EG&G INC.

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A STUDY TO DETERMINE THE OPTIMUM DESIGN OF A PHOTOGRAPHIC FILM FOR THE LUNAR SURFACE HAND-HELD CAMERA

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

SYSTEMS DIVISION

EDGERTON, GERMESHAUSEN & GRIER, INC.

NASA CR 92015

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A STUDY TO DETERMINE THE OPTIMUM DESIGN OF A PHOTOGRAPHIC FILM FOR THE LUNAR SURFACE HAND-HELD CAMERA

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Prepared for

National Aeronautics and Space Commission
Manned Spacecraft Center
Advanced Spacecraft Technology Division
Lunar Surface Technology Branch

SYSTEMS DIVISION

EDGERTON, GERMESHAUSEN & GRIER, INC.

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ABSTRACT

The performance of photographic tasks in outer space, and especially on the lunar surface, will be encumbered by unique problems not present during earthbound photography. Familiarity with the underlying principles of photographic films is necessary in order to appreciate the effects of the environment of outer space on films. A short discussion of the fundamentals of the photographic process is presented for the benefit of those readers who are unfamiliar with the subject. The subjects discussed include formation of a latent image and its development, relation between exposure and density, difference between negatives and reversals, image quality, spectral sensitivity, and the fundamentals of color photography. The lunar environment, with emphasis on one of the current theories of the photometric characteristics of the lunar surface, is discussed.

Also described are experiments performed to show the influence of a low-pressure environment on the behavior of several photographic films, and the effects of both high and low temperatures. Low temperatures, as a technique for producing temporary radiation protection of photographic films, shows promise. An experimental color film system was tested and found to be capable of photographing a scene with a large luminance range. A proposed high speed color film which should produce a faithful color record of subjects varying in brightness by more than 10,000 times is described. A second film which will produce high resolution pictures in a blue spectral region, and which, with a filter change, will record infrared pictures is also proposed.

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PREFACE

This is a final report to NASA on an engineering study-program to determine the optimum design for a photographic film to be used in a hand-held camera by astronauts on the lunar surface. The work was performed under NASA Contract No. NAS 9-3613 for the Lunar Surface Technology Branch of the Advanced Spacecraft Technology Division of the Manned Spacecraft Center. The work described is the result of an intensive six-month investigation conducted by the scientific and photographic engineering personnel at Edgerton, Germeshausen & Grier, Inc.

The EG&G work was closely related to a parallel program on the design of a hand-held camera conducted by the Goertz Optical Company. Because of the interrelation between the two efforts, close coordination and liaison were necessary to effect an optimum over-all design for the camera-film combination. This coordination was provided by the NASA technical representatives through numerous discussions and several meetings which played an important role in directing the course of the investigations.

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CHAPTER 1

INTRODUCTION

Exploration of the lunar surface by astronauts is quite probable during the next decade. Present scheduling indicates that the United States expects to have astronauts landing on the moon by 1969 or 1970. The peoples of the world will await their return to earth with an interest which has been accumulating since the beginning of man. Because of this interest, the astronauts' account of their venture must certainly be augmented by pictorial records concerning the characteristics of the lunar surface. A camera system using photographic film is the most compact information recording system yet devised by man and, for this reason, will be the most valuable instrument employed by the lunar astronauts in their initial explorations.

The photographic process can record a range of wavelengths from the ultraviolet, which is too short for man's vision, through the visible region of human color sensation and into the near infrared region beyond the visible. Both as a scientific tool and as a means of recording and communicating information, photographic film is one of man's foremost allies in his exploration of the realm of the unknown. Photographic film records made on the manned lunar mission will certainly capture for the eyes of our world man's visual observations of the lunar surface and information beyond his visual capability through its ability to record images illuminated by ultraviolet and infrared solar energy.

Neither the color nor magnitude of the sunlight falling on the moon is quite the same as that reaching the earth's surface. The atmosphere surrounding the earth greatly affects the distribution of sunlight reaching the surface. Since the moon has essentially no atmosphere, solar energy falls unabated upon it. The resulting visual color sensation will be unfamiliar to the astronauts who might, upon their return to earth, experience difficulty

recalling the exact coloring of objects which they encountered. A film which exactly records colors as the astronauts see them on the moon will be a necessary adjunct to the astronauts' memory. Furthermore, once the image has been recorded and processed as a facsimile reproduction of the lunar scene, the film should then be capable of being duplicated with a color rendition which is familiar to earth-bound people.

In the presence of little or no atmosphere, the lunar photographer receives no assistance from what we are accustomed to call a day sky which on earth serves an exceedingly useful photographic function. Although the total photographable light emanating from the sky does not contribute more than thirty percent of the total incident light, the sky area is vast. The effect of such an extended light source is to fill in those shadow areas which are shielded from direct sunlight. Without a sky to serve this purpose, shadows on the lunar surface will appear ink black and receive light only from the reflection of nearby objects like crater walls or the earth if the earth is in a favorable attitude. The resulting abnormally high contrast greatly exceeds the recording capabilities of most photographic systems and is a problem requiring a solution for satisfactory lunar surface photography.

In addition to the absence of a sky the environment of outer space, particularly the vacuum, will create problems in using photographic materials. The vacuum environment will remove the water content of the gelatin binder and the support material which will reduce their tensile strength and allow cracks and fissures to form in the emulsion. Reduced pressure may also create problems of inadvertent static exposures caused by the discharge of electrostatic fields as the film is unwound.

Extremes in temperature, likely to be encountered on the lunar surface, will present a further problem by influencing the sensitivity of photographic materials. The high temperatures created in direct sunlight are likely to produce inordinately high fog levels, whereas the extremely

low temperatures present in the absence of sunlight might reduce the film's sensitivity to an impractical level.

A lack of both an atmosphere and a significant magnetic field on the moon allows cosmic radiation and high-energy particles from the action of solar flares to impact the lunar surface attenuated. Such radiation would, of course, expose photographic film and, if present at sufficient levels, the ensuing damage would degrade the visible light latent images in the film. Exposure to a critical dose of radiation will be evident, after development, as an overall uniform fog covering the entire film. Carried to extremes, the effect is a complete loss of photographic recording capability and the destruction of the information capacity of the film.

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CHAPTER 2

OBJECTIVES

A lunar surface hand-held camera will be carried aboard the Apollo Spacecraft and will be used by the astronauts on the lunar surface, outside the Lunar Excursion Module (LEM), to obtain photographs of various subjects for America's space program and various scientific disciplines. The purposes of the investigations described in this report are 1) to provide NASA with specific information on the capabilities of film in general, 2) to determine the optimum film (or films) for use in the lunar surface camera, and 3) to investigate on-board processing to determine if such equipment is required to escape radiation damage on the return to earth.

In the entire history of the photographic process few, if any, occasions have afforded the opportunity presented to the lunar astronauts to record for science an environment completely new to man. With this in mind and because of stringent weight limitations, it was NASA's desire to obtain as a result of this study the design of a single photographic film combining all the best characteristics that can now be found among the many species of film which are available commercially. Those characteristics which NASA felt were most desirable for this single film were

1. A spectral range from 2000 to 10,000 Angstroms,
2. An American Standards Association's (ASA) rating of 10,000 for the film when used under earth-shine conditions,
3. A resolution of 200 line-pairs per millimeter,
4. A color fidelity equal to the hue, saturation, and value of the subject being photographed, and
5. A film very insusceptible to radiation damage or fogging.

A single film embodying all the above characteristics is beyond the present photographic state-of-the-art. Thus, the film (or films) designed for the lunar mission must embody some compromises. The film (or films) must be designed to meet NASA's mission goals of highest priority, and those film characteristics which, while desirable, are least important to the mission must be sacrificed. One of the most important features of the present investigation is to perform the design trade-offs to obtain a film which is capable of being produced with current techniques and which will be optimized to fulfill the most important of the NASA lunar photographic objectives.

Because of the strict weight limitations and the extremes in environment to which the film will be subjected on the lunar mission, certain design constraints were imposed on the film study program by NASA. These constraints as defined by NASA are

1. The film must tolerate the range of environmental conditions (temperature, pressure, shock, vibration, radiation) which are expected to be encountered during all phases of the mission from the launch at Cape Kennedy through the return to earth.

2. The film can be contained within a pressurized or partially pressurized cocoon or container.

3. A total of 600 frames or 300 stereo-pairs will be required for each roll of film, and the total weight of the film cannot exceed two pounds.

4. Film size is assumed to be 70 mm in width.

5. Present volume constraints limit the volume of the camera and film to 1/4 cubic foot. Weight and space requirements in excess of this amount, especially if on-board processing is required, must be submitted to NASA.

The lunar illumination to be encountered was implicitly specified by NASA as an additional constraint by specifying the lunar photometric function.

(This constraint played a dominant role in determining the design of an optimum film for lunar photography.)

Guidelines for the film design study were furnished by NASA at the outset of the investigation. As the study progressed and the inter-relationship between the camera and film characteristics was established by NASA, these guidelines were modified somewhat to achieve an optimum overall system performance. However, for the sake of completeness, the initial guidelines are reported here:

1. For the purpose of the film study, influencing factors such as spacecraft windows, lenses, camera systems, etc. shall be ignored. The evaluation and ultimate recommendations shall be based solely on the film's capabilities and performance.

2. On-board processing equipment, if required to escape radiation damage on the return to earth, will be stored in the LEM during the translunar flight. This means that the equipment will be exposed to a hard vacuum for periods as long as a week, and the equipment must be able to withstand the extremes in temperature which may be expected in space and on the lunar surface. The equipment must also be able to withstand the launch and landing acceleration shocks.

3. The entire camera system and the processing equipment will likely remain on the lunar surface after the mission is accomplished; only the unprocessed and/or processed film will be returned to earth.

4. The hand-held camera, using the film developed from this study, will be used to obtain the following types of imagery:

   a. Detailed color photographs of lunar surface features and geological specimens that may be as small as 0.1 mm in linear dimension,

   b. Colored stereo-photographs of the lunar landscape surrounding the LEM,

c. Color photographs of the lunar surface near the LEM in the ultraviolet and infrared portions of the spectrum, and

d. Photographs of various celestial bodies, including the earth, in the ultraviolet, visible (color), and infrared with an angular resolution of one second of arc.

Mid-term briefings on the camera and film design studies were conducted concurrently by Goertz Optical Company and EG&G at the NASA Manned Spacecraft Center; at that time the work accomplished during the first four months by both groups was reviewed by NASA. At the conclusion of that meeting and as a result of their evaluation of the work to that date, the NASA technical representatives recommended that the design studies emphasize certain approaches that would lead to an optimum overall camera-film combination. In the case of the EG&G film-design program, the decision was made to concentrate on the design of two distinct film types.

Two films are recommended because a single film capable of performing the highest priority missions may introduce unwarranted complications. Each of the films is intended to provide coverage of two spectral regions: it is recommended that one film cover the visible region in color and also be sensitive to the ultraviolet spectral region; the second film would respond as black-and-white to the visible spectral region and also be sensitive to the near infrared spectrum. These films would be designed for use in conjunction with two alternate camera types which were recommended to Goertz Optical Company for study. The desired characteristics of the two films are given in Table 2.1

TABLE 2.1 DESIRABLE DESIGN CHARACTERISTICS OF TWO FILMS FOR USE IN THE LUNAR SURFACE CAMERA

Parameter	Combined Color and Ultraviolet (UV) Film			
	Ultraviolet/Color/Infrared Camera		Color/Infrared Camera	
	Color	UV	Color	UV
Wavelength coverage	4000-7000 Å	2400-4000 Å	4000-7000 Å	No response
Resolution	50 lp/mm	50 lp/mm	50 lp/mm	----
Exposure latitude	10^4 - 1	10^2 - 1	10^4 - 1	----
Speed	1000 ASA	----	1000 ASA	----
No. of stereo-pairs	300	300	300	----

Parameter	Combined Black-and-white (B&W) and Infrared (IR) Film			
	Ultraviolet/Color/Infrared Camera		Color/Infrared Camera	
	B&W	IR	B&W	IR
Wavelength coverage	4000-7000 Å	7000-9000 Å	4000-7000 Å	7000-9000 Å
Resolution	100 lp/mm	50 lp/mm	100 lp/mm	50 lp/mm
Exposure latitude	10^2 - 1	10^2 - 1	10^2 - 1	10^2 - 1
Speed	100 ASA	----	100 ASA	----
No. of stereo-pairs	300	300	300	300

At this point, we will recapitulate the objectives of EG&G's study program as follows:

1. To provide NASA with specific information on the capabilities of film in general,

2. To provide film designs which can match the desired characteristics specified in Table 2.1 and which are compatible with the constraints imposed by environment and weight limitations, and

3. To investigate the necessity of on-board processing equipment to determine if such equipment is required to escape radiation damage.

Besides documenting the work performed to accomplish the above objectives, NASA requested that the final report direct itself toward answering the following specific questions:

1. State if one film can be developed that has the desired film capabilities, and outline the design specifications of the film. If not, state why, giving an alternative solution and design specifications.

2. What filters will be required for use with the lunar film to record the normal visible range or what filters to record the ultra-violet and infrared range?

3. Will emulsion thickness affect acuity and resolution?

4. To what degree will the use of filters affect the ASA rating of the lunar film?

5. How much humidity is required to keep the film in a usable state?

6. How do temperature extremes affect the film recommended in this study and film in general regarding resolution?

7. What is the expected fog level due to radiation? How will this affect resolution?

8. Would freezing the lunar film in a given solution help preserve and protect it from radiation?

9. What degree of processing is required to preserve the latent image from damage caused by radiation?

10. What degree of reliability can be expected from on-board processing?

11. Will radiation affect processing chemicals?

12. Will temperature and humidity extremes affect on-board processing?

13. Will the processor operate in the lunar environment?

14. What precise environmental data would you require at the moment of exposure to aid in the laboratory processing of the returned photographic film?

The first of the three main objectives is covered by Chapter 3 of this report. Experimental investigations and studies pertaining to the film designs and the on-board processing study (objectives 2 and 3) are detailed in Chapter 4. Conclusions reached as a result of these investigations and studies are given in Chapter 5 with a discussion which answers the fourteen specific questions that NASA raises. Recommendations are given in Chapter 6.

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CHAPTER 3

BACKGROUND

3.1 THE PHOTOGRAPHIC PROCESS

The word photograph is a combination of two Greek words: "photos" meaning light, and "graphos" meaning to write. A photographic film is literally a "light-writing" film or one which records the pattern of light that strikes it. Photographic material in common use today is so highly sensitive to light that it must be manufactured and stored in almost complete darkness. Since it can be examined only after it has recorded an image and has been chemically processed, the structure and mechanism of photographic films, although in common usage everyday, is not known to the average user.

3.1.1 Construction. The light-sensitive element of photographic materials consists of one or more extremely thin coatings of silver halide microcrystals embedded in a colloidal medium-like gelatin. These coatings or photographic emulsions are generally less than a thousandth-of-an-inch thick and are exceedingly delicate and susceptible to damage by abrasion and scratching. The emulsion is coated on top of a material whose primary function is to support and strengthen the delicate light-sensitive element. The support for roll-films and motion-picture films is usually colorless, transparent, and flexible, and the support is many times thicker than the emulsion. The overall thickness seldom exceeds five or six thousandths of an inch and, for special applications, is sometimes less than three thousandths of an inch. Glass plates serve as the support for certain applications, while different types of paper are used to support photographic-printing emulsions.

The silver halide microcrystals, or grains, are the actual light-sensitive elements of photographic emulsions. These very small grains of silver chloride, silver bromide, or silver chlorobromide range in size from

one-half to several microns in diameter and tend to be flat or platelike in shape. Their function is to absorb radiant energy and undergo a change in state which can be amplified millions of times by subsequent treatment in the proper chemical solutions.

Clear gelatin is used to control the quality of the microcrystals and to hold them in suspension. At the same time, the retaining gelatin must be chemically inert and yet permit liquid chemicals to penetrate and to react with the suspended crystals. Emulsions generally have a greater volume of gelatin than silver halide grains and are somewhat elastic besides being capable of absorbing liquids.

The support or base material generally does not participate in the mechanism of image formation, recording, or processing and serves essentially as a means of mechanical support for the delicate emulsion. The transparent flexible support for sheet, roll type, and motion-picture films consists of an acetate material which is strong and dimensionally stable. Another support material, introduced a few years ago, is often used in applications where overall film thickness must be minimized; this polyester material has many times the shear strength of acetate and provides sufficient strength for a photographic emulsion with a thickness of only two thousandths of an inch. Because of difficulty in splicing pieces of this material, it is not widely used for motion-picture films.

3.1.2 Theory of the Photographic Process.[1,2,3] The light-sensitive elements of a photographic film consist of microcrystals of certain silver salts. Emulsions with high photographic speed have large grains of silver bromide containing small amounts of silver iodide. Smaller grains of the same silver halide combination result in films with less speed. Materials used for making photographic prints are generally made with silver chloride grains of very small dimensions.

3.1.2.1 The Latent Image. The action which takes place when light impinges upon the photosensitive emulsion is basically one involving energy absorption. The lattice structure of the silver halide crystals contains impurities which constitute a structural weakness. After exposure to light and subsequent immersion in the proper chemical solution, conversion of the grains to free metallic silver appears to commence at the points of structural weakness. These points, or sensitivity centers, contain small amounts of silver sulfide and are often located at many places throughout the crystal. Grains which do not contain such centers do not appear to be sensitive to light. Thus, it is assumed that the silver sulfide specks act as catalysts to collect silver atoms, liberated by the action of light upon the silver halide crystal. The average sensitivity usually increases with the size of the grain because the number of sensitivity centers is usually increased in direct proportion to grain size.

Quantum mechanics explains latent-image formation by assuming that the absorption of light quanta by silver halide grains injects electrons from the halide ions into conduction bands where they are free to wander throughout the crystal lattice. Some of these electrons become trapped in the sensitivity centers and produce a negative charge which prevents additional electrons from entering the center until the negative charge is reduced by recombination with interstitial silver ions. The silver ions which migrate throughout the crystal enter the sensitivity centers and use the trapped electrons to form neutral atoms of silver. When a sufficient number of neutral silver atoms have coagulated, a stable latent image is established.

A quantum of visible light liberates only one electron if it is absorbed. Experiments have shown that a grain requires absorption of several quanta if developability is to be achieved. High energy particles like alpha particles release thousands of electrons into the conduction bands while passing through an emulsion. Many small latent-image centers are established throughout

the grain with which the high energy particles have collided. Further collisions by high energy particles increase the number of the silver atoms in the centers, producing larger centers which develop more readily.

The incidence of a large amount of energy over a short time period on a silver halide grain produces an avalanche of electrons and appears to favor the formation of many small latent-image centers. A single high energy particle or a large number of light quanta can liberate a surplus of electrons. The effect of the surplus negative charge on the sensitivity center which is produced by the first few trapped electrons, prevents additional trapping. By the time a sufficient number of interstitial silver ions have migrated into the centers, neutralizing the charge by forming neutral silver atoms, the avalanche of electrons has dissipated. This gives rise to a non-linear effect which is termed short exposure time or high intensity reciprocity failure. The latent-image centers, although plentiful in number, do not trap a sufficient number of silver atoms to permit formation of a developable center. Prolonged development will minimize the effect but often at the expense of increased-background density.

Quanta arriving at a lower rate and corresponding to a low intensity over a very long time period tend to produce large latent-image specks but fewer in number. This is termed long exposure time or low intensity reciprocity failure. Thermal motion causes some of the silver atoms formed in the specks to breakup. Latent-image specks are not stable until they contain a critical number of silver atoms. When the rate at which the light quanta arrive is so low that the break-up rate of the silver aggregates exceeds the rate of addition of new silver atoms, the latent image never attains a stable level. With insufficient numbers of silver atoms in the single speck, the grain is not capable of development. The exposure effect is an apparent loss of sensitivity as the low intensity reciprocity failure manifests itself.

3.1.2.2 Processing. The latent image produced in a photographic emulsion by the action of sufficient radiant energy becomes detectable as a darkened image on an otherwise light-colored background of silver halide. The use of developing agents reduces by milions of times the radiant energy required to produce the same darkening, making the photographic process a most sensitive and practical recording system.

The process of development is one of reducing the silver halide grains to free metallic silver which is readily detectable as a black deposit. Because developing agents will ultimately reduce all grains, a practical developer is one which will reduce exposed silver halide grains to the free metallic state at a greater rate than those grains which have not been exposed. Thus, practical development is a rate-dependent phenomenon which affords a means of discrimination between exposed and unexposed portions of the photographic emulsion. Prolonged contact with developing agents would ultimately reduce all of the grains to metallic silver which would result in a complete loss of discrimination between exposed and unexposed grains of the emulsion. Practical development, therefore, is terminated by the simple procedure of inactivating the developing agents before the unexposed grains are affected. At this point, the remaining unreduced silver halide grains may be removed by immersion in silver halide solvents known as fixing agents, or development may be continued by reactivation of the developing agents. If the remaining silver halide is removed by a fixer, further reduction will not take place and the film may be examined in the light.

There are two distinct types of development processes which will allow discrimination between exposed and unexposed silver halide grains. One is termed physical development in which many liver atoms are deposited from solution onto those few silver atoms comprising the latent-image centers. The other process is referred to as chemical or direct development and, for many practical reasons, is the one in common use. Physical development

undoubtedly accompanies, to some extent, the process of chemical development. In a chemical developer containing a silver halide solvent, the main part of development appears to be an intensification reaction. Silver dissolved in the developer solution is deposited on grains which have already been partially reduced to free silver and thus intensifies and increases the size of the original grains.

Each grain suspended in the gelatin is surrounded by a negatively charged barrier layer of adsorbed gelatin and halide ions which present a retarding force to the penetration of developer to the grain. Those grains which have been exposed contain potentially weak points in the barrier at the latent-image centers. Silver ions from the crystal lattice which are put into solution by the liquid of the developer penetrate the charge barrier and soon become adsorbed on the silver specks of the latent-image centers. Once such adsorption occurs on the crystal, the protective charge barrier layer is broken, and the developing agent can then easily penetrate the grain, thus allowing reduction of the entire grain to proceed.

The protection afforded the silver halide grains by the gelatin produces a further complication in restricting the transport of chemicals in and out of the emulsion. Once reduction of a grain commences, the chemical complexes formed by the interaction must be removed and replaced by fresh chemicals if further reduction is to proceed. The transport through the gelatin of these chemicals depends for the most part upon diffusion. Within the gelatin emulsion, the transport is limited by internal pressures and temperature effects. At the boundary between the gelatin emulsion surface and the developer solution, the complexes which are formed at the grain sites and which have diffused to the surface present a boundary layer barrier to incoming fresh solution. This barrier severely restricts the interchange of chemicals and slows down the process of silver reduction of the exposed grains. The unexposed grains, on the other hand, are not so restricted and

in time will be reduced to free silver, resulting in a high fog value.

Agitation of the film during processing tends to breakup the emulsion surface barrier of the developer complexes, permitting fresh solution to be transported by diffusion into the emulsion. The complex byproducts removed from the surface are then diffused into the remaining developer solution and, to a degree, exhaust the developer. With sufficient concentration of these byproducts, the developer action becomes ineffective and must be replaced with fresh chemicals.

Silver reduction is most active in highly alkaline-developer solutions and slows down as the developer pH is lowered. At a sufficiently low pH, usually an acid condition, development activity ceases. Thus, development of a latent image can be brought to an abrupt halt by a rapid reduction of the solution pH. A common practice in the processing cycle includes immersion of the films in an acid-stop bath after the desired developing time has expired. Further reduction of silver halide ceases immediately in the acid-stop bath. The film is then placed in a fixing bath which removes the remaining silver halide grains and leaves only a visible black silver image in those areas where light struck the emulsion. The black image will ultimately be attacked and destroyed by the dissolved chemicals if not removed by water-washing to leave only the permanent image in the emulsion.

3.1.2.3 Exposure Response Characteristics. The previous paragraphs have described the general mechanisms, leading to the production of black silver deposits in photographic emulsions which have been exposed to radiant energy and treated in suitable chemical solutions. The response of silver halide grains to absorbed energy varies with the size of the grain, the larger grains being more sensitive. Most photographic emulsions consist of a random mixture of different sized grains resulting in different degrees of blackening as a function of exposure. The exposure is further attenuated as the light is absorbed in traversing the emulsion. Both

factors are instrumental in producing the different degrees of sensitivity in a photographic emulsion.

3.1.2.3.1 Negative Film. The photographic response to varying amounts of exposure can best be described by means of a graph which plots the degree of blackening as a function of exposure. Exposure is defined as the product of intensity of illumination, I, and exposure time, t. The degree of blackening is represented by the term density, D which is the logarithm to the base 10 of the ratio of the incident to the transmitted light of the developed image. Practical reasons dictate that the exposure should also be expressed logarithmically to the base 10. The resulting graph, shown in Figure 3.1, is known as an H and D characteristic or D-log E curve and represents the response of a typical negative photographic film to the action of different amounts of exposing energy when processed with a fixed set of processing conditions.

At the left of the graph, the resulting density is uniformly low and represents that value produced by development action without benefit of exposure to light. It is referred to as fog density but is more appropriately termed background density, since it includes any discoloration or density of the emulsion and its support. At a threshold level, the film starts to respond to greater exposure by a measurable increase in density. Additional exposure produces greater amounts of density, resulting in an upswing to the curve, finally reaching a point where density becomes uniform with increasing exposure. The upswing in the curve, or the toe region, shows an increasing effect of the response system. Beyond the toe region, the system attains uniform response in the straight-line portion and density production is a linear proportion with exposure. The slope of the angle, α, formed by the exposure axis and the straight-line is termed gamma, γ, and its value is determined by the ratio of $\Delta D / \Delta \log E$. Ultimately, all grains become exposed and no additional density is produced. The gradual reduction in slope beyond the straight-line is termed the shoulder region.

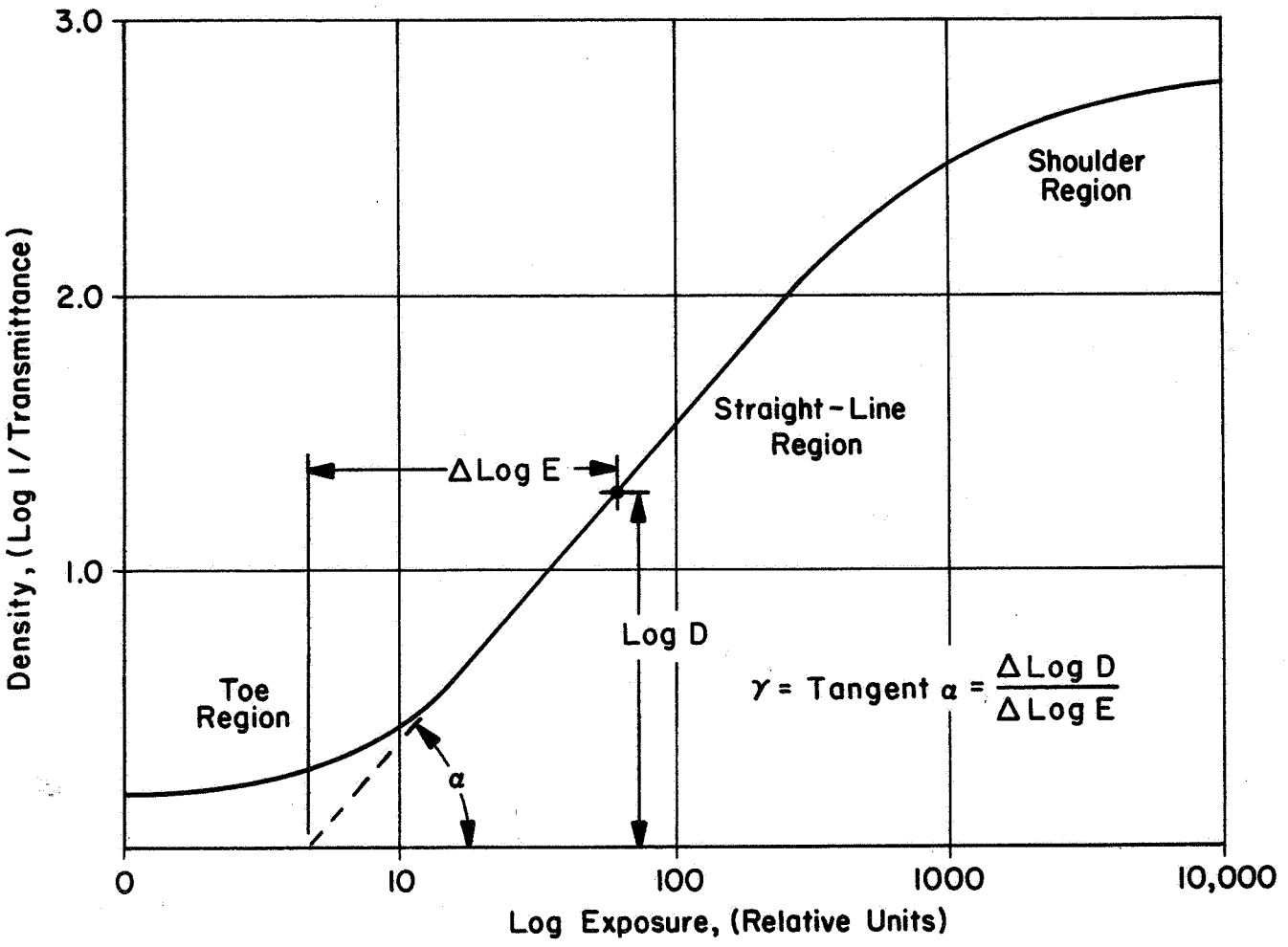


Figure 3.1 D-log E curve for a typical photographic negative film.

The slope of the straight-line region or gamma is controlled by the amount of development the film receives. Prolonged development increases gamma up to a limiting value, gamma infinity, which, while not mathematically infinite, is the greatest slope which the emulsion is capable of attaining. Prolonged development beyond this point produces excessive background density with no increase in maximum density and effectively reduces the slope of the straight-line. Values of gamma approaching gamma infinity tend to compress the exposure range over which the film is responsive thus creating a narrow latitude film. For purposes of scientific data reduction on the original negative, this is often an advantage because of the increased measuring precision. Relatively large differences in density are produced by small changes in exposure or scene brightness. The precise value of gamma desired is dictated by the intended use for the negative.

Negatives for which the primary purpose is pictorial must be printed onto a positive type photosensitive material and require low gamma values. Both optical and photographic characteristics of positive-printing materials restrict their exposure latitude to narrow limits in order to produce an acceptable facsimile of the original scene. Since the density contained in the negative image serves as the exposure modulator for the narrow latitude positive print material, it is necessary to maintain a low gamma in the negative in order to print the proper range contained in it. A gamma of 0.6 to 0.8 is best suited for pictorial negatives, while a value of 1.0 is often chosen for scientific films. The latter gamma of 1.0 is somewhat of a compromise value which will still permit satisfactory prints to be made from the original negative.

3.1.2.3.2 Reversal Film. Certain modifications of the processing procedure will permit most negative photographic films to be developed into direct positive images. Such a procedure is called reversal processing and yields a positive image, the negative image being destroyed during the chemical treatment. For optimum results with

reversal processing, the construction of the film is usually altered and produces a positive image with somewhat finer grain than the negative image. The exposure response of a film processed by reversal processing can be described by a D-log E curve whose general shape exhibits the reverse characteristics of the curve for negative materials. A typical reversal positive D-log E graph is shown in Figure 3.2. Maximum density for reversal-processed films occurs below the threshold value where no exposure is received. A threshold exposure for reversals is the value at which reduction in maximum density commences and the shoulder region corresponds to the toe region of a negative D-log E curve. The straight-line region is proportional to exposure although opposite in slope to the negative. The actual slope for reversal processing is considerably greater than that for a negative film. The toe region represents saturation or the leveling-off in exposure response beyond which the film is no longer effective.

The major advantage of reversal processing is that it produces a direct positive image suitable for projection onto a screen. The optics of image projection reveals that a great deal of unwanted non-image forming light is present with such systems. Undesirable scattered light reduces the maximum density of the projected image resulting in a washed-out and tonally-distorted facsimile of the original scene. Such tone distortion may be effectively reduced by producing an intentional increase in contrast of an image intended for projection. Inspection of the characteristic curve of Figure 3.2 shows that the gamma is considerably higher than the corresponding value for a negative film. This is accompanied by a greater maximum density and results in a film image of increased contrast. The scattered light produced during projection of the image on the screen has the effect of reducing the maximum density. The screen-image contrast is thus reduced and the projected image appears to be a faithful tonal representation of the original scene.

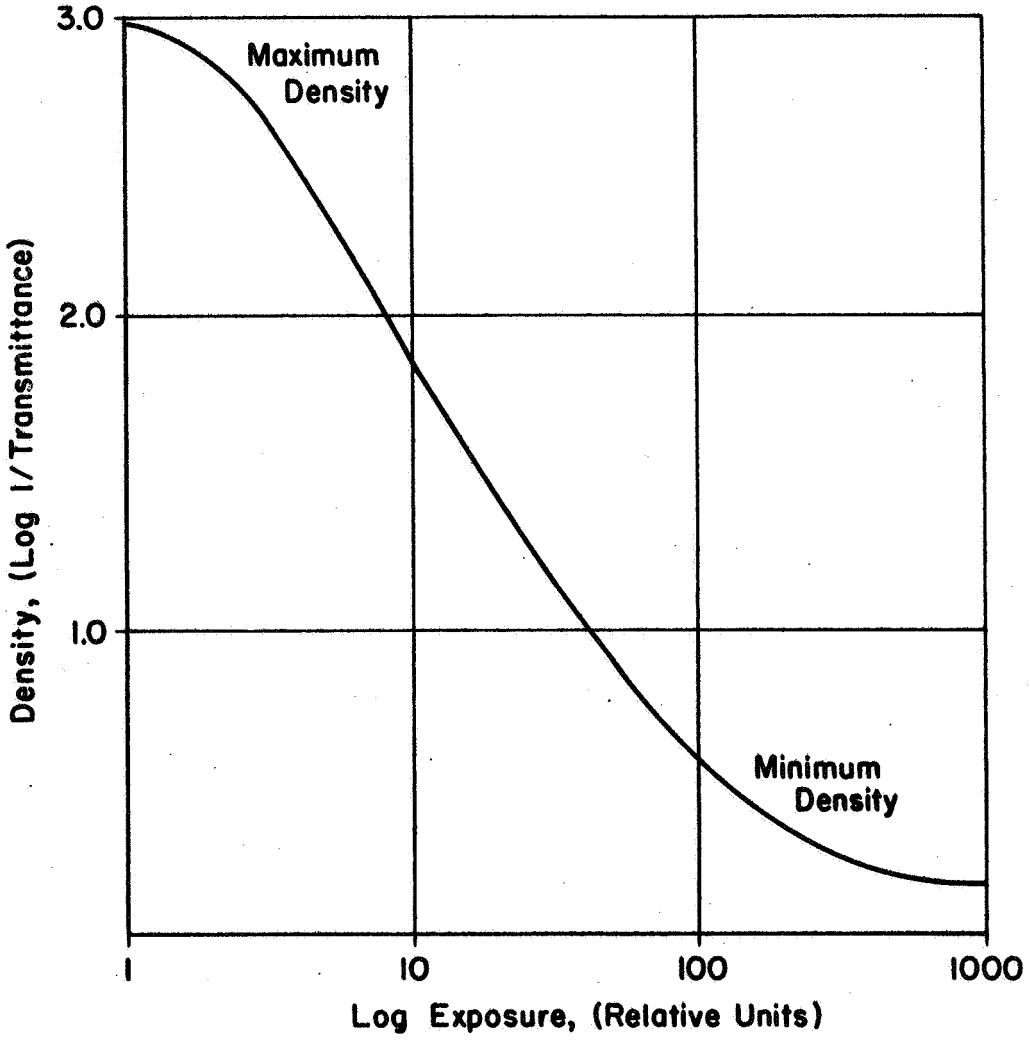


Figure 3. 2 D-log E curve for a typical reversal film used for projection.

