Environmental Radiation Measurements on Mir Station

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INTRODUCTION

Hypothesis

A series of passive integrating measurements of environmental radiation with dosimeters located inside the Mir Space Station will significantly expand the U. S. database at the 51.6° inclination orbit, provide detailed information on shielding effects, allow intercomparison of dosimetric methods and provide data for extensive testing of model calculations.

Objectives

Measurements of linear energy transfer (LET) spectra were made in the range of 5 to 1000 keV/μm using CR-39 plastic nuclear track detectors (PNTDs) in six area passive dosimeters (APDs).

Total absorbed dose was measured with thermoluminescent detectors (TLDs) in the six APDs. The combination of absorbed doses and LET spectra measured with the PNTDs allowed total dose, total dose equivalent and average Quality Factor (QF) to be determined for each APD location inside Mir.

Comparisons are being made between LET spectra, dose and dose equivalent measured with different types of dosimeters including the APDs and other dosimeters currently in use on Mir. In addition to the University of San Francisco (USF) detectors, each APD contains a detector stack from Institute of Medical and Biomedical Problems (IMBP) in Moscow. Comparisons between these detectors will be for identical shielding geometry. APDs are also placed near the NASA-JSC TEPC microdosimeter and other Russian flight dosimeters. The agreement between dosimeter measurements by different countries and institutions is an important consideration in establishing a broad, reliable database for the radiation environment in space.

Comparisons will be made between LET spectra and absorbed dose measurements and corresponding calculations based on environmental models and transport codes. Shielding at each of the six APD locations will be determined with the aid of a three dimensional mass model of Mir. The trapped particle models (AP8, AE8), galactic cosmic ray energy spectra models (Creme, Badhwar and O'Neil) and codes for propagating radiation through matter (BRYNTRN, HZETRN, HETC) are tested in these comparisons. Refinement of the modeling to the point where doses can be accurately projected for any space flight (with exception of unpredictable solar particle event doses) is a major goal for NASA. Space flight measurements are a necessary part of this development.

Comparisons will be made between NASA 2, -3 and -4 measurements to determine the change in radiation environment over time. The measurements will be made with identical APDs in the same locations on the Mir.

Background/History

The use of TLDs to measure absorbed dose and CR-39 PNTDs to measure LET spectra has become standard on missions of the U. S. Space Shuttle. APDs similar to those deployed aboard Mir during the NASA 3/Mir 22 mission have been included on several Space Shuttle missions since the inception of the program. These dosimeters have also been used aboard the Long-Duration Exposure Facility, the ESA Eureca retrievable spacecraft, numerous Russian/Soviet Biocosmos missions and aboard Mir itself.

METHODS/RESEARCH OPERATIONS

Calibrations of TLDs with standard ^{137}Cs source (Pre- and Postflight).

Calibrations of PNTDs with accelerated heavy ion beams (Pre- and Postflight).

Readout of TLDs for absorbed doses (Postflight).

Readout of PNTDs for LET spectra (Postflight).

Combining of absorbed doses and LET spectra into total dose and total dose equivalent (Postflight).

Functional Objectives

FO1. Measure absorbed doses at six locations inside Mir.

FO2. Measure LET spectra (LET > 5 keV/μm) at six locations inside Mir.

FO3. Combine measurements into total doses and total dose equivalents for six locations inside Mir.

FO4. Measure depth dose at STD platform location outside Mir.

FO5. Measure LET spectra versus depth at STD platform location outside Mir.

Hardware Items

HW1. TLDs (^{7}LiF- Harshaw TLD-700). 180 of size 1/8 x 1/8 x 0.035 inch. PI-provided.

HW2. CR-39 PNTDs. 238 plates of size 4.5 x 4.5 x 0.06 cm. PI-provided.

HW3. APD boxes (Lexan). 7 boxes of 9.8 x 9.8 x 5.2 cm outer dimensions. PI-provided.

HW4. TLD reader (Harshaw Model 4000). PI-provided.

