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ANALYSIS OF RADIATION DAMAGE TO ATM FILM

By R. D. Shelton and A. C. deLoach
Space Sciences Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

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ABSTRACT

Potential radiation damage to Apollo Telescope Mount (ATM) photographic film is analyzed in view of the fact that they will be subjected to a proton flux during the mission. Proton dose rates are calculated as functions of orbital inclination, altitude, and shielding thickness; film sensitivities to proton radiation are determined experimentally. Film darkening is then expressed as a function of elapsed time in orbit.

It is concluded that several ATM films would not survive the radiation environment; research and test programs are underway to provide substitute emulsions which can be protected with a modest shielding requirement.

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SPACE SCIENCES LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM X-53666

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SUMMARY

Since Apollo Telescope Mount (ATM) photographic film will be subjected to a proton flux during the mission, potential radiation damage must be analyzed from that standpoint. Proton dose rates are calculated as functions of orbital inclination, altitude, and shielding thickness; film sensitivities to proton radiation are determined experimentally. Film darkening is then expressed as a function of elapsed time in orbit.

It is concluded that several ATM films would not survive the radiation environment; research and test programs are underway to provide substitute emulsions that can be protected with a modest shielding requirement.

INTRODUCTION

The Apollo Telescope Mount (ATM), a manned orbiting observatory dedicated to the advancement of solar physics, is scheduled for launch during the next period of maximum solar activity. The ATM contains five astronaut-operated experiments designed to gather data in the soft X-ray and extreme ultraviolet portions of the solar spectrum, as well as white light photographs of the corona. The principal means of data acquisition involves the use of photographic film, the processing of which will take place on the ground after retrieval.

The orbital parameters of the ATM mission are such that the cluster will frequently pass through the South Atlantic Anomaly. As a result, all on-board photographic film will be subjected to a flux of protons, the exposure to which causes an ionization process to take place within the emulsion. Since this process is similar to that which occurs when the desired latent image is formed, the film will be darkened, or fogged, by the proton radiation. The degree of fogging is a function of the film's response to a particular type of radiation, and because those films contemplated for use in the ATM experiments vary greatly in sensitivity, it is quite possible that one film might be rendered useless while another is unaffected. It is the purpose of this report to predict the proton fog level of each ATM film as a function of time and shielding thickness in the prescribed orbit so that proper steps can be taken to protect the more sensitive films during their exposure to the radiation field.

ORBITAL CALCULATIONS

An investigation of the radiation problem may be logically divided into the following analyses:

1. Determine the charged particle distribution in space, energy, and time.

2. Calculate the radiation environment encountered by the spacecraft for a particular set of orbital parameters.

3. Compute the particle spectra incident on the film as the result of a shielding analysis.

4. Establish the sensitivity of each ATM film to the local radiation environment, expressed in terms of the net density accumulated as a function of time.

5. Demonstrate quantitatively the dependence of film fogging on shielding, orbital parameters, etc., so that the more influential variables can be selected for possible manipulation.

The best available environmental data to date are given by the Vette collective model [1]. These particle distributions are input with a set of orbital parameters to a machine code [2, 3] which computes the particle flux encountered in real time and the average flux integrated over many orbits. Radiation point dose rates are then determined from the modified spectra which survive variable depths of shielding material. Figure 1 shows the free-space proton flux in the ATM orbit; each peak represents a passage through the anomaly. Such a plot illustrates the obvious need for strict time-lining of EVA activity. In Figure 2, the proton, electron, and bremsstrahlung dose rates are shown as a function of shield thickness. Note that a modest amount of shielding is sufficient protection against the electron and bremsstrahlung radiation. Note also that shielding is relatively ineffective in reducing the proton dose; this is because the proton spectrum has a large high-energy component. Figures 3 and 4 illustrate the dependence of the proton dose rate on orbital altitude and inclination,

