiation from a ruby rod with the C axis oriented 90° to the optic axis is plane polarized. The polarizer is mounted to pass this polarization. As the light passes through the Kerr cell the polarization is rotated 45°. The beam rebounds from the external mirror and is rotated another 45° through the Kerr cell. Thus, the field vector is cross polarized to the polarizer on the return trip, and no feedback is allowed. After a suitable delay to allow the percentage inversion to reach a much higher level than normal for threshold, the Kerr cell voltage is quickly switched off, maximum feedback is allowed, and the giant pulse is generated.

The other sequence of events that can be used is one that Melpar is currently employing in its giant pulse work. Basically, the only difference in the physical arrangement is that the polarizer and Kerr cell are interchanged and that the polarizer is cross polarized to the light instead of parallel to the field vector. Thus with no voltage on the Kerr cell no optical feedback is allowed. Again, after

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[1] F. J. McClung and R. W. Hellwarth, J. Applied Physics 33, p. 828 (1962)

a suitable delay, a high voltage pulse is applied to the Kerr cell, and the plane of polarization is rotated 90°. The wave can now pass through the polarizer to the external mirror, reflect, pass back through the polarizer, and back through the Kerr cell. In other words, the optical cavity is now complete.

The advantage of this latter arrangement is that since the Kerr cell is to be actuated only momentarily, a pulse transformer can be used to generate the high voltage for the cell instead of a d.c. power supply.

Because of the stimulated Raman effect in the nitrobenzine liquid, a solid state Faraday rotator would be preferable to the standard Kerr cell, especially at the peak powers requested for this sytem. This effect when it occurs in solids is called the Pockel's effect, but it would be utilized in the same manner as is the Kerr effect.

KDP (potassium dihydrogen phosphate) and ADP (ammonium dihydrogen phosphate) crystals are the materials that are commercially being used at the moment. The Faraday rotation is achieved by applying a strong electrical field along the direction of propagation in this material. At the moment, transparent or grid shaped electrodes are being used to apply the high voltages. This interferes with the optical path to some extent and introduces additional losses. Also, it may be that the absorption by these electrodes when the laser does emit will be sufficient to completely vaporize the coating. This difficulty could be easily circumvented by straightforward design of specially shaped electrodes employing a hollor center. Alternatively, one might employ Copper

Chloride crystals which operate under a transverse electric field exactly like the Kerr cell. Unfortunately, only a limited amount of work has been done on this material; so, much development work remains to be done before a commercial package using this material becomes available.

Another modification using Faraday rotation employs ordinary barium flint glass. Here, the rotation is obtained by subjecting the material to a strong longitudinal magnetic field, generated by discharging a capacitor through a coil wrapped around the glass. As is pointed out elsewhere in the proposal, minimum switching time is of the utmost importance in generating maximum peak powers. If only a single LC circuit is used and allowed to "ring", the switching time will be much too long for optimum results. By employing standard pulse shaping techniques this inexpensive approach definitely holds promise.

Another approach to Q switching has been developed to a high degree of reliability and performance. This involves mechanical optical switching, i.e., speed rotating mirror or prism. The rotating system possesses the advantage of having no additional components internal to the laser cavity to provide further losses, but it also possesses the disadvantage of not being able to change the shape of the switching pulse as easily as can be done with electronics. And, it may be that the effective switching time of the rotating system can never be made as short as would be optimum for maximum peak power. A thorough analysis of the relative merits of electro-optical switching and mechanical optical switching is necessary to determine which of the two approaches would ultimately lead to the better system. Such an analysis is recommended as an initial part of the proposed development program.

