N93-13163

IIaO ULTRAVIOLET AND NUCLEAR EMULSION FILMS RESPONSES TO ORBITAL FLIGHTS ON STS-3, STS-7, STS-8, AND STS-40.

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ABSTRACT

Two types of film were flown on STS-40 space shuttle mission in June 1991. The IIaO special purpose ultraviolet film showed continued desensitization because of various thermal and cosmic ray interactions. The films were exposed to the space orbital environment for 9 days. There were several built in launch pad delays of the shuttle mission. However, there was adequate monitoring of the temperature variations on board the shuttle that allowed for adequate knowledge of the thermal film history. This IIaO film was flown on the ASTRO I mission and is currently stated for use with the ASTRO II mission. A 50 micron thick Illford Nuclear emulsion film was also placed on a 175 micron polyester base. The exposure to space produced several cosmic ray interactions that were analyzed and measured using Digital Image Processing techniques. This same nuclear emulsion film was flown on STS-8 and produced a similar number of cosmic ray and thermal interactions. From previous experimentation of film using various laboratory electromagnetic radiation sources (e.g., alpha, beta, and neutron particles), we have been able to infer the possible orbital interactions of both IIaO and nuclear emulsion films. The characteristic responses of IIaO on STS-40 compared favorably to the results obtained from previous STS-7 and STS-8 gas can experiments. The results indicate sufficient evidence correlating increased density on the film with possible cosmic ray, thermal and shuttle out gassing interactions.

INTRODUCTION

Since the first major use in 1974, scientists have used over 400 rolls of photographic film in space to obtain sensitometric data. The present research team prepared 3 canisters of IIaO film along with packets of color film from the National Geographic Society, which were then placed on the Space Shuttle #3 (STS-3). The ultimate goal was to obtain accurate data concerning the background fogging effects of IIaO film as it relates to total environmental factors. This included an examination ground based packaging and loading of the film from Goddard Space Flight Center to Kennedy. In addition, the following interactions with film were examined: 1) effects of solar wind; 2) effects of humidity; 3) cosmic ray interactions; 4) Van Allen Belt radiation exposure; 5)thermal effects; 6) the effects of reentry and off-loading of film during take-off; and, 7) an examination of orbital flight of film for 8 days, 3 hours, and 15 minutes. The objective of this experiment was to examine the total densitometric changes caused by all of the above factors.

Methods

The Laboratory of Solar Physics and Astronomy, at Goddard Space Flight Center, has used large quantities of IIaO film in rockets and space shuttle flights. During the Ultra Violet Image Telescopic Experiment, the UIT launched a payload which used 70mm IIaO film. This was a requirement for the laboratory to quantitatively determine the aging effects associated with the sensitometric images on film. Spectroscopic IIaO film for this experiment (Figures 2 & 3) was obtained from the same roll of Kodak film Mfg. date 5-76 A5J. The film was loaded into specially prepared aluminum anodized packages that fit on the Space Shuttle's Getaway Special Container. One roll of film was cut from the same stock and maintained as the control. The control was maintained at a temperature of 22 degrees centigrade at Goddard Space Flight Center. After the mission, the three rolls of IIaO film were shipped back to the Small Payload Section of the Laboratory of Astronomy and Solar Physics. One film and the control film were developed as Set I, while the other IIaO sample film was developed as Set II.

Results and Discussions

Using a Macbeth Densitometer, measurements were obtained from the film every 2 centimeters, developing 3 columns of data. Significant differences were found when samples were compared with the control. Sample A and Sample B had a 5.26% increase in optical density or fogging background, while the film developed shortly after its arrival at Goddard Space Flight Center displayed a 3.8% increase in the optical density or the fogging background. An analysis of the data for each sample film aboard the Space Shuttle (Figure 5, 6 & 7) indicated variation in intensity with respect to fogging levels as a function of position on the film. There was increased random variation toward one end of the film. However, the actual orientation of the film in the Space Shuttle was not known. One hypothesis is that high energy cosmic rays penetrated the aluminum film cartridges aboard the Space Shuttle causing secondary reactions that produced variations towards one end of the film due to the wrapping procedure used in placement of the film in the canisters. Another hypothesis is that thermal effects cause density variations. Aluminum containers have been found to innately fog various UV films along with the wrapping geometry of film in the canisters.