3.1.2.4 Sensitivity. Photographic films undergo changes upon the absorption of radiant energy and only that energy which is absorbed will cause a photochemical change to occur. Silver halide grains have peak absorption at short wavelengths. However, because the grains are held in place by gelatin, the energy contained in the short ultraviolet will not expose the grains because it is absorbed by the gelatin before reaching the silver halide crystals. The transmission of gelatin, plotted in terms of density as a function of wavelength in Figure 3.3, shows that appreciable attenuation occurs at 2900Å and that almost complete absorption takes place below 2500Å.[4] Hence, ordinary photographic film exhibits little or no sensitivity to ultraviolet below 2500Å, unless special sensitization has been performed. Application to the surface of the emulsion of a layer of ultraviolet fluorescing material extends the sensitivity to wavelengths considerably shorter than 2000Å, but the magnitudeof the added effective sensitivity is no more than 1/100 the sensitivity at 3000Å. The curve in Figure 3.4 shows the spectral sensitivity response of a high-speed emulsion with the extension to very short wavelengths affected by a fluorescing sensitizer.[5] Short wavelength energy is absorbed by the material and causes fluorescence which emits a very low level blue light. The visible light emission is responsible for the exposure of the film even though the exciting radiation was ultraviolet.

Spectral sensitivity curves of the various silver halides characteristically show peak sensitivity in the ultraviolet and blue portions of the spectrum. Toward the red end of the spectrum, the photochemical effect for unsensitized films monotonically decreases, becoming very small above a wavelength of 5000Å.

The addition of certain dyes to the silver halide grains in the emulsion increases the sensitivity to longer wavelengths. When sufficient energy is absorbed by the absorbed-sensitizing dye, a photochemical reaction occurs and the emulsion becomes effectively sensitive to those wavelengths where

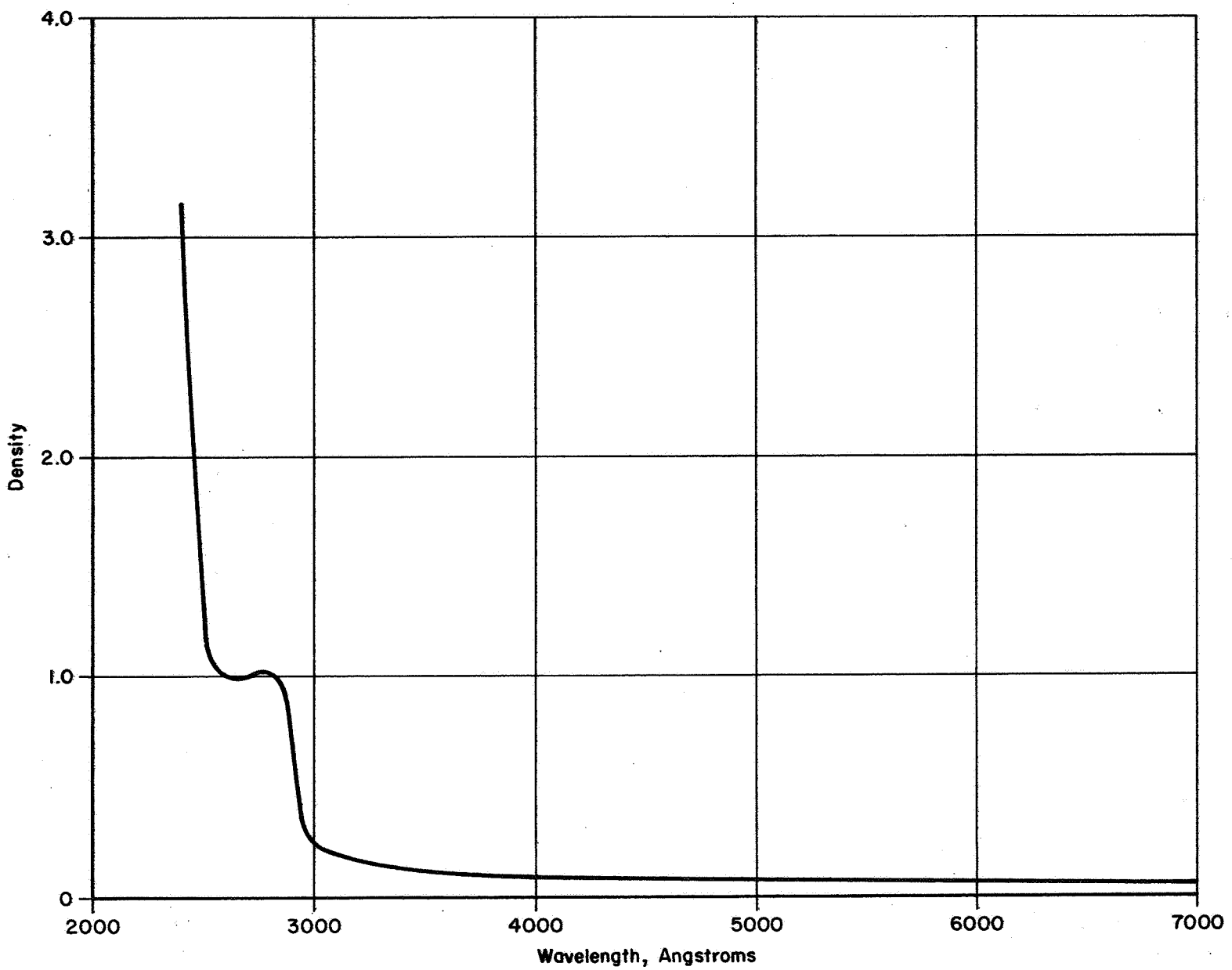


Figure 3.3 Spectral density characreristics of clear gelatin, 0.1 mm thick (from Kodak Wratten Filters, Kodak Publication No. B-3).

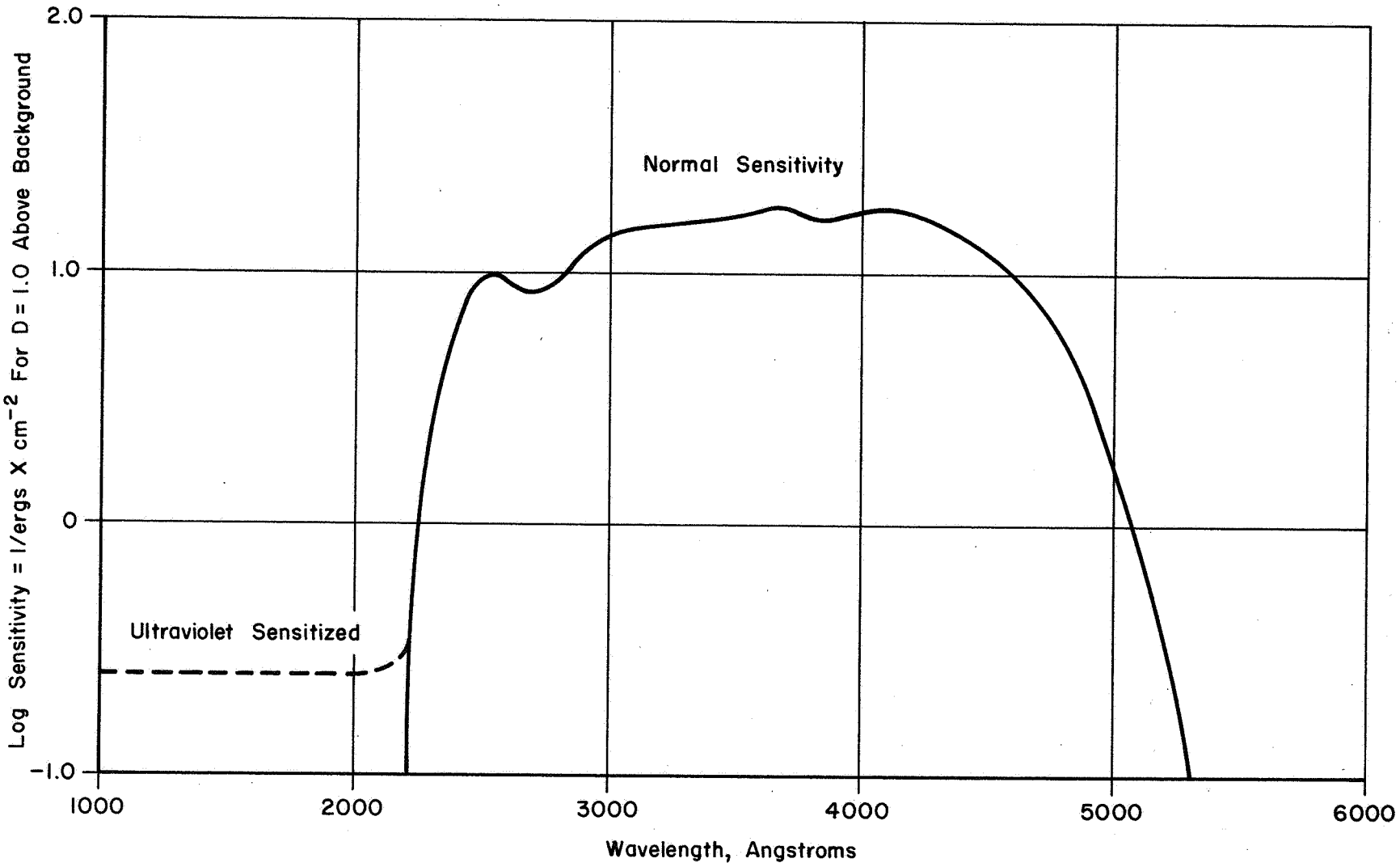


Figure 3.4 Spectral sensitivity response of Spectroscopic Type 103-0 which has been sensitized to ultraviolet with Kodak Ultraviolet Sensitizer No. 2.

previously there was little or no response. Not all dyes will react in this manner. Only a certain few are considered as spectral sensitizers for photographic films and only when they are adsorbed in critical amounts to the silver halide grains.

Sensitizing dyes are available which extend the photosensitive capabilities to wavelengths somewhat beyond 1 micron (10,000Å). The resultant peak sensitivity in the infrared seldom occurs at wavelengths greater than 10,000 to 11,000Å and the sensitivity beyond 13,000Å is negligible. For practical exposures in recording pictorial scenes, spectral sensitivity beyond 9000Å is of little value because of the rapid decline in sensitivity just short of this wavelength. The spectral response of a high-speed infrared sensitive film is plotted in Figure 3.5 along with a common type negative, Plus-X, for purposes of comparison.

3.1.2.5 Image Quality. The ability of a photographic emulsion to produce sharply-defined detail in an exposed and processed image may be described in terms of the film's resolving power and acutance. The resolving power of an emulsion is a measure of the limit to which fine detail in an image can be recorded, while acutance is a measure of the degree of sharpness apparent in the borders or edges of the recorded-image elements. The combined effects of an emulsion in altering resolution and acutance are included in the modulation transfer characteristics of the film. These characteristics describe the overall effect of diffusion and scattering of light upon the elementary image structure.

3.1.2.5.1 Resolving Power. Photographic resolution is associated with the emulsion characteristics of exposure, granularity, turbidity, and sharpness. A measure of the resolving power of an emulsion is obtained by imaging onto the film a test pattern of alternating dark and light lines of varying size. The result, after processing, is usually expressed as the maximum number of dark lines per millimeter just distinguishable in the developed image. The range of brightness between the

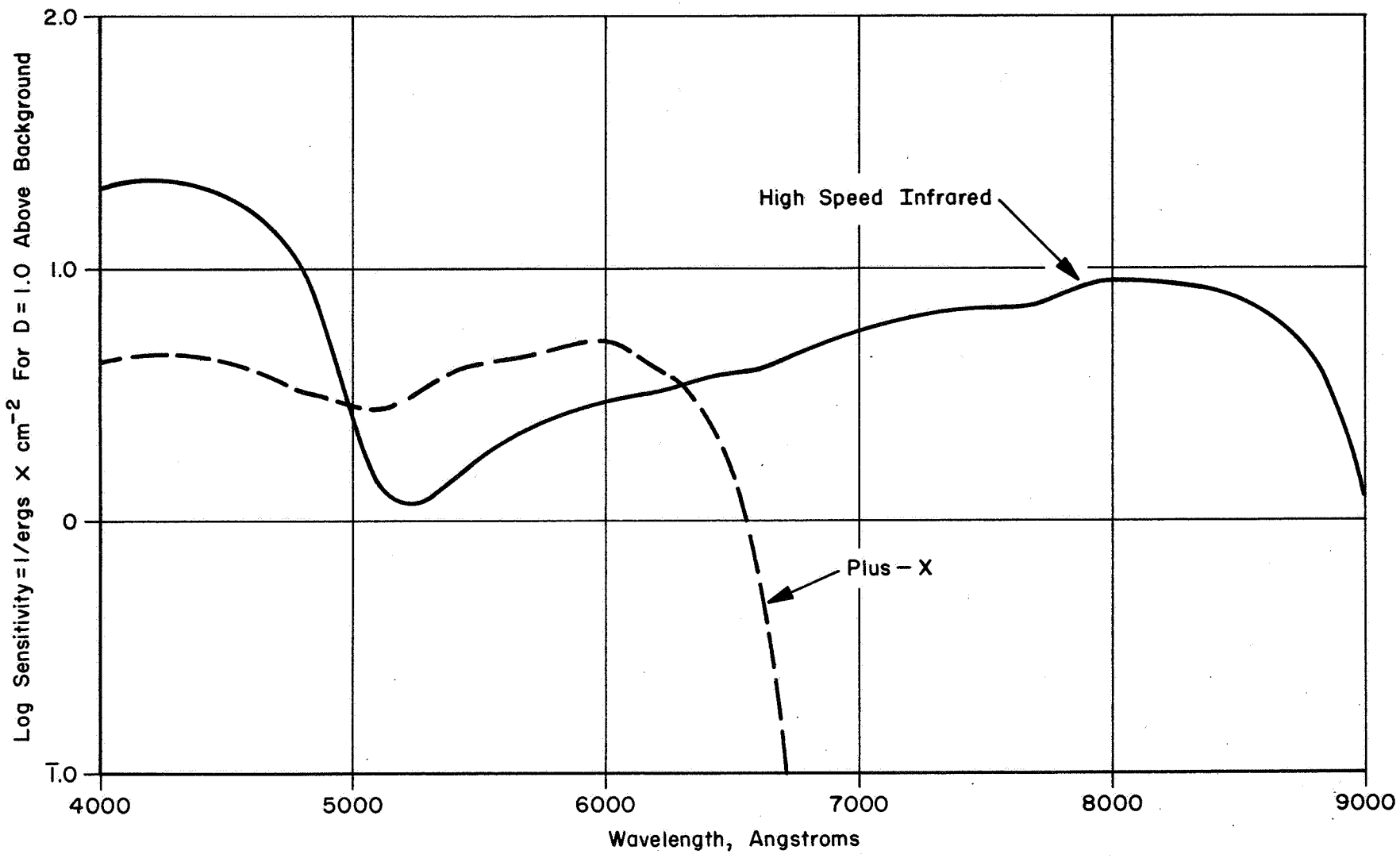


Figure 3.5 Comparison of spectral response of Kodak High Speed Infrared and Kodak Plus-X negative films, plotted at the same scale.

dark and light lines of the test-target influences the photographic resolving power. Resolution increases as the target brightness range increases, reaching a maximum at a range of 1000. It is, therefore, customary to test resolving power of photographic films using a target contrast of 1000.

Most of the currently available photographic films show a resolving power limit of the order of 100 lines per millimeter. Many of the less sensitive materials have higher values whereas ultra fast films are generally limited to somewhat lower resolution. The grains of even the fastest films are small by comparison to the resolution values obtained, hence it is believed that individual grain size does not limit resolving power. Regardless of film speed, which is governed basically by grain size, the best emulsion resolution is attained when the grains are all very nearly the same size.

Photographic emulsions are suspensions of silver halide grains in a layer of gelatin and, except for silver chloride which is nearly transparent, exhibit a considerable degree of turbidity. Incident light, upon striking the various grains, is partially absorbed, reflected, and diffused as it progresses through the emulsion. The reflected and scattered light affects nearby grains outside the area of the image pattern. These accidental exposures cause a spreading of the image elements and result in loss of resolving power. Restriction of exposure to the emulsion surface minimizes the extent of the diffusion and often produces greater image resolution. However, if the surface grains are widely separated, the edges of the image elements are not continuous and this results in an apparent reduction of sharpness.

3.1.2.5.2 Acutance.[1, 6] The density distribution across the border of an image element affects judgement of picture sharpness. Turbid emulsions scatter and generally diffuse the incident light in all directions. This causes elementary image edges to spread in a diffuse fashion and if the contrast is low, the image appears to be unsharp. Higher contrast of the elementary image border increases the

apparent sharpness. The term acutance is a measure of the density distribution across the boundaries of microimages, produced by diffusion of non-image forming light. Acutance, hence apparent sharpness, increases as the edge density differential increases. Although emulsion turbidity plays a dominant role in the mechanism of image sharpness, emulsion composition appears to be the governing factor in controlling acutance. Emulsions, containing grains of predominantly uniform size regardless of film speed, produce sharper images than those containing a large distribution in grain size.

3.1.2.5.3 Modulation Transfer Function.[7, 8]

The modulation transfer characteristics describe the behavior of an emulsion as influenced by the factors of exposure, acutance, and resolving power. Instead of using the normal sharp-edged parallel line test-pattern, a special target is employed which has a sine-wave type density distribution across the edges. The target consists of a series of straight parallel lines varying arithmetically in both width and spacing from one end of the pattern to the other. The density distribution across each line of the series varies sinusoidally, as shown in Figure 3.6, with a density difference between minimum and maximum of the order of 3.0.

The test-pattern is used as a negative with which printed images are exposed onto the photographic film to be evaluated. The varying density serves as the exposure modulator, and the changing frequency of line spacing records the resolving power limitations of the emulsion being tested. Figure 3.7 shows the density distribution across each line of the exposed and processed image. Except for opposite values of density, an ideal response would produce an exact duplicate of the original test-pattern negative. Deviation in the minimum and maximum densities, as spatial frequency increases, represents the modulation occurring in the response of the film. This modulation is caused by the effects of emulsion turbidity and the edge contrast of microimages. At low spatial frequencies the pattern is faithfully duplicated

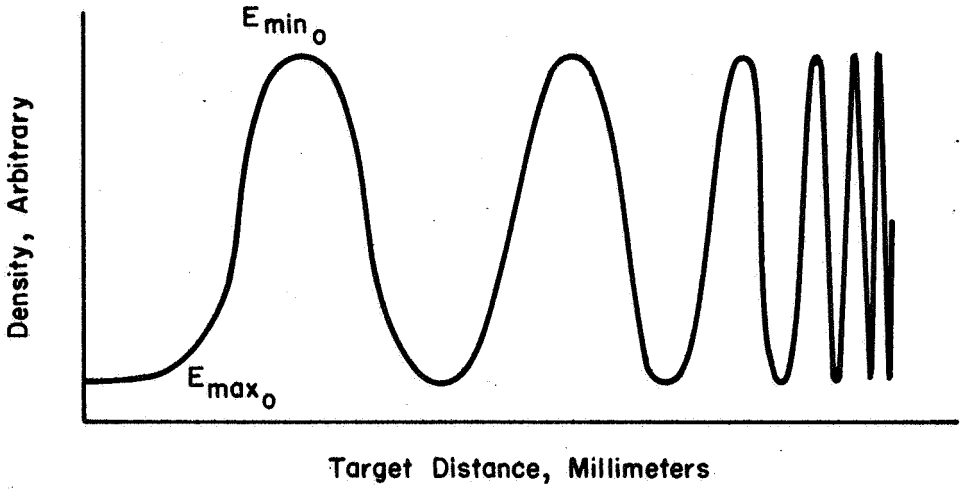


Figure 3.6 Density distribution across lines of test pattern.

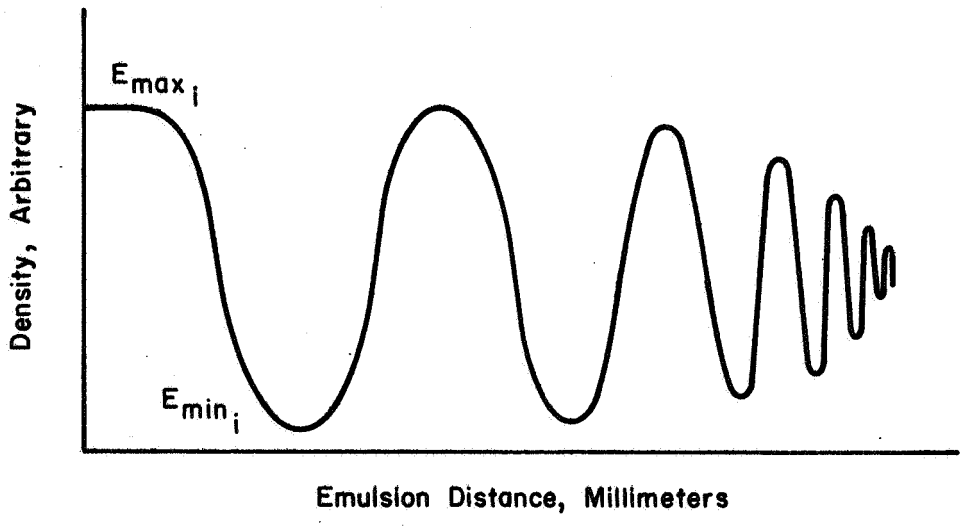


Figure 3.7 Density distribution across lines of film being tested.

with no distortion. Distortion occurs as frequency increases, and the areas which should be low in density commence filling-in while the corresponding high density areas show a decrease in value. Ultimately, both levels attain an intermediate but uniform density as the limit of resolution is reached. A plot of the ratio of modulation in the image and the original pattern as a function of the spatial frequency is the modulation transfer characteristic of the emulsion being tested and is illustrated in Figure 3.8.

3.1.3 Spectral Sensitivity.

3.1.3.1 Natural. The silver halide grains suspended in gelatin have an inherent spectral sensitivity which is closely associated with their absorption of radiant energy. All primitive silver halide grains have strong absorption in the ultraviolet and violet portions of the energy spectrum, and this is in close agreement with their spectral photographic response. Energy absorption in the emulsion increases with decreasing wavelength and becomes so efficient at 3000Å that very little energy is transmitted beneath the first few layers of grains. Being restricted to the topmost grains, an image exposed by ultraviolet radiation and subsequently processed will be found to suffer from lack of density and contrast. At still shorter wavelengths, the gelatin containing the suspended grains further absorbs the incident energy before it reaches the silver halide. Below 2500Å the effect of absorption by the gelatin is so severe that no effective energy reaches the grains, and film sensitivity approaches zero. Commercially available films with considerable improvement in sensitivity to short wavelength radiation contain a minimal amount of gelatin with the grains almost on top of the binder. Such films are extremely delicate and difficult to handle because the gelatin affords little protection to the grains. The gelatin cannot be completely eliminated because of its required protective capacity for the silver halide. Practical considerations demand that the grains be physically held in place by an adequate bond and this function is suitably

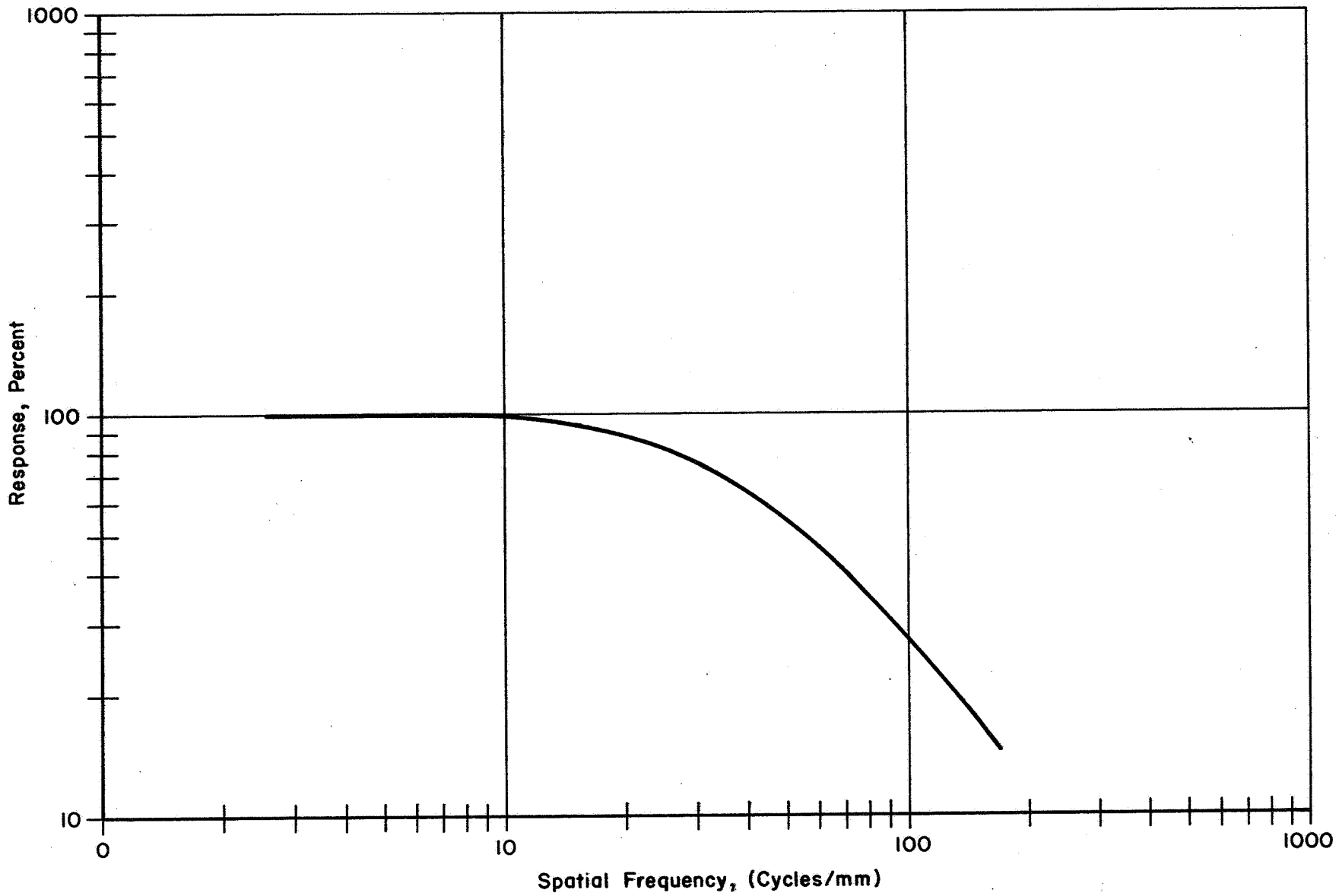


Figure 3.8 Modulation transfer characteristic of Kodak Panatomic-X Film, from Kodak Pamphlet No. P-49.

performed by gelatin. An additional protective factor required of the gelatin is provision of the mechanism whereby the developing agent can discriminate between exposed and unexposed silver halide grains. Without a thin layer of gelatin surrounding them, all grains, whether exposed or not, would be reduced to metallic silver by the developing agent and there would be no detectable image.

3.1.3.2 Ultraviolet. The special photographic emulsions available for short wavelength radiation are intended for spectrographic recording. Although they are sensitive to wavelengths shorter than 2500Å and even respond to wavelengths approaching 500Å, they are not suitable for practical pictorial recording because of low sensitivity, low contrast, and limited-exposure latitude. In addition, such emulsions have greater sensitivity to longer wavelengths than they have at 2500Å. A spectrograph physically separates, by dispersion, the various wavelength regions and prevents overlap of other spectral zones to which the emulsion is more sensitive. Thus, spectral lines, even though weak, can be recorded without interference from those spectral regions to which the emulsion is much more sensitive. A non-spectrographic pictorial record on the other hand, cannot be successfully obtained in the 2000 to 2500Å range unless all longer wavelengths to which the film is more sensitive are excluded. Such exclusion is necessary to prevent the weak image, produced by the short wavelengths, from being dominated and effectively masked by the much stronger image formed with longer wavelength radiation. Optical filters required to accomplish this task are not available, and since the solar light source radiates less energy in this region than in the longer wavelengths, it will not be possible to obtain pictorial records with wavelengths shorter than 2500Å.

3.1.3.3 Visible.

3.1.3.3.1 Chemical Sensitization. A silver chloride emulsion is colorless and appears to be nearly transparent to the eye. It has a spectral sensitivity extending from the ultraviolet into the visible spectrum of blue or violet. Silver bromide emulsions, pale yellow in color, also contain ultraviolet sensitivity in addition to a considerable sensitivity to the blue-green portion of the visible spectrum. As noted in the curves of Figure 3.9, the sensitivity of silver bromide emulsions, even though exceedingly low, extends through the visible and into the near infrared spectrum which probably accounts for emulsion fog when subjected to heat. The photographically useful limit, however, does not extend beyond 4900Å. The addition of varying proportions of silver iodide to a silver bromide emulsion increases the sensitivity to longer wavelengths as shown in Figure 3.10. Extended spectral sensitivity produced by these and other chemical methods is limited in a practical sense to wavelengths barely in the visible green region. Optical sensitization of the silver halide grains is a more effective method for extending spectral response.

3.1.3.3.2 Optical Sensitization. Optical sensitization requires the adsorption of a critical amount of certain organic dyes to silver halide grains. Such adsorption imparts sensitivity to the grains in spectral regions of longer wavelengths to which the primitive grains are insensitive. The resultant extended sensitivity depends upon the light absorption characteristics of the adsorbed dye. The dye is tightly held to the silver halide crystal by strong van der Waals forces and provides a source of photoelectrons which are liberated by the action of light absorbed by the dye. These mobile electrons are transferred to the crystal lattice, ultimately migrating to the sensitivity centers where they combine with silver ions, forming the latent image of metallic silver atoms.

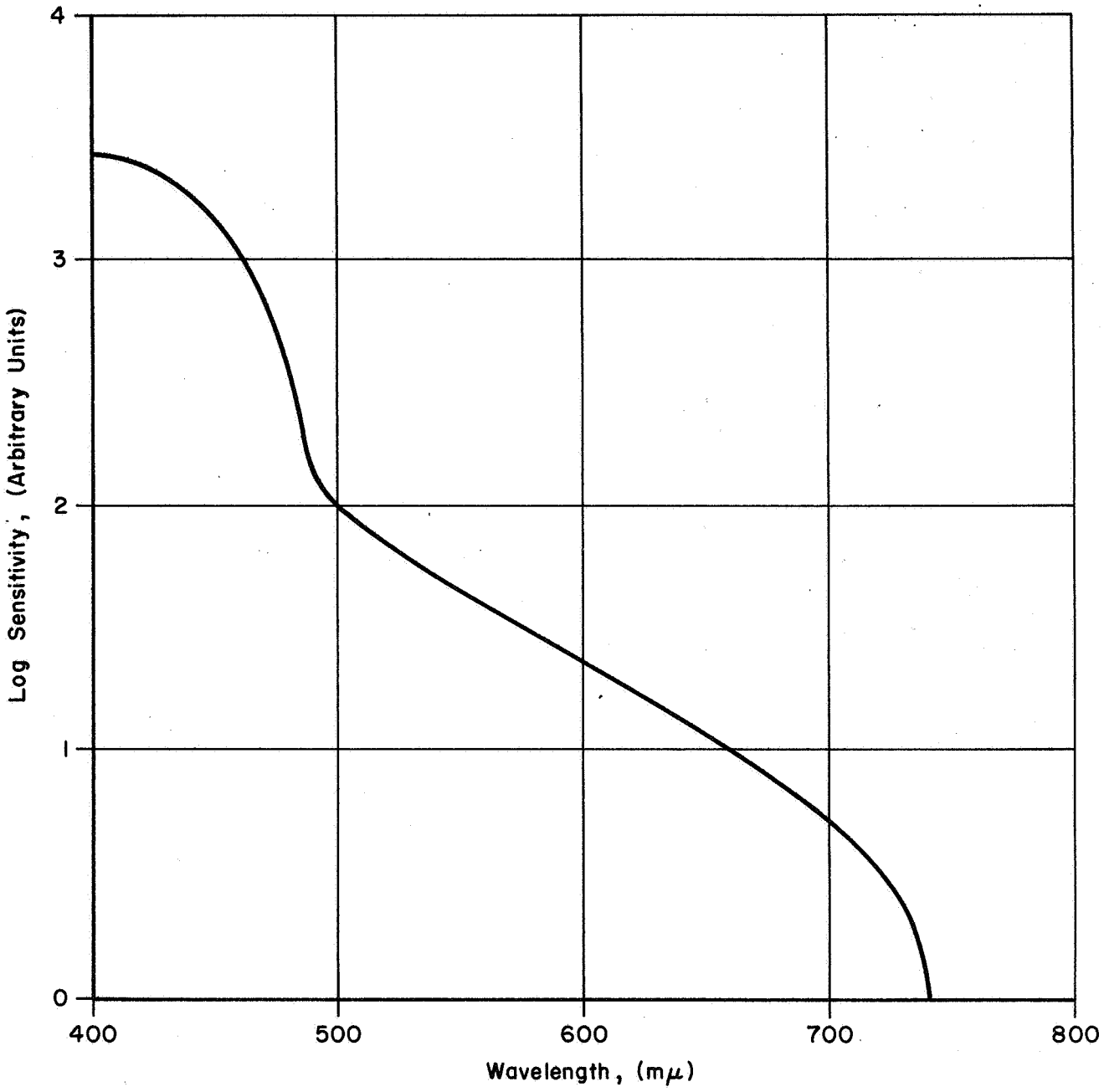


Figure 3.9 Spectral sensitivity of a typical silver bromide emulsion showing sensitivity extending to the near infrared, (from Mees, Theory of the Photographic Process, Revised Edition, 1954).