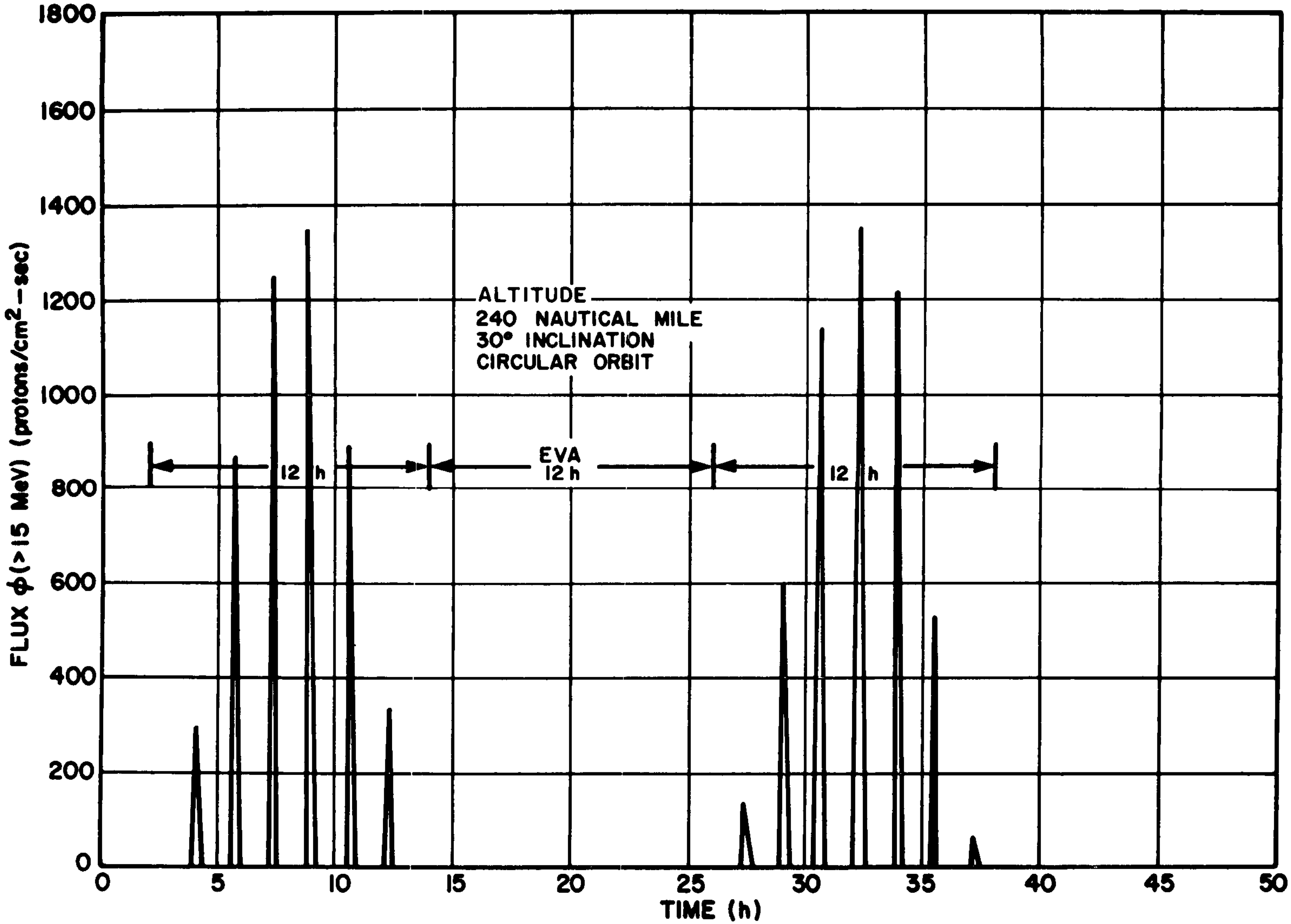

FIGURE 1. PROTON FLUX IN THE SOUTH ATLANTIC ANOMALY, ATM ORBIT

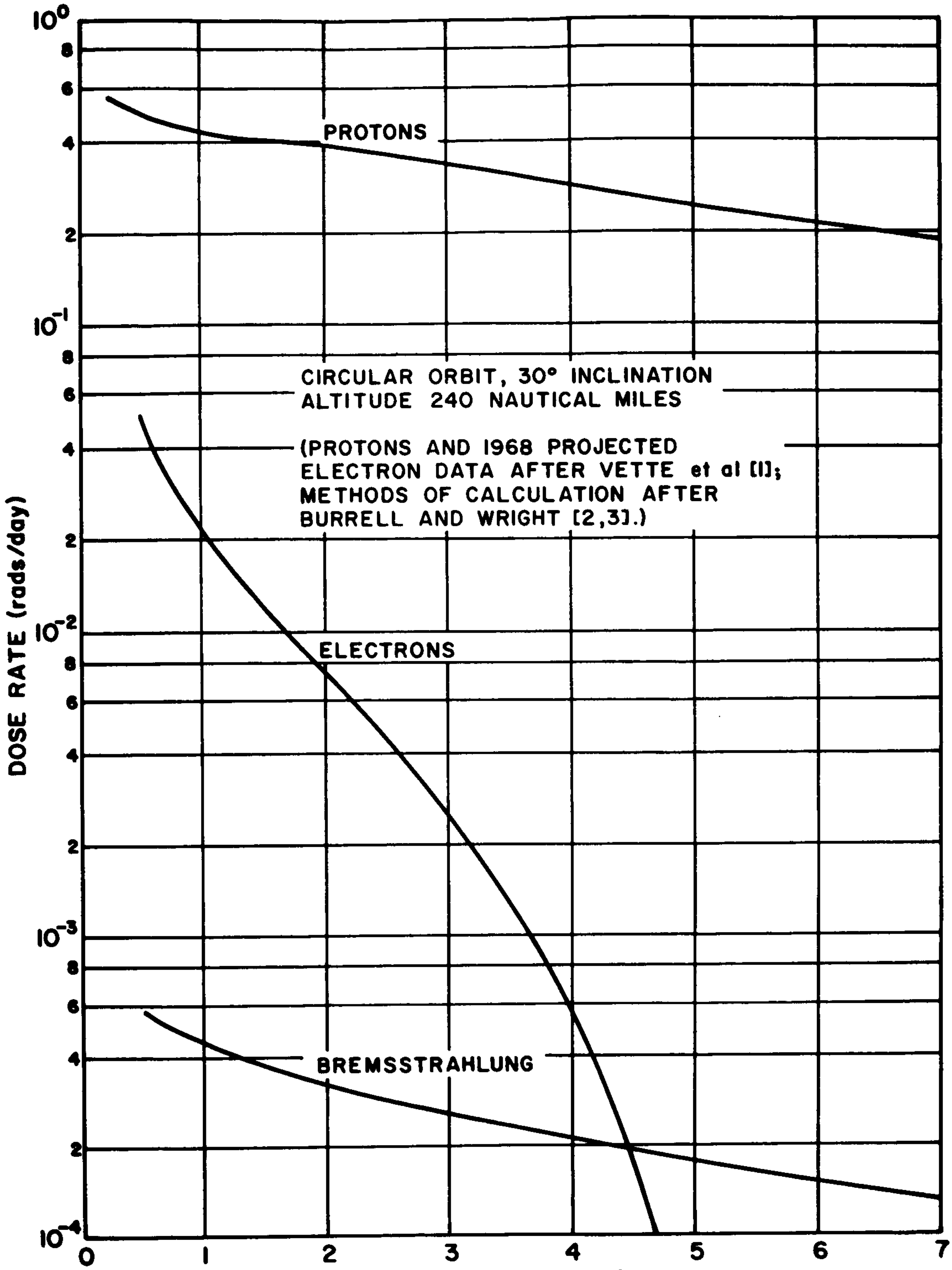

FIGURE 2. RADIATION DOSE RATES IN ATM ORBIT

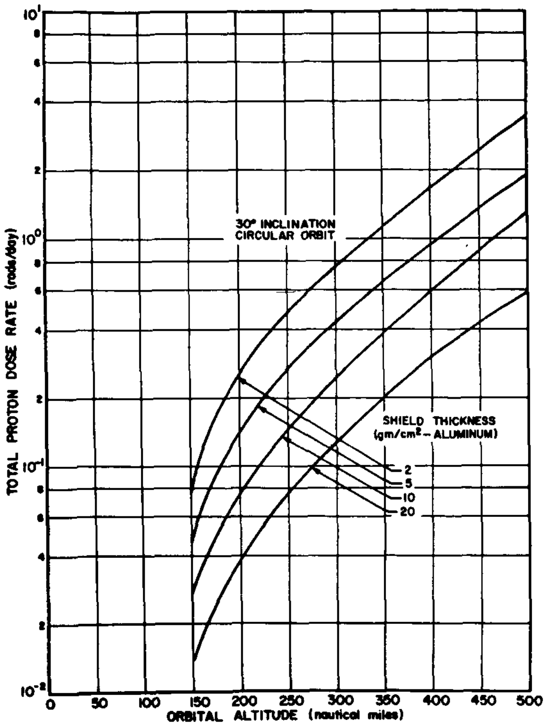

FIGURE 3. SENSITIVITY OF PROTON DOSE RATE TO ORBITAL ALTITUDE

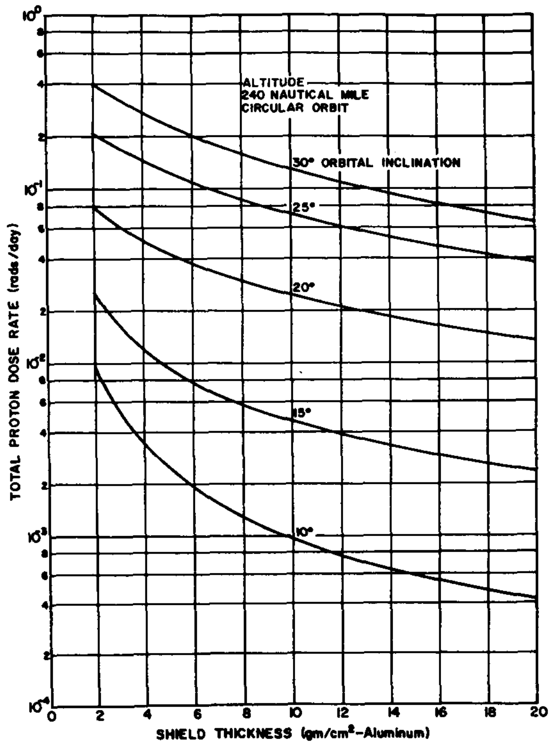

FIGURE 4. SENSITIVITY OF PROTON DOSE RATE TO ORBITAL INCLINATION

respectively. From these figures, it is seen that a 100-mile altitude reduction lessens the dose rate by approximately a factor of six, while an inclination change to 10° would reduce film fogging by two orders of magnitude.

FILM EXPERIMENTS

In order that the severity of the radiation problem be properly defined, the response of each film to protons of different energies must be determined. Depending on the film in question, available proton data were either limited or nonexistent. The Space Sciences Laboratory of Marshall Space Flight Center thus initiated a program to generate the required information, with the assistance of NASA scientists at Langley Research Center who were experienced in the experimental techniques involved. The team consisted of R. Potter and W. Breazeale, NASA-MSFC; R. Adams and G. Hill, NASA-Langley; A. Brake, Sperry Rand, attached to NASA-MSFC; A. Koehler, Harvard; and J. Beaver, ORNL.