To illustrate the energy storage capability of ruby lasers, consider a rod 15 cm long by 1.5 cm in diameter, doped to a concentration of 1.6×10^{19} chromium atoms per cubic centimeter. Then, imagine all these atoms pumped to the upper level of the R_1 emission line. The stimulated emission can at most cause 1/2 of them to emit. Thus there could possibly be $\frac{1.6}{2} \times 10^{19}$ photons per cm^3 emitted. The energy of one photon at 6943 Å is 2.861×10^{-12} ergs. Hence the maximum energy that can be emitted is 2.3×10^7 erg/cm^3 = 2.3 joules/cm^3. The volume of this rod is 26.6 cm^3, and hence the maximum energy that can be emitted by one pulse is about 64 joules.

In giant pulse work this is the best that can be achieved, and therefore a rod (or rods) having about eight times this volume would probably have to be used in order to achieve 300 joules in one pulse.

In view of the preceding, it is of interest to note that in normal pulsed lasing action, it is possible to pump a rod to threshold, emit a spike of radiation, and then repump the rod to threshold. This can be repeated many times during the duration of the pump pulse. Hence, the total energy out can be (and often is) much more than the maximum that can theoretically be stored at one time in a rod pumped to 100% inversion.

The Full Transmission Mode

Normally, the maximum possible power output of a solid state laser is not obtained, as the Fabry-Perot cannot be 100% transmissive on one end. However, one end (or both ends) is usually quite transparent. So, the advantage to be gained by "switching outisde the cavity," which is only a factor of $\frac{P_o}{T_w}$ where T_w is the output transmissivity, is not great. Nevertheless, making the Fabry-Perot mirrors highly reflective, then "switching outside the cavity," does yield a power output greatly in excess of the normal power output. This is true even though the "normal" power output in such a case is very much less than for a more advantageous choice of mirror transmissivity.

Although such a method was arrived at independently by Melpar, the first (and best) published analysis is due to A. A. Vuylsteke (JAP, 34, No. 6, June, 1963). Dr. Vuylsteke calls this mode the "Pulsed Transmission Mode," a title very similar to that utilized by Melpar.

Basically, the principles are very simple, as follows:

a. Low effective reflection from both ends is achieved while pumping the ruby rod in the usual manner.

b. The highest possible reflection coefficients are switched on after maximum effective pumping is achieved.

c. Then, essentially "completely opening one end" (and assuming a true step function switch) results in a power output $\frac{\quad_s}{\tau}$, where $_s$ is the very high energy stored in the cavity due to both "normal Giant pulse storage" and the extremely high reflection coefficients used, while $\gamma = \frac{L}{c'}$ (L being the length of the Fabry-Perot and c' being the average velocity of light in the Fabry-Perot).

The system actually shown by Vuylsteke (op. cit.) is not practicable, since $\sim$ 100% reflectivity at one end will allow lasing to take place before the proper time, even with the other end uncoated and its highly reflective mirror deactivated. Therefore, dual switching is not only very advantageous but is absolutely essential if the highest possible power is to be realized. It is also highly important that

$$\gamma = \frac{L}{c'} \gg \gamma_{(switching)};$$

thereby demanding a long Fabry-Perot together with nanosecond switching techniques.

For those interested in a rather refined analysis of the full transmission mode, reference is made to Vuylsteke's paper (op. cit.). Melpar believes, however, that a greater practicability can be achieved by means of the "long" Fabry-Perot concept and has analytically investigated the details as an internal research project. Simple rod scaling techniques can be adequate as a first approximation to a field device.

Amplification Techniques

In addition to attempting to scale up existing rods to larger sizes, it has also been suggested[1] and demonstrated that a pumped ruby

[1] P. P. Kisliuk and W. S. Boyd, Proc. IRE 49, p. 1635 (1961)

rod can be placed in tandem to a ruby laser oscillator to increase the final output. This approach, though it would not lead to the ultimate in efficiency, would, however, not be restricted by the size limitation of current crystal technology. Thus, it presents a straightforward approach to reaching the primary objective of obtaining peak output powers near 10^{10} watts.

A number of points must be kept in mind in estimating the single pass gain that might be realized from such a secondary amplifier. Frantz and Nodvik[1] have pointed out the effects of a finite pulse width. Qualitatively, it is easily seen that the trailing edge of the pulse does not receive as much amplification as the leading edge and hence there is a net effect of shortening the pulse duration. This effect probably has no importance to the desired system, however.