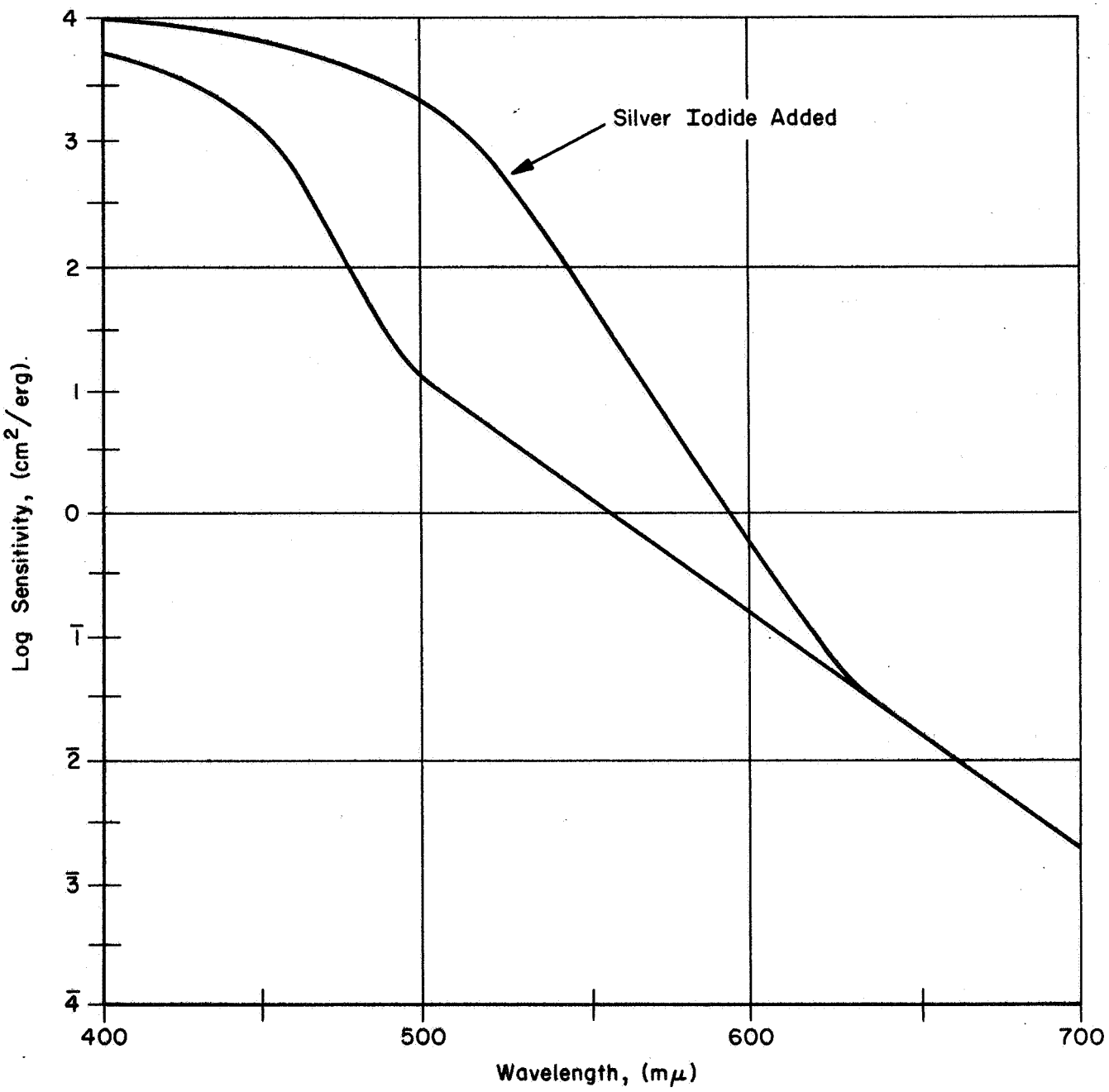


Figure 3.10 Spectral sensitivity of silver bromide emulsion showing increased sensitivity towards longer wavelengths when silver iodide is added, (from Mees, Theory of the Photographic Process, Revised Edition, 1954).

Although the spectral absorption characteristics of the adsorbed dye dictate the effective photosensitivity created, the action of the colored dye is not one of simple filtration of the incident energy. The effectiveness of the dye to confer sensitivity to the silver halide depends completely upon absorption of the energy by the dye and the transfer of the liberated electrons to the grain sensitivity centers. For optimum efficiency of the reaction, the adsorbed dye seldom covers the grain completely and is never present in more than a monomolecular layer. Greater amounts of dye tend to produce desensitization of the grain probably because the dye then behaves like a filter.

3.1.3.4 Infrared. Effective sensitization may be achieved in almost any portion of the visible and near infrared spectrum through use of the numerous dyes or dye combinations now available. However, no dye has yet been discovered which will optically sensitize a film to the far infrared. The practical limit for peak sensitivity to the infrared appears to be about 8000Å, although satisfactory pictorial records at practical exposure levels can be obtained at 9000Å. Special sensitizers are available which extend the photographic response beyond 13,000Å, but the level of sensitivity is extremely low and emulsions thus sensitized are of little value for pictorial photography at wavelengths of about 9000Å.

3.1.4 Film Speed. The speed of a photographic material is a numerical expression of its sensitivity to light for conditions of exposure and development which conform to normal use.[9]

Throughout the evolution of the photographic process, various methods have been used to describe the relative speed of photographic emulsions. Only in recent years, however, has there been an attempt made for standardization between manufacturers and users of photographic products. In the United States the two most common methods now being used to define film speed are the ASA method and the Exposure Index method.

Film speed numbers are derived from the D-log E curve of a particular type of film which describes the inherent sensitivity of an emulsion for specific conditions of exposure and development. Arithmetic film speed is defined as the reciprocal of the exposure required to produce a specific range of tonal values as indicated by the equation

$$S = \frac{k}{E}$$

where k is a constant and E is the exposure which produces a density 0.10 above background.

It is necessary that a rigidly-fixed procedure be followed to determine the speed of an emulsion. Specifications must be set on the exposure time, modulator, type of light source, and spectral filtration. Processing of the sample must be accomplished in a special formula developer at a specified temperature and in a container of a certain size. Agitation, fixing, washing, and drying are also thoroughly stated in the procedures.

The characteristic curve of the emulsion is measured, using the ASA's units of printing density. The density, thus obtained, is plotted against the log of the exposure to form the characteristic curve for the emulsion.

3.1.4.1 ASA Film Speed - Black-And-White Negative Material. The new ASA procedure for determining film speed is illustrated in Figure 3.11, where two points, M and N, are shown on the curve. Point M is located 0.1 density units above fog-plus-base density. Point N lies 1.3 log-exposure units from Point M in the direction of greater exposure. The developing time of the negative material is so chosen that Point N lies at a density interval $\Delta D = 0.80$ above the density at Point M. When this condition is satisfied, the exposure E_m, corresponding to Point M, represents the parameter from which film speed is computed.

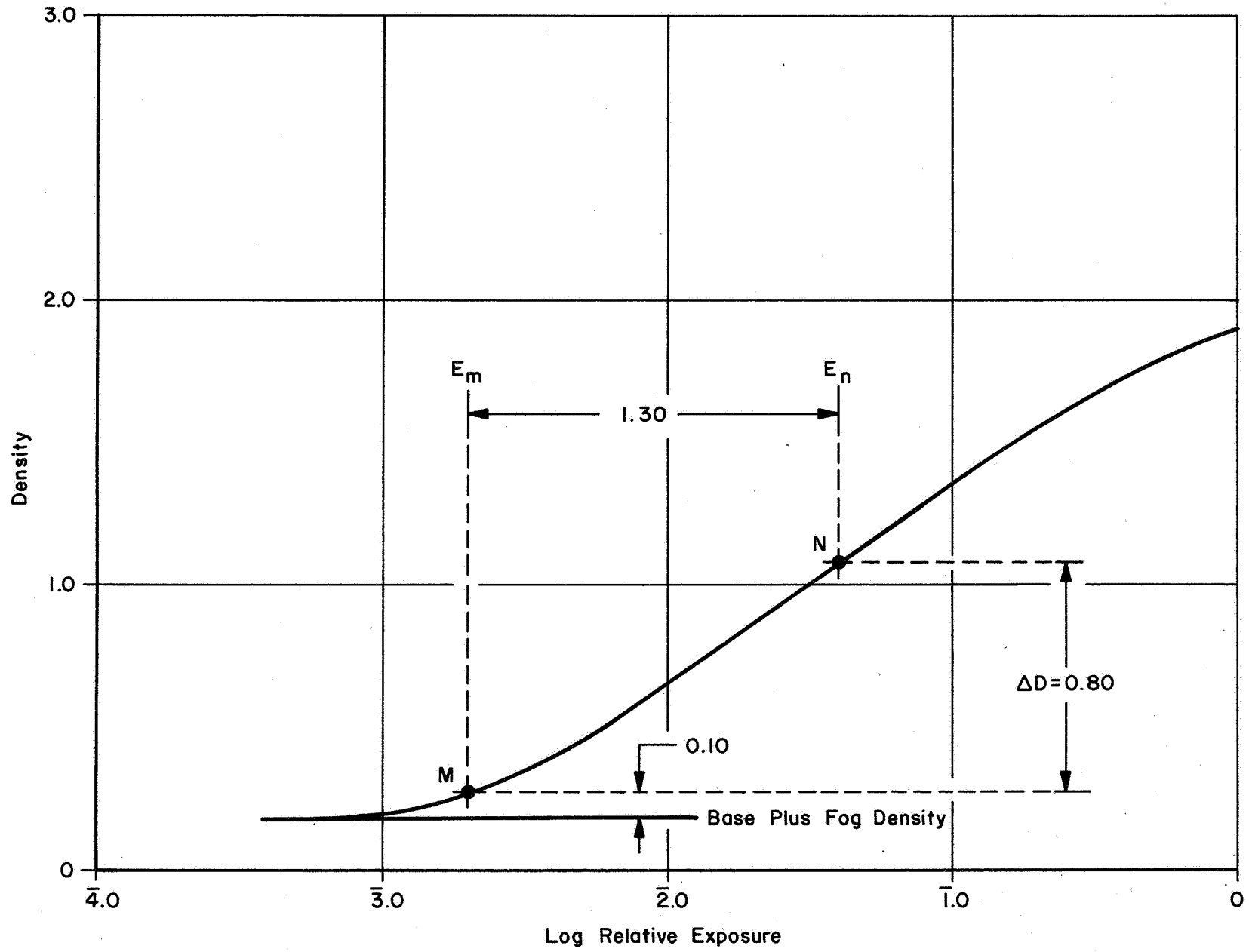


Figure 3.11 Method for determining speed.

The arithmetic speed is computed by use of the formula $S_x = \frac{0.8}{E_m}$ where S_x is the arithmetic speed, and E_m is the exposure (expressed in meter-candle-seconds) corresponding to the Point M on the D-log E curve.

3.1.4.2 Exposure Index. An exposure index is a measure of the speed of a photographic film and is used for determining the proper camera settings which will produce a high quality pictorial record of a scene. The picture quality must closely match a visual impression of the scene. The close association with vision suggests that an exposure index is meaningless for photographing in either ultraviolet or infrared spectral regions.

Forced development of a film can produce an apparent increase in film speed because it permits an acceptable picture, but not of high quality, to be obtained with less exposure. In any method of determining film speed, a true increase in speed is represented on the D-log E curve by a lateral shift along the exposure axis. By definition, this is only possible by altering the emulsion composition and not by changes in the development procedure, since the developing procedure is fixed. The exposure index of an emulsion can be altered by forced development, creating the effect of increased speed.

3.1.4.3 Exposure Reciprocity Effects on Film Speed. Exposure is defined as the product of intensity of illumination, I, and exposure time, t. The photographic reciprocity law states that identical film response will result if the product of I and t remain constant. Although this law is valid over a normal range of intensities, it fails seriously at both low and high intensity levels and is perhaps best known for its failure.

Failure of the reciprocity law quite often results in an apparent increase or decrease in film speed. Most photographic emulsions exhibit both a high and a low intensity failure with a minimum effect occurring

usually between 0.1 and 10 seconds. A true failure of the reciprocity law is sensitometrically illustrated by a shifting of the D-log E curve along the exposure axis. This is characteristic of a loss or gain of film speed. Some emulsions do not exhibit a change in apparent speed but are subject to a lowering or an increase of the slope of the curve. This is commonly referred to as a reciprocity effect and not a reciprocity failure. Figure 3.12 illustrates the relationship between the reciprocity failure and the reciprocity effect.

3.1.5 Color Photography. Color is a natural extension of black and white photography and adds another dimension to the pictorial representation of the original scene. The general theory describing the photographic process for black and white materials is also applicable for color films because silver halide grains are the light-sensitive elements for both systems. Major differences are in the film construction and chemical ingredients of the processing chemicals.

3.1.5.1 Theory. Color rendition in photography is based upon color sensations produced in normal vision. Circumstantial evidence suggests that the mechanism of human vision is responsive over no more than three broad spectral bands in which variation in stimulation produces a multitude of color sensations. A goal of color photography is, therefore, photographic representation of a scene in which the mechanism of vision receives the proper stimulus to create the same illusion of color as that produced from direct observation of the scene.

An ideal photographic color process would generate separate spectral band pictures of a scene in which each recorded image would stimulate only one of the eye's color sensors. Current physiological knowledge of the human eye lacks sufficient detail to permit construction of such a color process. No anatomical evidence exists which defines the exact spectral divisions of the color sensors or how they operate.

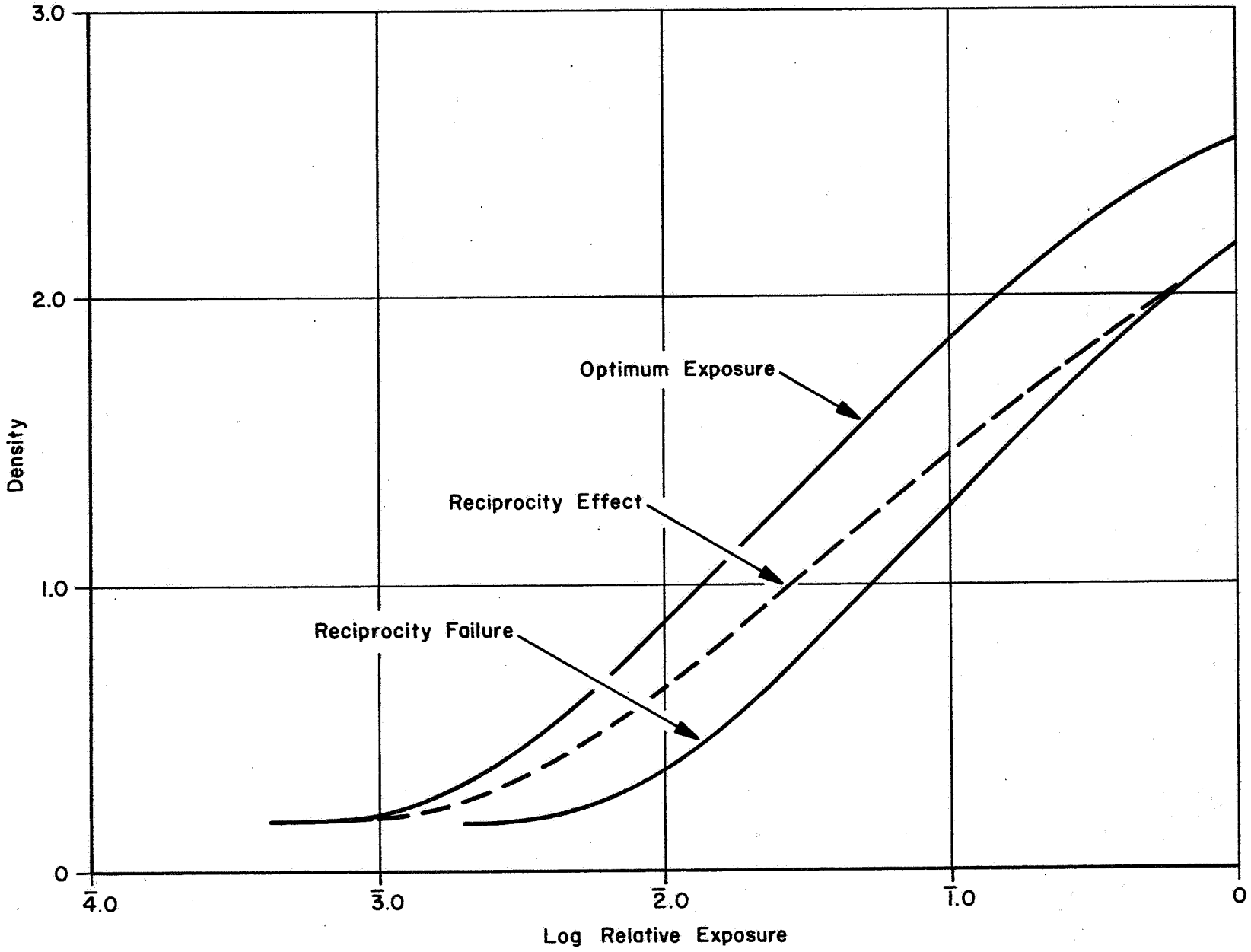


Figure 3.12 Exposure reciprocity.

Various attempts have been made to define the ideal division of the spectrum in order to produce satisfactory color reproduction by means of photography. The minimum number of spectral bands which photographically produces an effect of color vision appears to be two, and a variation of the two-color concept was most recently reported by Land.[10] Limitation of two spectral recording bands introduces considerable distortion in color fidelity in which certain color sensations are conspicuously poor. The minimum spectral division for practical color photography producing satisfactory color fidelity appears to be three, with one band covering the blue, another the green, and a third the red spectral region.[1, 2, 3, 11]

3.1.5.2 Methods. Three-color photography may be generally described by two different processes called additive and subtractive color. Each process employs the same spectral bands for recording the primary exposure. The major difference between them is the method of final presentation to the observer. The additive process most nearly duplicates the eye's response because each picture is presented as a separate primary color.

3.1.5.2.1 Additive Color. Stimulation of the human eye color receptors by appropriate amounts of the primary colors—blue, green, red—produces a neutral color sensation ranging from white to black depending upon the degree of stimulus. Maximum stimulation of all three colors produces white, hence the terminology additive wherein the addition of all colors produces white. Unequal portions of primary colored light produces a color differing from the primaries. For example, yellow is the color sensation produced by equal portions of green and red light with a deficiency of blue light. Yellow is, therefore, considered as minus blue because of the absence of a blue stimulus. A deficiency of green is a color sensation called magenta or minus green. The closest natural color of magenta is the flower of the fuchsia plant. Likewise the sensation of cyan, which is a blue-green, is referred to as minus red or the absence of a red stimulus.

Dye colors of the three primaries—blue, green, red—cannot be intermixed or superposed because each color absorbs two thirds of the spectrum. A mixture of only two would absorb all the spectral colors and the mixture would appear black. For this reason blue, green, and red colored photographic images cannot be registered together to form a color photograph. They can, however, be separately projected with all three images being registered at the screen.

Taking advantage of a psychological phenomenon associated with color vision, it is possible to produce a color picture with a single film. Because the eye will fuse small adjacent areas of different colors into a single color sensation, the photographic image may be composed of a geometric pattern of small areas of blue, green, and red. Colored light from each area is visually fused and produces the proper color sensation in the eye. Thus, the picture appears to be a color photograph.

3.1.5.2.2 Subtractive Color. The subtractive process does permit direct superposition of colors and, therefore, is a more practical approach to color photography. The three colors contained in the superimposed picture presented to an observer are complementary to the blue, green, and red primaries. Ideally each of these complementary colors would absorb only one third of the spectrum and completely transmit or reflect the remaining two thirds. Superposition of equal amounts of any two would not affect one third of the spectrum and would modulate the remaining two thirds in proportion to the concentration of the colors. Addition of the third color of equal concentration would produce a neutral gray or black, depending upon the degree of light absorption. The colors used in the subtractive process are yellow, magenta, and cyan, which were previously described, and are the colors which artists use and improperly term primaries of yellow, red, and blue.

3.1.5.3 Negative. The ability to superimpose colored photographic images of the subtractive process permits use of a single film in which three images are recorded in separate layers. Such multilayer color films can be processed as negatives or reversal positives. Although the exposure of each layer is accomplished using the primary spectral bands of blue, green, and red, the color comprising the images of either negative or positive system must always be yellow, magenta, and cyan, respectively. In all negative systems, the tonal scale of the original scene ranging from white to black is reproduced in an opposite relation with white producing the greatest density. Color must also be reproduced ir the opposite manner in a color negative. For example, yellow in the original scene will be reproduced as a primary blue in the negative and a primary red would produce a cyan image.

3.1.5.4 Reversal. Color reversal films reproduce both tonal and color scales in proportion to the original scene because the intended use is usually for direct viewing or projection. The dyes used in the subtractive process have certain deficiencies which do not permit attainment of complete color fidelity. Although reproduction by reversal gives a close approximation to the original scene, the color deficiencies are amplified when making duplicates, and a considerable departure from fidelity results. The effect of color distortion when making duplicates can be minimized by use of a special color negative which contains integral color correcting masks.[12] This procedure distorts the appearance of the color negative but is effective in removing undesirable color from the succeeding prints.

A primary objective of a color photograph is the creation of an impression which is consistent with the viewer's concept of the appearance of the original scene. In particular, the picture must faithfully reproduce neutral tones as contained in the scene. A color film is essentially a combination of three separate films operating as a unit. Each of the separate emulsions, after processing, produces a colored image which may be

described by a D-log E characteristic curve. Ideally, all three curves would have the same shape and would be coincident along the exposure axis. When an approximation of the ideal match is attained, the color film will reproduce neutral tones, and it is in color balance. A change in the color of the exposure illumination will cause an unequal shift in position of the D-log E curves, and the film will no longer reproduce neutral tones. This deviation in apparent speed of the three emulsions may be rectified during exposure by use of colored filters. Essentially, this procedure repositions the D-log E curves back into coincidence to achieve a new color balance which is a prime requirement for reversal films.

Color negatives have a somewhat greater exposure range than reversal films and therefore are less critical to color balance during exposure. The greater exposure range permits use of a color negative over a broad change in effective color temperature of the light source with the proper color balance being achieved in making the print. Commercially available Kodacolor negative film has sufficient exposure range to cover color temperature differences ranging from tungsten to daylight illumination, whereas no available color reversal film can tolerate more than a $200^{\circ}K$ shift in color temperature.

3.1.5.5 Image Quality. The same factors which influence the quality of a black and white photographic image also apply to color photography. Instead of having a single emulsion to contend with, the image quality of color films is modified by the effects produced in three separate images. The turbudity affects upon acutance and resolving power are most noticeable in the bottom layer of a multilayer color film. Unfortunately, the cyan image color of the bottom layer is the most predominant visual color of the three colors used and thus most strongly influences the visual appearance of total image quality.

In order to minimize the affects of diffusion of image forming light, the various emulsion layers are held to minimal thickness. Red light must be transmitted by both the blue and green sensitive layers before reacting with the red sensitive layer. In traversing the blue and green emulsions, it becomes diffused, thereby modifying the image quality of the bottom layer. Reduction in thickness and turbidity of the blue and green sensitive layers also reduces the diffusion and permits better image quality to be achieved in the bottom layer. As a result of the precautions taken in the construction of multilayer color films, the image quality is only slightly inferior to black and white films. Although many black and white films are capable of resolving 100 lines per millimeter or better, the average photograph as normally recorded is limited to a much lower value because of inaccuracies in lens focus. A nominal value of 30 lines per millimeter appears to be the practical level most often achieved. For this reason, an image quality difference is seldom encountered between color pictures and black-and-white photography. Image resolution of 75 to 100 lines per millimeter appears to be the order of magnitude for multilayer color films.

3.2 PHOTOGRAPHIC FILM IN A SPACE ENVIRONMENT

The environmental conditions of space impose many problems on a photographic film system which it does not normally have to contend with. Factors such as low atmospheric pressure, large temperature extremes, and the possibility of radiation exposure from solar flares or general cosmic radiation will influence the behavior of photographic films.

3.2.1 Lighting. Photometric characteristics of the lunar surface, established by years of observations from the earth, demonstrate that lighting conditions on the moon will present a photographic problem. Regardless of the nature of the lunar surface, which still remains the subject of considerable controversy, the outermost layer or covering is responsible for the peculiar

reflection of light incident upon the moon. The moon's peculiar reflection characteristics are associated with an anomolous backscatter phenomenon. It produces the visual effect of an apparent flattening of a three-dimensional surface. For centuries, man's impression of the moon has been that of a flat disk, but this appearance was not seriously appreciated until the first quarter of the twentieth center. The backscattering phenomenon will create a problem for an observer on the lunar surface in that his judgment of distance, size, and shape of the lunar ground will be made difficult because of the lack of modeling or shading. Unless the sun is at an appropriate angle to create shadows, the backscattering phenomenon might preclude detection of changing contours along the ground. Shadows, on the other hand, would tend to offset the apparent flatness and would permit some degree of contour observation. Normal stereoscopic vision will aid somewhat in contour judging but will be limited in effectiveness by the observer's relatively small interocular separation. Photographic interpretation from the results of wide angle or exaggerated stereophotography may permit contour and surface pattern analysis of this apparently dimensionless lunar ground.

Shadows, which would be most helpful in allowing easier detection of ground contours, will create another problem for both the astronaut observer and the photographic film. The ink-black shadows will appear to be devoid of detail because the moon does not have a sky of diffuse light to partially illuminate them.

Sources of light other than the sun—starlight, earthshine, and in particular light reflected from the sunlighted ground in the near vicinity of the shadows—will assist somewhat in illuminating the shadow. However, because of the low reflection characteristics of the lunar surface and the backscattering phenomenon, the level of light available to the observer or the photographic film will be exceedingly low. The resulting scene contrast between the sunlighted and shadow ground will seldom be less than 10,000 to 1.

3.2.2 Low Pressure.[13] It has been reported that low pressures in the order of 10^{-6} mm Hg do not cause a change in the sensitometric properties of one particular photographic film. A high definition film of very low exposure index was given an exposure while being subjected to a pressure between 10^{-5} and 10^{-6} mm Hg. The result of this exposure was the same as an exposure made on a similar film under normal atmospheric pressure. However, films subjected to such pressures will encounter a loss in moisture content of the emulsion as well as the support. Sufficient reduction of the water content causes the tensile strength of the gelatin to weaken and, if not properly handled, will cause cracks to form in the silver halide gelatin emulsion. Winding the film with the emulsion side toward the center of curvature will minimize such cracking.

The construction and electrical characteristics of a photographic film promote the build-up and accumulation of static electricity on its surface. The simple process of unwinding a roll of film charges up the surfaces as one lap of film is peeled away from the next on the roll. Because film is a poor conductor, the electrons produced in the peeling process accumulate in localized areas and ultimately discharge to other areas. The discharge of static electricity, occurring on the surface of the film, is accompanied by a burst of light which fogs the film and produces an objectionable pattern in the processed image.

The mositure content of a photographic film is closely associated with a change in electrical resistance on the film surfaces. Films with high moisture contents exhibit low surface resistance, thereby preventing accumulation of an electrical charge on the surface. Low moisture content is accompanied by increased surface resistance and a resultant static charge. Since one of the effects of low atmospheric pressure on photographic films is the loss of mositure, the possibility of accumulation and discharge of static electricity is increased. Coating both sides of a film with a gelatin layer

reduces the tendency to produce static discharges because the two contacting layers are similar. Another solution might be the application of a metallic silver layer to the support side of the film which would conduct the electrons away as soon as they were formed. This metallic silver layer would be removed during processing of the film.

Films tightly wound and exposed to very low pressures lose moisture slowly. Such a film may be exposed to the pressures of space for long periods of time before a significant loss in moisture content is encountered. This fact would thus permit reloading of a camera in space or on the moon provided that the film was spooled for daylight loading and the procedure was carried out in subdued light. Reduced moisture content will not affect a latent image, and the film rapidly recovers its moisture when brought back to normal atmospheric conditions.

3.2.3 Temperature Extremes.

3.2.3.1 High Temperature. Photographic film is adversely affected when subjected to a high temperature environment for prolonged periods of time. At temperatures of $+120^{\circ}F$, the silver halide crystals of a high speed emulsion would form a latent image after several hours to produce a noticeable fog upon development. With further increased temperatures, the time required to produce a similar result would be reduced. This is probably the result of the low level primitive sensitivity to near infrared indicated in Figure 3.9. Most photographic films can tolerate a critical fog level without serious degradation of their sensitometric characteristics. At fog levels greater than 0.7 above background density, films begin to suffer an apparent loss of speed until ultimately they no longer respond to exposure. This level is reached at temperatures considerably lower than those at which physical damage to the film occurs. Once the silver halide crystal has been subjected to a high temperature environment, it is permanently altered and is then capable of development without exposure to light.

3.2.3.2 Low Temperature. The effects of low temperatures are not permanent and disappear when the film temperature is raised back to normal room temperatures. The two major but temporary effects which low temperature has on a photographic film produce a loss of sensitivity and a decrease in mechanical strength by removing moisture from the film. An investigation by Evans,[14] on the effect of temperature on sensitivity, reports a loss of sensitivity of several emulsions at -75°C and -180°C. Figure 3.13 shows the loss of spectral sensitivity of a high-speed panchromatic emulsion that Evans investigated. The curve indicates that the sensitivity has been reduced uniformly by a factor of 4 at a temperature of -76°C. When the temperature is lowered to -180°C, the sensitivity loss is not uniform across the spectral range of the film. At 400 millimicrons, the sensitivity is lowered by a factor of 16, while at 600 millimicrons, it is only one percent of the original sensitivity. The investigation showed that, in general, the loss in sensitivity at low temperatures is greater in the optically sensitized spectral region than in the region of primitive sensitivity of the silver halide. The effect on a color film of low temperatures would not only be a lowering of film sensitivity but a loss of color balance.

3.2.4 Radiation. The space and lunar environment is hostile to the normal photographic processes. The presence of a radiation environment during the journey to and from the moon, as well as on the lunar surface, presents a potential hazard to photographic films. Generally, films which are very sensitive to light are also quite sensitive to high-energy particle radiation. The resulting radiation damage to a photographic film is very similar to the damage caused by excessive heat which was previously discussed. Exposure to a critical dose of radiation will be evident, after development, because of an overall fog covering the entire film.[15] Greater radiation exposure will produce a greater fog with an effective loss in film speed. Sufficient fog would ultimately degrade the image quality. High-speed photographic films will generally suffer more damage at lower levels of radiation

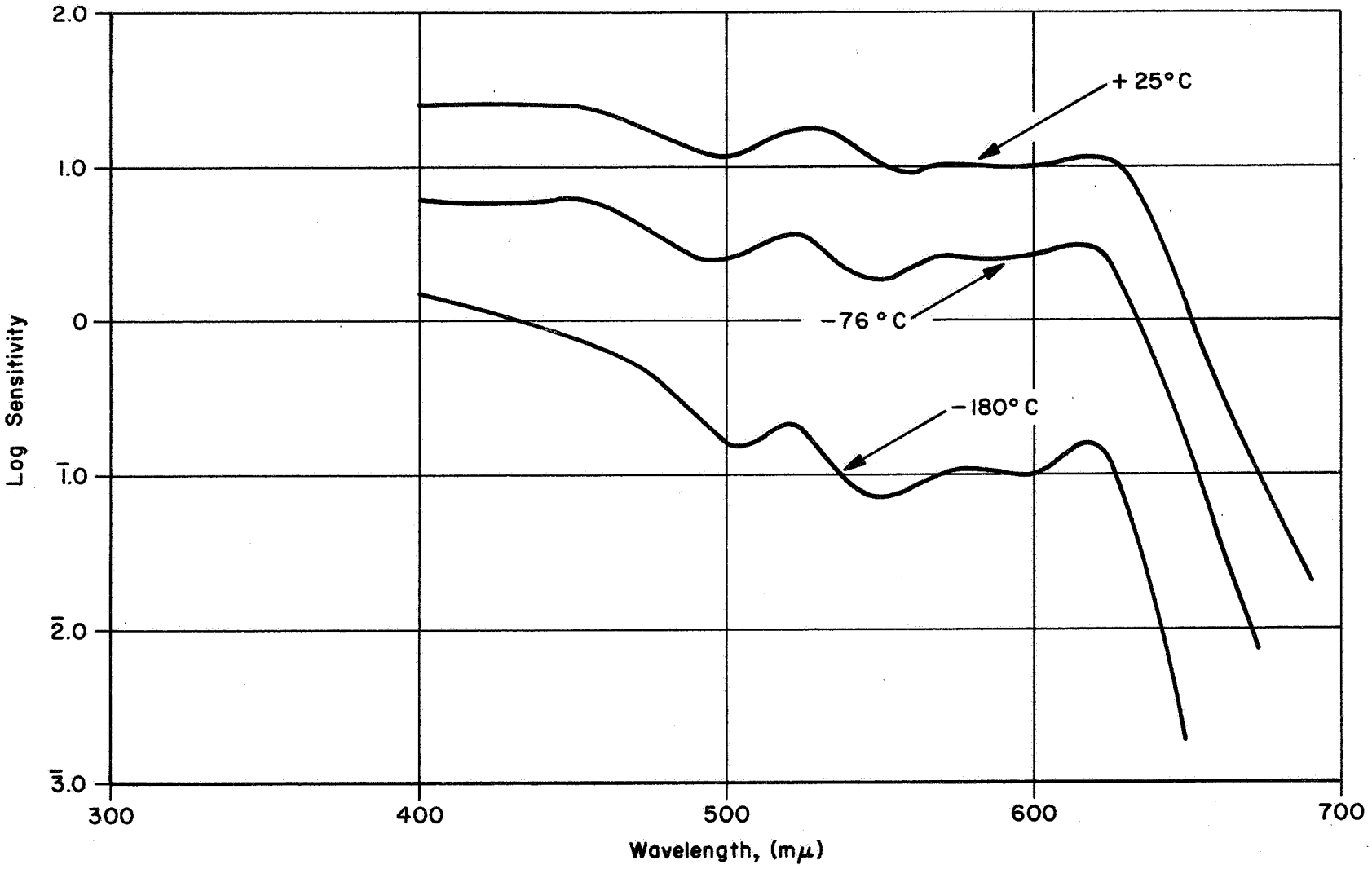


Figure 3.13 Effect of temperature on a high speed panchromatic emulsion.

than will the less sensitive or slower films; therefore, the high speed films will probably require greater amounts of radiation shielding to ensure adequate protection.

Based on recent computations, a "best-estimate" of the shielding requirement for the lunar radiation environment was determined by D. E. Robbins of the Manned Spacecraft Center (MSC).[16] These data may be used to determine approximate amounts of certain materials required to reduce the incident (proton) and knock-on (neutron) particulate radiations to tolerable dose levels.

The solar flare particle intensities are calculated on the basis of high altitude and optical measurements during the upper half of the 19th observed sunspot cycle (1956 to 1961). A probability of 0.92 is assumed that if an event is encountered during the mission, it will contain no more than 1.0×10^8 particles/cm^2 > 30 Mev for the 14-day Apollo mission, or no more than 3.2×10^7 particles/cm^2 > 30 Mev for the 8.3 day mission. It is also assumed that there are the same number of protons and alpha particles of equal particle "rigidity"; i.e., equal momenta per unit charge.

Solar protons and the accompanying recoil neutrons and gammas cause silver halide grains to transform into metallic silver as in the case of bombardment by light quanta. The energy transfer is a direct excitation and ionization process for incident-charged particles (e.g., protons), but is mostly an indirect process involving secondary emission of protons and electrons in the case of incident uncharged particles and quanta (e.g., neutrons and gammas, respectively). The specific ionization is defined as the number of ion pairs produced per centimeter of path length. These ionized radiations range over two orders of magnitude, and the density produced, after processing, is approximately proportional to this quantity. For example, 30 Mev protons have about the same specific ionization as 15 kev electrons, and both have about 10 times the specific ionization of either 1 Bev protons or 500 kev electrons.

Films not only differ in their sensitivity to the types of radiation, but also in their relative sensitivity to light and nuclear radiations. One incident gamma ray can make one or more silver halide grains developable, while it takes several light quanta to transform just one grain. This sensitivity dependence complicates any attempts to selectively discriminate the light and radiation activation processes.

In addition to this instantaneous fogging of the film by the primary and secondary radiations, a delayed fogging may be caused by the emitted radiations from radioisotopes in the emulsion. This will result from the thermal neutron activation of silver, the dose from which was determined by Mercer and Golden[17] to be given by

$$D = 0.52 \times 10^{-10} \overline{(nvt)} \, t_{Ag} \text{ rad}$$

where $\overline{(nvt)}$ is the average thermal neutron flux, n/cm^2, and t_{Ag} is the emulsion silver content, mg/cm^2. For an $\overline{(nvt)}$ of 9.6×10^8 n/cm^2 and a silver content of 2 mg/cm^2, D is calculated to be 0.10 rad.[18]

Thermal neutrons are extremely effective in fogging film because of the above activation present in a typical solar flare process and because of their high specific ionization. Compared to 300 Mev protons, slow neutrons (< 1 Mev) have a specific ionization about two orders of magnitude greater, while energetic neutrons ($\simeq$ 10 Mev) are about one order of magnitude greater. It would thus appear that the knock-on neutrons could present formidable fogging problems unless adequate shielding is provided.