The cyclotrons at Harvard University and Oak Ridge National Laboratory (ORNL) were used to irradiate film samples with monoenergetic proton beams. Exposures reaching several dose levels at 50, 90, and 130 MeV were carried out at Harvard, and at 10.1 and 17.6 MeV on the ORNL machine, after which the film was returned to MSFC for processing. Table I lists those films irradiated and the conditions under which they were processed.

TABLE I. PROCESSING CONDITIONS FOR PROTON IRRADIATED FILMS

FILM	KODAK DEVELOPER	TIME	TEMP.
KODAK SPECTROSCOPIC FILM, TYPE 103-0	D-19	4 min	68°F
KODAK SPECIAL SOLAR RECORDING FILM, TYPE SO-375	D-19	8 min	68°F
KODAK PLUS-X AERIAL FILM, TYPE 3401	D-19	8 min	68°F
KODAK PANATOMIC-X AERIAL FILM, TYPE 3400	D-19	8 min	68°F
KODAK SWR FILM	D-19 (1:1)	2 min	68°F
KODAK IMPROVED SWR FILM	D-19 ALSO DK-20	4-8 min/box 8 min	68°F 68°F
KODAK PATHE FILM, SC5	D-19	2 min	68°F

The fogging effectiveness of a proton beam depends on the energy of the protons. Thus, a plot of net film density versus particles/cm^2 yields for each film a family of five curves, one for each of the monoenergetic cyclotron beams. Subsequent analysis of these data resulted in the removal of the energy dependence by a mapping of each family of curves into a single curve of film density versus time. Details of the analysis are given in the Appendix. Figures 5-11 show the results for each type of film and for several thicknesses of shielding.

