RAD: The Space Shuttle Radiation Environment And Its Effect on High Sensitivity Film

(STS-85/STS-91 SEM Experiment)

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ABSTRACT

The "RAD" (Radiation Assay Device) SEM experiment consists of two parts: a set of passive radiation dosimeters and several rolls of high speed color photographic film. The experimental package was flown on two separate high inclination shuttle missions, STS-85 (57^{o}) and STS-91 (51^{o}). The goal was to accurately measure the amount and type of radiation exposure to a typical payload in low earth orbit and to evaluate the possible effect on commercial sensitized photographic products that might be used in a small shuttle payload for research documentation.

BACKGROUND

The radiation environment of low Earth orbit has been studied throughout the space age, primarily from the point of view of health and safety. Space flight, and to a lesser extent atmospheric airplane flight, does expose the body to higher levels of radiation than would be the case at sea level. Although the space shuttle flies outside of the radiation shield of the atmosphere, it is operating within the magnetosphere, which is the earth’s most important radiation barrier. During periods of low solar activity, the orbital radiation environment is considered an acceptable health risk for the relatively short duration of a shuttle mission. Higher inclination missions would be expected to show somewhat increased radiation levels since the shuttle is operating nearer to the poles where the magnetosphere is weakest.

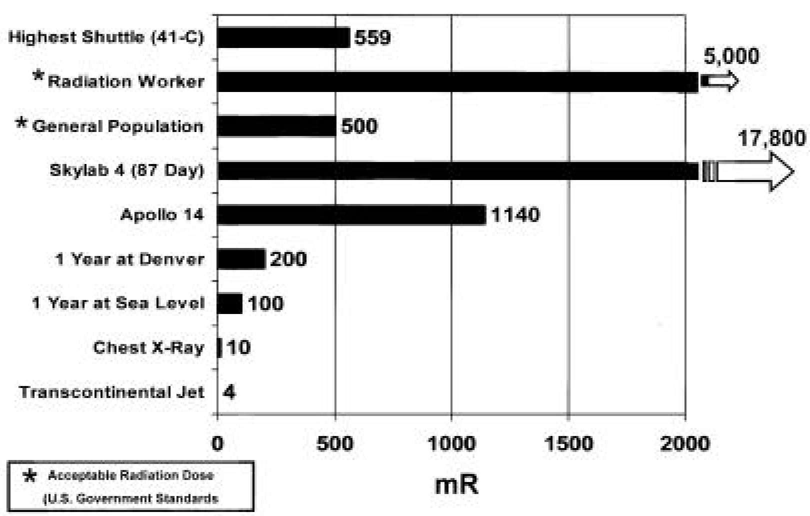

Figure 1. Radiation exposure for different conditions

Generally speaking, a typical shuttle mission should expose the crew to a radiation dose similar to living one year in the mountains. Shuttle mission STS-41C recorded the highest dose with the crew getting an exposure during their eight-day mission that was slightly higher that the U.S. government acceptable radiation dose for the general population for one year. Even this dose is only a tenth of the acceptable one-year dose for a worker in the radiation industry. A longer duration mission such as Skylab or Mir can expose the crew to doses many times the limit, but since it is a one time exposure, the health risks are considered acceptable. The greatest fear is a major solar flare which can expose a protected crew to doses up to 100 REM (100,00 mR) per hour. The radiation levels on a high inclination flight during a quiet solar period were not expected to significantly effect film shielded within the substantial physical structure of the payload and assembly. Practical experience with less sensitive films in previous payloads such as G324 (GeoCam) had shown no noticeable problems.

Experimental Design

Both the passive radiation dosimeters and the photographic film were carefully matched to control samples, which were treated identically in every respect except for the space flight itself. A sample of film from the same emulsion batch was processed immediately after purchase to serve as a control for any fogging due to normal film aging during the eighteen-month experimental period. Another control film sample was stored in normal room conditions at sea level. This sample was processed at the same time as the space-flown sample. The primary film selected was Kodak Royal Gold 1000 high-speed color negative film. Samples of several other popular commercial high-speed transparency and negative films were also flown but without full controls.

The radiation dosimeters were custom made by R. Craig Yoder, Ph.D. and Mark Salasky at Landauer Inc. Two pair of dosimeters were produced, one pair to serve as a ground control and one pair to serve as a mission sample. Each pair of dosimeters consists of an Optically Stimulated Luminescence (OSL) package and a Neutrak 144 package.