3.3 LUNAR SURFACE CHARACTERISTICS

3.3.1 Horizon. The moon is about one quarter the size of the earth with a diameter of approximately 2000 miles. Assuming the surface to be perfectly spherical and free of depressions or hills, an astronaut standing on the surface would observe the horizon at about 1.4 miles in any

direction. But, the surface is not perfectly sherical. It contains craters and hills so,that the distance to the observed horizon may be different.

3.3.2 Atmosphere. Direct observation from the earth indicates that the moon has no atmosphere of significance. Estimated pressures above the lunar surface are of the order of 10^{-10} mm Hg. Such low pressure accounts for the absence of a sky to supply diffused and scattered light. The appearance of what exists as a lunar sky would not change between night or day except for the presence of the sun. More stars would be visible from the lunar surface at any time than could ever be seen from earth under the best of "seeing" conditions. Because there is essentially no atmosphere, the stars would not twinkle and would appear to be considerably brighter than from the earth. In similar fashion, the sun would also appear brighter and cast shadows with a contrast magnitudes greater than similar earthly shadows. With no light-scattering sky to illuminate the shadows cast by the sun, the shadows are exceedingly dark and will present a strange appearance to the observer. Human vision has a brightness adaptation capability which enables the eye to accommodate to a large brightness range. The exact mechanism is not clearly understood, but essentially the image areas receiving the most light are somehow desensitized in favor of those areas which receive less light.[19, 20] Thus, even though the shadows on the moon may be darker than the sunlit areas by more than 10,000 times, human vision through brightness adaptation may be able to discern detail in the very dark shadows. Normal photographic films do not possess this ability for accomodation and, therefore,are limited in the brightness range over which they perform acceptably.

With no atmosphere, solar energy extending well beyond the visible into the infrared and ultraviolet arrives at the lunar surface in abundance. Unless filtered out, the ultraviolet component will seriously affect the proper color rendition recorded by a typical color film. The blue sensitive portion of the film, which has an inherent ultraviolet sensitivity, would receive

excessive exposure from the ultraviolet and, therefore, would not be a true representation of the visible blue sensation.

The temperature extremes between full sunlight and shadows may present mechanical as well as sensitometric problems to a film system. When a film is subjected to a high temperature for a sufficiently long period, the recording properties become seriously impaired because a permanent transformation takes place within the silver halide grains. Grains become developable without exposure to light and a high density background is recorded. Extremely low temperatures, on the other hand, temporarily reduce the film sensitivity which is regained when the film temperature is increased to a normal range.

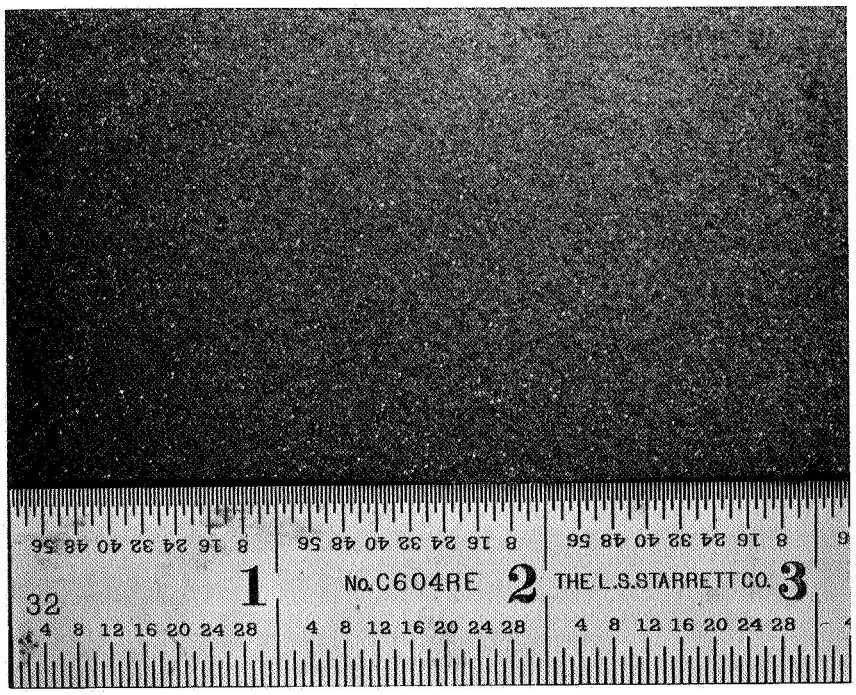
3.3.3 Macrostructure. The lunar surface apparently contains craters—ranging in size from 180 miles in diameter to a few feet—mountain ranges, ridges, valleys, and rills. There appear to be numerous bits of debris scattered within certain areas.

3.3.4 Color and Reflection. The Pictorial Lunar Map, supplied by the Corps of Engineers of the Army Map Service, is an exaggerated color map indicating the general color pattern of the lunar surface. This shows the moon having large areas of yellow and green with smaller areas of browns and reds. It is quite probable that considerably more color detail is present on the actual surface which is not resolvable from earth. The reflectivity of the various lunar features is not constant but has observed albedos ranging from a few to nearly 20 percent. The average reflectance appears to be about 7 to 8 percent, which is a charcoal gray. Whatever color and tone exists on the moon will be present in the sunlit portions and in the shadow areas and thus will present a recording problem for a film system. Human vision has a property termed color constancy which allows the observer to see a color in full light and in shadow and recognize the color to be the same. Color photography not having this ability will record the colors as modified by the

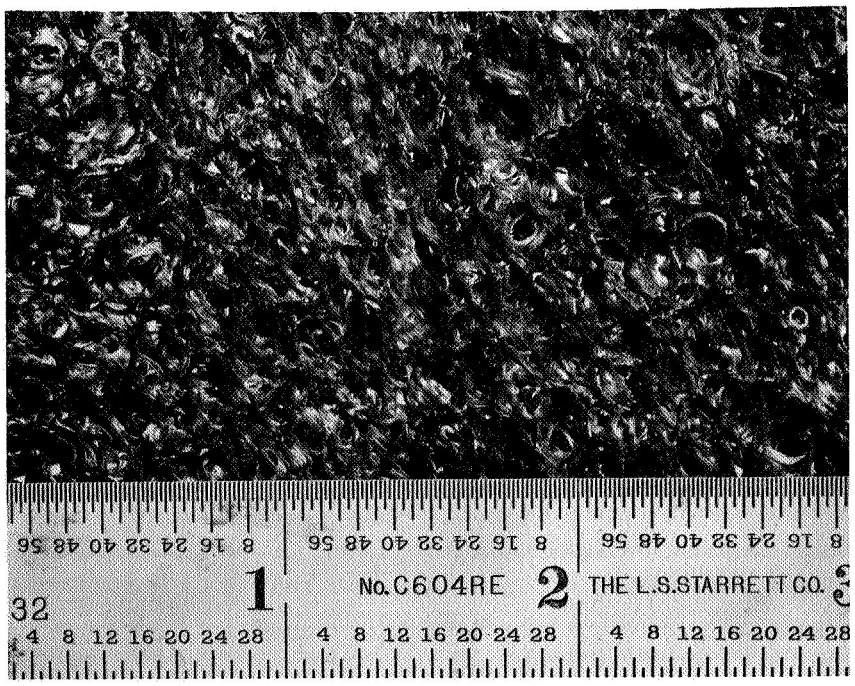
degree of illumination. With the narrow exposure latitude of normal color films, color saturation in shadow areas may completely disappear.

3.3.5 Microstructure. Considerable differences of opinion exist relative to the microstructure of the lunar surface. A literature search has revealed a report in the August 1963 Journal of Geophysical Research by Hapke and Van Horn which is of timely interest to this lunar film study. They suggest that the topmost lunar surface is composed of a layer of very fine powdered rock held together by electrostatic charges. The size of the powdered particles extends from several microns down to fractional micron dimensions. Van der Waals attraction is supposed to bind these particles in a random fashion which they call "fairy castle stacking", and these stackings produce a porous structure consisting of many cavities or voids. Light, which has the proper direction to enter the cavities, emerges after reflection in a parallel but opposite direction from the incident beam and is thus autocollimated. Model surfaces which backscatter light as sharply as the moon generally have fractional void volumes of the order of 90 percent. The structural 10 percent remaining accounts for what reflectivity there is. According to Hapke and Van Horn, certain artificial cellular sponges when dyed to give the proper albedo are a good approximation of the structure and appearance of the lunar surface. This material has cavity diameters of the order of 1/2 millimeter. U. Clanton from the Manned Spacecraft Center has suggested a pumice-in-lava form as being representative of a possible lunar surface structure.[21] A sample of such a material from a California lava field has void diameters averaging several millimeters and has an effective albedo of 8 percent. Surface detail of the cellular sponge polyurethane material and the lava pumice are shown in Figure 3.14.

The unique optical feature of porous structures is the manner in which incident light is reflected. The structural material of individual particles may have a high reflectance, but the average light return is low because of



a) Enlarged photograph of polyurethene cellulose material.



b) Enlarged photograph of California lava pumice.

Figure 3. 14 Materials simulating lunar surface structure.

the cellular structure of cavity upon cavity. An illuminated porous structure returns the most light along the same axis as the illuminating source and appears brightest from the direction of the light source. From this direction, no shadows will be apparent and surface contours will not be discernible; craters, hills, valleys, and rills will appear with no dimension like a flat evenly-illuminated area.

3.4 STEREOSCOPY

Recent discussions on the subject offers strong support for the use of stereoscopic photography in order to distinguish lunar surface contours under illuminating conditions which produce a flat appearance.[22] Stereoscopic photography uses the principle of binocular vision in which the images produced in each eye are slightly dissimilar. Each eye effectively sees a slightly different view of a three-dimensional object, and the brain fuses the visual signals into a single impression of the scene and produces a mental illusion of depth. A similar illusion of three dimensions may be obtained by viewing a pair of photographs of a scene recorded from slightly different angles. In viewing the picture pair, a special optical device is used which permits each eye to see only one picture. As in normal binocular vision, the processes of the brain combine the separate picture-views into a single mental picture which appears to have three dimensions. The angle formed between the two eyes and the object being viewed is apparently a mental guide for establishing a scale of the perceived three-dimensional scene. In normal vision, a large angle is encountered when viewing nearby objects of small scale. Therefore, if photographs are recorded with a wide angular separation, the brain accepts the pair of pictures as being a scale model and the depth perception appears exaggerated.

An article by Bela Julez, in the February 1965 issue of Scientific American, suggests that familiarity of shape or surface contour is not

necessary for the visual perception of depth. Patterns which appear to be a random distribution produce a sensation of three dimensions when viewed binocularly. An example of depth preception from an apparent random distribution of geometric shapes may be observed by stereoscopic examination of the illustration shown in Figure 3.15

Figure 3.15 Three dimensional image pairs composed of an apparently random distribution of dots which forms an unfamiliar pattern or surface texture. When viewed through a stereoscope, these images produce an illusion of depth in which a square central portion of the pattern appears to float above the larger square.

3.5 COMMENTS ON DESIRED FILM CAPABILITIES

It is obvious that the first manned lunar surface expedition can accomplish only a limited number of experiments. The adverse environmental conditions coupled with severe weight limitations make it necessary to devise the optimum possible experimental equipment. Photography being no exception, an effort must be directed towards simplification without serious compromise in the recorded data.

3.5.1 Single Film. It is obvious that a single film capable of fulfilling the entire photographic assignment would be highly desirable. There are several reasons, however, why a single film might not be the optimum solution to the problem. If the roll of film became damaged from any number of causes, the entire photographic mission would be a failure. Possible causes of damage would include faulty processing, excessive radiation, high temperature storage, inadvertent exposure to light, and high humidity or water damage. A single film to accomplish the photographic mission would necessarily contain certain compromises which might be out of proportion to the value of using a multipurpose film. For optimum results, the various elements comprising the photographic film system require different types of processing. A single multipurpose film must, of necessity, be processed as a unit thereby minimizing complete effectiveness. Image definition deteriorates as the image-forming light penetrates deeper into an emulsion. A multipurpose film would necessarily consist of many emulsion layers, thereby increasing its thickness and degrading image quality.

3.5.2 Spectral Range. A photographic film can be made to cover the spectral range from 2000 to 10,000Å, but the sensitivity will not be uniform. As discussed in Section 3.1.3, the gelatin binder suspending the grains of silver halide effectively limits practical sensitivity to 2500Å. Reduction of the gelatin content enables high sensitivity to be maintained to somewhat shorter wavelengths, but energy absorption of the grains reduces the contrast below a useful level. Sensitization with ultraviolet fluorescing materials does not produce practical sensitivity for pictorial results. At the longer wavelength, extreme practical sensitivity levels are not achievable beyond 9000Å because no efficient sensitizing dye is currently available to accomplish this task. Infrared photographic recordings at wavelengths somewhat beyond 13,000Å have been made spectroscopically, but the exposure times required were impractical for hand-held cameras.

3.5.3 Exposure Index 10,000. The fastest currently available photographic film has an exposure index of 3000 and in order to attain a value this high, the film must have a thin high-speed emulsion coated on a highly reflective backing.[23] If effect, the emulsion is exposed twice: when the image light passes into the emulsion, and the second time on the way back out after returning from the high reflectance backing. Films which are rated with a 10,000 exposure index are no more sensitive to light than the 3000 speed film. They are basically the same emulsion which has been specially treated to produce an effective increase in exposure index. So treated, these films produce a more useful image in the weak exposure region, but they do not respond to lower exposure levels than the normal untreated films.

3.5.4 A Resolution of 200 Lines Per Millimeter. Films with a high degree of light sensitivity do not generally have a high resolving power capability. A resolution of 200 lines per millimeter is beyond the capability of high-speed films. An intermediate speed film with an exposure index of 100 could attain a resolution of 200 lines per millimeter in a spectral band restricted to the shorter wavelengths if the exposure was limited to the surface of the emulsion. Used in this manner, the usable exposure range would be reduced and would probably not exceed 100.

3.5.5 Color Fidelity. A film's ability to faithfully record hue, saturation, and value or tone as visually observed is severely limited because the photographic system lacks many of the capabilities of human vision. The terms color constancy, brightness constancy, and local adaptation are phenomena associated with human vision and are partly a physiological and partly a mental interpretation. A color photographic film with an extended exposure range increases the film's ability to faithfully record a scene. However, the dyes used to form the colored images have inherent spectral deficiencies which preclude ultimate fidelity. Accurate reproduction of a neutral tonal range will aid markedly in creating a realistic color impression of what the scene might have looked like.

3.5.6 Insusceptibility To Radiation Damage. The latent image in a photographic film is created by the liberation of electrons. Any mechanism which liberates sufficient electrons into the silver halide crystal lattice of an emulsion will produce a developable latent image. Light, X-rays, gamma radiation, and high energy particles liberate electrons within the sensitive crystals. Unless an emulsion can be desensitized and sensitized back again at will, silver halide photographic films probably cannot be completely radiation hardened. Reduction in the emulsion temperature to extremely low values (-196°C) restricts latent-image formation but does not completely eliminate its production. Extremely low film temperature does offer a possibility for protection against radiation damage. Lowered temperatures will not destroy a latent image which has already been produced, but the mobility of ionic silver, one of the necessary components in latent-image formation, is greatly reduced and effective sensitivity is temporarily lost. Full sensitivity is regained at normal temperatures of +20°C. In the event of solar flare activity, some protection can be achieved by reducing the film temperature. At the cessation of the radiation danger the film can be brought back to normal temperature and photography may be resumed.

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CHAPTER 4

INVESTIGATIONS

Many of the effects of a space environment upon photographic films have been previously investigated and reported.[13] Generally, the studies were not made under the extreme conditions believed necessary for use on the lunar surface. Therefore, it was necessary to perform a limited number of experiments, and this chapter describes the various experiments which were conducted in compliance with the lunar film study program.

4.1 LOW PRESSURE FILM EXPERIMENTS

With the assistance of Dr. John W. Salisbury and Mr. Paul Ramos, the facilities of the Lunar Environment Laboratory of Air Force Cambridge Research Laboratories at Bedford, Massachusetts, were employed to subject certain photographic films to low pressure atmospheres. The vacuum chamber, normally capable of attaining pressures of 5×10^{-11} mm Hg, is an Ilikon Associates sealable chamber with a capacity of 3 cubic feet. It is evacuated by a mechanical roughing pump and molecular sieve, and final pressure is achieved with a diffusion pump.

4.1.1 Mechanical Effects. The purpose of the first experiment was to determine possible mechanical failures occurring in films subjected to low pressure. The gelatin binder was of particular interest because previous information suggested that a peeling or cracking phenomenon might occur. Unprotected strips of Plus-X, Kodachrome II, Ektachrome Daylight ER, and XR film were placed in the chamber and remained at 10^{-10} mm Hg for 5 days. Close inspection of the films after removal revealed no observable changes.

4.1.2 Latent-Image Stability. The next experiment was intended to reveal sensitometric changes in the latent image of these films which were exposed prior to the evacuation process. Special light-tight aluminum cans,

modified to permit pressure evacuation, were used to contain sensitometrically exposed strips of the four films. These cans were the type normally supplied by Eastman Kodak for shipping and storing unprocessed 35 mm amateur Kodachrome film. They are light-tight by virtue of an overlapping threaded cap. A soft gasket material integral with the inside of the cap forms a moisture seal when the cap is firmly in place. Modification to permit evacuation consisted of notching the top edge of each can, thus making the moisture seal ineffective and allowing free movement of air without affecting the light-tightness.

Two sets of film packages were prepared as described above. One set was placed in the chamber and held at 10^{-10} mm Hg for 5 days, while the other served as a control at normal atmospheric pressure. Both sets of sensitometrically exposed films were then processed and the resulting densities were compared. No difference was observed between the control films and those subjected to the low pressure.

4.1.3 Latent-Image Formation. The third experiment, using the same vacuum chamber, was performed to determine the affect of low pressure on the mechanism of latent-image formation in Ektachrome Daylight ER film. In order to accomplish this, a special sensitometer had to be made which would expose the film inside the vacuum chamber. A Nikkor daylight developing tank for processing a 120 size amateur film was modified to contain a special film holder which also served the purpose of a small sensitometer. This unit consisted of a solid block of opaque plastic containing six evenly spaced quarter-inch holes extending from top to bottom of the block. A miniature General Electric 327 light source, positioned at the top of each hole, exposed a circular area of film which was held in firm contact with the bottom of the block. Ventilation holes were located in each side of the block which permitted the light-source cavities to be pressure evacuated. Electrical leads from each light source were fed through the cover of the Nikkor tank and were connected to a terminal block which extends through the wall of the evacuation chamber.

An external 28-volt battery was connected to each terminal through separate switches so that each light source could be turned on independently.

Film was loaded in the assembly in a darkroom and the Nikkor tank was then positioned in the chamber. When evacuation of the chamber had reached equilibrium at approximately 10^{-10} mm Hg, each light source was turned on for an appropriate time to produce a graded series of exposures on the film at this reduced pressure. This film, along with a control film exposed the same way at atmospheric pressure, was processed and the resulting densities of both films were compared. No essential difference was observed.

4.2 HIGH TEMPERATURE EXPERIMENTS

The sensitometric properties of an emulsion can be altered with time at elevated temperatures. As this product of time and temperature is increased, changes in the emulsion characteristics become more noticeable until a point is reached when the film no longer responds to changes in light exposure. The effect is an increase in the density level of the background and a lowering of contrast. At a given level of time and temperature, the affects on different emulsion types vary. As a general rule, the higher the speed of the emulsion, the greater the effect of time and temperature.

4.2.1 Procedure. The effect on film of elevated temperatures for prolonged periods of time was investigated using a temperature-controlled oven with a large access door. The usable volume of the oven was 1.6 cubic feet and could be operated at a temperature ranging from room temperature to +400°F. The oven was heated to selected temperatures, and sensitometrically-exposed strips of film were inserted in the oven for various periods of time. For one experiment, the film strips were placed in small light-tight metal cans. The procedure was later refined, for a second series of experiments, to enable the film strips to be placed inside the oven and to be suspended by hangers without opening the large access door. The films were inserted through

light-tight vent holes on top of the oven. This procedure enabled a constant temperature to be maintained inside the oven. The temperature range of the tests was from +160 to +280°F, covering a time period from 2 minutes to 50 hours. Three types of emulsions were tested in the oven: Plus-X, Royal-X Pan, and High-Speed Infrared.

4.2.2 Effect on Latent Image. Plus-X film was tested to observe the overall sensitometric effect when kept for 6 hours at temperatures of +150 and +180°F. Sensitometrically-exposed film strips were kept in small metal cans and placed inside the oven. At the end of the six-hour storage period, these films along with control samples held at room temperature were processed. The pre-exposed sensitometric scales were measured and plotted as D-log E curves and showed that the curve shape was affected by the 6-hour exposure at both +150 and +180°F. Neither condition produced a significant change in film speed; nevertheless, there was a definite increase in the fog level as shown in Figure 4.1.

4.2.3 Time and Temperature. Royal-X Pan and High Speed Infrared films were tested to determine the time required to produce 0.10 density above background at various temperatures. The film strips were suspended in the oven with hangers. Constant temperature was maintained throughout the test in close proximity to the film strips.

During the test, it became apparent that the amount of water vapor in the test chamber was influencing the effect of temperature on the sensitometric properties of the film. At low temperatures, the time required to produce the proper density became inconveniently long for the single strip method that had been used. A method was tried that incorporated small sealed film cans which would allow a number of tests to be run simultaneously. Higher fog densities were produced by this method for a given time than those produced by the film hanger technique. It is theorized that the higher fog densities were the result of water vapor trapped within the sealed container

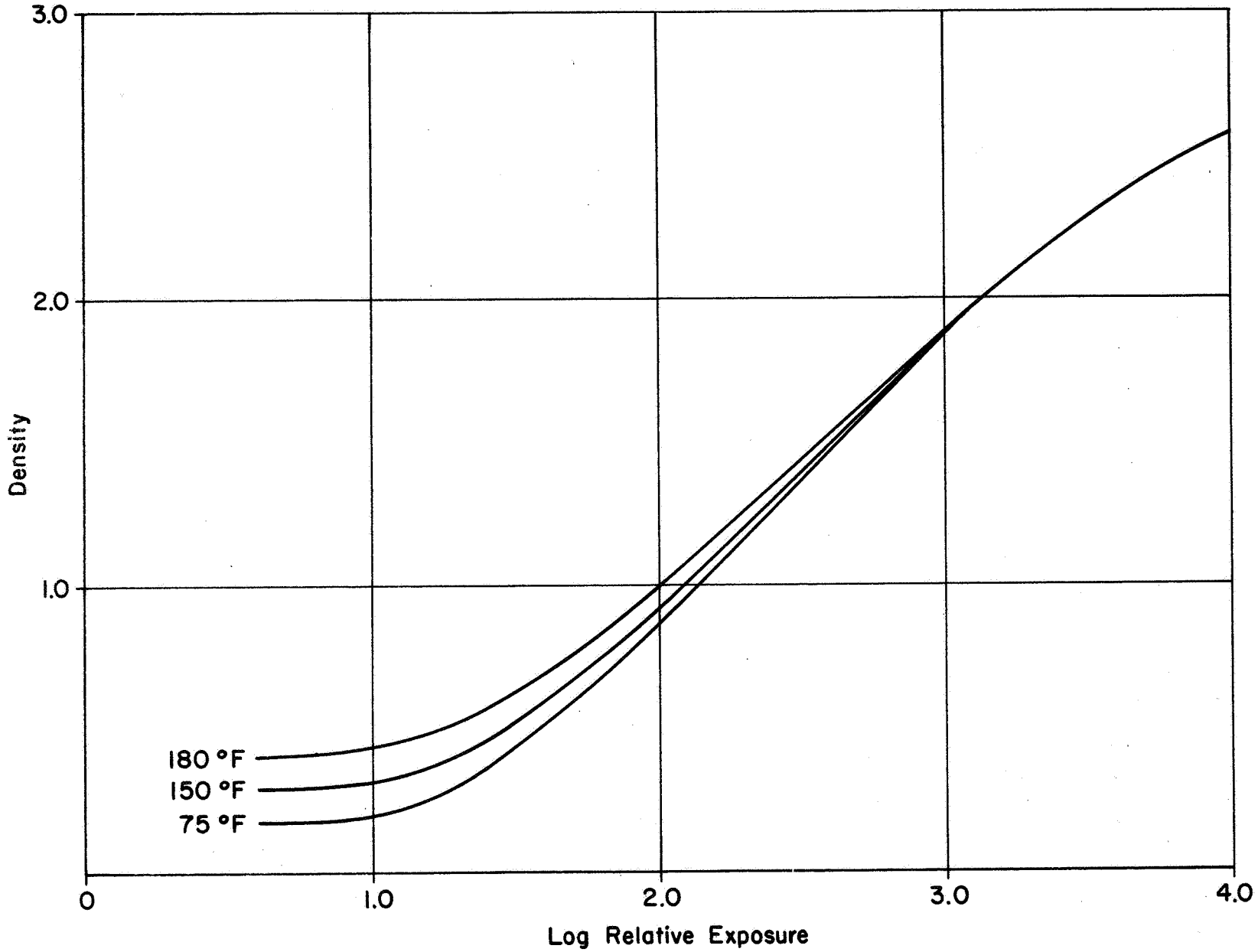


Figure 4.1 Effect on sensitometric characteristic of Plus-X negative film exposed to high temperature for 6 hours.

which accelerated the formation of latent-image fog. It is apparent, from the results of this test, that greater care must be exercised in the preparation of the film for the Apollo program to avoid trapping water vapor within the sealed film-container or camera housing.

The results from the time-temperature tests on Royal-X Pan and High Speed Infrared film are shown in Figure 4. 2. These tests were conducted using the film hanger technique. There was no attempt to control the relative humidity in the room containing the oven. The relative humidity in the room was 60 percent, and in the oven at +200°F it was approximately 30 to 40 percent.

4. 3 CRYOGENIC TEMPERATURES

The affects of very low temperatures upon certain sensitometric characteristics of two different photographic films were investigated by immersion of the films in liquid nitrogen at -196°C (-321°F). A conventional thermos-bottle insert was used as a container for the liquid nitrogen, and a camera lens filter holder was modified to fit over the thermos-bottle opening to hold a small piece of film submerged in the nitrogen.

4. 3. 1 Latent-Image Stability. Pieces of Royal-X Pan and Ektachrome Daylight ER color film were sensitometrically exposed at room temperature and then positioned in the film holder and completely submerged in the liquid nitrogen until temperature equilibrium had been reached. The films were then removed and acclimatized to room temperature before processing. These films and similarly exposed control films which remained at room temperature were processed together, and the resulting densities of the low temperature films were compared with those of the control films. No differences were observed.

4. 3. 2 Latent-Image Formation. The next experiment, using the same film types, investigated the influence of liquid nitrogen temperature upon the mechanism of latent-image formation. Unexposed film samples

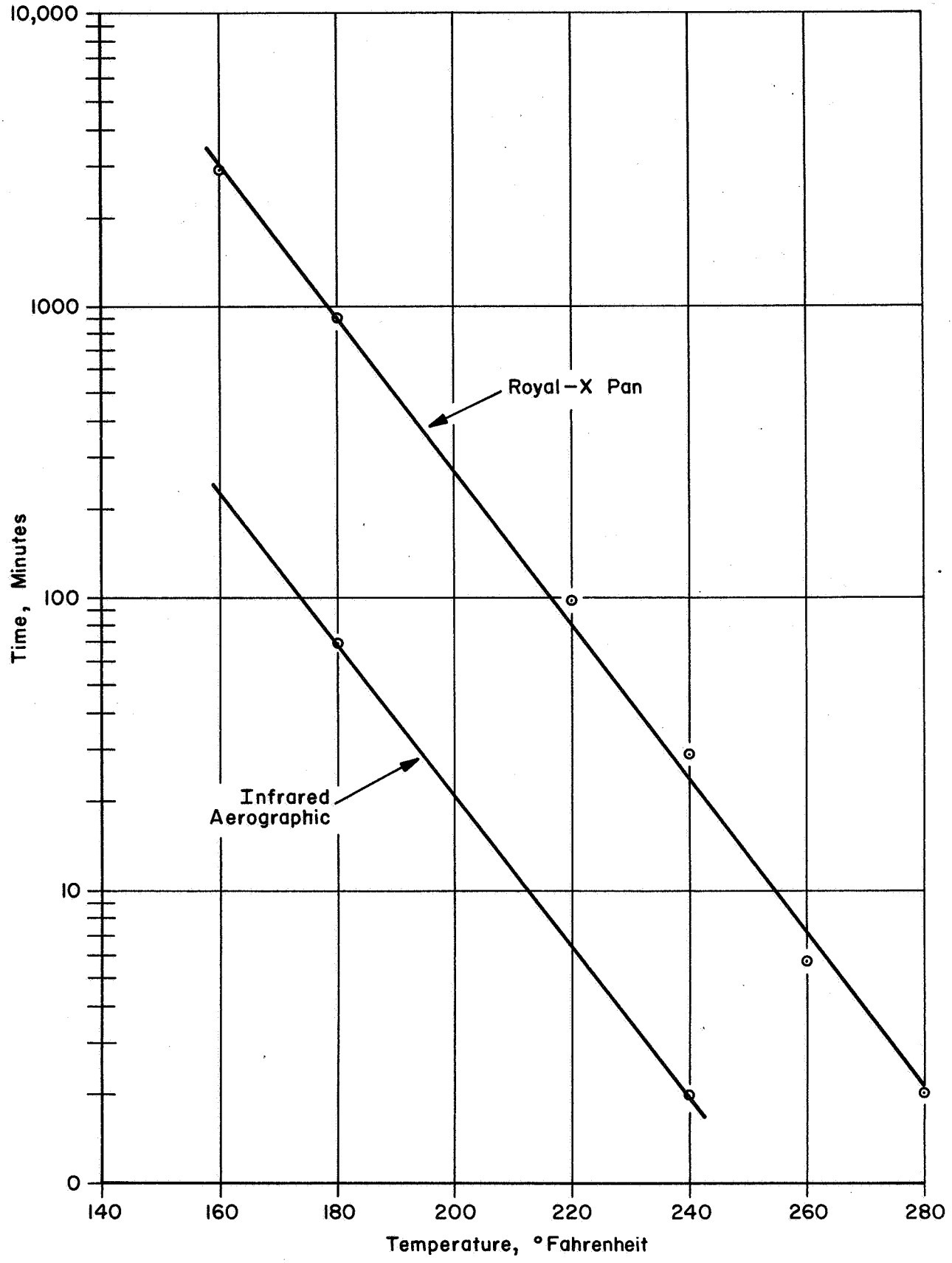


Figure 4. 2 Time-temperature required to produce 0. 10 fog density above background when developed to 1. 0 gamma.

were submerged in liquid nitrogen using the same apparatus described above; see Figure 4. 3. Upon reaching temperature equilibrium, the films were given a graded series of electronic flash exposures through a special step wedge in contact with each film type. A similar exposure series was applied to other film samples in the same apparatus but at room temperature without liquid nitrogen. These films were then processed together, and the densities of the low temperature exposed films were compared with the room temperature exposed films. The resulting densities are plotted as a function of log relative exposure in Figures 4. 4 and 4. 5 and clearly show that the low temperature affects the formation of the latent image. The Royal-X Pan film shows a loss in speed, a pronounced loss in maximum density, and a low gamma. The color film curves show a maximum loss in speed approaching 50 times for the red sensitive layer and only a moderate speed loss for the blue sensitive layer. This substantiates studies made by Eastman Kodak in which dye sensitization is much less effective at extremely low temperatures than at room temperature.[24]

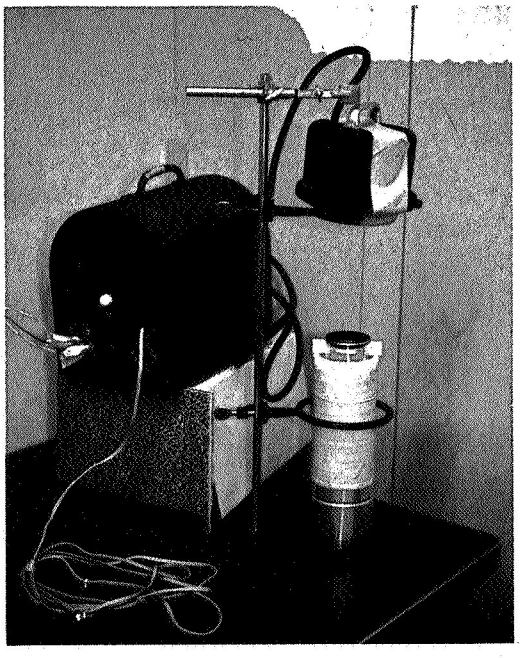


Figure 4. 3 General Radio Type 1532-B Strobolume positioned for white light experiments.

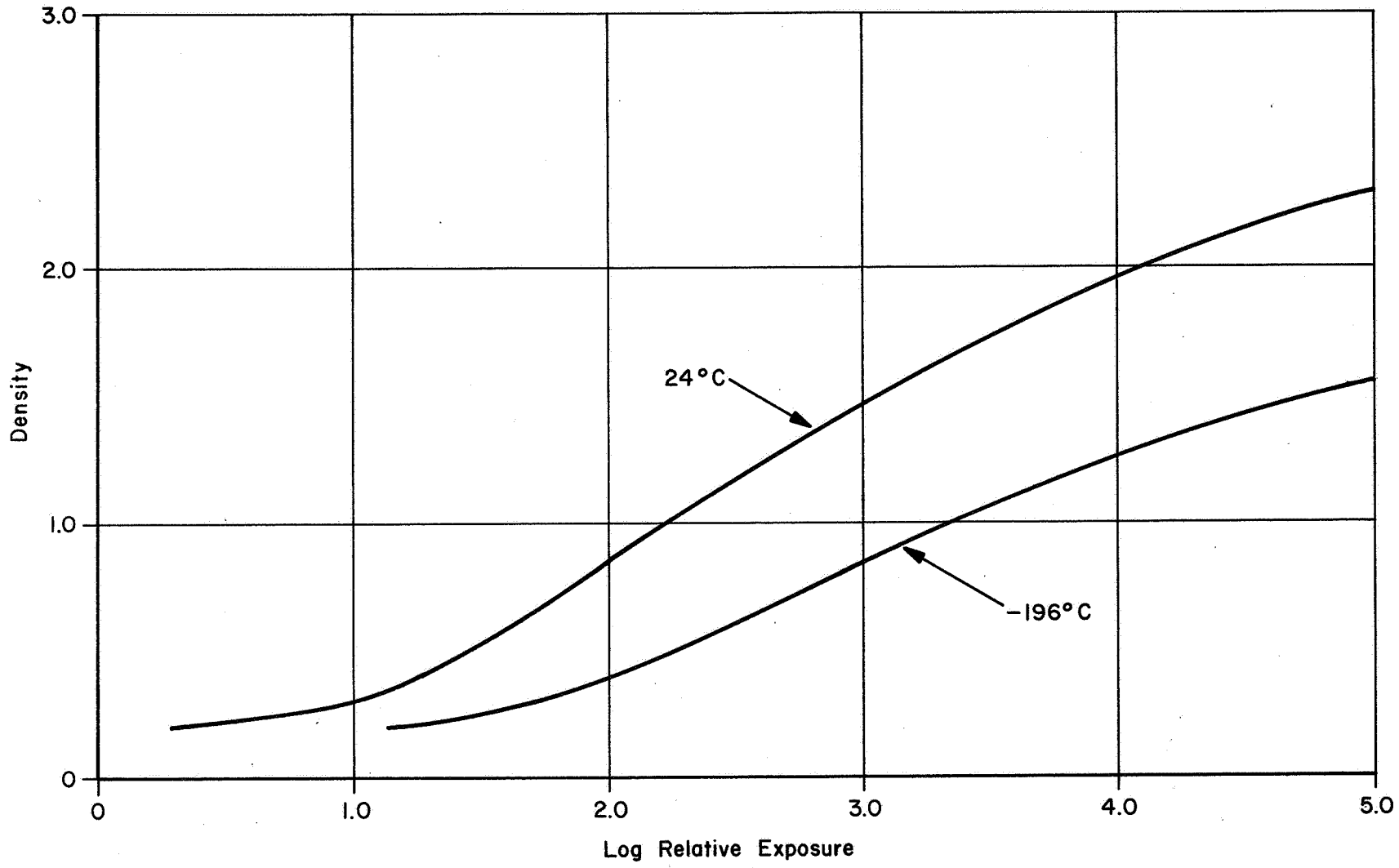


Figure 4.4 Comparison of white light sensitometric exposures applied to Royal-X Pan film at room and liquid nitrogen temperatures.

