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APPENDIX M

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by

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PROTON CALIBRATION OF LOW ENERGY NEUTRON DETECTORS CONTAINING ^{6}LiF

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Introduction

Neutron detectors composed of layers of ^{6}LiF placed between films of plastic nuclear track detectors (PNTDs) have been used on numerous space missions to measure thermal and resonance neutron fluences. The detectors have typically been mounted in pairs, with one of the pair covered by Gd or Cd foil to absorb out the thermal neutron component. The neutrons are detected through the $^{6}Li(n,\alpha)T$ reaction which has a high cross section at thermal energies (950 b) and declines with increasing neutron energy ($\sigma = 150.2/\sqrt{E_n}$). The ^{6}LiF layer becomes a radiator foil for the PNTD films. The emitted α-particle track densities are counted in the PNTDs and are converted to neutron fluences through detector calibrations and response calculations.

The accuracy of these neutron measurements has recently been questioned by Keith et al. (1992). The reason has to do with the high fluences of energetic protons incident on the spaceflight detectors during the measurements. There are reactions other than neutron absorption by ^{6}Li which can produce α-particle emissions, such as $^{6}Li(p,\alpha)$, $^{7}Li(p,\alpha)$ and $^{19}F(p,\alpha)$. They believe it possible that a large fraction of the α-particle tracks counted on these detectors are induced by protons rather than neutrons. If true, the measured neutron fluences would be overestimated and the large deviations in the ratios of proton and neutron fluences present in the spacecraft, plus proton spectrum fluctuations, would result in inaccuracies of uncertain magnitudes.

The purpose of the present calibrations is to measure the proton response of the detectors with accelerated beams having energies within the region of maximum intensities in the trapped proton spectrum encountered in near-Earth orbit. This response is compared with the responses of the spaceflight detectors when related to proton exposures. All of the spaceflight neutron measurements have been accompanied by TLD absorbed dose measurements in close proximity within the spacecraft. For purposes of comparison, the spaceflight TLD doses are assumed to be proton doses.

Experiment

Detectors were assembled from layered arrays of ^{6}LiF and ^{7}LiF TLDs (TLD-600 and TLD-700) with films of CR-39 PNTDs on both sides. The individual TLDs are 0.635 cm square and 0.089 cm thick. The ^{7}LiF detectors were included to reveal the effect of the ^{6}Li isotope in determining response to protons. The detector components were covered with dense cardboard sheet during the irradiations.

Detectors were mounted in pairs (one of each type) side-by-side for the irradiations. The proton beams were incident at 45° angles to the surface of the PNTD and LiF layers. Proton beam energies of 80 and 153.6 MeV were obtained at the Harvard Cyclotron Laboratory. The detectors exposed to 80 MeV protons were given 15.1 rads, while those exposed to 153.6 MeV were given 9.88 rads. These doses correspond to 1.085×10^8 and 1.129×10^8 protons/cm^2, respectively. A third pair of detectors traveled with the others for background purposes.

After return of the detectors, the CR-39 films were removed and processed by standard techniques to delineate the latent tracks and provide good visual discrimination between short, stopping α-particle tracks and other tracks present in the surfaces. The etchant used was 6.25N NaOH at 70° and the etching time was 4 hr. The films were scanned and the track densities counted at 200x under an optical microscope. Spaceflight detectors are read out using the same methods.

Measurements

The measured track densities per rad are given in Table A-I-1. The error limits given are calculated from the standard deviations based on counting statistics plus a 10% uncertainty due to track classification. The added uncertainty derives from the nature of the track size distribution. On spaceflight detectors, the track counting is relatively easy because the targeted tracks, short, stopping α-particle tracks from the $^{6}Li(n,\alpha)$ reaction, are relatively distinct from other tracks present with few border-line events. The proton-irradiated detectors contained a more undifferentiated track size distribution. This made track classification more difficult and may have caused added track density variations of up to ± 10%, after background subtractions.

The track densities found for ^{6}LiF are greater than for ^{7}LiF at 80 MeV, but less than at 153.6 MeV. However, the uncertainties in the measurements may account for the differences. The track densities at 153.6 MeV are greater than at 80 MeV when calculated per rad but are about the same when calculated per incident proton.

Included in Table A-I-1 are the results of calculating track densities per TLD rad for 17 spacecraft measurements. The spaceflight track densities used were those measured for the resonance neutrons. Because of the way thermal neutron track densities are found from the pair of flight detectors (subtraction of the Gd-covered-detector track densities from uncovered-detector track densities) all of the tracks produced by space protons would be included with the resonance neutron component. There were large variations in the spaceflight measurements of track density per TLD rad, with a trend to very low values for high altitude flights. At high altitudes high doses of lower energy protons are encountered in the SAA. The data suggest that these protons are relatively inefficient at producing secondary neutrons through interactions with the spacecraft material.

In comparing spaceflight track densities with those measured for protons it is seen that there is approximately a factor of 100 between them. This implies that the proton-induced fraction of track densities attributed to resonance neutrons in spacecraft measurements averages about 1% and would not be expected to exceed 4% on any mission.

Conclusions

Based on a simulation of spaceflight protons by 80 and 153.6 MeV accelerated protons, the average overestimate of measured resonance neutron fluences during LEO missions is about 1%. Since the accuracy given for these spaceflight measurements is about a factor of 2, the proton contribution is not significant. Track densities of short-range, stopping α particles, measured with ^{6}LiF and ^{7}LiF radiator foils were not significantly different, implying that the p,α cross-sections of the radiator foil isotopes are comparable at these proton energies.

Reference

J.E. Keith, G.D. Badhwar and D. J. Lindstrom (1992) Neutron spectrum and dose-equivalent in Shuttle flights during solar maximum. Nucl. Tracks Radiat. Meas. 20(1), 41-48.

Acknowlegement

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TABLE A-I-1. Track Densities of Stopping α-Particles Induced by Protons

Proton Energy (MeV)	Radiator Layer	Track Density (cm^{-2} rad^{-1})	(Tracks/Proton)
80	^{6}LiF	9.3±1.8	1.29±0.25 x 10^{-6}
80	^{7}LiF	6.8±1.3	9.5 ± 1.8 x 10^{-7}
153.6	^{6}LiF	11.0±2.1	9.7 ± 1.9 x 10^{-7}
153.6	^{7}LiF	15.4±2.1	1.36±0.19 x 10^{-6}
Spaceflight	^{6}LiF	1060±670*	