An accurate prediction of available shielding must take into account the detailed mass distribution of the entire clustered configuration; such a study is

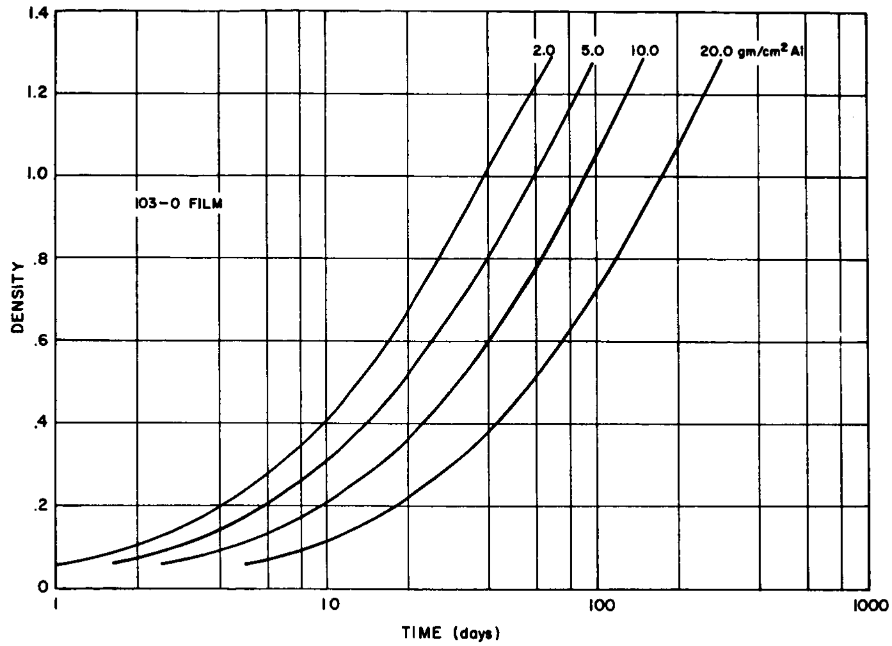

FIGURE 5. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, 103-0 FILM

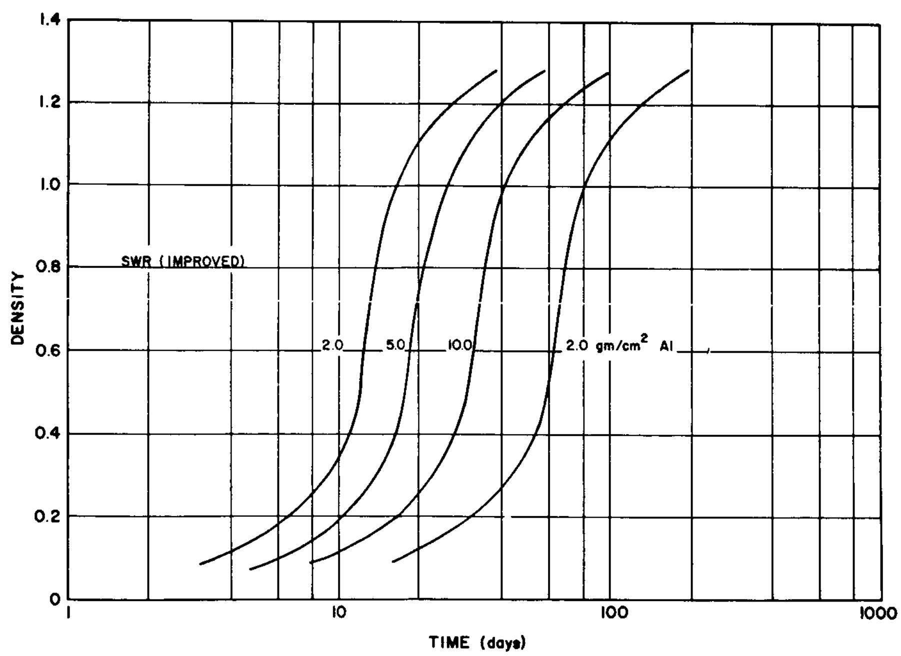

FIGURE 6. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, IMPROVED SWR FILM