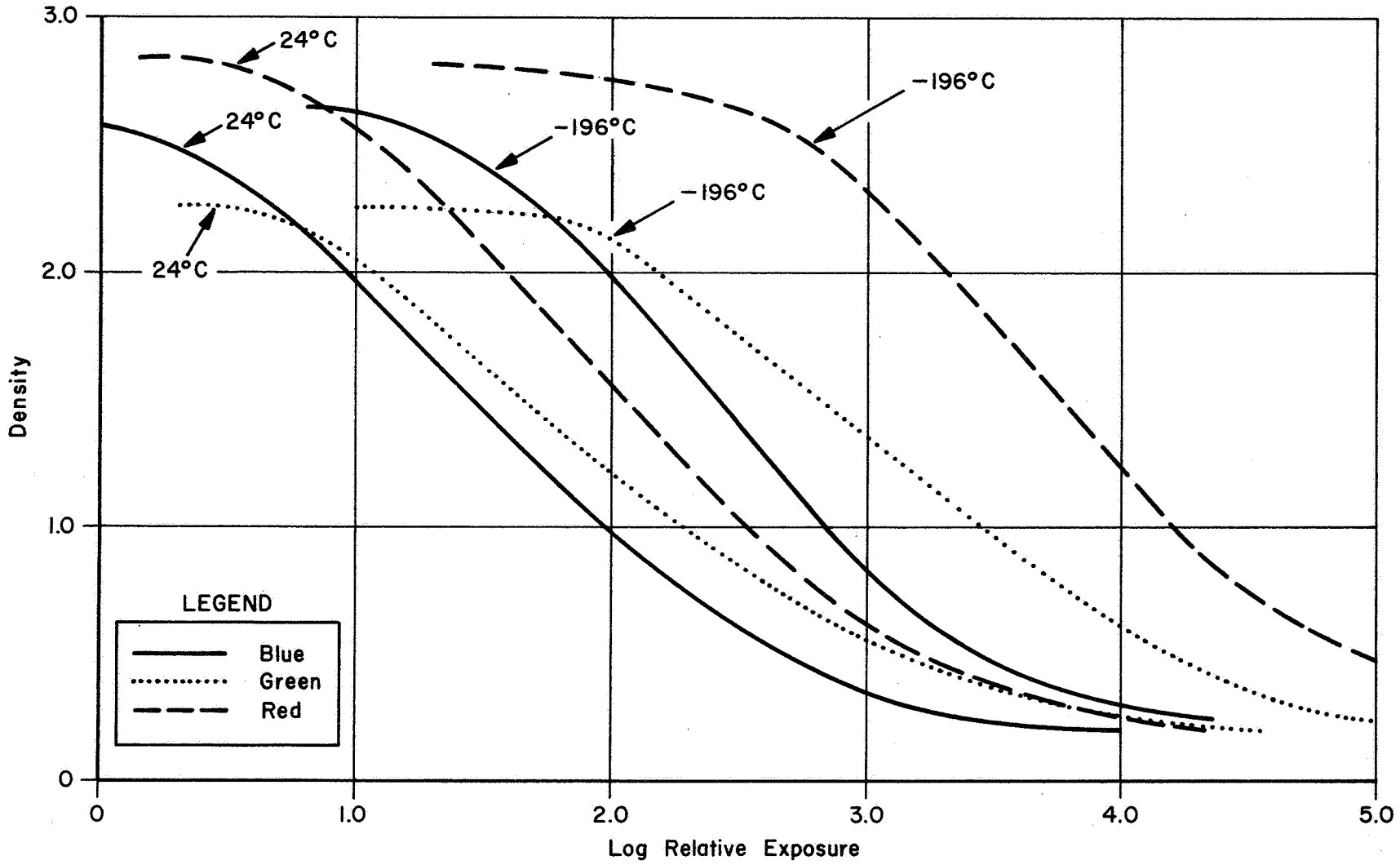


Figure 4.5 Comparison of white light sensitometric exposures applied to Ektachrome Daylight ER at room and liquid nitrogen temperatures.

4.4 RADIATION EXPERIMENTS

The investigation of radiation effects on the lunar film was conducted in two broad areas: shielding considerations and radiation-hardening techniques.

4.4.1 Shielding Considerations. Table 4.1 presents radiation dose data which was obtained from Robbins for the Apollo Mission.[16] Unfortunately, the maximum possible radiation hazard could occur at a time when the film would be least protected; i.e., during solar flare activity, at which time highly energetic protons (possibly up to one Bev) could be expected.

The shielding requirement is 6 and 15 gm/cm^2 for a 92 percent probability that the film will receive 4.0 and 0.5 rad, which is the radiation dose absorbed in human tissue.[25] Since the film must be housed in a canister, cassette, magazine, or similar device in or on the camera, the proper selection of a fabrication material could be a major factor in reducing the radiation level at the film.

Table 4.2 lists the required thicknesses of various structural materials to provide the reduction of possible solar flare radiation doses to the 4.0 and 0.5 rad level.

Tungsten would appear to be a logical choice for the 6 gm/cm^2 shielding requirement of 4.0 rad at the film, on the basis of thickness requirement and structural integrity. Steel could also be utilized in the event tungsten is otherwise unsatisfactory. The severe shielding requirement of 15 gm/cm^2 to reduce the dose at the film to 0.5 rad makes it impractical to consider any of the materials with the possible exception of tungsten which would require a thickness of 5/16 inch.

Shielding thicknesses of 10 gm/cm^2 will attenuate the typical flare proton spectrum by approximately two orders of magnitude. The attenuation process could be accomplished in part (see Appendix A) by the (p, xn) nuclear reactions resulting in the production of epithermal neutrons. These energetic neutrons are

TABLE 4.1 SPACE RADIATION DOSES, APOLLO MISSION

Radiation Source	Free Space Total Skin Dose	Probability Of Occurrence (percent)	Remarks
Cosmic (Galactic protons)	0.1 to 0.3 r/week	100	
Geomagnetically trapped radiation (Electrons and protons)	2 to 10 r/mission	100	"Van Allen Belts"
Solar flare eruptions (Protons and alphas)	≃100 r skin dose in LEM ≃67 r in command module $>10^4$ r "shirt sleeve" exposure	0.1	Dose rate peaks about 20 hours after onset of particles. For $<5 \times 10^8$ particles/cm^2/event, no significant alpha dose; for $<5 \times 10^8$ particles/cm^2/event, dose contribution from several hundred Mev alphas is significant.

TABLE 4.2 SHIELDING-THICKNESS REQUIREMENTS

Structural Material	ρ (gms/cm^3)	Shield Thickness 6 gms/cm^2 (cm)	(in)	Shield Thickness 15 gms/cm^2 (cm)	(in)
Be	1.84	3.26	1.29	8.17	3.22
Mg	1.7	3.52	1.40	8.80	3.50
Al	2.7	2.22	0.87	5.54	2.18
Ti	4.5	1.34	0.53	3.34	1.31
Mn	7.4	0.81	0.32	2.03	0.79
Fe	7.8	0.86	0.30	2.14	0.75
Cd	8.7	0.69	0.27	1.72	0.64
Pb	11.0	0.54	0.21	1.35	0.52
W	19.0	0.32	0.12	0.79	0.31

not as effectively shielded using proton absorber materials, suggesting that a composite shielding structure may be necessary. One such combination would be a layer of tungsten to absorb protons, a layer of iron to absorb and moderate fast neutrons, a layer of hydrogenous material to absorb and attenuate slow neutrons, and a second layer of tungsten to attenuate recoil gammas produced in the collisions of neutrons and protons with nuclei of iron and hydrogen.

An experimental determination to indicate the possible extent of fogging caused by neutrons and recoil gammas under various shielding conditions was performed, using the EG&G Linear Accelerator (LINAC). The 18 Mev electron beam from the LINAC produces 3.5×10^3 neutrons per square centimeter per pulse > 3 Mev. A total irradiation time of 10^5 pulses (about 1 microsecond duty cycle per pulse) produces a neutron flux roughly approximating a "worst case" condition of neutron production in the outer proton shielding material. Table 4.3 lists eight shield conditions which have been evaluated in this

TABLE 4.3 TEST CONDITIONS FOR NEUTRON-SHIELDING INVESTIGATION

Test Condition	Shield A (cm Fe)	Shield B (cm H)	Shield C (in. Pb)
1	0	0	0
2	0	0	2
3	0	3.8	2
4	5.1	1.3	2
5	5.1	3.8	2
6	5.1	3.8	0
7	1.3	3.8	2
8	5.1	0	2

neutron flux, Table 4.4 lists the LINAC flux parameters, and Figure 4.6 schematically presents the geometrical configuration of the test setup. Four emulsion types were studied in this experiment: Royal-X Pan (RXP), Plus-X (PX), Kodachrome II (KDII), and Extended Range (XR). Table 4.5 presents the data obtained for these emulsion types and various test conditions.

From this data, it appears that an optimum film-shielding configuration may exist. For example, test condition 4 indicates the least film density due to irradiation, but the amount of shielding is not maximum under this test condition. Therefore, a more detailed experimental-shielding study is required to fully determine the optimum shielding configuration which will result in a favorable balance between neutron and recoil gamma production.

4.4.2 Radiation Hardening Techniques. Aside from direct shielding, the most probable method for reducing the effects of radiation on photographic emulsions consist primarily of desensitizing the emulsion. A truly radiation-hardened film does not exist, but techniques have been suggested for temporarily desensitizing an emulsion to both light and radiation. Thus,

TABLE 4.4 EXPERIMENTAL PARAMETERS FOR PHOTOGRAPHIC EMULSION TEST

Test Condition	Beam Energy (Mev)	Average Target Current (amps)	Pulse Width (μsec)	Rep Rate (pps)	Total Beam Pulses	Integrated Target Current (Coulomb)	S^{32} Neutron Flux Monitor ($n/cm^2 > 3.0$ Mev)
1	18	45×10^{-6}	4.5	180	2×10^5	4.78×10^{-2}	$14.1 \pm 0.02 \times 10^8$
2	18	45×10^{-6}	4.5	180	2×10^5	4.56×10^{-2}	$5.55 \pm 0.02 \times 10^8$
3	18	45×10^{-6}	4.5	180	2×10^5	4.68×10^{-2}	$2.42 \pm 0.02 \times 10^8$
4	18	45×10^{-6}	4.5	180	2×10^5	4.52×10^{-2}	$1.24 \pm 0.05 \times 10^8$
5	18	45×10^{-6}	4.5	180	2.08×10^5	4.62×10^{-2}	$1.5 \pm 0.2 \times 10^8$
6	18	45×10^{-6}	4.5	180	2×10^5	4.54×10^{-2}	$2.5 \pm 0.1 \times 10^8$
7	18	45×10^{-6}	4.5	180	2×10^5	4.56×10^{-2}	$2.0 \pm 0.02 \times 10^8$
8	18	45×10^{-6}	4.5	180	2×10^5	4.65×10^{-2}	$2.12 \pm 0.08 \times 10^8$

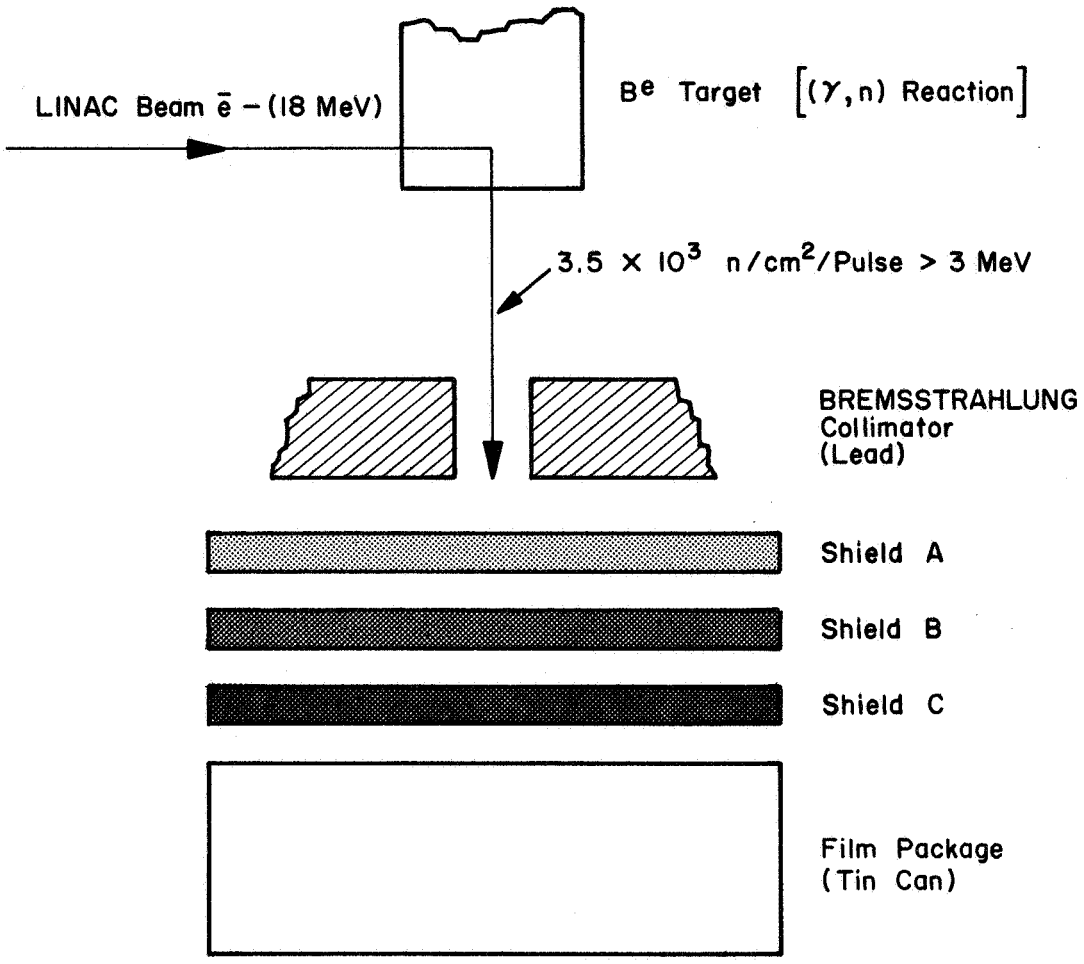


Figure 4.6 Geometric configuration for LINAC shielding investigation.

TABLE 4.5 LINAC EXPERIMENTAL DATA

Test Condition	Net Density RXP	PX	KDII	XR	Neutron Flux Incident On Film Container ($n/cm^2 > 3.0$ Mev)
1	2.06	1.68	3.38	1.60	$14.1 \pm 0.02 \times 10^8$
2	1.48	0.60	0.25	0	$5.55 \pm 0.02 \times 10^8$
3	1.22	0.46	0.08	0.88	$2.42 \pm 0.02 \times 10^8$
4	0.64	0.15	0.02	0.32	$1.24 \pm 0.05 \times 10^8$
5	0.98	0.25	0.04	0.52	$1.50 \pm 0.2 \times 10^8$
6	1.66	1.33	0.91	1.21	$2.50 \pm 0.1 \times 10^8$
7	0.92	0.87	0.15	0.60	$2.00 \pm 0.02 \times 10^8$
8	0.92	0.25	0.04	0.52	$2.12 \pm 0.08 \times 10^8$

while the film is being stored, it might be possible to "de-activate" it until the desired exposure is to be made. The film would then be processed immediately or returned once again to a desensitized state which would not degrade the latent image.

4.4.2.1 Cryogenic Desensitization. As mentioned in Section 4.3, desensitization to white light when a photographic emulsion is exposed at reduced temperatures has been observed.[14] To determine experimentally the corresponding desensitization at low temperatures of emulsions to nuclear radiations, several different emulsion types were exposed, while immersed in a cryostat, to the radiations from an appropriate radioactive source. After processing, the densities of the films at various exposure levels, when compared to identical films at room temperature, provided a measure of the temperature effect.

The four films irradiated for study in this first experiment were Royal-X Pan (RXP), Royal Pan (RP), Ektachrome Daylight ER (EDER), and Extended Range (XR). White light D-log E curves were obtained from control films processed simultaneously with the data films.

Although a proton source would best simulate the major component of the lunar radiation environment, the inherent difficulties in procuring and using such a source necessitated the selection of a more readily available type of radiation. Since the radiation would be required to pass through a depth of liquid nitrogen much greater than the mean-free-path of any readily available isotope emitting charged nuclear particle radiation, a gamma source was selected. Hard gammas have about the same specific ionization as high energy protons; for example, Co^{60} gamma specific ionization is 1.4, and 340 Mev proton specific ionization is 1.6.[26] Thus, substitution of a gamma for a proton source is justified and not detrimental to the experiment.

A 1-millicurie Cs^{137} source was procured after preliminary experimentation with a 9.4-microcurie source indicated that the higher strength source was required to obtain practical exposure periods in liquid nitrogen. The source was sealed in a one-inch diameter, one-quarter inch thick lucite disk by the manufacturer, ISO/SERVE, Inc. Figure 4.7 shows the source in the irradiation fixture. This source was used under AEC By-Product Material License 20-1667-1.

Figure 4.8 is a plot of the dose as a function of exposure for 1 millicurie of Cs^{137} at a distance of 1-1/2 inches. The upper curve gives the dose for the bare sealed source, while the lower curves are for various conditions of attenuation. These dose values were determined from measurements made using a Tracer Lab Model SU-14 GM survey meter.

Figure 4.7 Cs^{137} source in the disassembled irradiation fixture.

In order to achieve a low film temperature, it was desired that the film be irradiated while submerged in liquid nitrogen, but without the requirement of immersing the source. The extreme temperature change could cause the lucite to fracture, allowing the radioactive cesuim-barium mixture to be scattered.

The lens filter adapter, described in the cryogenic experiment, was used to contain the source and to hold the film at a fixed distance of 1-1/2 inches from the source. Figure 4.9 is a side view of this fixture, while Figure 4.7 shows the fixture disassembled but with the source in place. Alligator clips fastened to spacers provided the means of holding the film at a fixed distance from the source.

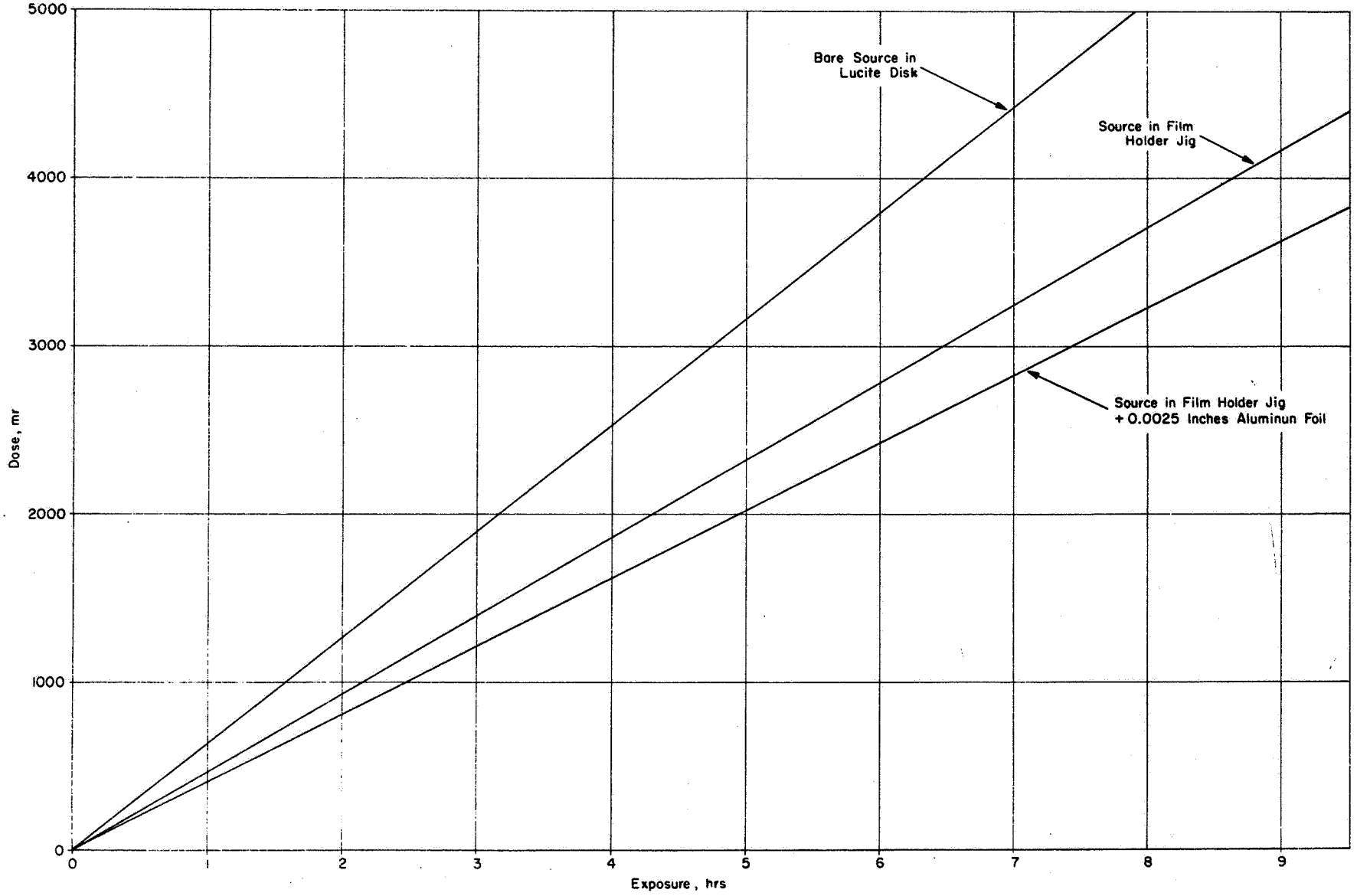


Figure 4.8 Dose versus exposure to a 1.0 millicurie Cs^{137} source at 1.5 inches.

The test pieces of film were wrapped in a 2.5-mil, heavy-duty aluminum foil of the commercially available "quilted" variety. This provided a light-tight seal for the film with a minimum amount of shielding from the Cs^{137} gammas. The foil was sprayed on the inner surfaces with black paint to minimize fogging from scattered light which must pass the triple folds. Figure 4.10 is a top view of the irradiation fixture with the wrapped film "package" in place.

In use, the irradiation fixture, with the film in place, sits on the rim of a conventional thermos-bottle insert filled to the brim with liquid nitrogen as shown in Figures 4.11 and 4.12. The depth of liquid nitrogen above the film package was adjusted to one-half inch maximum and dropped to zero in approximately 15 minutes owing to boil-off. A manual refill procedure was followed and found to be satisfactory for this short-term program.

A number of data points at different dose levels were obtained for liquid nitrogen and room temperatures. The films were processed by standard procedures with control scales to facilitate normalization of the curve slope or processing gamma. Table 4.6 lists the pertinent processing data for each emulsion type.

The small film sizes of 1-1/2 x 1 inches necessitated that development be done in test tubes. Violent agitation assured uniform development, allowed fresh batches to be used economically, and provided for better control of uniformity.

An estimate of the dose received by the films was made using the data shown in Figure 4.8, the attenuation factors for liquid nitrogen, and the sensitivity of the different emulsions.

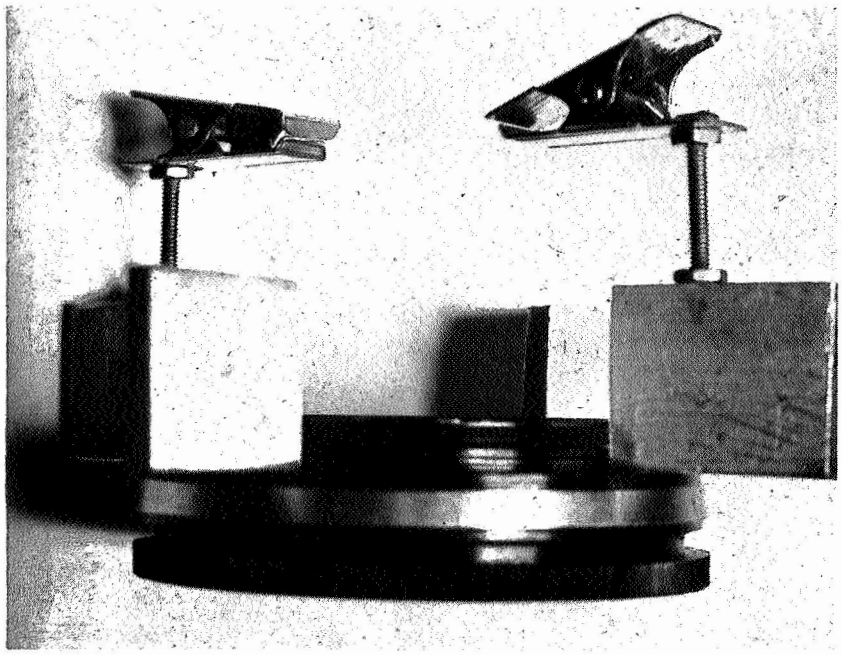


Figure 4. 9 Side view of irradiation fixture.

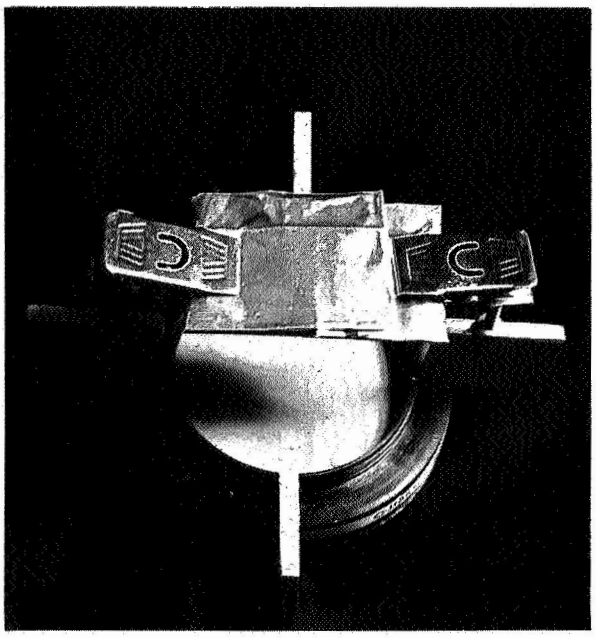


Figure 4. 10 Top view of irradiation fixture with "film package" in place.

Figure 4.11 Irradiation fixture, with film in place on thermos insert filled with liquid nitrogen.

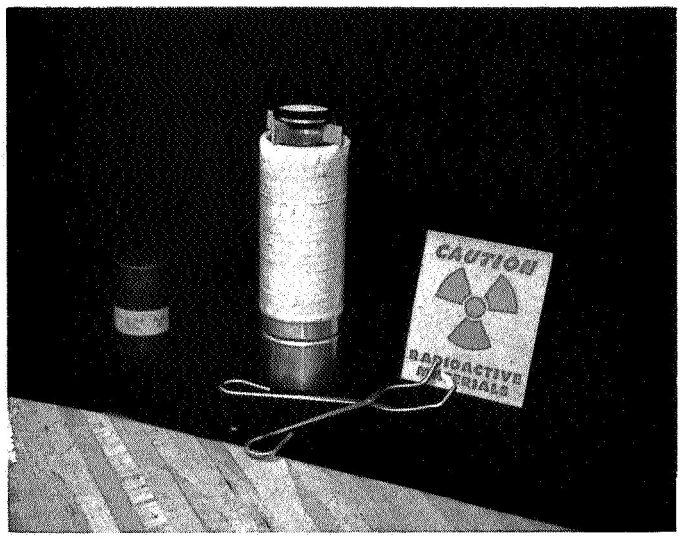


Figure 4.12 Irradiation fixture in use: Cs^{137} storage pig, left; thermos insert (filled with liquid nitrogen) with irradiation filter in place, center; and source handling tongs.

TABLE 4.6 PROCESSING DATA

Emulsion Type	Developer	Development Time (min)	Development Temp. (^{o}F)	Processing Gamma	Sensitometer Exposure Time (seconds)
RXP	DK-50	8	75	1.0	10^{-4}
RP	DK-50	6	75	0.8	10^{-4}
EDER	E-3	10	75	1.5 (max)	10^{-4}
XR	C-22	14	75	0.7 (max)	10^{-4}

The liquid nitrogen attenuation factor is determined in the following manner. If the maximum depth of liquid nitrogen equals 1/2 inch and the density of liquid nitrogen equals 0.8 gm/cm^3, then the liquid nitrogen mass absorption coefficient (μ/ρ) for Cs^{137} gamma (667 kev) equals 7.5×10^{-2} cm^2/gm. The transmission of 667-kev gamma equals I/I_o, where I is intensity of the gamma after passage through liquid nitrogen, and I_o is the initial intensity.

$$I/I_o = \exp\left[-(\mu/\rho) \cdot \rho \cdot x\right]$$

where

μ/ρ is the mass absorption coefficient,

ρ is the density of the medium, and

x is the path length through the medium.

Substituting,

$$I/I_o = \exp\left(-7.5 \times 10^{-2} \times 8 \times 10^{-1} \times 1\right)$$

$$\ln I/I_o = -6 \times 10^{-2}$$

$$I/I_o = 0.94$$

$$= 94 \text{ percent}$$

Since the average depth will be closer to 1/4 inch because of liquid nitrogen boil-off, it will be unnecessary to correct this insignificant attenuation.

The four films under investigation were stacked from top to bottom in each aluminum-foil packet: RXP on Top, RP below RXP, EDER below RP, and XR film on the bottom. A measurement of the relative transmission of Cs^{137} gammas through these emulsions was made using the average of readings from the Tracer Lab SU-14 survey meter and a Nuclear-Chicago Cutie-Pie survey meter. Table 4.7 supplies the necessary film dose correction factors determined from the measurement.

TABLE 4.7 FILM DOSE CORRECTION FACTORS

Emulsion Types	Relative Attenuation
RXP	1.0
RP	0.77
EDER	0.62
XR	0.51

(Note that the aluminum-foil correction factor is included in the bottom curve of Figure 4.8.)

Figures 4.13, 4.14, 4.15, and 4.16 present the Cs^{137} irradiation data for the four emulsion types. A decrease in sensitivity of one order of magnitude is observed for RXP at exposure levels in excess of 500 mr. The

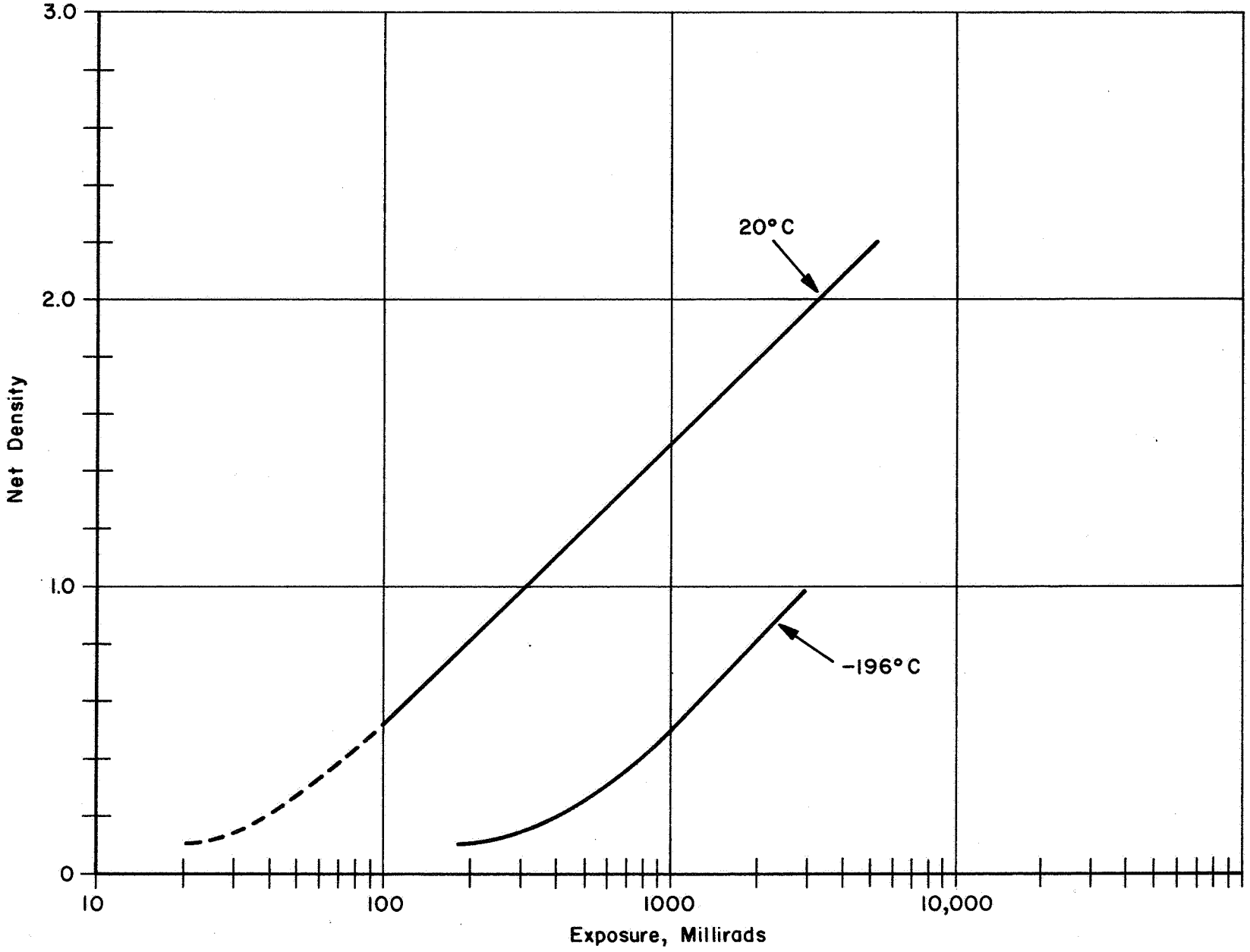


Figure 4.13 Comparison of C_s^{137} sensitometric exposures applied to Royal-X Pan film at room and liquid nitrogen temperatures.