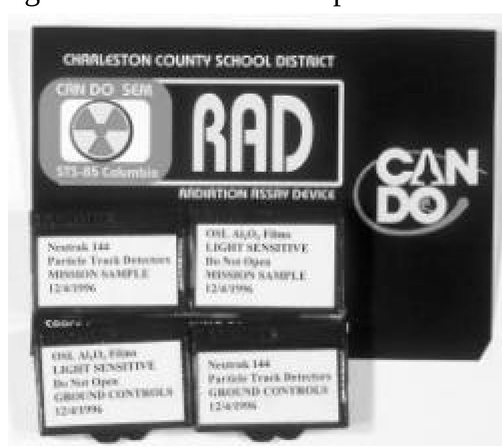

Figure 2 – RAD, dosimeters and flight package

The OSL detector consists of specially prepared sapphire (al_2O_3) powder bonded to a clear styrene film base. Luminescence is used to measure the radiation dose received. The OSL detector measures primarily low Linear Energy Transfer (LET) radiation such as electrons and photons. The package contains 15 detectors, some of which are encased by a 1 mm thick aluminum attenuator. The attenuator acts as a filter to separate low energy x ray and electron dose from the dose due to high-energy photons and electrons.

The Neutrak 144 particle track detectors assess dose from high LET radiation made up principally of protons, helium nuclei, and to a lesser extent, heavy ions. Eleven Neutrak 144 detectors are included in each package. Each detector is a piece of allyl diglycol carbonate plastic also known by the trade name CR-39. High LET radiation disrupts the chemical bonds at the locations where they strike. After exposure the detector is etched in a caustic bath, which causes the radiation-damaged sites to become visible as pits or tracks. The number of tracks under microscopic examination is directly correlated to radiation dose.

The expectation was that a typical shuttle mission would show radiation levels somewhat higher than the ground control but at doses of minimal physiological effect and below the sensitivity threshold of the film products.

DOSIMETER RESULTS

Upon return of the payload, the radiation dosimeters were returned to the manufacturer for analysis. The passive dosimeter results for the space-flown film showed dosages of low LET radiation approximately twice that of control levels (68.2 vs. 145.6 mR) and dosages of high LET (higher energy) radiation that were many times greater than control (8.4 vs. 126 mR). The average control total dosage was <100 mR and the average payload dosage >250 mR. This result was consistent with previously published data and showed that STS-85 had a fairly typical radiation environment compared to other shuttle missions. The total exposure of 272 mR applied to the crew represents the equivalent of approximately 18-month normal background radiation living at the elevation of Denver Colorado.

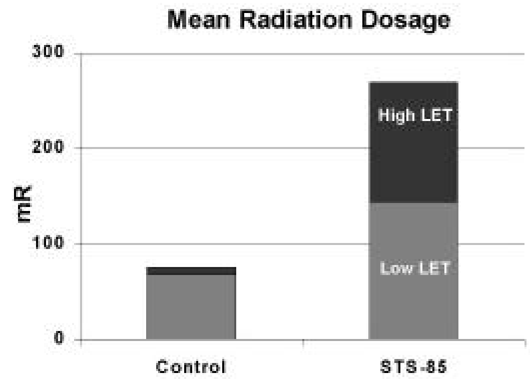

Figure 3. Dosimeter result for STS-85

FILM RESULT

Surprisingly however, the ISO 1000 color negative film showed a level of fogging not only obvious to the naked eye but also significant enough to seriously degrade any images recorded. The question was how to reconcile the low radiation levels as shown on the dosimeters with the dramatic fogging of the film.