Densitometric Response of IIaO Film Flown on STS-7

Three canisters of 35mm IIaO film were flown on STS-7 in a getaway special canister in cooperation with NASA's Plasma Physics Branch and the Naval Research's Solar Astronomy Branch. The results indicated a large degree of thermal aging during the space shuttle mission. Future requirements for films used aboard the space lab and on the UIT (Ultra Violet Imaging Telescope) will include the following : 1) ultraviolet films may be exposed directly to a particular vacuum of space at various altitudes, thus giving rise to concern for metallic outgasing of chemicals that may cause permanent damage to the film's emulsion; and 2) the IIaO film used on the UIT may not be exposed directly to space, but may be exposed to the ionospheric fields associated with a low orbiting space shuttle. Finally, the major factor that causes fogging of film has been thermal exposure.

Experimental Set-Up

Using a sensitometer, a continuous roll of IIaO film was exposed for ten seconds using a General Electric Lamp 328 at 195 ma + 3 ma with a 10 - 18 hour calibration burn in time. The film was loaded in three 35mm canisters, sealed in air and attached to the getaway special canister containing other special ultraviolet films. The film was loaded in the canisters approximately 22 days before the launch of the Space Shuttle Columbia.

Discussion

During the loading or preflight launch and post-flight analysis (Fig. 8), that the IIaO film had been exposed to some type of thermal aging effects. The exact nature of these effects was not apparent as we examine the temperature profiles for STS-7. However, there was concern that the rapid increase in temperature from approximately -15°C - +22°C in 1.5 hours after touchdown of the shuttle on the West Coast could explain the exaggerated thermal effects. There was another real concern which was associated with the fact that the shuttle landed on the West Coast and the automatic temperature cut-off control was turned off approximately three days before the shuttle arrived at Cape Kennedy where the getaway special canister containing the film was unloaded. Analysis of terrestrial thermal and aging effects produced similar curves as observed in this experiment, but the slopes of the individual curves tended to vary dramatically. In conclusion, there were observed densitometric changes in comparing the control films and flight film, though both had been developed at the same time as the flight film received from STS-7.

Experimental Set Up for STS-8

This research team was able to use one of the canisters to place four rolls of IIaO film of STS-8, one roll of Illford G5 nuclear emulsion, and one roll of a new batch of IIaO. The Naval Research Laboratory set-up was using a very sensitive ultraviolet film to study the effects of space on the ultraviolet emulsions. The shuttle orbit was low enough to expect some minimum cosmic ray damage to the film as well as tracks on the nuclear emulsion film. The Getaway Special was aligned in the bay of the shuttle with bay portals pointed to the earth for cooling purposes as shown in Figure 9.

The temperature profiles for STS-7 and STS-8 were very similar in that, it went from a temperature of approximately 23°C degrees centigrade before launch to -22°C during the flight. This increased the optical density of the wedges. The major differences between STS-7 and STS-8 occurred because STS-7 had to land in California where the automatic temperature control devices and appropriate air conditioning units for the shuttle cargo were not present. Once the shuttle had landed, one can measure the diurnal temperature variations (Figure 8). Terrestrial experiments have shown that less dense wedges produce densitometric increases as the temperature increases over a number of days (Figure 12). The diagram shows the effects of the first 3 step wedges including the aging effect of the background at 32°C. Lowering of the temperature decreases the slope of the curve for each of the darker step wedges (Figures 11 & 14). Aging effects show the slope variation at 21°C and at 32°C over a 90-day period.

A most interesting effect occurs at the darker patterns. They tend to decrease in density, while the lighter patterns tend to increase in density. Furthermore, the IIaO film seemed to perform nonlinearly for temperature values above 67 or 68°C (Figure 13). The least dense step wedges tend to show dramatic increases in density above 68°C while the darker wedges show a reduction of temperature above 70°C. The slope of the curves of these films increased further when the ambient temperatures increased.

A brief examination of the aging effects will assist us in understanding the observed effects on the film caused by exposure to the space environment of the shuttle (Figure 14). We used a microdensitometer to contrast and compare the terrestrial film as well as the shuttle flight film (Figure 15). Using this technique we were able to calculate the signal to noise ratio for flight as well as control film. On STS-8, the signal to noise ratio increased while the control film decreased. The signal to noise ratio computed for STS-7 shows that at higher exposures, the signal to noise ratio was less than the flight films (Figure 16). But at lower exposures, the control and flight film seem to have larger signal to noise ratios (Figure 17). This difference may be caused by additional thermal activity within the canister as shown in Figure 17 and the lack of appropriate air conditioning equipment at the California landing site.