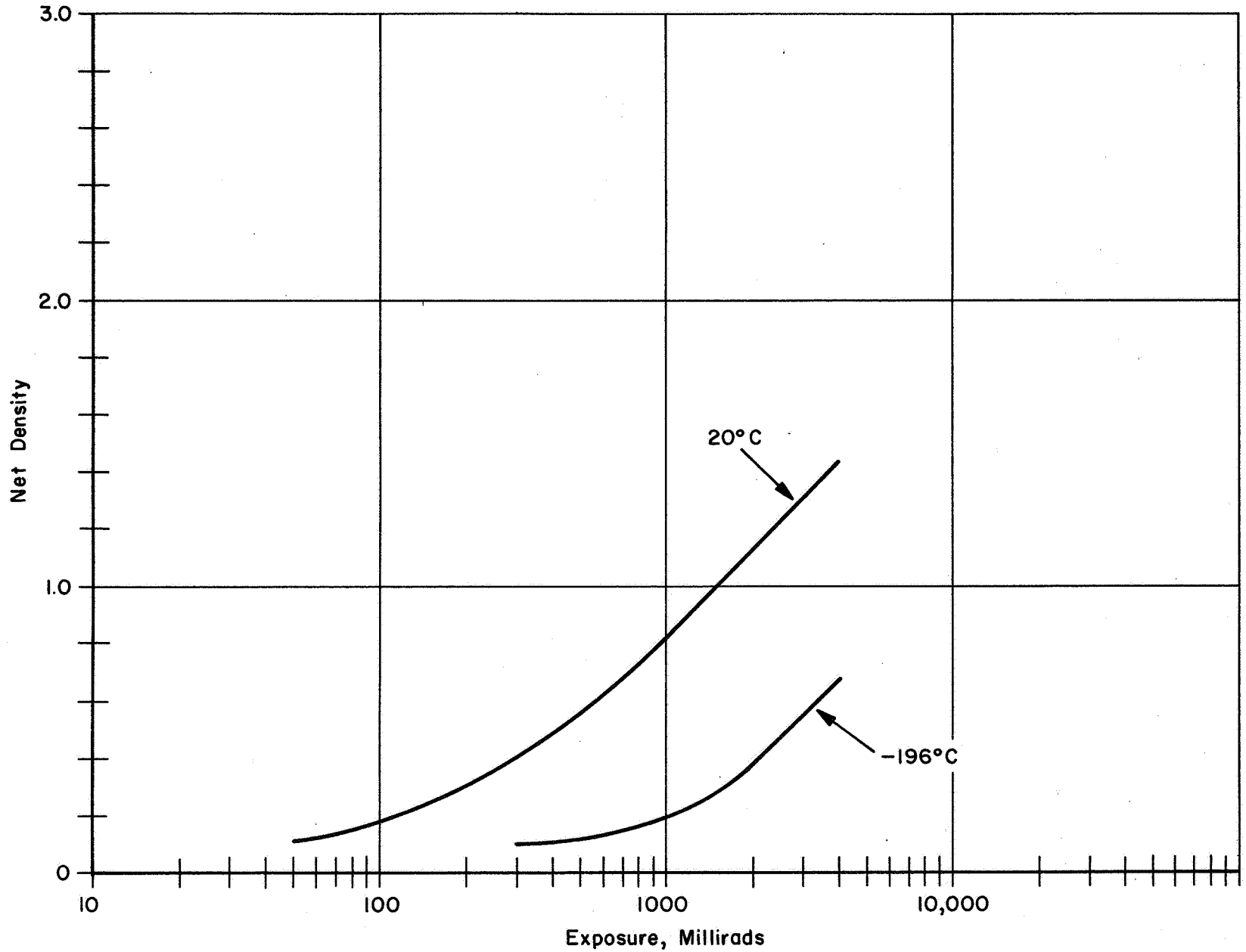


Figure 4.14 Comparison of C_s^{137} sensitometric exposures applied to Royal Pan film at room and liquid nitrogen temperatures.

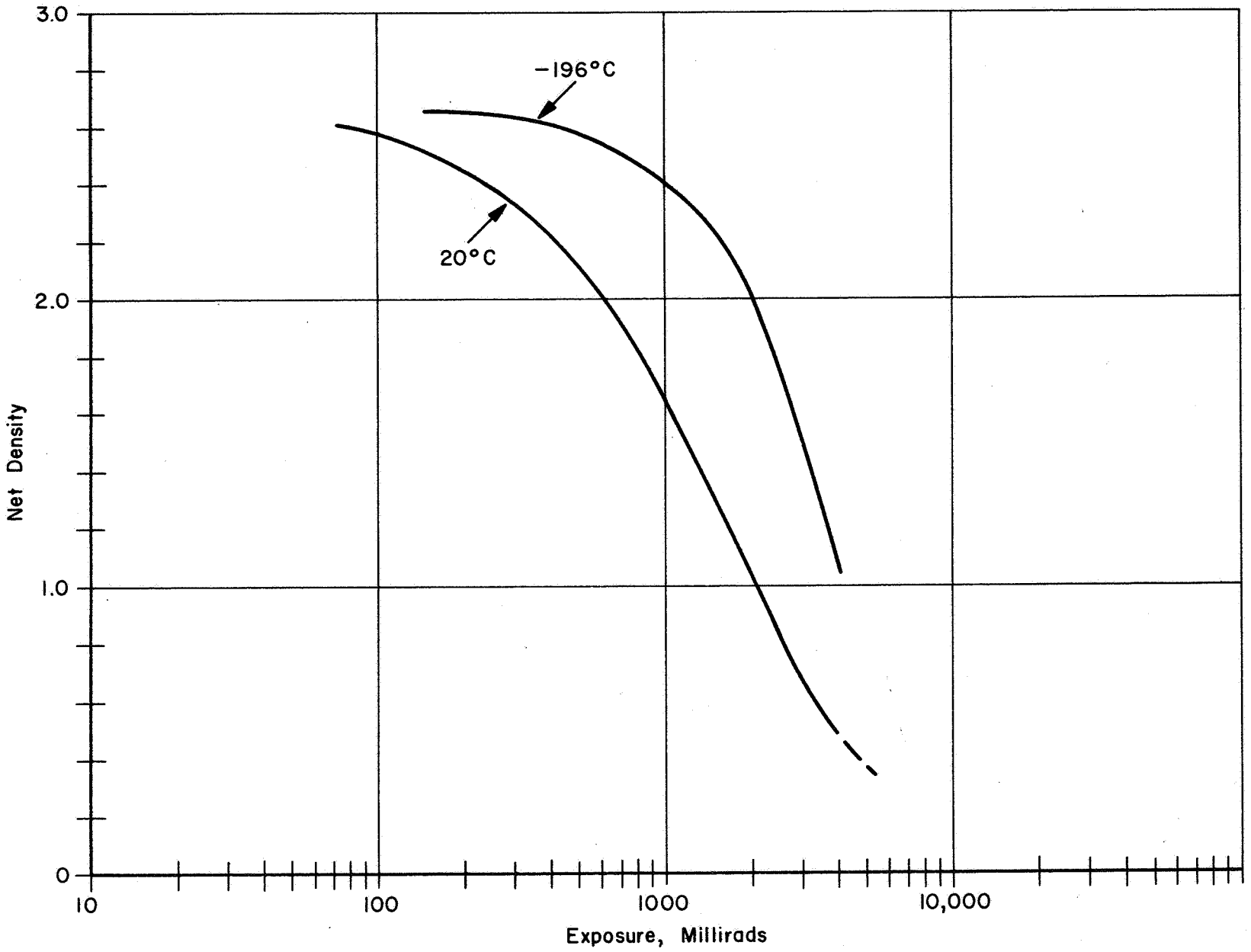


Figure 4.15 Comparison of Cs^{137} sensitometric exposures applied to blue sensitive layer of Ektachrome Daylight ER.

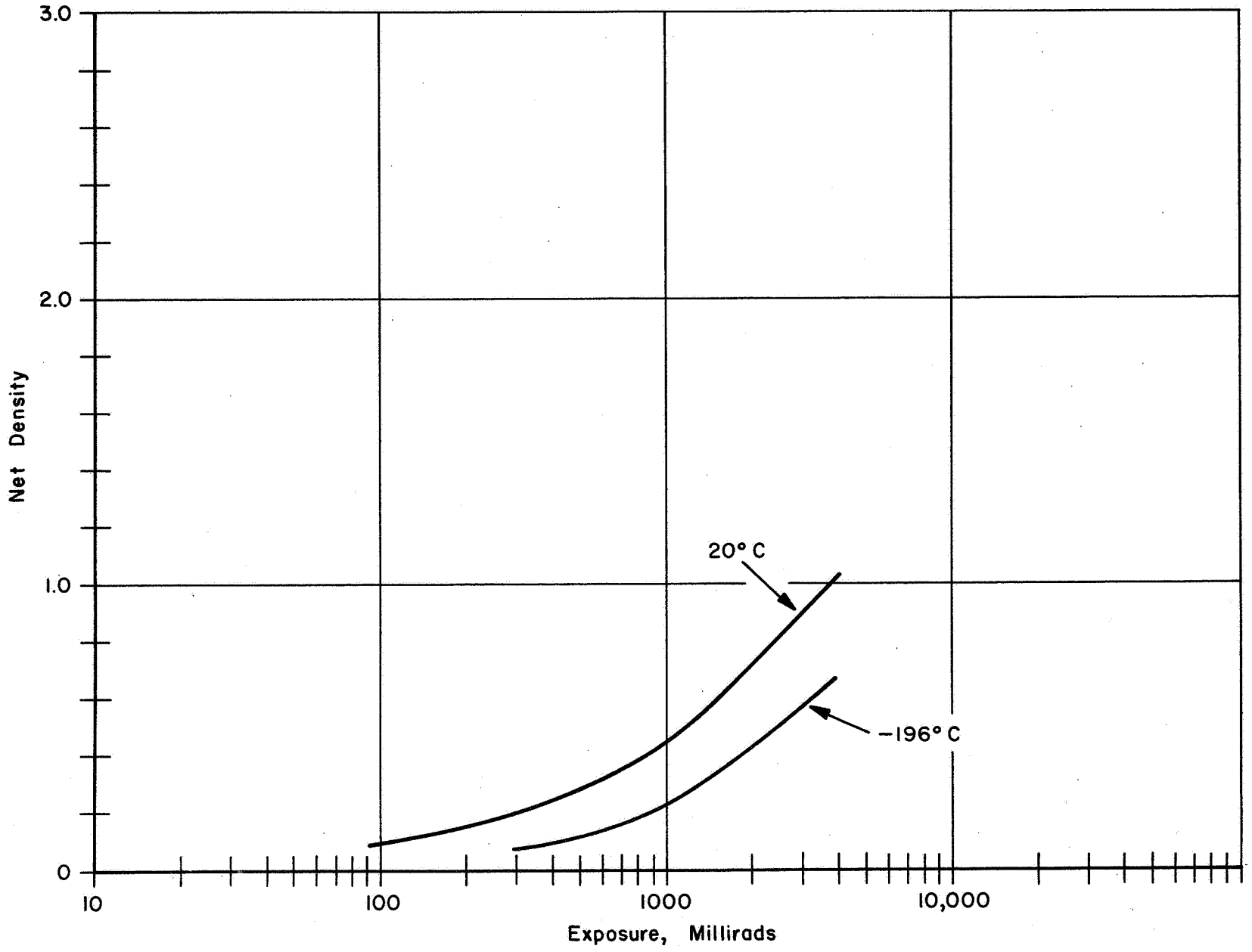


Figure 4.16 Comparison of C_s^{137} sensitometric exposures applied to fast layer of XR film at room and liquid nitrogen temperatures.

high speed layer of XR only experienced a decrease in sensitivity by a factor of 2-1/2, and the blue sensitive layer of EDER was desensitized by a factor of four at exposure levels between 500 and 2000 mr.

Although the degree of gamma desensitization is disappointingly small in relation to the white light desensitization, the experimental data did reveal useful information regarding the overall desensitization characteristics of emulsions with silver bromide crystals.

Referring to Figures 4.13, 4.14, 4.15, and 4.16 again, it is noted that gamma desensitization factors of approximately 10 for RXP, 5 for RP, 2-1/2 for XR, and 4 for EDER were obtained. From these data, it is suggested that "radiation-hardening" might be effectively attained in a photographic film by storing the film at very low temperatures when not in use. If films with a high photographic speed are necessary for the lunar film, low temperature storage and shielding would appear to be an effective way to protect the film in the event solar flare activity presents a radiation damage hazard.

An understanding of the correlation of this desensitization factor with some emulsion characteristic could be useful in the design of the lunar emulsion. The most obvious starting point would be the geometric characteristics of the silver halide crystals. The four emulsions were studied microscopically to determine grain geometries and concentrations. A Unitron BN-13 microscope was used to photograph the undeveloped emulsions.

A sample of each film was obtained and the emulsion softened in warm water. A part of the emulsion was carefully scraped and smeared onto a microscope slide. A photograph of the smear at 800X magnification yielded crystal images of measureable dimensions. For each film sample the average diameters of fifty silver halide crystals were obtained. From the data mean diameters, mean cross-sections, and mean volumes of the crystals were obtained through appropriate computations for each of the film types. Results of the calculations are summarized in Table 4.8.

TABLE 4.8 SILVER HALIDE CRYSTAL GEOMETRIC CHARACTERISTICS

Film	Mean Diameter (microns)	Mean Cross-Section (square microns)	Mean Volume (cubic microns)	Standard Deviation On Diameters (microns)
XR_1	1.12	1.54	2.42	0.85
XR_2	1.31	1.88	2.96	0.83
EDER	1.06	1.30	1.75	0.73
RP	0.98	1.07	1.31	0.65
RXP	1.73	2.99	4.96	0.91

It was assumed for ease of computation that crystal shapes were spherical; then the following formulas apply:

$$\text{Mean diameter} = \bar{d} = \bar{d}$$

$$\text{Mean cross-section} = \bar{a} = \frac{\pi}{4}\,\overline{d^2}$$

$$\text{Mean volume} = \bar{V} = \frac{\pi}{6}\,\overline{d^3}$$

$$\text{Standard deviation of diameters} = \sigma(d) = \left[\overline{d^2} - (\bar{d})^2\right]^{1/2}$$

Bars denote averages or expectations of the quantities involved; thus, $\bar{d}$ is the average of fifty samples of crystal diameter. $\overline{d^2}$ is found by squaring each sample diameter and averaging the squares. Similarly, $\overline{d^3}$ is an average of the cube of each sample diameter. The factors $\frac{\pi}{4}$ and $\frac{\pi}{6}$ are present because of the assumption of spherical crystal shapes; i.e., the cross-section

of a sphere is $\pi r^2 = \frac{\pi}{4} d^2$, and the volume of a sphere is $\frac{4}{3} \pi r^3 = \frac{\pi}{6} d^3$. It is significant that the averages described above amount to (a) calculating a set of sample cross-sections and averaging to obtain mean cross-section, and (b) calculating a set of sample volumes and averaging to obtain mean volume. This is done to avoid large errors inherent when inserting the average diameter $\bar{d}$ into the formulas: $\alpha = \frac{\pi}{4} d^2$ and $V = \frac{\pi}{6} d^3$. The standard deviation, $\sigma(x)$, is defined as the square root of the variance and may be expressed as

$$\sigma^2(x) = E\left[(x - \bar{x})^2\right]$$ where E stands for the averaging operation.

Thus, $$\sigma^2(x) = E\left[x^2 - 2x\bar{x} + \bar{x}^2\right] = E(x^2) - 2\bar{x}E(x) + \bar{x}^2$$

and since $$\bar{x} = E(x)$$

$$\sigma^2(x) = E(x^2) - \bar{x}^2$$

or $$\sigma^2(x) = \overline{x^2} - (\bar{x})^2$$

thus $$\sigma(d) = \left[\overline{d^2} - (\bar{d})^2\right]^{1/2}$$

The standard deviation is a measure of the spread of the individual d's about $\bar{d}$.

Two sets of parameters appear for XR film in the table. The row marked XR_1 presents computations from the statistical data as directly recorded. However, the row marked XR_2 is biased by exclusion of crystals with diameters less than 0.5 micron. This was done when it was concluded that grains from other than the top layer in the emulsion of XR may have been scraped into the sample. The grains in the lower layers are, in general, finer than grains in the top layer, which is the most sensitive layer and the layer of primary interest. Since the distinction between the XR_1 data and the XR_2 data is arbitrary, both sets are included in Table 4.8 and in Figures 4.17, 4.18, and 4.19. Together they serve only to indicate the order of precision of the data at this point.

These graphs present crystal geometric parameters as functions of the desensitization factors previously determined. Figures 4. 20 through 4. 22 present silver halide content of emulsions as functions of the desensitization factor. The quantities of the first three graphs have been described above. Data for the latter three graphs has been taken from Table II of C. E. K. Mees, The Theory of the Photographic Process, New York, Macmillan Company, 1962, page 39. It is assumed that the "protrait film" listed in Mees is similar to Royal Pan film and that the "high speed roll film" is similar to Royal-X Pan film. Silver halide density is obtained from the table through

$$\rho = N_{\rho o} \overline{V}$$

where ρ is the silver halide density in the emulsion in grains per cubic centimeter, N is the number per cubic centimeter of halide crystals, and $\overline{V}$ is the mean volume of halide crystals given by

$$\overline{V} = \frac{4}{3} \frac{1}{\sigma\pi} (\overline{\alpha})^{312} .$$

The table in Mees presents N and $\overline{\alpha}$. Although the table in Mees does not give data on XR or EDER film, estimates for silver halide density were made by examining samples of developed emulsions. The number of developed grains per cubic centimeter was taken for N, while $\overline{V}$ was obtained from the study of crystal geometric sizes.

Figure 4. 20 presents silver halide density per square centimeter of emulsion area which was obtained by multiplying the silver halide density by the emulsion thickness. Thicknesses were taken to be as follows: 3 microns for XR top layer; 5 microns for EDER blue layer; 8 microns for RP, and 15 microns for RXP. Figure 4. 21 presents the normalized silver halide density obtained by dividing the silver halide volume density by the emulsion thickness. Figure 4. 22 presents silver halide density in grams per cubic centimeter as a function of desensitization factor for the four emulsions.

Upon examination of Figures 4. 17 through 4. 22, it is not readily apparent how to draw continuous curves connecting the points. However, the purpose of the data at this time is not to arrive at precise dependencies of desensitization upon emulsion properties, but to show where such functions might or might not exist. It would be the aim of further study to extract the most significant correlations among properties.

With this in mind, Figures 4. 17 through 4. 19 tend to indicate a lower desensitization factor with finer halide grains. Whether a minimum should be present is not significantly indicated by the graphs. Figure 4. 20 tends to show a lower desensitization factor with less silver halide per square centimeter of emulsion area. Figure 4. 21 may indicate a lower desensitization factor with an emulsion of high density per unit emulsion thickness. The spread of points in Figure 4. 22 remain too large to indicate any trends. It might be noted that dense but thin emulsions are composed of fine silver halide grains. Thus, the data does move in a specific direction, which should be a basis for further study.

4. 4. 2. 2 Erasure of Radiation Fog by Hydrogen Peroxide. This investigation was prompted by an experiment which described a procedure for the erasure of latent images caused by alpha tracks in nuclear emulsions. The chemical reaction of the technique involves the oxidation of the silver latent image by hydrogen peroxide:

$$2Ag^{o} + H_2O_2 + 2H^{+} \rightarrow 2Ag^{+}\ 2H_2O\ .$$

A laboratory investigation of the feasibility of using hydrogen peroxide as a means of erasing latent images caused by gamma radiation was conducted. Royal-X Pan film was exposed to gamma radiation from a Cs^{137} source. After processing, the developed density of the irradiated film was 0. 14 above the background level of a control unirradiated film. Another irradiated film was

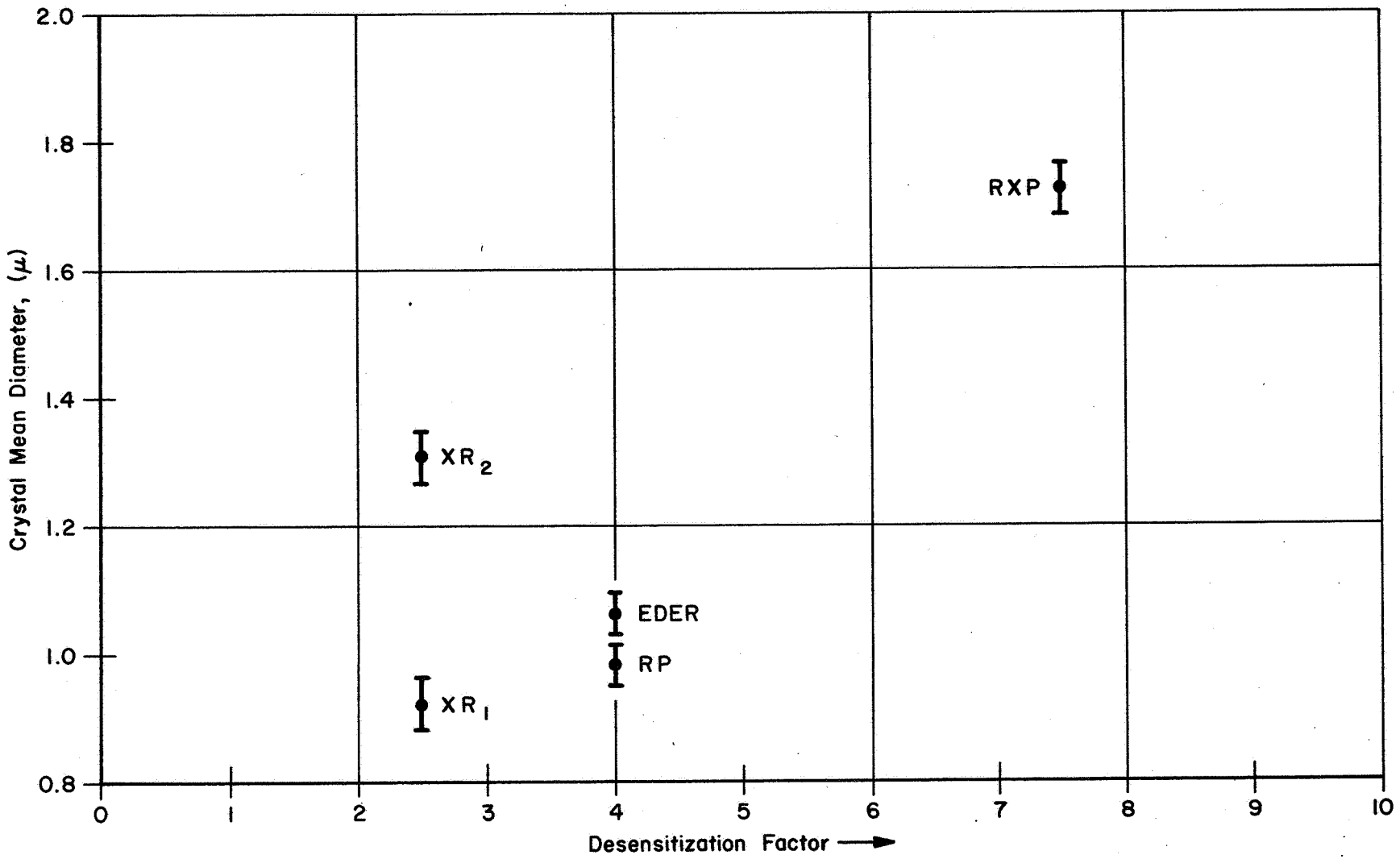


Figure 4.17 Cryogenic desensitization of several photographic emulsions as a function of average grain diameter.

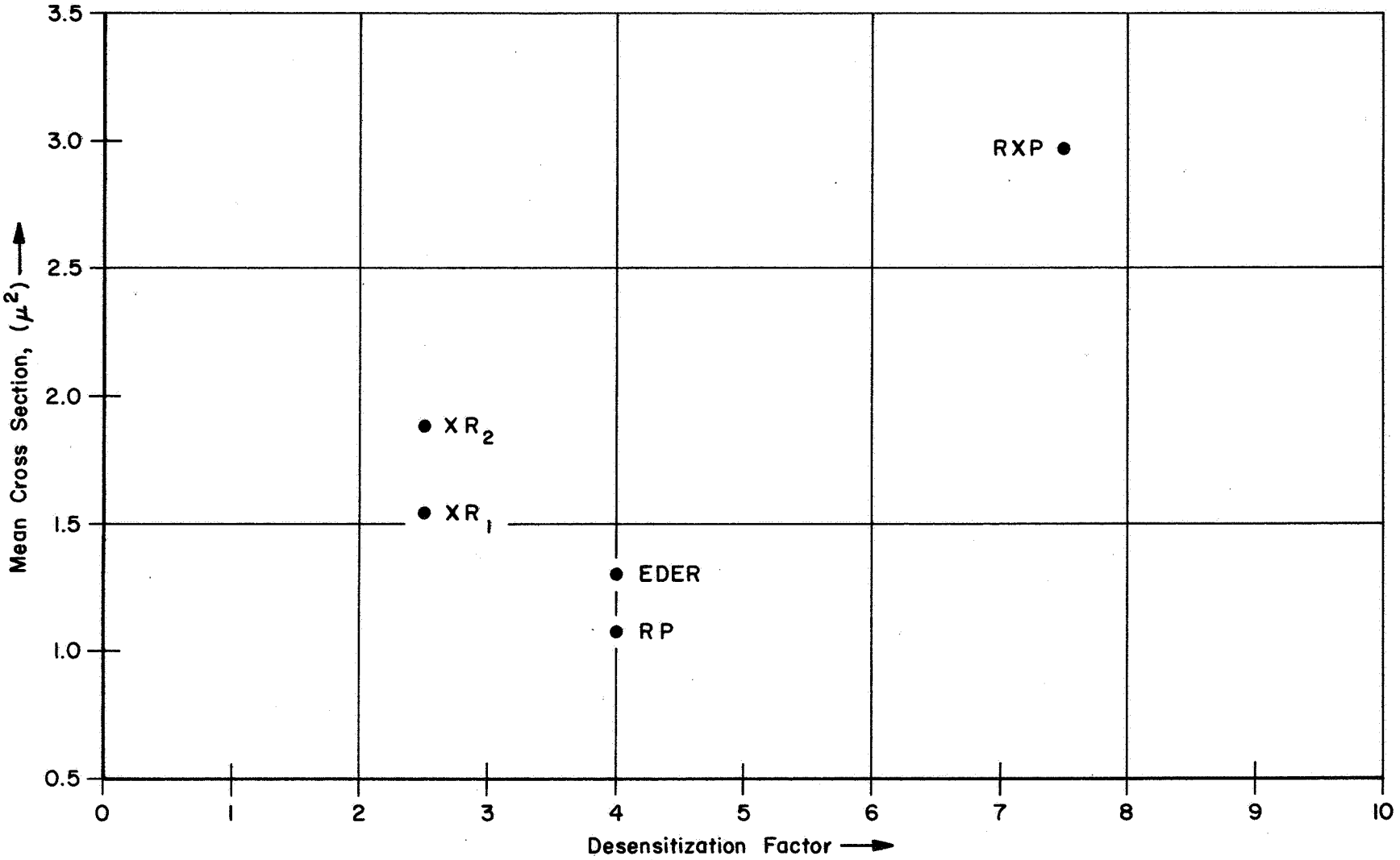


Figure 4.18 Cryogenic desensitization of several photographic emulsions as a function of average grain cross-section.

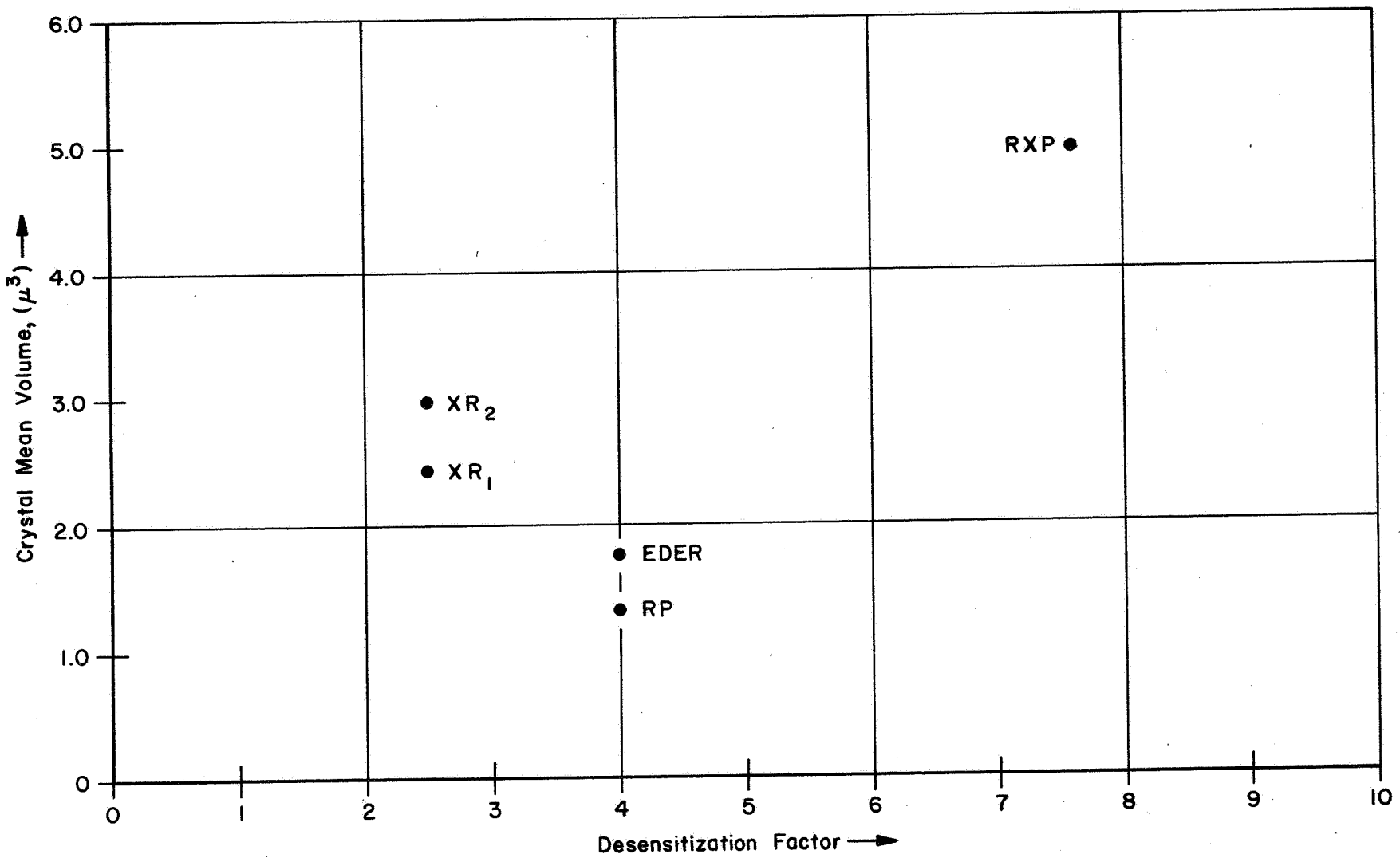


Figure 4.19 Cryogenic desensitization of several photographic emulsions as a function of average grain volume.

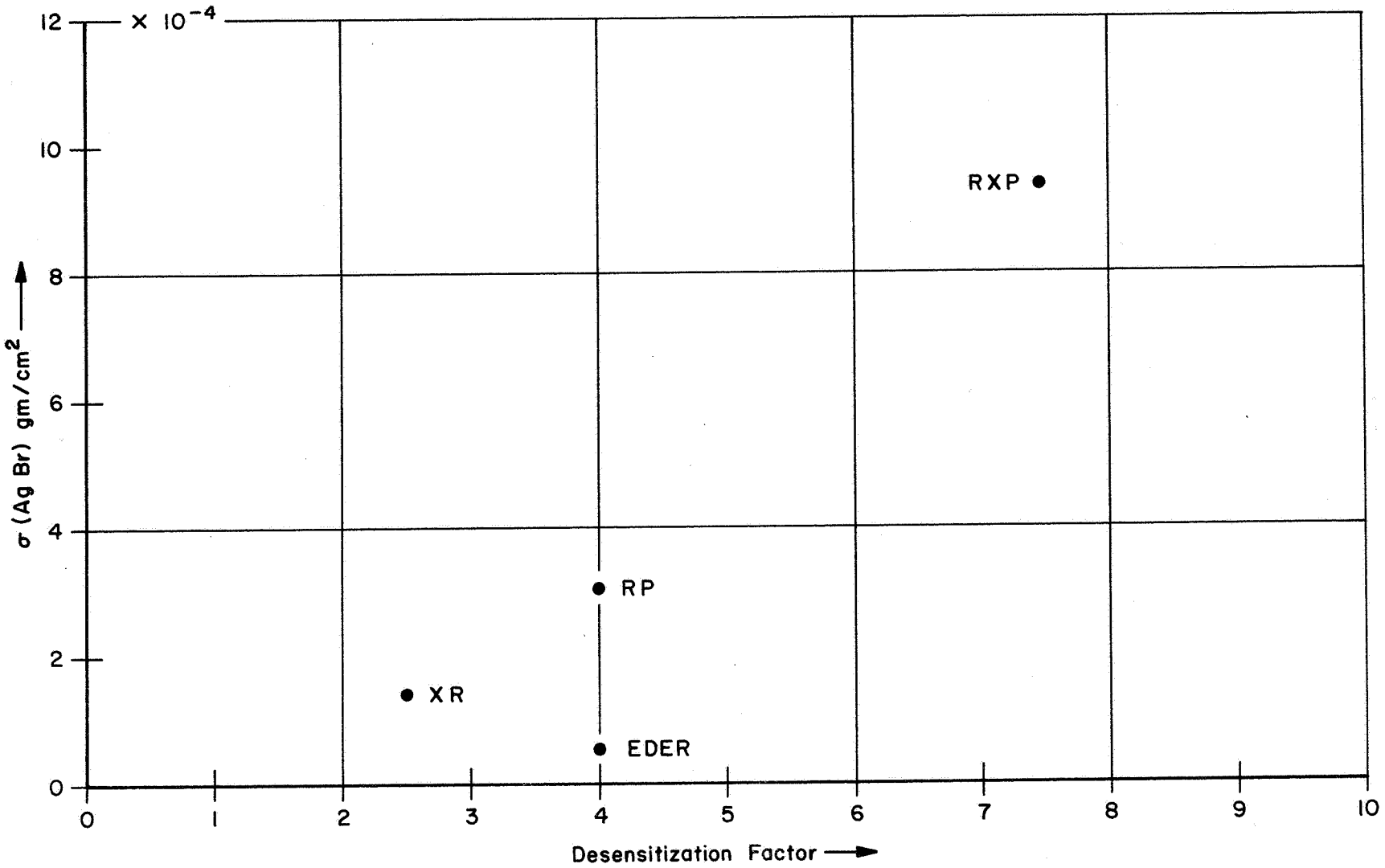


Figure 4. 20 Cryogenic desensitization of several photographic emulsions as a function of grain mass per unit emulsion area.