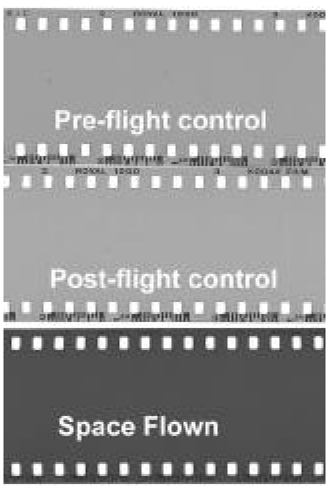

Figure 4. Film samples

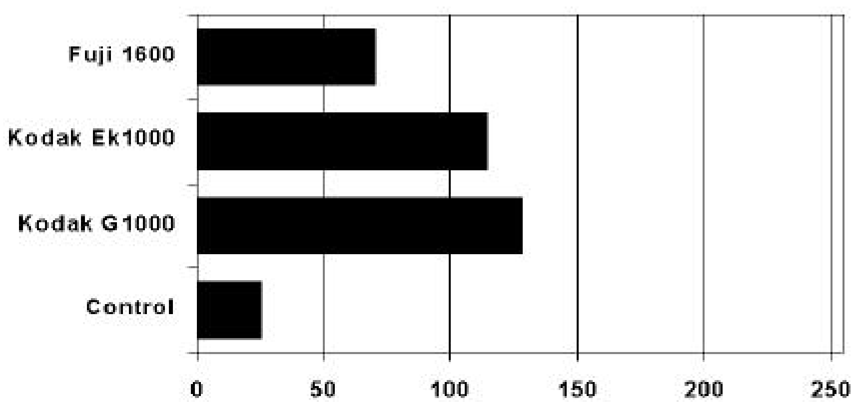

Figure 5. Results by film type

The fog density level was consistent on each roll of the Kodak Royal Gold 1000 film flown. The pattern of fogging was even showing no evidence of shadowing. A re-flight on STS-91 demonstrated a similar although less dramatic result. Over film types flown showed varying degrees of fog density which did not correlate directly to film sensitivity or manufacturer. Fujicolor Super HG 1600 (ISO1600), the most sensitive film flown, actually showed a significantly lower density than either of the ISO 1000 films. A roll of Fujichrome Provia ISO 400 color transparency film showed no significant damage. The results indicate that ISO alone cannot serve as a reliable indicator of the likelihood of film damage due to radiation. Actual testing of samples should be used to verify film suitability before use in a payload.

The degree of fogging on the primary test film was so unexpectedly high that it raised the question whether it was due to radiation alone. Long storage times, the dry nitrogen atmosphere and possible heat exposure were other possible factors.

VERYFYING THE FILM RESULTS

A separate experiment was designed to establish whether the observed film result was consistent with the STS-85 background radiation levels shown by the dosimeters. Since the film and dosimeters were carried in the same experimental housing, the radiation exposures to each should be identical. The long standing Can Do Project's Business-Education Partnership with the Medical University of South Carolina made accurate testing possible. Dr. Don Fry of the M.U.S.C. Department of Radiology set up a test to expose film samples to measured x-ray radiation doses. The films were exposed to doses of 328 mR (closest possible match to the flight dose of 272 mR), 1186 mR and 4650 mR using a standard hospital x-ray unit. The test and control film samples were also compared to film exposed to a standard airport security x-ray machine (dosage unknown). The film samples were then processed under controlled conditions. The film was digitally scanned and measured by computer densitometry using the facilities of the M.U.S.C. Department of Pathology Image Analysis Core Facility.

Figure 6. The author and Dr. Fry x-ray the film

Figure 7. Scanning the film

Figure 8. Computerized densitometry

The results indicated that the shuttle mission had a far greater effect on film than multiple passes through an airport security check. A single pass through an airport machine approximately equals the normal background fogging of the film during eighteen months aging. The shuttle flown film density was somewhat higher but similar to the density from an equivalent medical x-ray dosage (based on the dosimeter results from the same flight).