Not so easily seen, but something which quantitatively evolves from their theory, is the fact that the net gain is not expressed as the simple exponential, exp. α L. (α is the calculated gain per unit length arrived at from threshold conditions.) Rather, it is a more complicated expression with the net effect of reducing the gain. Further, their theory indicates that, as the photon density approaches $10^{19}/cm^2$ for a .05% doped ruby, the gain degenerates to merely linear amplification, instead of any resemblance of exponential growth.

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[1] Lee M. Frantz and John S. Nodvik, J. of Applied Physics 34, p. 2346 (1963)

Other effects such as end losses and crystal imperfection must also be considered. Even with these additional losses and the conservative theoretical approach, it initially appears that power gains of 6 times might realistically be achieved for a 6" x 1/2" rod pumped to 25% inversion. This would demand primary giant pulses on the order of 200 megawatts in order to achieve outputs around 10^9 watts. This is definitely feasible.

Pumping Advancements

Present flash lamps leave much to be desired, especially with regard to matching the bulk of their light output to the absorption band of a laser specimen. As long as moderate output energy, low repetition rates and low efficiency can be tolerated, as they can in many circumstances, the standard xenon flash lamps are quite satisfactory. As the required output energies and repetition rates rise, however, low overall efficiency cannot be tolerated, and the flash lamp is the major source of trouble. Especially for mobile weapons applications, the smallest power supply and energy storage bank should be used, resulting in a requirement of optimum efficiency.

Insofar as pumping in the visible is concerned, it is most advantageous to have the pump light incident parallel to the c axis; although this actually lowers the efficiency slightly for the 4200 Å absorption band, it raises it by a factor of about two for the 5600 Å absorption band. In many cases, with coolants, etc. present, we can neglect the ultraviolet absorption band, even though it is of very high cross-section.

What sort of gas combinations should we consider? Strong lines applicable to the two main absorption bands of ruby are the following:

A. Helium:

a. 4121 Å ($2^3P-5^3S_1$)

b. 4471 Å (2^3P-4^3D)

c. 5875 Å (2^3P-3^3D)

d. 4009 Å ($2^1P_1-7^1D_2$)

e. 4143 Å ($2^1P_1-6^1D_2$)

f. 4387 Å ($2^1P_1-5^1D_2$)

B. Argon:

a. 5689 Å

b. 5495 Å

c. 5888 Å

C. Mercury:

a. 4047 Å ($6^3P_0-6^3S_1$)

b. 4358 Å ($6^3P_1-6^3S_1$)

c. 5461 Å ($6^3P_2-6^3S_1$)

d. 5769 Å ($6^1P_1-6^3D_2$)

e. 4339 Å ($6^1P_1-7^3D_2$)

f. 4347 Å ($6^1P_1-7^1D_2$)

g. 5790 Å ($6^1P_1-6^1D_2$)

h. 4077 Å ($6^3P_1-7^1S_0$)

i. 4108 Å ($6^1P_1-9^1S_0$)

Without considering further examples, it is clear that a gas mixture of He, Ar, Xe, and Hg should be investigated, probably with concentrations varying in the order indicated (from greater to lesser concentration). There is actually a large ensemble of Argon lines varying from 5495 Å ($2p_9$-$6d'_4$) to 5888 Å ($2p_9$-s_5) (16 lines) of comparable excitation cross-section; these should be appropriate to pumping the 5600Å absorption band of ruby. The helium is most appropriate for pmping the 4200Å absorption band, and the mercury is applicable to both absorption bands. Semi-quantitatively at least, there seems to be little doubt that an appropriate mixture of the indicated gases would be far superior to a simple xenon flash lamp.