Signal to Noise Ratio of Aging Film

An analysis of the signal to noise ratios for IIaO film aged for 8,9,21, 17, and 71 days indicated that a certain amount of aging reduces the signal to noise ratio over the short term, but will increase the signal to noise ratio over long periods of time (Fig. 18). An examination of the interaction of protons at varying dosages and energies indicated that the very light wedges are very sensitive to proton interaction with the emulsion while the very dark patterns tend to be less sensitive to very high MEV protons (Figure 19). MEV vs. dosage measurements were obtained by using the Harvard University Cyclotron.

Using the Harvard University Cyclotron, we bombarded the IIaO film with alpha particles, (Fig. 18) searching for parallel interactions in the space shuttle due to cosmic rays interactions. We bombarded the IIaO film using alpha particles at 47 MEV, 79 MEV and 153 MEV for the 6.8 rad dosage. We expected to see similar results when we examined the films from the shuttle, however, we did not observe similar results (Fig. 19). There was however, difference in the toe of the curve, but the toe and the shoulders did not seem to respond. As a result we did not conclude that there was any dramatic cosmic ray activity (Fig. 20A).

Microdensitometric Analysis

When comparing similar step wedges that have been aged from 3 to 71 days, one can immediately see an increase in granularity. However, this was not consistent for all step wedges as it was for the middle wedges. The denser the wedges, the more one observes the converse of less granularity. As aging increases, granular definition between step wedges seems to decrease, while other step wedges under densitometric aging will produce a heavier granularity indicative of increased grain structure.

Microdensitometric Comparison of Control vs. Flight Film

The control film of STS-8 for step wedge 3 had a larger grain structure than flight film. Similarly on STS-8 strip 4, a new batch of IIaO film showed slight increase in granularity toward the darker wedges (Figure 24). Conversely, the least dense step wedge controls are heavier than the traces for the flight film (Figure 25). Microdensitometric traces from STS-8 showed greater granularity for the flight film than for terrestrial controls (Figure 27).

A new approach to examination of the IIaO film emulsions is the utilization of scanning electron microscopy to investigate surface grains and structure of film. Varying the voltage of the probe electrons, we were able to examine grain structure under the surface of the emulsion at the proper accelerating voltage of the electrons. All IIaO films were coated with gold palladium using standard sputtering techniques. Using 1,000X Magnification (Fig. 27), it was evident that energy of the electrons within the scanning electron microscope striking the emulsion was crucial in viewing grain structure of film. Further experiments will examine aged film and observe exactly how the grains change (Figure 28). We found that a working voltage for SEM ISISS 40 between 2-10 kilovolts was sufficient to produce clear images without flaring. The flaring of the image from the SEM produces a 4.8% increase in the total area of the grain under investigation from direct measurements of the micrograph. As the energy of the electrons increased, there was a flare effect as each grain enlarged (Figure 29). The one grains beneath the surface of the emulsion were observed. Using scanning electron microscopy, we can examine some of the grains below the surface if the charging voltage is appropriate.

We also looked at the step wedges of film under the electron microscope. The extreme left represents the least dense, and the extreme right represents the denser wedges. (Figures 33, 34, & 36). As the density increased, the size of these grains seems to decrease. Using this technique, we measure and acquired some statistical understanding of structure (Figure 38). Qualitative analysis techniques of energy dispersion revealed a large Ag peak along with traces of Cu, Na, S, and Ar peaks as shown in Figure 38. These trace element peaks are associated with the elements used in the development process and other materials in the emulsion.

Reciprocity Failure of IIaO Spectroscopic Film

Reciprocity failure was examined for IIaO Spectroscopic Film. The failure was examined over two ranges of time from 1-31 seconds, and 1 - 180 minutes. The variation of luminance was obtained by using thirty neutral density filters. A standard sensitometric device imprinted the wedge pattern on the film as exposure time was changed. Our results indicate reciprocity failure occurred for higher density patterns within the first minute. Multiple failure occurred at 13, 30, 80, and 180 minutes.

Materials and Methods

Twenty-seven wedge patterns were placed on IIaO spectroscopic film in total darkness using a light sensitometer with a 24 hour burn in time for the bulb. Each film section was exposed to the light sources for specific periods of time. Time intervals were from 1-30 seconds, 1-11, 15, 19, 22.5, 25, 27, 30,35, 40, 45, 59, 90, 125, and 180 minutes respectively. The film was then developed using Kodak D-19 developer, rapid fixer, hypo-clearing agent and photo-flo solutions. In total darkness, and in a water bath at a temperature of 20°C ±1.5°C, one section of film was placed in Kodak D-19 developer and gently agitated for four minutes using a specific soak and agitating pattern. The film was washed in water for 30 seconds, shaken, then placed in Kodak rapid fixer solution, using the exact same pattern of agitation and soaking, and gently agitated for four minutes. The film was then removed and rinsed in water for 30 seconds, washed in water for one minute, and then hung to dry. After developing, the optical densities of the wedge patterns were read using a Macbeth Densitometer.