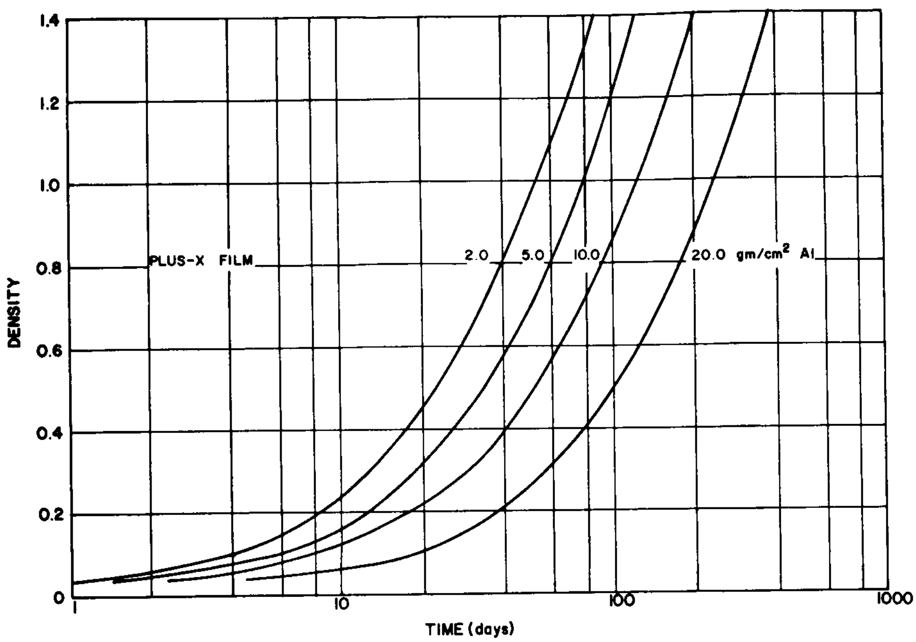

FIGURE 7. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, PLUS-X FILM

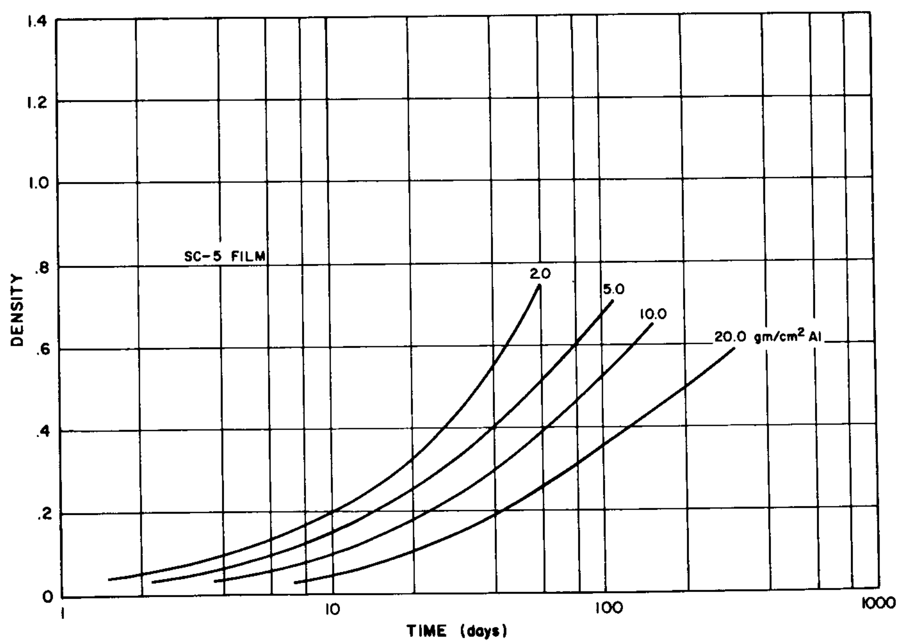

FIGURE 8. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, SC-5 FILM

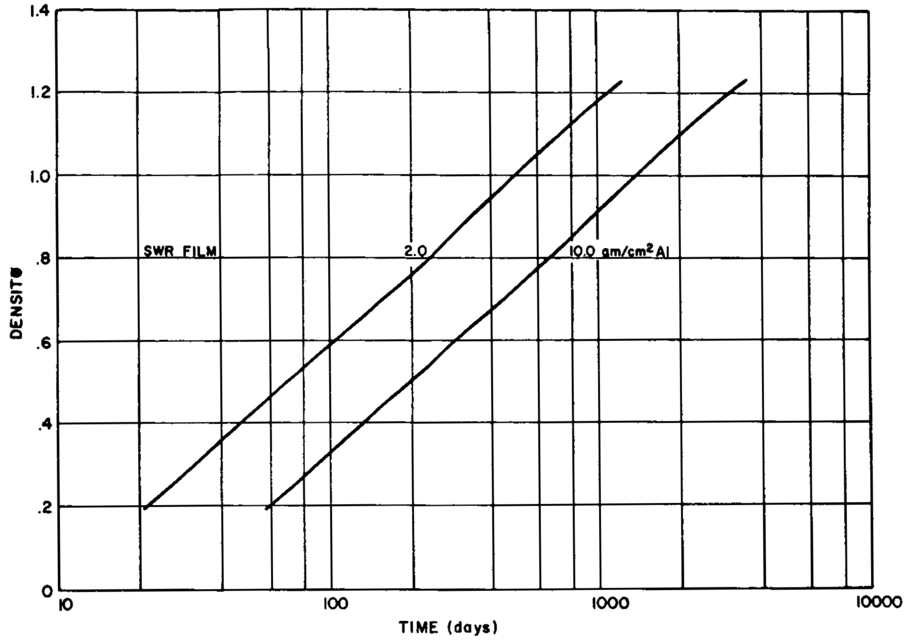

FIGURE 9. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, SWR FILM

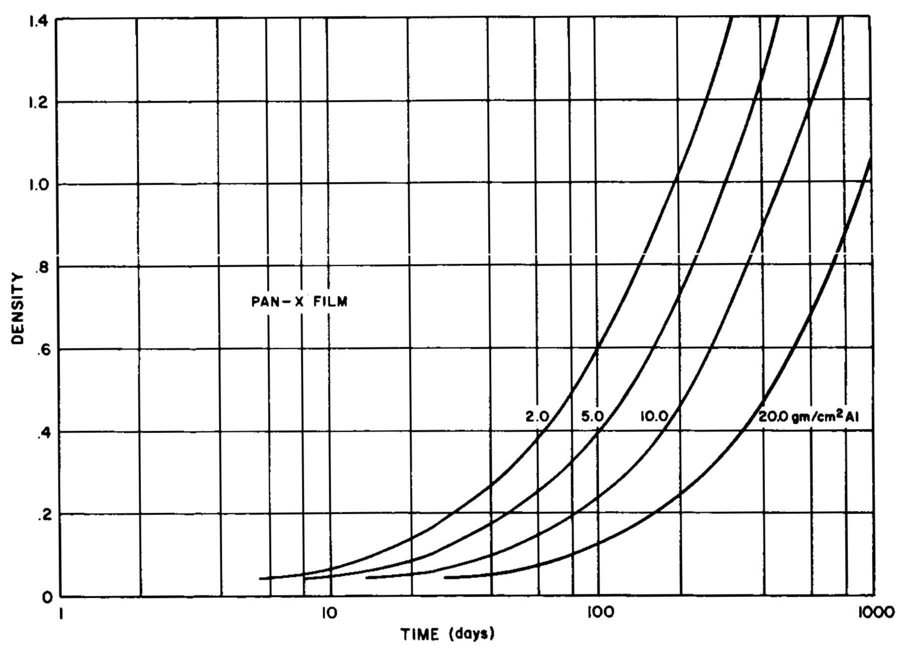

FIGURE 10. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, PANATOMIC-X FILM