In addition to a better choice of gas or gases for the pump lamp, an important consideration is that of the phase-space distribution function of the exciting electrons. The excitation frequency is given by

$$v_{x_i} (r, t) = \int_{v_{x_i}}^{\infty} v \sigma_{x_i} f (\vec{r},\vec{v},t) \, d\vec{v} \quad ,$$

so that the optimum form of the phase-space distribution function, $f(\vec{r},\vec{v},t)$, depends upon the cross-section shape under consideration. C. T. Knipp (PR 37, 756 (1931) showed that an H-type discharge gave some 50 times more light intensity from a given discharge than did an E-type discharge. As the usual flash lamp discharge is "E-like," it is apparent that some improvement should be sought in this area. Melpar has done an enormous amount of work in this field, and there is no question but that we can improve the flash lamp situation from such principles alone! Of course, we do wish to continue the general flash lamp approach, so that "H-like" discharges such as the theta pinch deserve appreciable attention.

Another approach is somewhat more complicated; it consists of having one mirror $\sim$ 100% reflective at the laser wavelength and nearly 100% transmissive at the pump wavelengths. Then, making the c-axis also the ruby axis, the end window high pressure steel flash lamp is employed. This gives short pulses of large energy, so that some short time after the flash lamp pulse has disappeared the "highly reflective" and the "one end full open" portions of the full transmission mode cycle can be carried out. This also allows the cooling problem to be optimized, while employing a very advantageous pumping scheme. Such a pumping scheme is also of advantage for the amplifier portion of an oscillator-amplifier ruby laser system.

Another possibility is the use of an appropriately doped coolant as both the cooling and secondary pumping agent. That is, it may be possible to select a doped coolant which will absorb heavily and fluoresce at either (or both) the 4200 Å or 5600 Å absorption bands. In such a manner a primary flash lamp radiating most of its energy in an inappropriate region of the spectrum might be transformed into a much more efficient overall laser pump device. It will be necessary to investigate a number of liquids, but doped chelates would show some initial promise.

Cooling and Matching Techniques

It is easy to see, since the absorption coefficient changes from 0.4 cm^{-1} at room temperature to 10 cm^{-1} at 77° Kelvin, that a sizeable increased gain per unit length is automatically achieved by cooling. Thus the threshold goes down and the efficiency goes up. It is therefore imperative that some sort of cooling be provided.

As part of the in-house program at Melpar, the theoretical aspects of heat transfer from cylinders to flowing gases or liquids were considered some time ago. This was done primarily to estimate the difficulty of cooling high repetition rate lasers. In that study it was shown that the effective heat absorption (and light absorption) was proportional to the volume of the rod and the cooling was proportional to the surface area. Thus, for this type of geometry the most efficient cooling takes place for long crystals of small diameter. This generalization, however, holds only for the absorbing ruby medium. It has been demonstrated that cladding of a given diameter rod with non-absorbing sapphire possesses the advantage of providing additional cooling surface with no additional absorbing volume. Sapphire is chosen because the basic material in the crystal, aluminum oxide, is the same as for ruby, and, hence, the coefficient of thermal expansion is well matched. As a point aside, this procedure of cladding also yields other advantages. It provides an additional optical element that focuses more optical energy into the ruby, thus increasing the efficiency. Also, there is some evidence that cladding reduces the allowed number of so called "whispering modes" that can exist in the rod.

This same study also indicated that more efficient cooling would be accomplished by using transverse flow of the coolant rather than using longitudinal flow. Mechanical designs for achieving this would constitute a small part of the proposed development program.

The cooling of material to cryogenic temperatures poses a number of other practical problems such as boiling of the liquified gas (if one is used) and the frosting of the ends of the rod. Melpar is quite familiar with the techniques of overcoming problems such as these, having worked at cryogenic temperatures in a number of other research programs (e.g., cometary research and free radical optical excitation studies). It is therefore felt that the company possesses the capability to adequately design a good cooling system that will effectively incorporate the increased efficiency that comes from working with a laser system at these cryogenic temperatures.