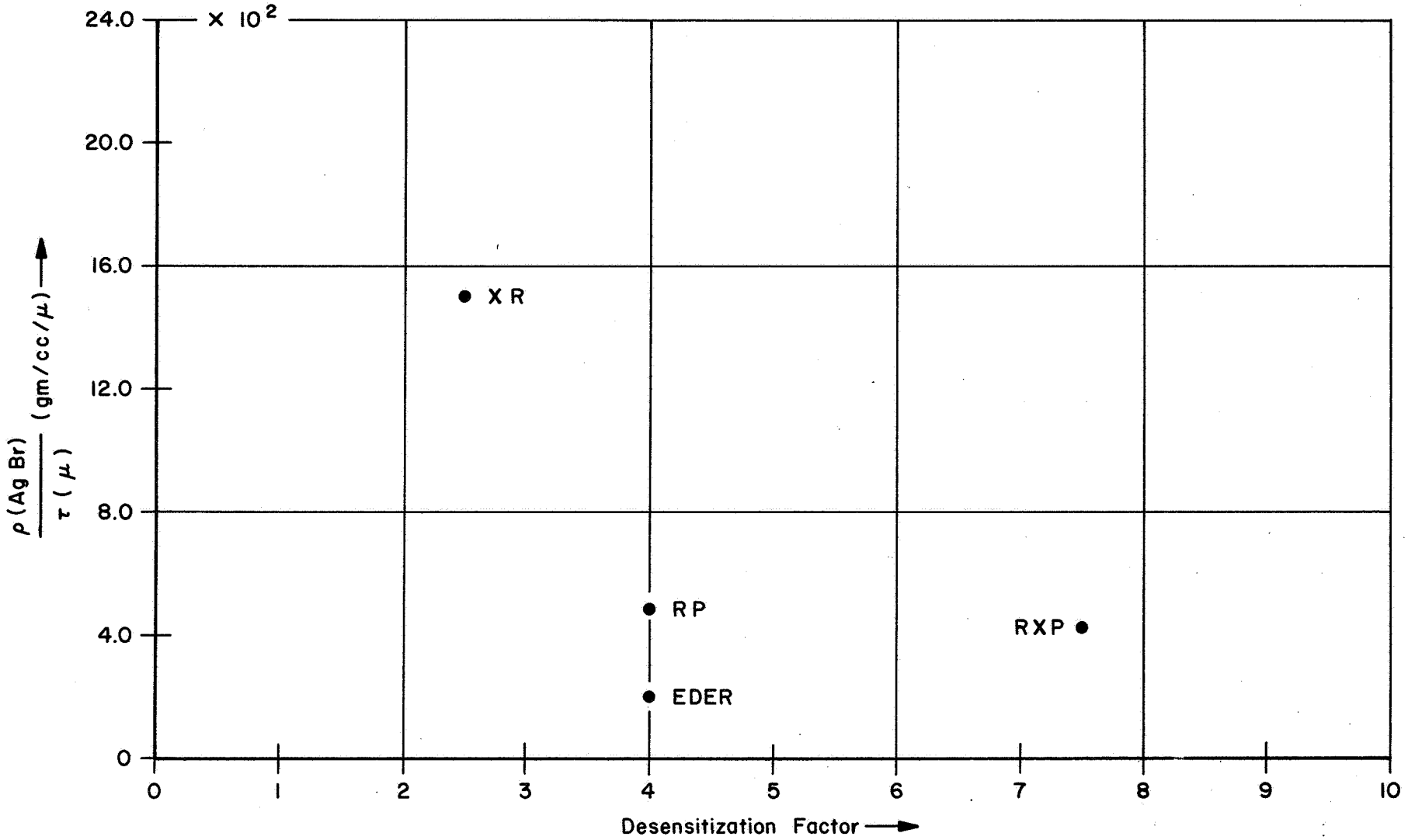


Figure 4. 21 Cryogenic desensitization of several photographic emulsions as a function of grain mass per unit volume per unit emulsion thickness.

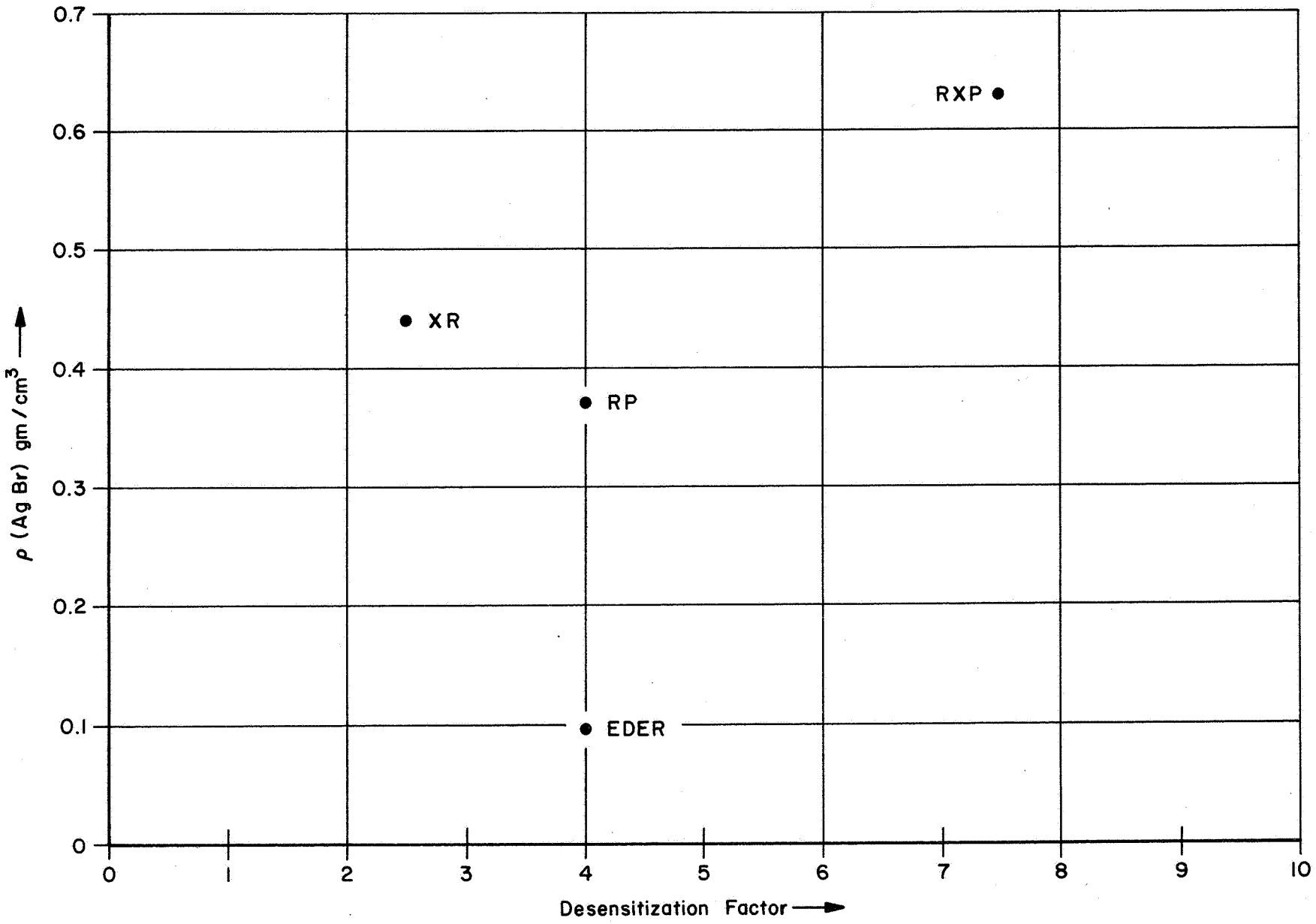


Figure 4.22 Cryogenic desensitization of several photographic emulsions as a function of grain mass per unit volume.

then processed in 3 percent hydrogen peroxide prior to image development. The density of the film increased instead of decreasing as expected. Upon addition of 2 percent potassium bromide to the hydrogen peroxide, the fog due to the gamma radiation could be erased by a ten minute pre-bath before image development.

The experimental results indicate that erasure of latent images caused by nuclear radiation can be carried out by treatment of the films in a hydrogen peroxide-bromide solution. Additional experimentation will be necessary to determine what effect this treatment would have on the subsequent light sensitivity of the film.

4.5 COLOR SEPARATION EXPERIMENT

Numerous attempts have been made to make color photographs by recording the scene through two color filters instead of the commonly accepted three primary colors of blue, green, and red. The latest attempt to record with only two colors was reported by E. H. Land of the Polaroid Corporation.[10] Use of only two instead of the three primary colors would offer advantage of simplicity for a lunar color film if the process could yield a faithful representation of the colors in the original scene. A photographic experiment was, therefore, conducted to determine whether or not a satisfactory color record could be obtained using only two color separation filters.

A color test chart was obtained and a series of exposures was made on 4 x 5-inch panchromatically sensitized Polaroid 3000 film. A range of Wratten color filters was selected which would divide the visible spectrum into pairs. Test exposures were made through these filters so that the scale of neutral grays appeared identical in each picture. The proper pairs of these photographic records were then viewed, in register, through the appropriate color filters to subjectively determine the color fidelity. Wratten filters 38A for the blue-green and 106 for the red-yellow records produced an optimum

spectral color sensation. However, none of the results produced sufficient hue or saturation fidelity to warrant further consideration of two-color separation photography for the Apollo lunar surface photographic mission.

4.6 EXTENDED RANGE FILM EXPERIMENTS

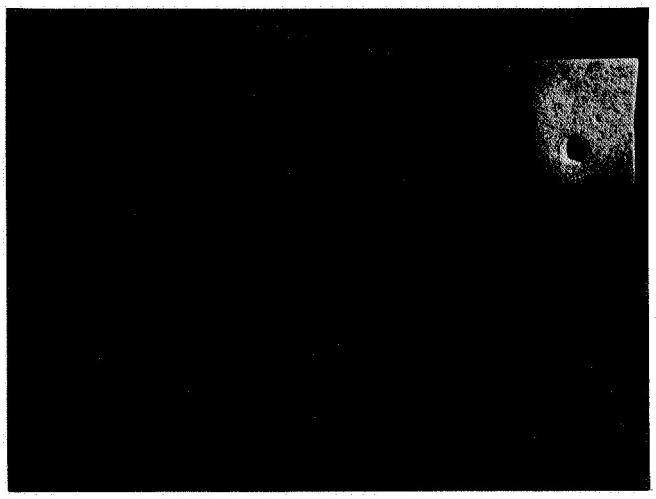
Experiments were performed during the first half of the study program to gain an overall appreciation of the anticipated lunar surface photographic problems. Some of these were necessary to verify the predicted behavior of film under photometric conditions similar to those associated with the moon while others demonstrated the limitations of the photographic process.

4.6.1 Polaroid 3000 Film. The purpose of the first experiment was to demonstrate the capability of a typical black and white negative material to record a scene illuminated with a great range in brightness. A geometric model was made from two pieces of a darkened cellular sponge whose surface simulated the accepted lunar photometric function.[28] Both sponges were suspended in the middle of a room with darkened walls. An American Optical microscope illuminator was focused on one of the sponges, and a light baffle was arranged to prevent the source from directly illuminating the other piece. By carefully aligning a reflecting card, the amount of light reflected from the shielded sponge was adjusted to be ten thousand times less than the light coming from the directly illuminated sponge. Separate exposures were then made on 4 x 5-inch Polaroid Land Film, Type 57, to determine the optimum exposure value for both the high-light level and the low-light level portions of the scene. As anticipated, the Polaroid pictures each exhibited only that sponge for which the exposure was optimum. The picture of the brightly-illuminated sponge gave no hint of the shadowed sponge whereas the properly-exposed picture of the shadowed sponge produced an ill-defined white area corresponding to the highly-illuminated sponge which even encompassed the shadowed sponge.

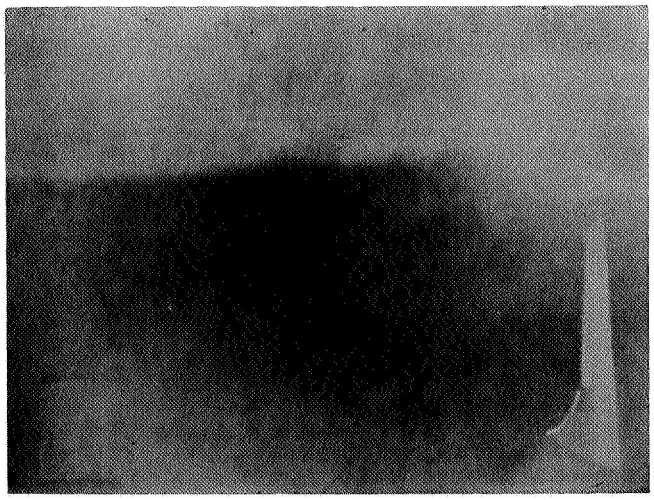
4.6.2 Royal-X Pan Film. The identical scene was next photographed using Royal-X Pan film to produce two negatives: one with optimum exposure for the shadowed sponge and the other producing a good image of the brightly-illuminated sponge. A satisfactory print was made from the latter negative showing detail in the brightly-illuminated sponge, but no trace of the shadowed sponge could be detected on the negative. The overpowering effect of scattered light within the emulsion prevented an acceptable print from being made of the low-light level sponge in the other negative which received optimum exposure for this portion.

Neither the Polaroid Land Film nor the Royal-X Pan film have sufficient exposure latitude to record this brightness range of ten thousand to one. Figure 4.23 is a reproduction of the best prints made from the Royal-X Pan negatives.

4.6.3 XR Film. The next experiment involved photographing the identical scene of the two sponges with a single exposure on XR film which is the extended-range film developed by EG&G.[29] An exposure value was selected to produce a good record of the low-light level sponge in the fast layer of the film. This was necessarily a lengthy time exposure because XR is not as fast as the other two films previously tested. The film recorded the brightly-illuminated sponge in both the middle and bottom layers and yielded acceptable prints of both the shadowed and the brightly-illuminated sponges. It should be pointed out, however, that without special print dodging procedures, a single print could not be made which showed both areas at the same time because the print paper does not possess sufficient range. Reproductions of the two separate prints from the single XR exposure are shown in Figure 4.24. These pictures show that XR film has sufficient exposure latitude to properly record, without tonal distortion, a brightness latitude of at least 10,000 to 1. Camera and subject vibration reduced image definition because of the excessively long exposure time of 15 minutes.

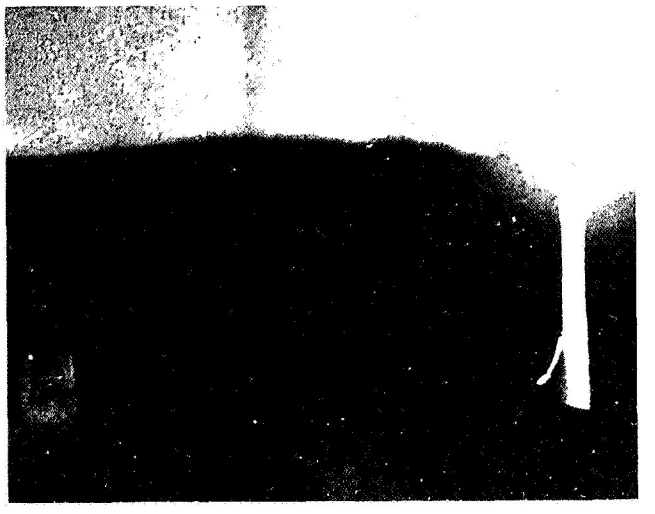


a) Print from negative properly exposed for brightly illuminated sponge.

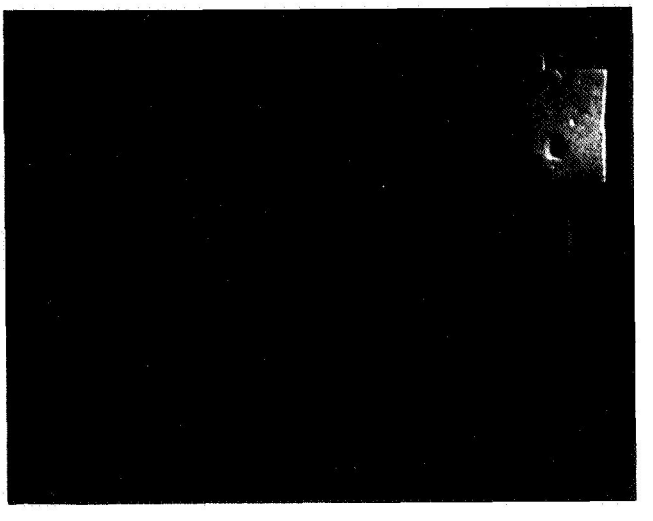


b) Print from negative exposed for the shadowed sponge.

Figure 4. 23 Royal-X Pan pictures of artificial sponges illuminated with a great range in brightness.



a) Printed from fast layer of XR negative.

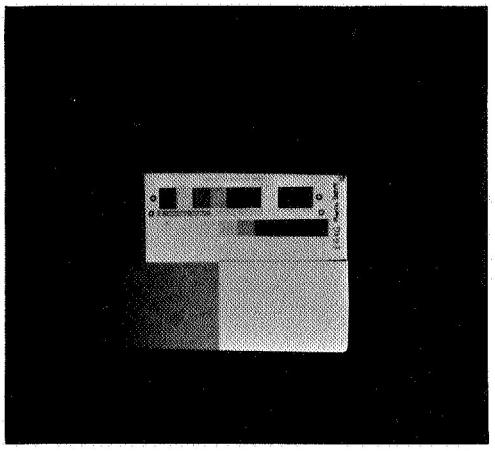


b) Printed from slow layer of XR negative.

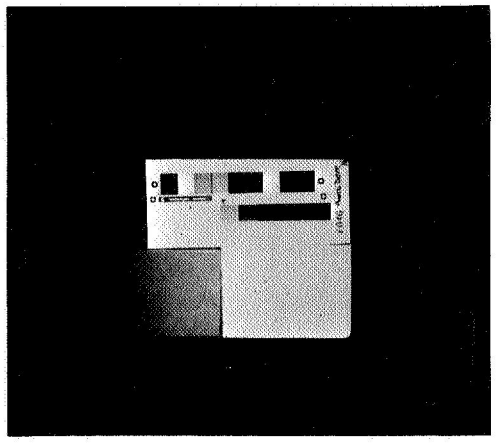
Figure 4. 24 XR pictures of artificial sponges illuminated with a great range in brightness. Both pictures were printed from the same negative.

4.6.4 Experimental Color Film. Multilayer color negative films have a more limited exposure latitude than black and white materials, and reversal type color films are even more restricted. However, taking advantage of a dual path optical beam splitter technique, separate color films could be positioned in each optical path with one film having a greater photographic speed than the other. With such a system, one of the films would record the highlight portions of the scene while the faster film simultaneously recorded the shadow areas. The two separate color records could then be superimposed in register after processing to form a composite color record which would contain both brightly-illuminated and shadowed elements of the scene in true tonal and color relation.

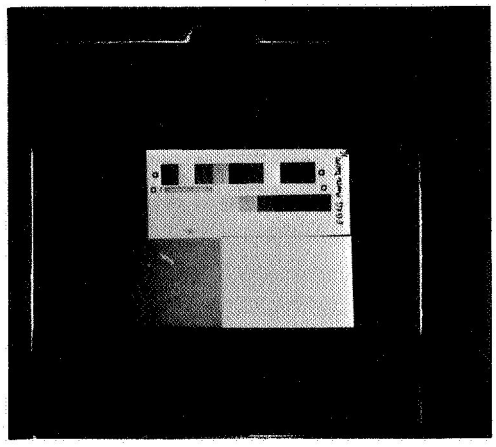
An experiment was performed to verify the principle of recording on separate films by superimposing them into a complete picture after processing. A color chart was photographed, using a series of different exposures, on Kodachrome II color reversal film. Commencing with an exposure just below threshold, each succeeding exposure was made at twice the value of the preceding one until complete overexposure or saturation occurred. The results, after processing, ranged from uniform black through the correct representation of the color chart to complete overexposure. Because the film characteristic curve indicates a nearly linear exposure latitude of one hundred, picture pairs were selected and superimposed in registration which differed in exposure by a factor of 128 or eight aperture stops. Examination of each registered pair showed that the color chart was faithfully recorded in both hue and saturation and that the tonal value increased as the effective exposure decreased. This experiment simulated the double film optical beam splitter system and verified the principle of operation. The pictures presented in Figure 4.25 are black and white reproductions of the composite color pictures in which printing time adjustments were made to normalize tonal differences.



minimum exposure



8 times minimum



128 times minimum

Figure 4. 25 Black and white reproductions of color transparencies with printing time adjusted to produce equal tone value.

Using the same type of Kodachrome film, an experiment was performed to determine the effect of a single scene of large brightness range upon the recording capabilities of a composite color film. The scene to be photographed consisted of two people standing in a darkened room with one person several feet nearer to the camera than the other. A Sylvania Sun Gun light source, positioned 4 feet to one side and directed at the nearer subject, was shielded in a black box and primarily illuminated one side of the person closest to the camera. No direct illumination from the light source reached the person in the background and the effect was an exceedingly high contrast scene. The amount of reflected light produced a luminance ratio of 100 to 1 between the two people. The total scene brightness ratio probably exceeded 100,000 to 1.

Two separate exposures were made on Kodachrome and differed by a factor of 100. The lens aperture and shutter were set at f/5.6 and 1/50 second for one picture and f/4 and 1 second for the other. Because the latter exposure time would produce an exposure reciprocity effect differing from the former, a color correction 10R-filter was used over the lens for the 1-second exposure. After processing, these Kodachrome transparencies were mounted in registration into a composite and produced a faithful color representation of the original scene. The tonal representation was exaggerated because the contrast of reversal films is inherently high for reasons necessitated in optical projection described in Chapter 3. The effect of the high picture contrast produces a visual impression of an exaggerated scene brightness range. Color internegatives with different exposure levels were made from the composite color transparency, and color prints were made from three of the internegatives, showing the capability of printing from composites. Figure 4.26 presents three color prints from the single composite transparency. The first print is optimum for the brightly-illuminated person while the last clearly shows the dimly-illuminated person. The middle picture is intermediate between the extremes and shows color and detail in areas not evident in either of the other two prints.

a. Color detail in brightly illuminated areas illustrates limitations of typical color reversal materials.

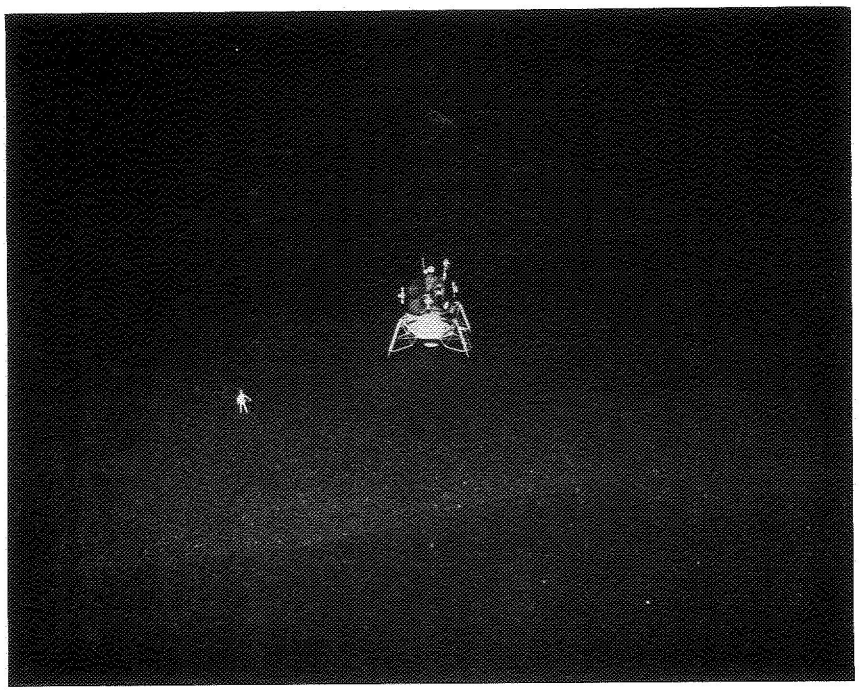
b. Greater printing time yields color detail in darker areas, but highlights are lost in overexposure.

c. Color detail not evident in first print results from still greater printing exposure.

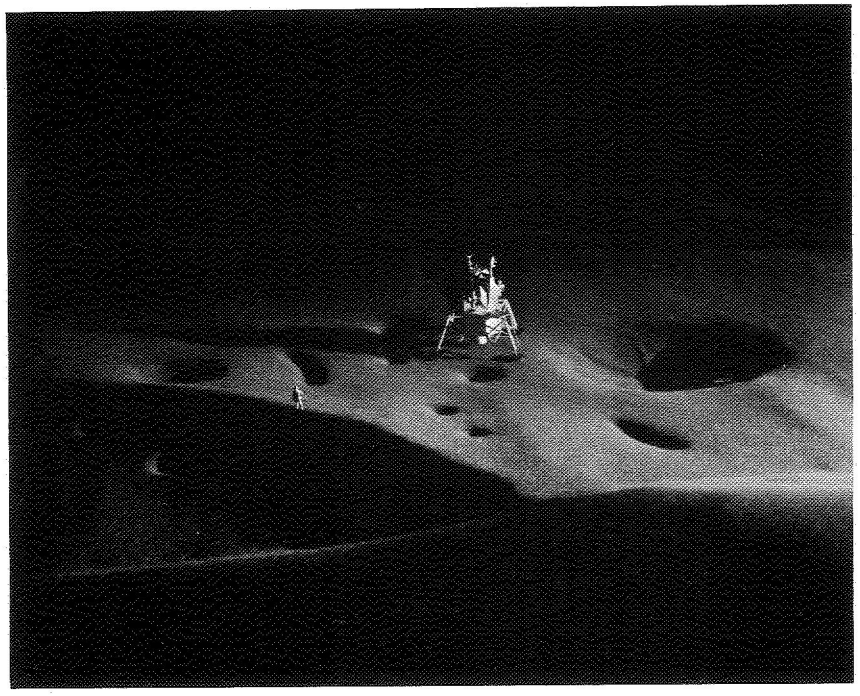
Figure 4.26 Prints enlarged 10 times from experimental extended range color reversal film using three different printing exposures. A shielded Sun Gun was located 4 feet to the left of the man in the foreground.

4.7 STEREOSCOPIC EXPERIMENTS

A sheet of 1/8-inch thick gray polyurethane, which is a cellular material, was firmly secured to a wire mesh frame containing dished depressions of varying sizes. The result was a 3 by 5-foot model which simulated a typical scaled down section of the lunar surface similar to that recorded by one of the Ranger Spacecraft. The cellular-structured polyurethane, with its 0.3 mm cavities and 10 percent reflectance, simulated to a close approximation the lunar surface photometric function. A Sylvania Sun Gun directed at the model from a distance of 15 feet was used as the only light source in an otherwise darkened room. When the phase angle approached zero, the surface appeared to be completely flat with no suggestion of contours. The surface had the same appearance at any viewing angle so long as the phase angle was close to zero degrees. This, of course, is partially explained by the fact that at zero phase angle no shadows can be observed because they are directly behind the objects casting them and are totally obscured. However, the surface photometric function explains the apparent flatness and lack of surface modeling by the mechanism of backscatter of the incident light. The microcavities which allow incident light to enter and finally reflect from the internal parts of the structure between cavities will permit only those light rays which are nearly parallel to the incident rays to leave the various cavities. Hence, the surface of the material effectively autocollimates light. The pictures shown in Figure 4.27 graphically demonstrate the effect of phase angle on the appearance of the simulated lunar terrain. The source of light for the picture on the left was located behind and slightly higher than the camera, resulting in a phase angle approaching zero. With very little evidence of contours, the terrain appears to be flat. Observance of a full moon from the earth gives the same flat appearance because no shadows are evident. As the phase angle increases, contours become evident by a fall-off in light from the various surfaces, and at different viewing angles shadows become noticeable. The



a) With a phase angle approaching zero no shadows are visible and surface appears flat.



b) The light source was moved to the right of the camera and produced well defined shadows.

Figure 4. 27 Photographs of simulated lunar surface showing the affect of shadows on visual ability to recognize surface contours.

right-hand photograph of Figure 4. 27 which was made from the same viewpoint illustrates the effect produced when the light source was moved far to the right of the model, resulting in well-formed shadows and a phase angle of 90 degrees.

The surface features of the latter picture are easy to recognize and a mental comprehension of the scene is immediate. The flat picture, on the other hand, requires prior knowledge of the features being examined and even then it is extremely difficult to discern them. If a second picture, similar in nature to the left-hand flat appearing scene, was made from a slightly different viewpoint, an illusion of depth or three dimensions would become apparent if both pictures were viewed simultaneously by means of a stereoscope. The picture pairs of Figure 4. 28 were exposed with a small angular separation between them. When viewed steoreoscopically, the surface contours and craters become more evident and are immediately recognized by the mental illusion of three dimensions. The camera was located about 5 feet in front of the model and the Sun Gun light source was 10 feet behind and

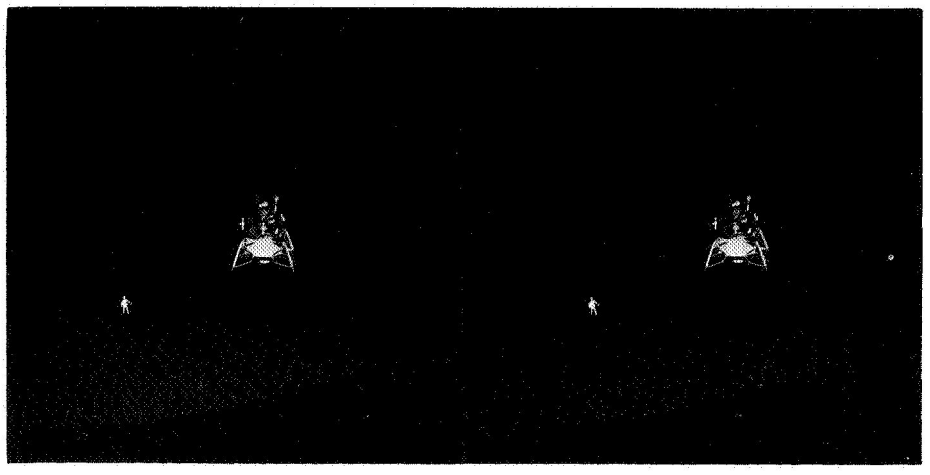


Figure 4. 28 Stereoscopic pictures of simulated lunar scene with a phase angle approaching zero. When viewed with a stereoscope an illusion of three dimensions is apparent and craters may be detected.

slightly higher than the camera. The optical axis formed a 30-degree angle with the plane of the simulated lunar surface. The camera was displaced sideways one inch between pictures which would correspond to a six-inch separation at 30 feet for a full scale model. When less separation was used, the illusion of depth was not as apparent. Increased separation of approximately 3 inches produced a greater sensation of three dimensions, but the exaggerated depth created an impression of a smaller scale model.

4.8 DISCUSSION OF ON-BOARD PROCESSING

The advantage of having the capability of on-board processing would be for the protection of the film from fogging by proton, gamma, and X-ray radiation after the primary picture had been recorded. Present color film processing methods, even to a partial extent, do not lend themselves to on-board application on the Apollo space vehicle due to space limitations and the requirement for large quantities of liquids, electrical power, heat, and air. New processing techniques that are currently being developed throughout the world are aimed more at rapid processing of simple black and white films than at weight and space considerations. New systems would have to be designed or expanded which would allow complete or partial development of the film under the restrictive conditions of the Apollo space vehicle.

4.8.1 Requirement. The best estimate available of the anticipated total radiation dosage during the lunar mission is 2 to 10 r inside the command module. The recorded image in a high speed color emulsion having a speed of 1000 would be useless with a superimposed radiation level of 10 r. Based upon an investigation of a color film with a speed of 100, a noticeable effect occurred when the film was subjected to a Co^{60} source for a total dosage of 0.5 r, the effect being a slight loss of contrast and a shift in color balance. In order to guard against effects of radiation fogging, the film must be protected by shielding or radiation hardening during the entire mission. One means of

doing this during the return voyage, is to partially process the film prior to the onset of radiation. Although impractical because of size and weight limitations, even multilayer color reversal films could be protected in this manner.

4.8.2 Extent of Processing Necessary. There is no need to carry the processing to completion in order to make the film insensitive to all forms of radiation. Such a process would greatly reduce the space and weight requirement of an on-board processing unit. Whether the process is for a black and white, a color negative, or a reversal material, the film should be immersed in a black and white chemical developer for the proper time to develop the negative silver image. Development ceases immediately when placed in an acid condition. Under this condition, the reduced negative silver image or the remaining silver halide, in the case of a color reversal material, would no longer be adversely affected by radiation exposure. Final processing of the film would be carried out to completion under controlled conditions of an earth-based laboratory. Partial processing of a color emulsion would be successful, providing the color couplers are incorporated within the emulsion layers. If the film was of the Kodachrome type where the couplers are provided in the processing solutions, on-board processing must be carried through to completion and would therefore not be practical. This is due to the complexity of the process wherein each layer must be treated individually throughout the processing cycle. In order to provide on-board processing of a Kodachrome Type film an excessive amount of space, electrical power, liquids, heat, and air would be required.

4.8.3 Types of Processing Available. The saturated web and related processing methods, which contain the processing chemicals saturated in a fabric or film support, have some advantage for use in a space vehicle over other techniques that are being developed. There are no free chemical solutions in this type of process to contend with nor is there a need for technically trained operators. The film is processed by placing it in contact

with the material containing the processing solution for a predetermined period of time. Space and weight considerations would be greatly reduced over more conventional methods. So far, the only films that are capable of being developed by the saturated web technique are black and white single layer emulsions. An extensive research program would be required in order to determine the feasibility of using this process with multilayer color films.

The viscous processing technique that is presently being investigated by several companies perhaps offers the best possibilities for on-board processing. Units are currently available only for black and white processing. These units have considerable weight and take up a large amount of space. A unit which provides only partial development could be designed that would greatly reduce the space and weight requirement. Complete color processing units, as presently conceived, would be prohibitive in size and weight.

A special Polacolor film package could be developed which contained its own processing solutions and might fulfill any requirement for an on-board processing capability in the Apollo space program. In a Polacolor system, a viscous processing solution is contained in small pods adjacent to each frame. Processing occurs when the pod is pressed between rollers, spreading the solution in direct contact with the emulsion layer. Such a system would require a special camera that could maintain atmospheric pressure and temperature control during processing and could separate the negative material from the positive color print after the appropriate interval of time. The roll of color prints could be removed from the camera housing for the return trip to earth. The camera could remain on the moon in order to conserve weight.

4.8.4 Practicality of On-board Processing. The advantage of having the capability of on-board processing is for the protection of the film from high energy radiation which would occur after the primary exposures and during the return trip from the moon. The obvious disadvantages are the

added space and weight requirement and the sacrificing of laboratory control processing of an earth-base facility. The advantages and disadvantages must be carefully weighed against the probability of the film receiving an intolerable exposure to high energy radiation after the primary pictures have been recorded. The practicality of on-board processing must also take into account the extent of the final film's reduced sensitivity at the low temperatures of outer space.

CHAPTER 5

CONCLUSIONS

Certain conclusions may be made concerning photographic films for use on the lunar surface. Some of these conclusions are based upon information gathered from published literature; others are the results of the limited experimental program conducted under this contract. Still other conclusions are extrapolations from published data collected during the experimental program.

5.1 LOW PRESSURE

5.1.1 Mechanical. Photographic films which are subjected to atmospheric pressure of the order of 10^{-10} mm Hg will lose moisture content rapidly unless tightly wound in a roll. The loss of moisture will reduce the film's tensile strength particularly in the emulsion which will crack if bent in a tight curve. Emulsion cracking in an extremely low pressure environment can be minimized by maintaining a large radius of curvature with the emulsion side of the film having a shorter radius than the support side.

5.1.2 Static Electricity. Low pressures, hence low moisture content of the film, encourage discharges of static electricity. If non-conducting dissimilar surfaces are peeled apart or slide across each other under conditions of low humidity, large electrostatic fields are generated which ultimately break down in a discharge and produce a flash of light which fogs the film. Static discharges, caused by peeling or sliding of one film against another, can be reduced by overcoating both emulsion and support with a thin layer of gelatin, thereby making both surfaces similar. Moisture will remain within a film if it is tightly wound or otherwise sealed against low pressure. Lengths of film losing moisture in a low pressure environment will fully regain their tensile strength upon reaching equilibrium at normal atmospheric conditions.

5.1.3 Latent Image. An environmental pressure of 10^{-10} mm Hg does not appear to alter a latent image formed under normal atmospheric pressure in Plus-X, Kodachrome II, Ektachrome Daylight ER, or XR film. A latent image formed in Ektachrome Daylight ER which is in a low pressure environment is not influenced by a pressure of 10^{-10} mm Hg.

5.1.4 Film Reloading. Provided that precautionary measures are observed to minimize film fogging by light, a camera may be reloaded under low pressure conditions without degrading the film's sensitometric characteristics.