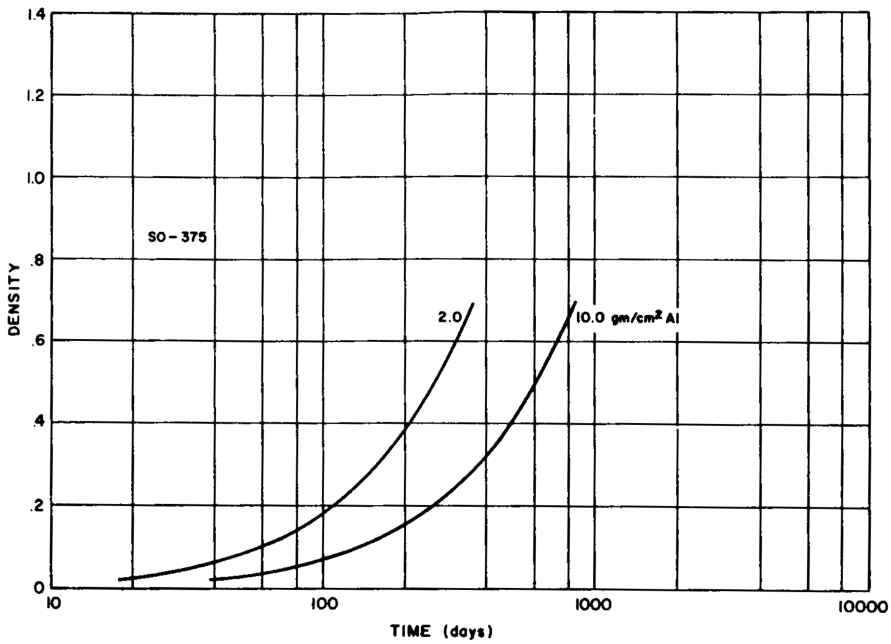

FIGURE 11. NET PROTON DENSITY VERSUS ATM ORBITAL TIME, SO-375 FILM

being performed by Lockheed. Their preliminary report [4] indicates that while in the ATM a representative film location is shielded by an equivalent spherical shell worth approximately 6 to 7 gm/cm^2 Al. Also, assuming that the Multiple Docking Adapter (MDA) is used for film storage, a typical storage box is surrounded by approximately 12 to 14 gm/cm^2 Al. Since it is not expected that a more detailed analysis will materially change the above results, a reasonable estimate of film density versus time for the entire mission can be obtained by following the 10 gm/cm^2Al shielding curves. The time in days to reach density levels of 0.2 and 0.6 are listed in Tables II and III, respectively.

TABLE II. DAYS TO ACCUMULATE 0.2 NET DENSITY

FILM \ SHIELD THICKNESS ($gm/cm^2 Al$)	2	5	10	20
103-0	4.3	5.8	9.8	18
SWR (improved)	6.6	10	16	31
PLUS-X	8.2	12	18	38
SC-5	11	15	23	42
SWR	21	41	60	130
PANATOMIC-X	34	49	87	170
SO-375	110	170	260	530

TABLE III. DAYS TO ACCUMULATE 0.6 NET DENSITY

FILM \ SHIELD THICKNESS ($gm/cm^2 Al$)	2	5	10	20
103-0	17	25	40	76
SWR (improved)	12	18	31	61
PLUS-X	28	42	64	130
SC-5	44	80	130	320
SWR	110	190	300	630
PANATOMIC-X	100	160	260	510
SO-375	310	460	720	1500

RESULTS

If the ATM orbital parameters remain as specified, and if no additional shielding is provided in the experiment area or storage location, SO-375 is the only film clearly resistant to radiation fogging. However, if we assume the cluster shielding average of 10 gm/cm^{2}Al, it also appears that SWR will survive the proton environment. The fate of SC-5 depends heavily on the tolerable density, as is readily seen by comparing Tables II and III; while a density of 0.2 is reached in three weeks, four months pass before the film accumulates a 0.6 density.

For the 103-0, Plus-X, and Improved SWR films, the problem is indeed serious. Goddard Space Flight Center and American Science and Engineering (AS& E) plan to use 103-0 in the X-ray experiments. Based on laboratory tests and previous flight experience, the Goddard experimenters have specified 0.2 as the 103-0 density upper limit. That level will be reached in approximately one week in the ATM (with 6-7 gm/cm^{2}Al shielding). Volume and weight limitations within the ATM package area seem to indicate that sufficient additional shielding cannot be accommodated. Since it appears that this film will certainly receive too much radiation in the present orbit, the authors are presently working with Mr. H. Murray Cleare of Kodak in an attempt to develop a substitute film for use in the X-ray/EUV region. One such candidate film, Panatomic-X with its gelatin overcoat removed, is currently undergoing tests at MSFC and GSFC. Preliminary results of exposures to 44 Å radiation by Goddard indicate that without the strongly absorbing overcoat the imaging qualities of Panatomic-X are comparable to those of 103-0 for equivalent exposure times. It is expected that exposure of the film to wavelengths covering a sufficiently wide portion of the spectrum may indicate that it can be utilized by both GSFC and AS& E in their ATM experiments. Such a film change is obviously desirable from the radiation damage viewpoint, since experiments by the Space Sciences Laboratory, MSFC, conclude that Panatomic-X is more resistant to proton fogging than 103-0 by an order of magnitude.

The High Altitude Observatory (HAO) is considering Plus-X for use in their experiment, with Panatomic-X as an alternate. Since the HAO desires quantitative photometric measurements from corona images out to several solar radii, their film can probably tolerate no more than 0.1 fog density. Plus-X will receive that limit in less than a week. However, in two weeks Panatomic-X will probably reach no more than a 0.04 - 0.06 level; during the 42-day storage period the effective shielding would have to be about 20 gm/cm^{2}Al, requiring additional shielding around the MDA storage box.

In defining their ATM experiment, Naval Research Laboratory (NRL) specified Improved SWR film (or SC-7, which is identical in proton response). Our experiments indicated that neither of these films could survive the 56-day radiation environment. The NRL also embarked on a film-irradiation program at their own facility; as a result, Improved SWR and SC-7 have been abandoned in favor of the less sensitive SWR.

CONCLUSIONS

It has been concluded that 103-0, Plus-X, and Improved SWR (or SC-7) would be fogged beyond acceptable limits if used by the experimenters on the ATM mission. However, it is probable that substitutes can be found for each. Improved SWR has already been eliminated; HAO is continuing to weigh Panatomic-X against Plus-X; and it is very possible that Panatomic-X without its overcoat is a good substitute for 103-0 in the X-ray/EUV region. However, should this film not be acceptable to the X-ray experimenters, Space Sciences Laboratory, MSFC, will continue to seek satisfactory film emulsions through a research effort in conjunction with GSFC and through our scientific interface with Eastman Kodak.