HW5. PNTD reader (image digitizer system). PI-provided.

HW6. Computers for data reduction and analysis. PI-provided.

HW7. TLDs (^{7}LiF- Harshaw TLD-700). 75 of size 1/8 x 1/8 x 0.0036 inch. PI-provided.

HW8. External Dosimeter Array (EDA) TLD stack holders. NASA-ARC -provided.

HW9. EDA PNTD stack holders. NASA-ARC - provided.

The passive dosimeters (APDs) which were used in this experiment began registering the environmental space radiation from the launch of STS-81 and continued to the landing of STS-84. The NASA 4 mission for the APDs therefore overlapped the two Shuttle flights. The measurements constituted a single session as described in Table 1 below.

Method/Protocol

The method for absorbed dose measurements involved:

a. Placing annealed TLDs into two plates at the front and back of each APD.

b. Transporting the 6 APDs on the Shuttle to Mir where they were mounted at different locations.

c. After return the flight TLDs were read out along with calibration and background TLDs.

d. Absorbed doses were generated from the calibration data.

The method for LET spectra measurements involved:

a. Placing 6 stacks of CR-39 plates at the sides of each APD.

b. Transporting the APDs to Mir as in b. above.

c. After return selected CR-39 plates were processed for readout. The processing included etching of the plates in 6.25N NaOH solution at 50° C for either 36 or 168 hr.

d. The processed plates are read out on a semi-automated image digitizer system. For each APD 6 plates are read out; one for each angular orientation in the APD (X, Y, Z) and for each processing time. The parameters measured on each plate are the major and minor diameters of the openings of the particle tracks located within a given area.

e. Track parameter files for the 6 measured plates from an APD, along with the etched thicknesses and the response curves for the CR-39, are used to generate a 4 solid angle averaged LET spectrum for the LET range > 5 keV/μm. The response curves are determined from CR-39 plates irradiated by accelerated particles of known LET. A database of calibration measurements made in the past at the LBL Bevalac, the German GSI accelerator and several Japanese accelerators are on hand. New calibrations are being performed at the Brookhaven AGS and the Japanese HIMAC heavy ion accelerators.

RESULTS

List of Pre-, In-, and Postflight Anomalies

Five APDs were returned on STS-84. These included APD Serial Number 0011 which was supposed to have been returned on STS-81, but was mistakenly left behind while Serial Number 0017 was returned. APD Serial Numbers 0013, 0014, and 0015 were returned. Serial Number 0018 was left aboard Mir to serve as an internal control for the External Dosimeter Array. Each APD was labeled NMC-# where NM refers to the NASA-Mir program, C refers to the NASA 4/Mir 23 mission and # is the number of the APD.

Completeness/Quality of Data

Readout of the TLDs is complete and absorbed doses have been determined for the four APD locations. The PNTDs have been processed and are currently being read out. The 26 layers of CR-39 PNTD from the four APDs plus two control layers of CR-39 PNTD have been analyzed. LET flux, dose rate and dose equivalent rate spectra have been generated for the 4 APDs. Dose measurements from TLDs have been combined with the integral LET dose equivalent spectra from PNTDs to yield corrected dose, average dose equivalent and average quality factor.

DISCUSSION

Status of Data Analysis

TLDs from the NASA 4/Mir 23 APDs have been processed and readout. Mission averaged doses and dose rates have been determined from TLDs included in each APD. CR-39 Plastic Nuclear Track Detectors (PNTDs) from the four NASA 4/Mir 23 APDs have been processed and have been read out using a semi-automated track analysis system. CR-39 layers oriented in the x, y, and z planes of each APD were selected for processing. One layer from each plane was chemically etched in 6.25 N NaOH solution at 50°C for 36 hours, while a second layer from each plane was chemically etched in 6.25 N NaOH solution at 50°C for 168 hours. Track data from each of the two layers at a given orientation were measured and the differential LET spectra for each detector was plotted. Detectors processed for 168 hours reveal the low-LET component for the spectrum while the 36 hour processed detectors reveal the higher LET component. The high LET component includes short-range tracks (~10 μm) produced by the target fragmentation of primary high energy protons on the carbon and oxygen nuclei of the detector. The two differential LET curves were then combined to produce one spectrum for each of the three measured axes. These three integral LET spectra were then folded together to produce an average integral LET spectra for the given APD. High LET results from the CR-39 PNTDs will be used to correct doses measured in TLDs and to determine total dose equivalent and dose equivalent rate at each APD location.