Results

An examination of the reciprocity failure for the 1 - 30 second exposure periods (separate wedge pattern that was exposed to an amount of light from 1 - 30 seconds sequentially) revealed that for two separate batches of film whose histories of use were different, there was reciprocity failure occurring at the darker wedge patterns. An examination of the very light patterns further showed the trend of reciprocity failure at the 30 and 31 seconds. It should be noted that the very darkest patterns had a marked decrease in reciprocity failure around the 30 second interval, with other variations occurring at 10, 15 and 19 seconds consistently with each variation of the pattern. The results showed that the reciprocity failure minimum points occurred at 13 minutes, 30 minutes, and 90 minutes, with a less defined failure at + 80 minutes. The middle density wedges indicated the same reciprocity failure points occurring at the same time. The darkest wedges showed remarkable stability for the first 10 minute exposure, but dramatic failures occur at 11 and 20 minutes, and dramatic reductions occurred at 30 minutes.

Conclusion

For exposure times of 30 to 31 seconds, darker wedges experienced failure more than light wedge patterns. This indicated that lighter wedges are less sensitive to Reciprocity Failure at short exposure times. As the exposure times increased, there appear to be some migration of grains in the darker wedges. The last three columns gave an appearance that double exposure had occurred. There was also an increased darkening of the film with increased exposure times. Fogging of the film was prevalent at 30, 45, 58, 90, and 180 minutes with increased exposure times. An examination of the reciprocity failure from 1 to 180 minutes completely demonstrated that reciprocity failure minimum points are at 13 minutes, 20 minutes, 30 minutes, and 90 minutes, whereas, less defined failure occurred at 11 minutes, with reductions at 30 minutes.

Results on STS-40

On STS-40, flown in June , this researcher sent IIaO film in space that was flown on the ASTRO I mission and will be flown on ASTRO II missions, which is slated for 1993-1994 (Figure 39). Illford nuclear emulsion film was flown on the mission and produced five major cosmic interactions (Figures 40,41, & 42). A small container of over the counter medications was also flown on this mission in order to measure the potency of these medicines after exposure to space. Selected amounts of aspirins, and Tylenol other drug were flown with the seals left unbroken while the rest remained sealed. This research is currently being analyzed by students and faculty of the Howard University School of Pharmacy.

When comparing control studies with experimental studies, interesting results have appeared when the IIaO film was exposed to various wavelength of electromagnetic radiation. Alpha and Beta particles consistently interacted with the low density wedges and reacted more with the darker step wedges. The high energy gamma rays effected the middle density wedges, producing a loop. Exposure of the same film caused darker density wedges to increase substantially by neutrons, infrared and thermal radiation had an effect on the toe and shoulder of the H and D curves.

The most important result of the reexamination of the IIaO film on the STS-40 produced an effect that involved heat and beta exposure density wedge increases, while analysis of the STS-8 seem to produce exposure levels similar to the gamma ray reactions observed on Earth. The results of the density measurements indicate that the STS-40 experienced higher thermal effects than STS-7 or 8 (Figures 43 & 44). There was a hold on the launch as well, which may account for this change, but a reexamination of the averages from all the separate density wedges seem to imply that the film was exposed to either thermal or cosmic ray influences (Figure 45).

Summary

The results of these studies have implications for the utilization of the IIaO spectroscopic film on future shuttle and space laboratory missions. These responses to standard photon energy sources will have immediate applications in a terrestrial or extraterrestrial environment with associated digital imaging equipment. The author is indebted to Gerry Baker and Al Stober of the Small Payloads Section of the Laboratory for Solar Physics and Astronomy for their hours of discussion and support. Special thanks go to Dr. Dan Klingsmith of the Interactive Astronomical Data Analysis Facility, also of the Goddard Space Flight Center, Greenbelt, Maryland for his patient assistance during the imaging processing of these films. Very special thanks go to Kevin Peters, Sean Gunther, Lisa Cunningham, and Deborah Wright for their careful assistance during the development process.