APPENDIX

ANALYSIS OF FILM DATA

In discussing the effect of a proton energy spectrum on the photographic film to be carried on the ATM mission, it is necessary to determine experimentally a function that gives proper weight to the various proton energies. The following analysis provides a means of incorporating experimental data, obtained by exposing film to monoenergetic, monodirectional proton streams, into an analytical scheme which describes the effect on film of a proton energy distribution in space.

The film density d' is defined by the equation

$$d' = \log_{10} (1/T) \tag{1}$$

in terms of the fractional transmission T of a standard light ray. The net density d associated with some exposure Q is written as

$$d' - d_0 = d = d(Q) \tag{2}$$

where d_0 is an initial background density and Q is the film exposure to radiation. In general, the dependence of d on Q, expressed as d(Q), and the Q associated with a given kind, energy, and amount of radiation will be determined experimentally.

It will be assumed for our purposes that exposures to various kinds and energies of radiations, simultaneously or in sequence, are strictly additive, so we can write

$$Q = \sum_i \sum_k Q_i (E_k) , \tag{3}$$

where E_k is the energy associated with the kind of particle identified by the subscript i. If there is a continuous distribution in energy of the particle population, equation (3) may be written as

$$Q = \sum_i \int Q_i(E)\, dE = \sum_i Q_i . \tag{4}$$

In discussing particle populations and film damage, it is convenient to define three functions. The particle differential energy spectrum $\phi(E,t)$ has units of particles/cm^2 sec MeV. We will neglect time dependence and write it as $\phi(E)$. We define the normalized differential energy spectrum as

$$\hat{\phi}(E) = \phi(E) / \int_E \phi(E)\, dE \tag{5}$$

and the time integrated differential energy spectrum as

$$\Phi(E) = \int_0^T \phi(E,t)\, dt = T\phi(E). \tag{6}$$

From the experimental data, we can see that some particles are more effective than others in producing film darkening or increase in density, and we define the exposure associated with the radiation with energies between E and E + dE as

$$Q_i(E)\, dE = \Phi_i(E)\, F_i(E)\, dE, \tag{7}$$

or

$$Q_i = \int \Phi_i(E)\, F_i(E)\, dE. \tag{8}$$

The function $F_i(E)$ may be viewed as a measure of the effectiveness of particles of the i^{th} kind in producing film darkening. In further discussions, the subscript i will be omitted and we will deal only with one kind of radiation, namely protons.

If one plots density d versus particles/cm^2, denoted by the symbol N, for several exposures to monoenergetic proton streams, curves such as shown in Figure A-1 can be obtained. It appears reasonable to combine all these curves into a single curve with the transformation

$$Q(E_k) = F(E_k)\; N(E_k) \tag{9}$$

which is another way of saying that the increase of film density with exposure is independent of the kind or energy of radiation if the exposure $Q(E_k)$ is defined properly. Note that equations (8) and (9) are similar, except that equation (8) is for a distribution in energy and equation (9) is for a monoenergetic stream, such as that encountered experimentally in the determination of the effectiveness function $F(E_k)$.

If a horizontal line is drawn at the level d_m in Figure A-1, values established for particle fluxes at different energies correspond to the same density d_m and, by definition, to the same exposure $Q(d_m)$. We denote these flux values as $N(E_k, d_m)$, since they are numbers which depend on the particle energy E_k and the film density d_m. From equation (9) we can write

$$Q(d_m) = F(E_k)N(E_k, d_m) \tag{10}$$

or

$$F(E_k) = Q(d_m)/N(E_k, d_m). \tag{11}$$

Equation (11) states that $F(E_k)$ is characteristic of a particle and its energy, although we may determine it by particular measurements of Q and N; accordingly, we remove the subscript k and write

$$F(E) = Q(d_m)/N(E, d_m) \; . \tag{12}$$

Equation (12) contains the reasonable assertion that the effectiveness of a particle is inversely proportional to the number required to produce a given density d_m.

From equations (7) and (11),

$$Q = \int \Phi(E)\, F(E)\, dE = \int \Phi(E)[\, Q(d_m)/N(E, d_m)\,]dE\, '. \tag{13}$$

Using the definition that

$$N\hat{\phi}(E) = \Phi(E), \tag{14}$$

we convert equation (13) to

$$Q = N \left\langle Q(d_m)/N(E, d_m) \right\rangle, \tag{15}$$

where we define the average for any quantity y (E) as

$$\langle y \rangle = \int \hat{\phi}(E)\, y(E)\, dE. \tag{16}$$

In dealing with particle populations, it is necessary to choose the units of Q so that it is easy to obtain a plot of density versus time for a particular