Final Research Findings

Table 3 shows the average dose and dose equivalent rates measured using TLDs and PNTDs for each of the four APDs exposed during the NASA 4/Mir 23 mission inside the Mir Core module. These data are also shown relative to the APD locations during the mission in Figure 1. The dose rates varied from 307 μGy/d for APD-2 to 375 μGy/d for APD-4. The average dose rate corrected for the high-LET component for the four APDs was 336 μGy/d.

Figure 2 shows the integral LET flux spectra measured using CR-39 PNTDs for each of the four NASA 4/Mir 23 APDs. There is good agreement in the curves at low LETs starting from ~5 keV/μm and extending to ~200 keV/μm. Above ~200 keV/μm, the four curves tend to diverge. This is probably due to the poor statistics in this region of the spectrum—there are relatively few particles of high-LET. Figure 3 shows the integral LET dose rate spectra measured for the four APDs. Dose rate falls slowly with increasing LET up to ~200 keV/μm, again illustrating the relative scarcity of high-LET particles. The same effect can be seen in Figure 4, the integral LET dose equivalent rate spectra for the four APDs. The slope of the curves are nearly constant up to an LET of ~100 keV/μm. The slope then gets progressively steeper up to an LET of ~1000 keV/μm. This indicates that while the number of high-LET particles was relatively small in comparison with low-LET particles (<100 keV/μm), the high-LET component is responsible for the major fraction of dose equivalent above 5 keV/μm.

Conclusions

The dose rates measured in the APDs on the Mir Space Station ranged from 307 to 375μGy/d with and average of 336 μGy/d. This is close agreement with the dose rates measured during the NASA 2/Mir 21 and NASA 3/Mir 22 missions. Since the shielding for these locations most likely remained more or less constant between the missions, the differences in the dose rate probably reflect differences in altitude of the Mir Space Station. The Mir is periodically boosted to higher altitude to counter the constant loss of altitude due to atmospheric drag. At higher altitudes, the Mir passes through a larger portion of the South Atlantic Anomaly and receives a greater exposure from the trapped protons in the region.

Differences in LET spectra measured for the four APDs probably reflect differences in shielding for the four APD locations. At high LET (>200 keV/μm) statistics also play a role in the LET differences. The change in slope between 100 and 250 keV/μm seen in the LET spectra from the previous two NASA-Mir missions is also visible in the spectra measured for the NASA-4/Mir 23 mission. A study is currently underway to determine whether this change in slope is caused by the peak in the cosmic ray spectrum from relativistic iron or whether it is from stopping protons and α-particles produced in high-LET target fragmentation events between trapped protons of the SAA and the nuclei of the stopping medium.

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TABLE 1. DATA COLLECTION SESSIONS/FUNCTIONAL OBJECTIVES

Session Name	FO#	HW#	Scheduled Day	Actual Day	Scheduled Subject	Actual Subject	Samples/ Parameters	Method
NASA4								
Internal space exposures	1,2	1,2,3	12 Jan 97 to 22 May 97	12 Jan 97 to 22 May 97	6 flight APDs	5 flight APDs	5 radiation exposures	Passive dosimetry
External space exposures	4,5	1,2,7, 8,9	Apr 97 to ~ June	29 Apr 97 to 5 Sep 97		1 flight EDA 1 flight APD		Passive dosimetry