Further increases in efficiency can be realized by more effectively transferring the optical pumping energy from the lamp to the rod. There are a number of ways that this can be accomplished. For example, with any sort of liquid completely filling the cavity, some improvement is received by the closer matching of the indices of refraction. If, however, the heat transfer is to be accomplished by using a gas cooled to low temperature, then another technique will be attempted. As far as Melpar knows this approach has never been tried. The procedure would be to coat the rod to 1/4 wavelength thickness with some material having the index of refraction equalling $\sqrt{n_R}$, (n_R = the index of refraction of the material making up the laser rod).

For ruby this would mean that a material having the index of 1.33 would be ideal. Magnesium fluoride, which is often used for this purpose, has an index of 1.38. Using it would reduce the reflection coefficient from 7.6% to 0.15% for normal incidence. This approach could also be used to advantage on sapphire cladding. In addition to matching radiation propagating inward, the coating would match radiation outward, increase the critical angle, and hence further reduce the allowed "whispering modes" in addition to that accomplished by sapphire cladding. Melpar possesses the capability, (in-house), and has had much experience in applying thin films to various materials.

The one other matching development that could be attempted is that of a pump lamp having a spectral distribution more closely approximating the absorption bands of the ruby.

ALTERNATIVE LASER SYSTEMS

Other Doped Crystals

There are a number of crystals of excellent quality which have been appropriately doped for laser action. The most familiar crystals, of course, are Calcium Tungstate and Calcium Fluoride, although several others are known. The lower energy per photon (most of the known dopings result in infrared lasers) is not a significant factor, and in some cases the efficiency exceeds that of the usual ruby laser.

In additon to C_aWO_4 and C_aF_2, other materials of interest are L_aF_3, S_rF_2, B_aF_2, and $S_rM_oO_4$. C_aWO_4 dope with N_d^{3+} may be of significant value for high power, as a large doping concentration is permitted

($\sim$0.15%) and operation at room temperature ($\sim$290°K) is quite satisfactory. For "heating up to room temperature"case, CA_aWO_4 with N_d^{3+} will give at least 1.5 times the energy per unit volume of laser crystal that Al_2O_3 with C_r^{3+} gives.

The rare earth trifluorides hold great promise, although the work to date is rather meager. They hold advantages similar to that required by a U^{3+} ion, which should be positioned in a fourfold symmetric charge compensated site volume. That is, the rare earth trifluorides are particularly adaptable to being doped by the usual rare earths, presumably resulting in a very compatible laser material.

Glasses

Some rather peculiar, inhomogeneous glasses, possessing no sensible proportions of SiO_2, B_aO, Sb_3O_3, etc. have been made to act as acceptable hosts for the N_d^{3+} ion. In other words, rather common, readily available glasses appear to offer great promise as easily fabricated hosts, in addition to offering easy doping. It is, indeed, difficult to believe that scattering losses can ever compare favorably with a good single crystal host of an acceptable nature.

Nevertheless, it is readily noted that a great opportunity exists for "tailoring"the absorption bands, so that it may well be possible to obtain overall efficiencies of a very high value. Secondary fluorescent dopings, probably not greatly influencing the rare earth doping ion, may result in an overall pump system with an order of magnitude or more increase in efficiency.

Other Schemes

Other laser schemes are also possible, some with high power capabilities and others which may be of value in an amplifier situation. Liquid lasers with a relatively long time "structure" hold promise, at least up to that power limit wherein the Raman effect becomes serious. For the times under consideration they are only a different type of glass; a glass of such a purity that liquid lasers may hold great promise.

Knowing the importance of the phonon-electron interaction(and assuming a knowledge of the deformation potential treatment of this subject--which is rather standard), it is clear that materials under extremely high pressure should be investigated. It may well be possible to develop a really high power "staircase laser," using phonon-electron interactions to cause population inversion of the electric field splittings. Other interesting anomalies may prove of great value when considering the use of ultra high pressure laser systems.