5.2 HIGH TEMPERATURE

Photographic emulsions have a primitive sensitivity which, although low, extends to infrared wavelengths. This energy produces a uniform fog which is noticeable after processing and increases with the length of time at a given temperature. In addition, the gelatin binder melts and the support material chars if the temperature exceeds +360°F. Acetate supported Plus-X negative motion-picture film becomes mechanically distorted when subjected to a temperature of +300°F for 6 hours.

5.2.1 Time Dependence. The production of fog density in photographic emulsions when subjected to elevated temperatures is time dependent. In two emulsions tested, Royal-X Pan and High Speed Infrared, the time was found to be exponentially related with temperature.

5.2.2 Moisture Dependence. Moisture content of an emulsion is closely associated with the factors of time and temperature in producing a fog density. The time-temperature tolerance increases inversely with moisture content in the emulsion.

5.2.3 Royal-X Pan Film. A fog density of 0.10 above background is produced in Royal-X Pan at +280°F for 2 minutes but requires 50 hours at +160°F. A fog density of 0.10 above normal background will slightly degrade recorded data in photographic films.

5.2.4 High Speed Infrared Film. The time tolerance for High Speed Infrared film is only 8 percent of that for Royal-X Pan film at the same temperatures. A multipurpose film which contains high speed infrared sensitivity would have a time-temperature tolerance of the most heat-sensitive infrared element. Unless temperature shielding is provided for this element, the data recorded in other elements of the film would be seriously degraded.

5.2.5 Pre-launch Storage. High cabin temperatures in the days preceding the launch suggest that the photographic films must be placed aboard the vehicle no sooner than the evening previous to the launch.

5.3 CRYOGENICS

Low temperatures cause a general decrease in the speed of photographic films. Greater loss in speed occurs at those wavelengths for which an emulsion has been dye-sensitized than for the wavelengths of primitive sensitivity. Reduced temperatures cause a loss of moisture, and gelatin emulsions become brittle and crack if the film is flexed at the temperature of liquid nitrogen (-196°C). Films frozen at -196°C will regain moisture content and mechanical strength when brought back to normal conditions of temperature and humidity.

5.3.1 Latent Image. Latent images formed at room temperature in Royal-X Pan film and Ektachrome Daylight ER film are not affected by immersing the film in liquid nitrogen and then warming up prior to processing. The formation of a latent image in both of these films is affected when applied at the temperature of liquid nitrogen. Royal-X Pan suffers a loss in white light film speed of about 4 times in addition to a reduction in gamma. The

red sensitive component of Ektachrome loses speed by a factor of 50 while the green component is reduced 20 times, and the blue element loses speed by a factor of 5 in addition to a reduction in slope. These unequal losses in speed and slope would result in a serious distortion of color.

5.4 RADIATION

5.4.1 Estimated Extent of Damage. With no protective radiation shielding, the lunar film could be rendered useless during the Apollo Mission by the accumulated dose from galactic and Van Allen radiations. The possible occurrence of a solar eruption would certainly ruin the photographic capability of the unshielded film.

Fortunately, the inherent shielding of the command module and film canister will limit the combined cosmic and Van Allen doses to about 0.3 to 0.7 rad for a 14-day mission. Additional shielding could reduce the affects of Van Allen radiation (primarily bremsstrahlung) on the film. It would account for less than 0.1 rad on a 14-day mission. Hardening techniques may effectively reduce the mutually unshieldable galactic cosmic ray dose which could be as high as 0.2 to 0.6 rad. The effects of solar flare particle bombardment are not as easily eliminated and will be discussed below. The solar protons and alphas will not be the major problem except for the very high energy protons (>100 Mev), but the production of fast, slow, and thermal neutrons in the shield material, as well as recoil gammas, will produce extensive blackening of the film after processing unless compensated by appropriate shielding considerations.

5.4.2 Hardening Techniques. Additional protection of the lunar film from the effects of ionizing radiations is possible by reducing its temperature to the cryogenic range, or by direct immersion into a bath or atmosphere which contains chemical reducers. The bleaching effect of this latter method will significantly reduce the potential fog level on the film prior to white light exposure but at the expense of a loss in film speed.

Desensitization of an emulsion by reducing the temperature to the cryogenic region has been moderately successful. The observed order of magnitude reduction in exposure is equivalent to reducing the fixed 14-day mission radiation level from 0.5 rad to 50 mr, a level which is not considered significant with regard to image degradation. Experimentation with lower temperatures may increase this desensitization factor.

Other hardening techniques such as emulsion composition, thickness, and backing, do not offer any immediate solutions to the hardening problem, but research in this field is being continued at EG&G.

5.4.3 Shielding Requirements. Based on analytical and experimental data, it is concluded that significant consideration of the radiation shielding requirement must be given the lunar film. Cosmic and geomagnetically-trapped radiation will not present a major problem from the standpoint of total dose and ease of shielding. The possibility of a solar eruption does present a major shielding problem as evidenced by the results of the LINAC neutron irradiation experiment.

Although the experimental evidence is insufficient to draw firm conclusions, it does appear that the required shielding against a possible major solar flare (i.e., Importance 3 or 3^+) will be significant. Even a very coarse estimate of the film shielding for solar flare particle bombardment is not possible with the limited data currently available.

5.5 COLOR SEPARATION

A division of the visible spectrum into two separate regions is not satisfactory for producing acceptable fidelity of either hue or saturation in color photography. A minimum of three colors is required, consisting of the primaries of blue, green, and red. Both the additive and subtractive color processes which use these three colors can reproduce color with fidelity of hue, saturation, and value over a limited exposure latitude. Additive processes

require individual color separation negatives or a single film containing a geometric pattern in which three separate images are isolated in the blue, green, and red primary colors. Subtractive color processes permit the use of multilayer films and may be either color negatives or color reversal positives. Multilayer color negative films must have dye couplers incorporated in the layers during manufacture. The dyes form colors during the development of the latent image. Multilayer color reversal films may contain built-in dye couplers or the colors may be added to the image during the second or reversal development stage of processing. The latter will enable color films to be obtained which have film speeds comparable to very fast black and white emulsions. Color films balanced for daylight conditions on earth will approach being properly balanced for color photography on the lunar surface.

No available color film has sufficient exposure latitude to accomplish that portion of the lunar color photographic mission which requires fidelity of hue, saturation, and value. Severe limitations of available color films makes it difficult to obtain acceptable color pictures on the moon even by strict observance of exposure settings. A specially designed exposure meter would be required to produce an exact calculation of the optimum exposure for each scene. Because of the marginal exposure latitude, proper exposure setting will be extremely critical. A slight color imbalance of the film caused from excessive heat or radiation will further reduce the effective latitude. The photometric function of the lunar surface suggests that light incident on the camera lens from the ground at the lunar horizon 1.4 miles away will be 10 times less than that from the subsolar point with an overhead sun. This spans most of the range of the linear exposure region of commercially available color films where fidelity of hue, saturation, and value are optimumly recorded. Differences in lunar surface albedo will account for an additional factor of 4 and distortion of hue and saturation in the color photograph will be strongly evident. Lunar shadows representing an increased scene brightness will

magnify the color fidelity problem and would not be within the capability of commerically available color films.

5.6 EXTENDED RANGE COLOR FILM

Commercially available multilayer color films of the direct positive or reversal type are limited to a total exposure response range of 1000 including the non-linear portions of low and high densities. Faithful color recording with these films is restricted to a range of 30. Since the lunar surface photometric function coupled with the albedo range exceeds the capability of color reversal films, it is concluded that films with greater range of exposure response are required for color photography on the moon. Available color negative films have a range of faithful color recording which is 2 or 3 times greater than color reversal films and, therefore, would be more suitable for lunar surface color photography. However, the additional latitude of color negatives is marginal and would require critical exposure settings because of the reflection characteristics of the lunar surface material. In addition, lunar surface shadows demand a film whose total recording capability exceeds a response range of 100,000 which is greater by an order of magnitude than the capability of the best color negative.

5.6.1 Two Separate Films. Exposure response of available color reversal films can be effectively increased by simultaneously exposing an identical scene on two separate color films and registering the separate films, after processing, into a single composite record. The effective exposures of the separate films should differ from one another by approximately 100 times. This can be achieved by using a high speed color film for one record and a low speed color film, properly attenuated, for the other record. The exact value of film speed difference would be dependent upon the shapes of the D-log E curves for both films and would be chosen to produce a smooth transition between the characteristic curves of both films.

5.6.2 Reversal Films. One possible solution would utilize an optical beam splitter which reflects 95 percent and transmits 5 percent of the incident light. Kodak High Speed Ektachrome Film Daylight Type ER with a speed of 160 could be used with the reflected beam, while Kodak Ektachrome Film Daylight Type with a speed of 32 would record in the transmitted beam. Thus, the slower film using the transmitted beam would require a scene brightness nearly 100 times greater than the faster film. The effect of the beam splitter would reduce the speed of the fast film to a value of approximately 100, while the slower film would appear to have a speed of only 1. Exposures of the brightest parts of the lunar scene would be adjusted to properly record in the slow film while the fast film would extend the recording capability to much lower light levels, recording considerable color detail in the shadowed areas. Anticipated luminance levels of a lunar scene, using a phase angle approaching zero and the highest albedo value, suggests that an optimum exposure will result in the slow speed film when using a shutter speed of 1/10 second and a lens aperture of f/5.6. The extended latitude of the film at this exposure value would permit faithful color and tonal recording of the brightest scene portions and extend down to luminance levels 1000 times less. This will not be sufficient to record detail in the heaviest shadow portions but should produce a faithful color record of the lunar scene which includes the lowest albedo values at a phase angle approaching 90 degrees.

The exposure time of 1/10 second is impractically long for a hand-held camera and, therefore, would require a sturdy support or tripod. A faster lens aperture of f/2.4 would permit the exposure time to be shortened to 1/50 second which is short enough for a hand-held camera.

5.6.3 Negative Film. Although color negative films could be utilized in the same manner described above and would result in a somewhat greater latitude, no available color negative material has as high a film speed as high speed color reversal films so the required exposure times would be even longer.

5.6.4 Experimental Film. An experimental prototype reversal color film is being made in which the anticipated film speed will be 1000. This film will not only be 10 times faster than the film described above, but it will also eliminate the need for two separate but simultaneous exposures on separate films. It is anticipated that the total recording response of this film will span a range greater than 1 to 100,000 and will be capable of faithful color recording from the sunlit moon ground extending to color detail in the shadows. In addition, the top element of this film will be sensitive to ultraviolet wavelengths down to 2500Å. Such recording will require special filtration which would exclude visible wavelengths. For use as a color film in the visible region, a filter would be required to prevent ultraviolet radiation from reaching the emulsion which would affect the color balance and degrade the hue and saturation fidelity. Image quality contained in the top element, whether exposed by ultraviolet or visible blue wavelengths, will probably exhibit a resolution capability of approximately 100 lines per millimeter when examined through a blue filter.

5.7 STEREOSCOPY

Photographic pairs simultaneously exposed with a 6-inch sideward separation of two lenses will be effective in revealing lunar surface contours even without shadows and with a phase angle equal to zero. The effectiveness will diminish as object distance is increased. Sensation of depth is barely apparent at 50 feet with a 6-inch separation between pictures when the phase angle is near zero and no shadows are evident. If the angle of view or the lighting changes, creating shadows in the scene, a sensation of three dimensions will be observed with a 6-inch separation at object distances of 500 to 1000 feet.

5.8 RELOADING CAMERA

The effects of low pressure (i.e., 10^{-10} mm Hg) will not preclude reloading of the camera with a fresh supply of film. The effect of low

pressure is primarily a loss of moisture content in the film when subjected to the low pressure for long periods of time. Loss of moisture makes the film brittle, but full recovery is attained when moisture is returned to the film under normal atmospheric conditions. Film subjected to 10^{-10} mm Hg for the short time which is required for loading a camera will not lose enough moisture to be detrimental to the normal mechanical handling of the film.

5.9 ON-BOARD PROCESSING

On-board processing, even to a partial degree, should not be considered unless, after further testing, the radiation shielding and hardening techniques prove to be inadequate. The complexities of such processing, including the bulk and weight of the necessary equipment, would be greater than the addition of adequate shielding against radiation damage.

5.10 ANSWERS TO 14 QUESTIONS

The following points are answers to the specific questions which were raised at the end of Chapter 2 by NASA, Manned Spacecraft Center.

1. A single film cannot be developed which would have all of the desired capabilities for use in the lunar surface hand-held camera. It is possible to develop a single film which will fulfill the photographic assignment, but it would include compromises. The film would be limited in the ultraviolet to a practical cut-off wavelength of 2500 and 9000Å in the infrared. The film speed in the visible spectrum would be limited to 1000, and the image resolution for color pictures would probably not exceed 70 lines per millimeter. The tolerance to radiation would be low because of the high film speed. A radiation dosage of 5 rad would seriously degrade image data. In order to maintain color fidelity of hue, saturation, and value the film must have an extended exposure latitude.

2. The apparent color temperature of the sun as observed from the earth is approximately 5000°K. The effective color temperature of daylight reaching the earth is higher than direct sunlight because of the contribution from the blue sky. Outdoor color films are balanced for 6400°K daylight. The earth's atmosphere absorbs a considerable amount of the solar energy in the ultraviolet to which most photographic films are very sensitive. In most color films, the ultraviolet which does arrive at the earth's surface is usually absorbed before reaching the sensitive emulsion so that it does not upset the color balance of the recorded colors.

The sun is very similar to a black body radiator with a surface temperature of 6000°K except for minor deviations in the ultraviolet.[32] Solar atmospheric absorption accounts for less energy emission at wavelengths shorter than 3000Å than that emitted by a true black body of the same temperature.[31] With essentially no lunar atmosphere, the major source of photographic light is the sun at a color temperature of 6000°K. A color film balanced for earth daylight would thus require a filter which would absorb the ultraviolet energy but would otherwise approach proper color balance for color photography on the lunar surface. A Wratten 2C+82A filter placed in the optical path would suffice to absorb the undesirable ultraviolet and would not lower the speed rating of the film by more than 10 percent.

Using the same film to make photographic pictures with ultraviolet energy, a Corning filter 7-54 will effectively absorb the visible spectrum and transmit 90 percent of the ultraviolet. This filter has a minor transmission in the near infrared which would expose the red sensitive layer of the color film. However, examination and printing of the ultraviolet record through a primary blue filter would eliminate the effectiveness of the red layer image. Use of a Wratten 89B filter for infrared recording will absorb all of the ultraviolet and visible spectrum but would transmit more than 85 percent of the energy from 7600Å beyond the practical cut-off of the film at 9000Å.

3. Emulsion thickness will affect acuity and resolution, with more degradation occurring in resolution, especially if the thickness is so large that it is beyond the depth of focus of the lens optical system. The actual emulsion composition is, perhaps, a more influential factor on acuity and resolution. Those elements within the emulsion which tend to scatter and diffuse image forming light are responsible for image degradation. Thus, a turbid emulsion will have an inferior image quality unless the image is restricted to the surface of the emulsion. Generally, a thick emulsion is less turbid per unit thickness than a thin emulsion.

4. The ASA exposure index of a photographic film is associated only with the photographic recording in the visible portion of the spectrum and has no significance in either the ultraviolet or infrared spectral regions. Because a filter is required for ultraviolet photography, film speed will be reduced by approximately 30 percent when using the Corning 7-54 filter. The ultraviolet absorbing filer, Wratten 2C+82A for color recording in the visible range, will reduce the ASA rating by 10 percent. The Wratten 89B infrared transmitting filter will reduce the infrared sensitivity by approximately 10 percent.

5. Humidity or the moisture content of an emulsion has very little effect upon the response or formation of a latent image when exposed to light. Formation of a latent image in an emulsion at equilibrium in an atmosphere of 10^{-10} mm Hg is no different from a film exposed under normal atmospheric conditions. The moisture content of an emulsion subjected to low pressure could be exceedingly low. Mechanical properties of photographic films are temporarily altered by low humidity. During manufacture, photographic films are packaged with a relative humidity of 45 percent. Loss of moisture by a factor of 10 appreciably reduces the film's tensile strength, but with proper design and handling of film transport in the camera no breakage will occur. Low humidity will encourage formation of electrostatic charges which could result in light-fogged areas in the emulsion where discharge occurs. Gelatin backing of the support will aid in reduction of such effects

even at a 5 percent humidity condition in the film. It is concluded that moisture content should be maintained at approximately 5 percent in order to keep the film in a usable condition. Because films recover rapidly, short immersion periods at reduced pressure and moisture conditions encountered during reloading will not adversely affect the film if the camera is repressurized in an atmosphere containing moisture.

6. Temperature extremes will affect image resolution of multilayer photographic films only if the various emulsion elements expand or contract unequally. Thermal coefficients of the elements are generally equal, so dimensional changes are uniform and resolution is not affected in either black and white or color films. Temperature changes during processing, even though limited to small values of $\pm 10^{\circ}F$, may cause uneven dimensional changes, producing emulsion reticulation which will degrade image resolution.

7. The expected radiation fog level for an unshielded film of a 1000 speed rating will be approximately 1.6 density units for a 10-rad exposure. This density will not affect image resolution but will seriously degrade the capability of the film to record photographic images. The sensitivity of the emulsion would be reduced more than 10 times, and tonal distortion would be severe with black and white films. Color films of equivalent speed ratings would show extreme hue and saturation distortion in addition to degraded tone.

8. Freezing the film in a liquid to temperatures of $-196^{\circ}C$ will offer some protection against radiation damage and will not affect image quality. The sensitivity of films is reduced by the low temperature and not by the presence of a liquid. Visible light sensitivity is also reduced by very low temperatures, so that the film must be warmed up before making ultraviolet, visible, or infrared photographic exposures.

9. Partial processing after exposure of most photographic materials will preserve the latent image from subsequent damage due to radiation. Action of the developer in reducing the latent image to free metallic

silver without removal of the undeveloped silver halide will suffice as protection against subsequent radiation damage if the pH of the film is made slightly acid upon completion of the image reduction stage. Completion of the process may be carried out at a later time with no significant deterioration of the image. Certain photographic color films cannot be partially processed because the remaining undeveloped silver halide must contain its original sensitivity to light in order to form colors during a subsequent processing phase. Even though partial processing of films, except as noted above, can effectively protect a previously exposed film against further damage due to radiation, it offers no protection for films not yet exposed. Because of its limited protection, partial processing is not recommended.

10. For simple black and white films, on-board processing could be made reliable. However, on-board processing of color films requires greater precision and is more complex than black and white films, thus reducing the reliability.

11. In general the radiation which might affect processing chemicals will have already damaged the film because it is more sensitive to radiation than the processing chemicals. If the film is shielded or protected from radiation, there would be no need for on-board processing.

12. Temperature and humidity will affect on-board processing. Low humidity will promote evaporation of the solution liquid, thereby increasing the chemical concentration. Carried to extremes, crystalization of the chemicals will occur and could cause mechanical damage to the emulsion. Temperature extremes will cause a change in the rate of reduction of the latent image with high temperatures and will produce mechanical damage to the emulsion. As the developer temperature increases, the rate of silver reduction increases, thus requiring more precision in controlling development time. A film which remains in the developer for too long a time produces a high fog level, and the developer no longer discriminates between exposed and

unexposed silver halide grains. The result is a loss in film speed and a reduction in gamma with an attendant high background density. The same effect is produced when films are subjected to heavy doses of radiation.

Low temperatures of the processing chemicals stop the rate of silver reduction when the liquid freezes to a solid. The addition of ethylene glycol to the solution lowers the freezing point and development can continue although at a slow rate.

13. Film processors will not operate properly in the lunar environment because at a pressure of 10^{-10} mm Hg, moisture necessary for development to take place will be removed from the developer. In order to successfully process film on the lunar surface, the processing system would require pressurization.

14. Environmental data recorded at the moment of each exposure is not essential as an aid in the laboratory processing of the returned photographic film. However, a total history of the accumulated radiation dose and the lengths of time which the film was subjected to various temperatures might be helpful. In addition, the shutter exposure time and any filters employed for each picture would be useful information. Calibration exposures of a gray scale and color patches should be made at some time while on the lunar surface and should be included with each roll of film. The test chart should be properly recorded in earth daylight with a similar film before sending the chart to the moon. On the lunar surface, calibration exposures should be made in full sunlight as well as in a shadow. Calibration exposures of the chart should be made with shutter times corresponding to those which would be used during the lunar photographic mission.

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CHAPTER 6

RECOMMENDATIONS

The study and investigation program of a film for use in a lunar surface hand-held camera has revealed several possible courses which are being recommended for further investigation. In addition, it is recommended that two separate films be used instead of a single film. Although a single film could be developed which would satisfy many of the requirements for the lunar surface photographic mission, it is our considered opinion that such a film would be more likely to jeopardize the final results because of certain compromises necessitated by a single film.

6.1 FILM FOR BLACK AND WHITE AND INFRARED

The surface macrophotographic requirement for a high resolution film with image resolution of 100 to 200 lines per millimeter can best be accomplished with a special emulsion coating composed of small grains and low turbidity. The emulsion thickness as well as the range of grain size will be minimal, thus producing a short exposure latitude. The emulsion will not be dye-sensitized, being sensitive only to the ultraviolet and blue spectral regions, nor will it contain a dye coupler. The effective exposure index rating will be 100 or less, and optical filters will not be required. The primary use of this emulsion will be high image resolution photography of objects ranging from a few feet to 20 feet from the camera. The scene contrast will be maintained within the acceptable limits of the emulsion latitude by means of artificial fill-in light. This emulsion will be coated on top of a second emulsion which will be sensitive to visible wavelengths and the infrared to 9000Å. Exposures which record in the infrared will require a filter in the optical path which will absorb visible light and transmit only infrared from 7000 to 10,000Å. A Wratten 89B filter will fulfill this requirement. The

infrared emulsion will have the same level of sensitivity between 7000 and 9000Å as the blue sensitive layer has between 4000 and 5000Å. (Fig. 3.4 and 3.5). With no dye couplers in either the blue or infrared sensitive emulsions, this multilayer film will be processed as a black and white negative.

6.2 ULTRAVIOLET AND EXTENDED LATITUDE COLOR FILM

A special multilayer film is recommended which will be capable of recording ultraviolet scenes, and then by interchange of a filter in the optical path, color pictures may be recorded in the visible spectral range. The film will be essentially a multilayer color film in which the high speed blue sensitive top emulsion layer is also sensitive to ultraviolet. With an extended exposure latitude in the color recording elements, the film will be processed by reversal to produce positive color images. The exposure index rating for the visible color recording will cover a range from 1000 to 10 and will correctly record color pictures using any film speed rating between these two values. In normal use on the lunar surface, it is recommended that a speed rating value of 10 be used for the majority of pictures made in direct sunlight. Used in this manner, the wide exposure latitude of the film will also permit correct color reproduction in the darker portions of the lunar scene and will allow more tolerance for possible color correction to be made subsequently in laboratory duplications. A recommended exposure setting using the speed rating of 10 would be 1/100 second at f/5.6 with a Wratten 2C+82A filter in the optical system. The color film will be balanced for a color temperature of 6400°K when used on earth without a filter. This color balance is the equivalent of natural daylight on earth. Although sunlight incident upon the lunar surface is only 6000°K, the effective color balance of the film will be reduced from 6400°K to this value by use of the ultraviolet absorbing filter, Wratten 2C+82A, and the resulting color pictures will be faithful reproductions.

Photographs of lunar scenes which are to be restricted to the ultraviolet will be recorded in only the top element of the multilayer film in which the spectral limits will be set by use of a Corning filter 7-54, which will absorb most of the visible wavelengths longer than 4000Å. This filter, with a peak transmission at 3200Å, will permit ultraviolet pictures to be made between 2500 and 3900Å. The resulting image after processing will be a yellow colored positive overlaid on a uniform primary blue colored background. Because of the blue background, the yellow image will be apparent as a positive of varying tones of black and would appear similar to a black and white print examined through a primary blue colored filter. In the laboratory, the ultraviolet recorded image could be duplicated as a normal black and white picture, using conventional photographic techniques.

The color pictures would be satisfactory for direct projection-viewing, but the projected image would be too dark to reveal the colors recorded in the dark regions of the scene. However, duplicate color transparencies or paper prints could be made in which the printing exposure is properly adjusted for the dark or intermediate tones in order to reveal the colors recorded in the shadows. Such duplicates would be faithful color representations in hue and saturation contained in the darker scene portions and would appear similar to the same scene if it had been recorded with more exposure.

Although this special multilayer color film has not yet been manufactured, the principle of operation has been successfully demonstrated as reported in Section 4.6.4 (See Figure 4.26). Several methods of construction of the proposed film are possible and it may be necessary to make experimental models of the various suggested designs in order to determine the final configuration. During the course of the necessary experimental stages of film construction, it may be possible to incorporate an infrared recording capability. Thus, such a single film might fulfill the majority of the requirements of the lunar mission.

Some of the problems involved in selecting the final design may be more clearly understood by referring to the two cross-sectional sketches shown in Figure 6.1. These sketches show only two of the many possible different methods of construction. The choice of these particular methods of construction has been made on the basis of simplicity. The film shown in Figure 6.1 a) is basically a simple combination of two standard multilayer color films, assembled one on top of the other. In order to adjust for the speed difference between the two color films, which will result in an extended exposure latitude, a neutral density filter is inserted between them. For example, if both sets of color emulsions have the same photographic speed, the neutral density filter would be required to absorb or otherwise attenuate light which reaches the bottom set of color emulsions in order to reduce its effective sensitivity. In this example if each color set has an exposure latitude of 100, then the bottom set must be reduced in sensitivity by 100 times. This is effectively accomplished by selecting a neutral density value of 2.0 which is a 100 times attenuator. The actual value of the attenuator will be dependent upon the inherent emulsion speeds of the color sets used and will undoubtedly be considerably less than 100.

Referring to Figure 6.1 a), a thin transparent support material, S, is covered on one side with a slow red sensitized emulsion, R_s, whose photographic speed is approximately 30. A slow green sensitized emulsion, G_s, also with a speed of 30, covers the red layer and a slow blue sensitive emulsion, B_s, of speed 30 is separated from G_s by a yellow filter layer, Y_s. The neutral density filter layer, ND, separates B_s from a fast 1000 speed red sensitized emulsion, R_f. A fast 1000 speed green sensitized emulsion, G_f, is placed on top of R_f and a yellow filter layer Y_f separates the green sensitive emulsion from the 1000 speed blue sensitive emulsion, B_f, which is the topmost layer of the film. Emulsion B_f is also sensitive to ultraviolet down to 2500Å. For illustration simplicity, certain special interleaving layers of gelatin are not shown.

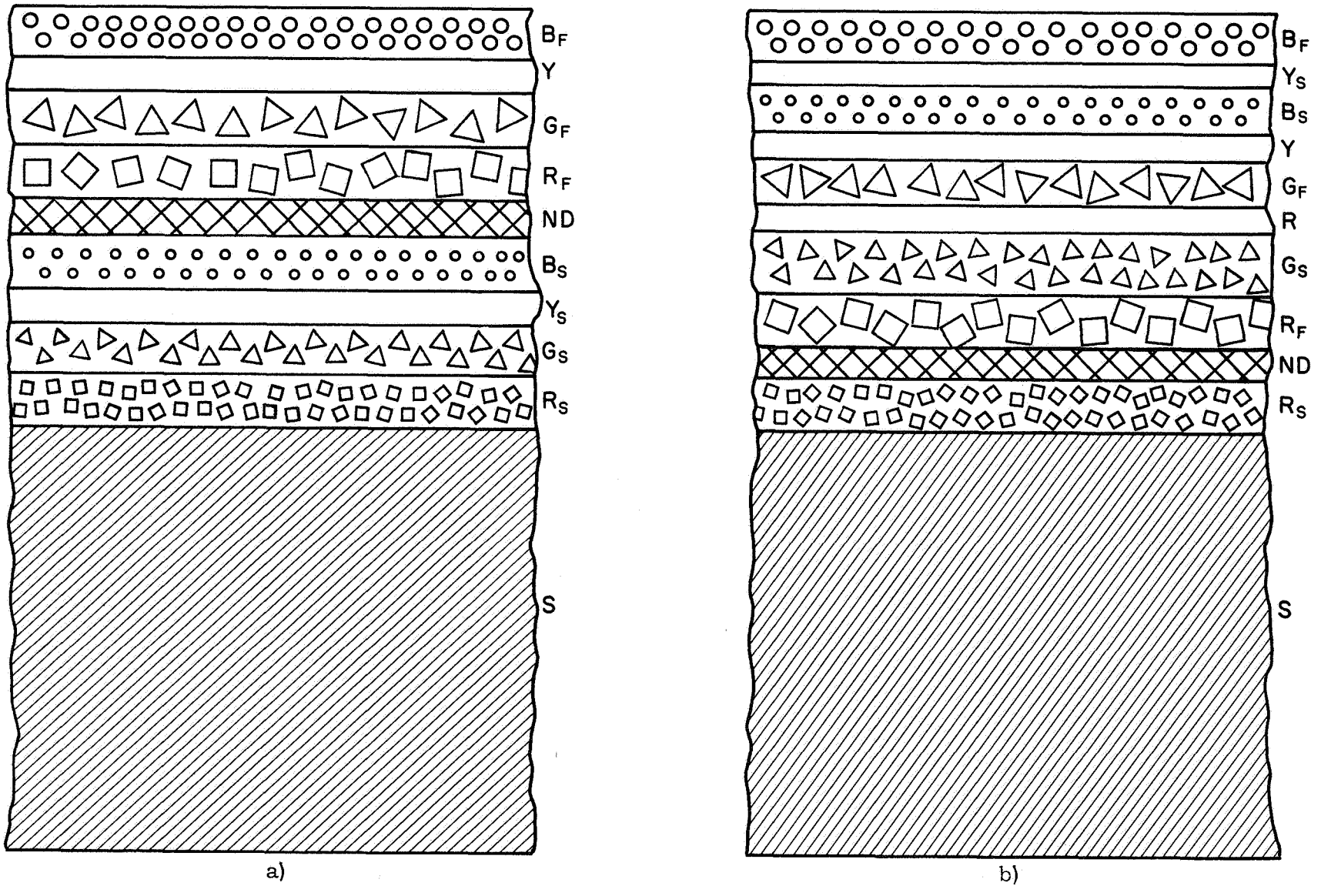

Figure 6.1 Cross sections of proposed special color film with an extended exposure response for use in a lunar surface hand-held camera.

The sectional view of Figure 6.1 b) shows another film construction which might be used. The basic difference between this construction and that previously described is one of arranging the color sensitive emulsions in pairs of different photographic speeds. Thus, both red sensitized emulsions form a pair with the faster layer on top of the slow layer with the speed adjustment accomplished by means of a neutral density filter interposed between them. The green sensitized emulsion pair, G_s, and G_f, are separated by a red colored filter, R, which serves to adjust the speed difference of the green sensitive emulsions without attenuating the light for the red sensitive emulsions. A yellow filter, Y, separates the green emulsion pair from the blue emulsion pair and serves the purpose of preventing any blue light from affecting the green emulsions. The slow blue emulsion, B_s, is separated from the overlying fast blue emulsion, B_f, by another yellow filter, Y_s, which adjusts the speed differences between the two blue layers. The fast blue layer, B_f, has a sensitivity extending to 2500Å in the ultraviolet and therefore has no gelatin overcoat. As with Figure 6.1 a), for clarity Figure 6.1 b) shows none of the special gelatin interlayers.

6.3 FUTURE INVESTIGATIONS

Between the present time and the occurrence of the first manned lunar landing, it is reasonable to expect numerous explorations into outer space. It is recommended that at least some of these space probes include photographic film experiments designated to verify the behavior of the films under true conditions of space. Much of the researched information covered by the current study was obtained from simulated space conditions, and verification using real space environmental conditions would be highly desirable.

It is also suggested that continuing effort be expended to improve the film system recommended in this report. This would include investigation of the processing methods and duplication techniques which would occur after film recovery in an earth-based laboratory.

Considerable attention must be given to the problems presented by the ionizing radiations of space. In addition to physical shielding, the inclusion of other protective mechanisms is suggested. These would include chemical erasure of fog and cryogenic desensitization during the journey to and from the moon.

The availability of cryogenic temperatures at the outside surface of the command module suggests the feasibility of desensitizing the exposed film during the journey. The possible availability of on-board liquid gases (e. g., LOX) is also recommended for consideration in this application. Chemical erasure techniques will not be as convenient, but may be more effective if an unusually severe solar radiation environment is encountered prior to pictorial exposure of the film.

Additional evaluation and application of both hardening techniques, as well as other data recovery and desensitization methods, is strongly recommended.

An evaluation of the lunar film in the anticipated radiation environment is very desirable. High energy proton accelerators are available for future investigation of radiation effects and shielding for the photographic film. Accelerators of suitable energy are located at Oak Ridge National Laboratory, MIT, the University of Minnesota, Rutgers, and the University of California. Table 6. 1 lists some of the characteristics of these machines.

TABLE 6.1 PROTON ACCELERATOR DATA

Accelerator Type	Location	Beam Data		Remarks
		Maximum Proton Energy (Mev)	Current Available (μa)	
86-inch Cyclotron	ORNL	22.4	15	140/hr machine charge. Lowest flux is 10^8 protons/second.
42-inch Cyclotron	MIT Laboratory for Nuclear Science	7	10 to 15 (10^{-3} defocussed)	No formal irradiation services available.
Tandem Van DeGraaff	Rutgers University	15	- - -	Not yet operational.
Bevatron LINAC	University of California Lawrence Radiation Laboratory	19.5	- - -	Injector for Bevatron.
Standing Wave LINAC	University of Minnesota	68	$\approx$5	

APPENDIX A

NEUTRON PRODUCTION UNDER HIGH ENERGY PROTON BOMBARDMENT

The mechanism for the production of neutrons by high energy protons has been reviewed briefly.[32, 33, 34, 35, 36, 37] The extent of such production (i.e., the cross-section) is dependent on several factors such as incident proton energy, target atomic number and density. At peak flare proton energies (hundreds of Mev), the effect of nuclear interactions in the target material dominates the relatively small amount of ionization, although some uncertainty exists as to the extent of this dominance.[32, 36] A sharp increase in (p, xn) reactions is noted from within a few Mev of the nuclear threshold energy up to very high energies.[33] For example, a sharp maximum at 90 Mev for the yield of the reaction Bi^{209} (p, 8n) Po^{202} has been detected.[37]

An approximation of the magnitude of the fast neutron flux produced during solar flare proton bombardment can be made by using data obtained from cosmic ray measurements.[34] The formation of "stars", nuclear disruptions from cosmic ray interactions with target nuclei, are estimated to number approximately 4×10^{-3} per cm^3 (air) per day at an elevation where there is a cosmic ray flux of about one proton per cm^2 per day.[38] For an assumed flare flux of 10^6 protons per cm^2 per day, it is then determined that the "star" production, n_s, is

$$n_s = \frac{4 \times 10^{-3}/cm^3\ (air)/day}{proton/cm^2/day} \times 10^6\ protons/cm^2/day$$

$$= 4 \times 10^3/cm^3\ (air)/day$$

But it has also been determined that four neutrons are produced per star.[39] Thus, $n_n = 1.6 \times 10^4/cm^3$ (air)/day.

For a 14 day mission, the total neutron production is

$$n_n \simeq 2 \times 10^5/cm^3 \text{ (air)}$$

Applying this neutron production calculation to the film shielding problem, one notes the following:

1. The shield density is at least 10^4 greater than that of the high altitude air, resulting in considerably greater neutron production than the above $10^5/cm^3$.

2. Neutron fluxes of 10^8 to $10^9/cm^2$ > 3 Mev have been shown (paragraph 4.4.1) to produce extensive film fogging.

It is concluded, from this cursory examination of the neutron production mechanism, that there is a good possibility of film damage from knock-on neutrons occurring during solar flare activity.

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