TABLE 2. LOCATIONS OF THE APDS ON MIR

APD Serial Number	Mir Module	Location
NMC-1	Core	near location of TEPC/NAUSICAA dosimeters
NMC-2	Core	near N-4 Dose A-1 dosimeter: in adapter module near side window
NMC-3	Core	near N-5 Dose A-1 dosimeter: at center-control desk
NMC-4	Core	near N-6 Dose A-1 dosimeter: also near Russian operational dosimeter R-16

TABLE 3. DOSE AND DOSE EQUIVALENT RATES MEASURED DURING THE NASA 4/MIR 23 MISSION

APD No.	Total Dose Rate (μGy/d)	Dose Equivalent Rate (μSv/d)	Mean Quality Factor
NMC-1	341 ± 8	678 ± 21	1.99 ± 0.08
NMC-2	307 ± 7	656 ± 23	2.14 ± 0.09
NMC-3	375 ± 9	653 ± 13	1.74 ± 0.05
NMC-4	321 ± 7	659 ± 21	2.05 ± 0.08

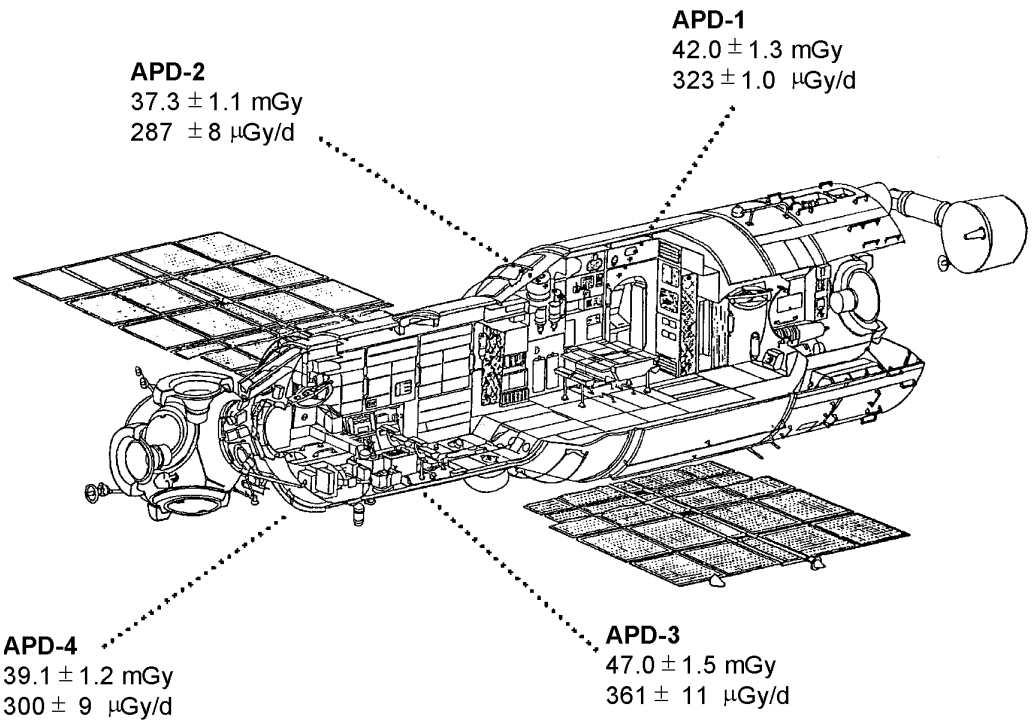


Figure 1. Dose and dose rates measured by TLDs inside the Mir Space Station during the NASA 4/Mir 23 mission by the USF Environmental Radiation Measurements Experiment