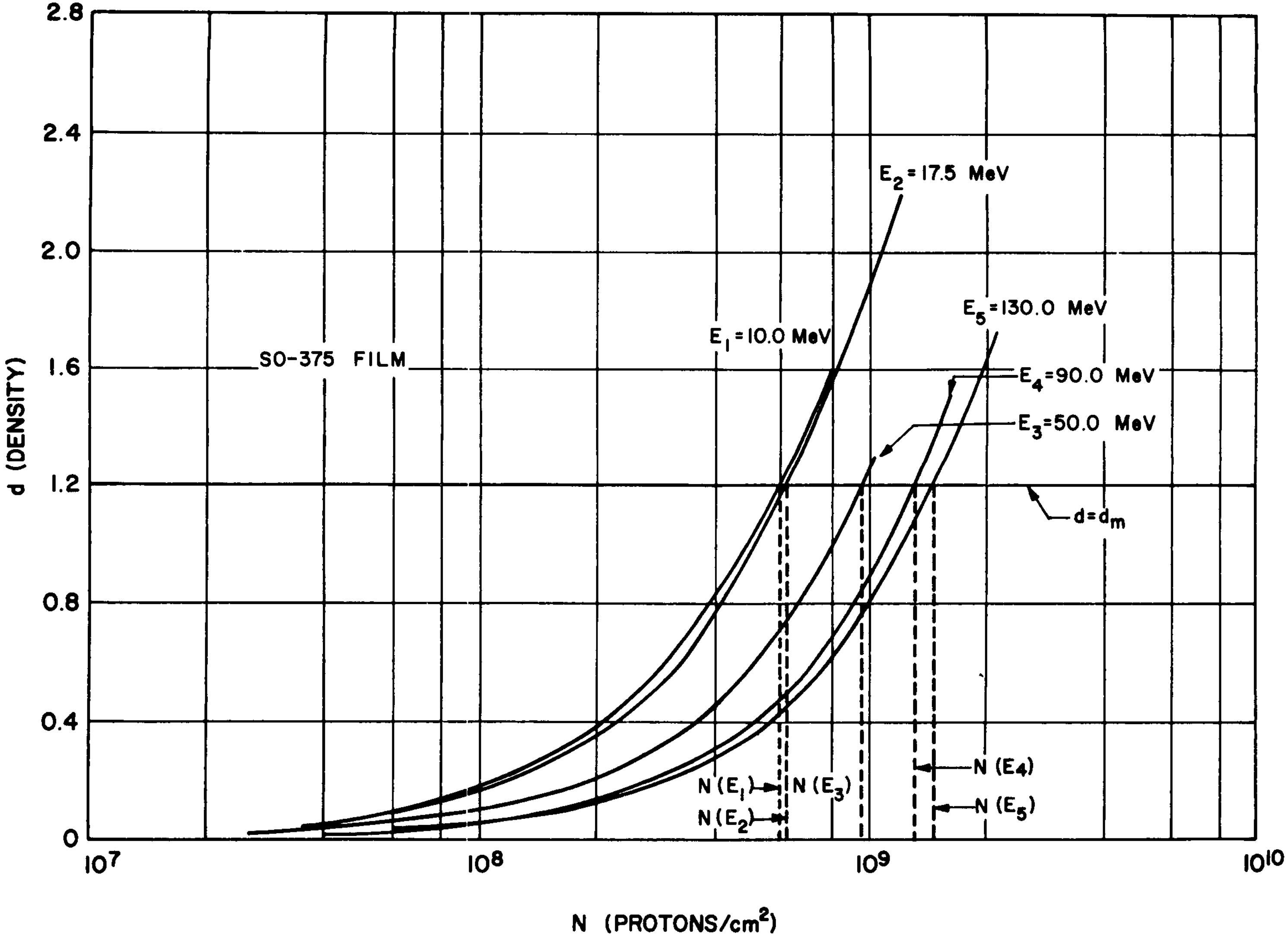

FIGURE A-1. DENSITY VERSUS PROTON EXPOSURE FOR A TYPICAL ATM FILM WITH PROTON ENERGY AS A PARAMETER film. Accordingly, we define

$$Q = N, \tag{17}$$

the particles/cm^2 for the radiation exposure, so that we require

$$\left\langle Q(d_m)/N(E, d_m)\right\rangle = 1. \tag{18}$$

Since $Q(d_m)$ is a constant for our particular measurement,

$$\left\langle Q(d_m)/N(E, d_m)\right\rangle = Q(d_m) \left\langle 1/N(E, d_m)\right\rangle = 1. \tag{19}$$

Therefore,

$$Q(d_m) = 1/\left\langle 1/N(E, d_m)\right\rangle . \tag{20}$$

Substituting equation (20) into equation (12) gives the following:

$$F(E) = \frac{1}{\left\langle 1/N(E, d_m)\right\rangle} \cdot \frac{1}{N(E, d_m)} \tag{21}$$

With this definition of F(E), we return to equation (9) and write

$$Q = F(E_k) N(E_k) \tag{22}$$

as the change of variable which maps all the density versus N (E_k) curves onto each other (i.e., equates each exposure to monoenergetic radiation, in terms of particles/cm^2, to an exposure to a spectrum $\phi(E)$ in terms of particles/cm^2).

To achieve the desired result, namely a curve of film density versus time for a particular orbit and a particular film behind a specified shield, we proceed as follows:

1. Establish a normalized energy spectrum $\phi(E)$ for the particular orbit and shield.

2. Establish a curve of $1/N(E, d_m)$ from curves of d versus $N(E_k)$, choosing a convenient value of d_m as shown in Figure A-1.

3. Compute $Q(d_m) = \langle 1/N(E, d_m) \rangle^{-1} = 1/\int [\hat{\phi}(E)/N(E, d_m)] \, dE$.

4. Compute curves of $F(E) = Q(d_m)/N(E, d_m)$.

5. Map each curve of d versus $N(E_k)$ onto a single curve of d versus $Q = N$ by the change of variable $Q = N = F(E_k) N(E_k)$.

6. Plot curves of d versus T, using $N = T \int \phi(E) \, dE$.

The foregoing discussion has described an analytical scheme for incorporating experimental data, in the form of measured film darkening associated with monoenergetic, monodirectional proton streams, into a method of predicting the effects of the space proton spectrum on photographic film.

REFERENCES

1. Vette, J. I., et al. : Models of the Trapped Radiation Environment, Vols. 1-3, NASA SP-3024, 1966-1967.

2. Burrell, M. O.: The Calculation of Proton Penetration and Dose Rates, NASA TMX-53603, Aug. 17, 1964.

3. Burrell, M. O. and Wright, J. J.: The Calculations of Electron and Bremsstrahlung Penetration and Dose Rates, presented at the 13th Annual Meeting of the American Nuclear Society, June 1967.

4. LMSC-A842261, AAP Film On-Orbit Storage Protection, June 30, 1967.

APPROVAL

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ANALYSIS OF RADIATION DAMAGE TO ATM FILM

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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