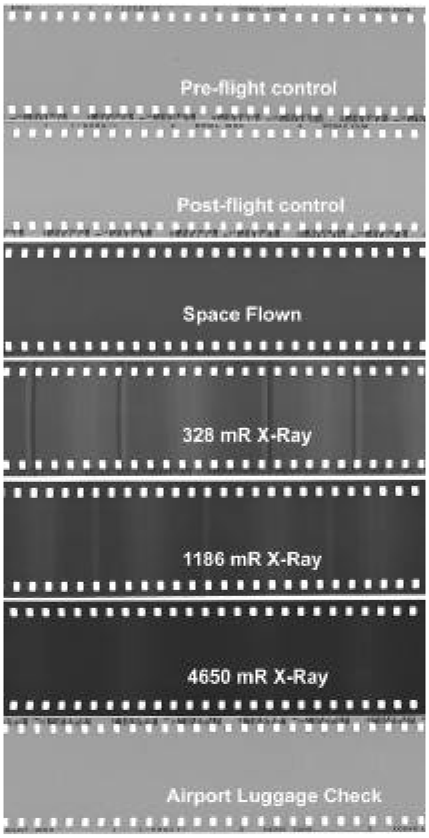

Figure 9. Test and flight films

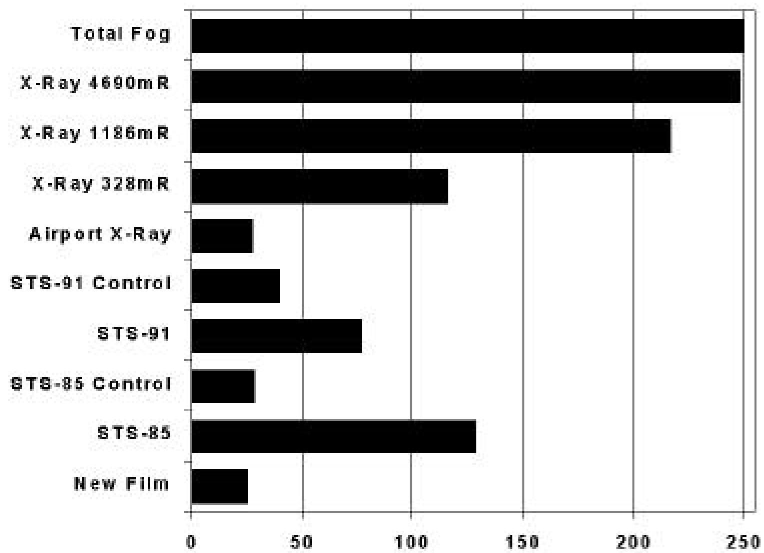

Figure 10. Density values measured by computerized denitometry for test and space flown film

TEST RESULTS

The comparison between the x-ray samples and the STS-85 film samples showed a density level that was consistent although the space-flown film showed a slightly higher density even though the measured radiation level was slightly lower. The x-rayed film showed distinct patterns (shadowing) that were not evident in the space sample. This is a result of the "point source" nature of the clinical x-ray machine as opposed to the diffuse source of natural radiation. The density on the flight sample is very likely enhanced by the unintentional film sensitization caused by prolonged exposure to a dry inert gas atmosphere (a process similar to that employed by astronomers to increase emulsion sensitivity for long exposures to dim light). Such sensitization would show the most effect on slow long time exposures, which characterizes the background radiation.

CONCLUSIONS

Modern high-speed film emulsions are extremely sensitive to exposure to the high-energy form of radiation experienced in low earth orbit. The payload structure does not provide sufficient shielding to block this high LET radiation. These results indicate that high-speed photographic films are possibly not suitable for image recording in space shuttle payloads without special shielding. Preference should be given to lower sensitivity films where possible and testing should be used to verify the choice of material.

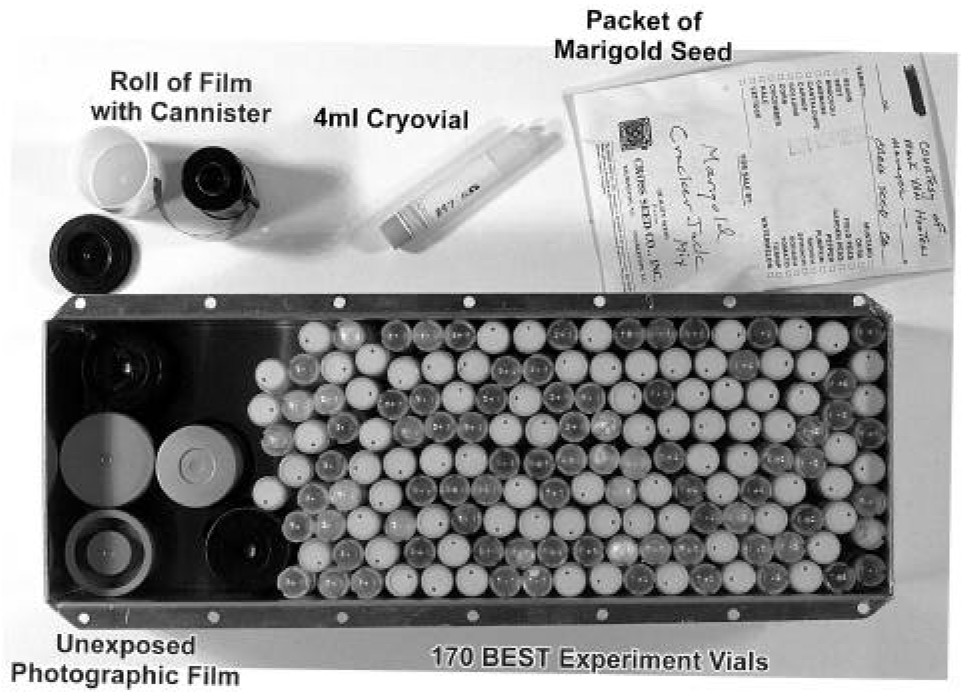

Figure 11. The SEM passive experiment housing showing the film and other contents. The RAD dosimeter package is shown above.

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