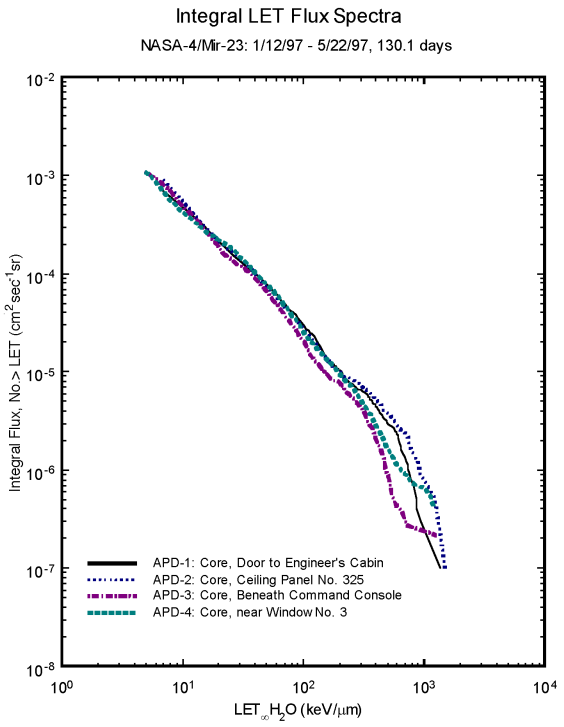
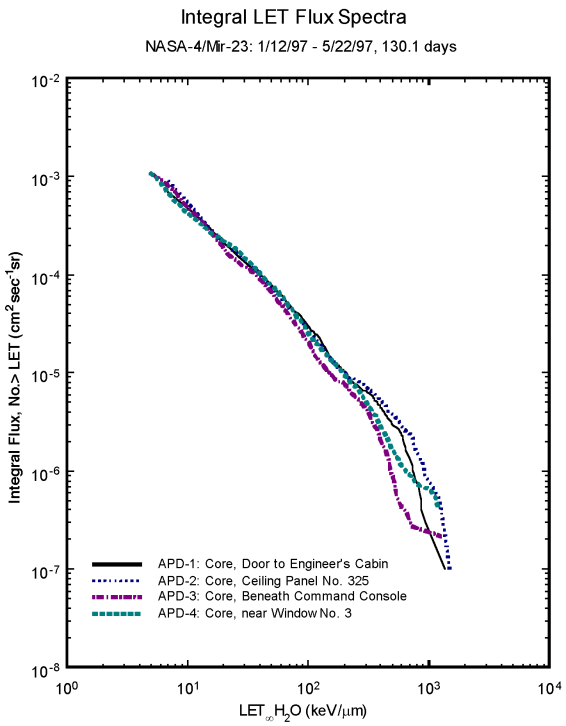


Figure 2. Average integral LET flux spectra measured in the four APDs exposed in the Mir Core module during the NASA 4/Mir 23 mission.



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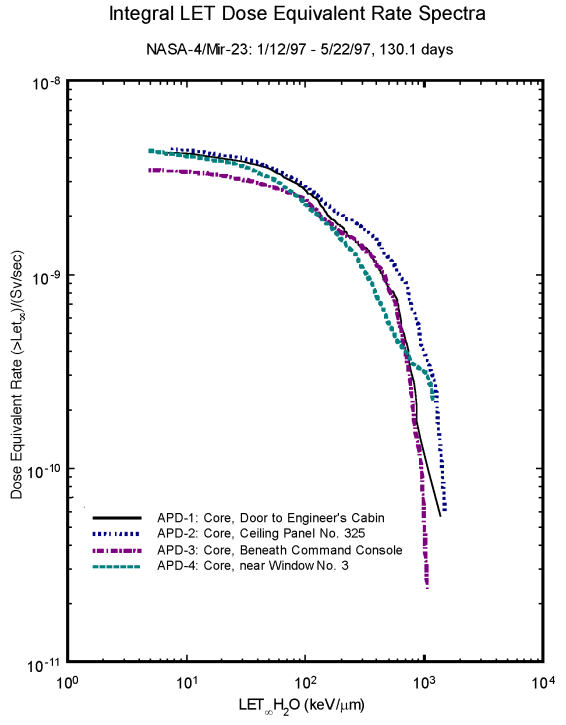

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