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Abstract

We report on the results of mixed-field irradiations of straw-tube, plastic scintillating fiber, and avalanche photodiode components. These irradiations are being carried out at the one-MW PULSTAR research reactor facility at North Carolina State University. A special sample holder was designed that allows relatively uniform irradiation of samples up to 5 ft long, without bending or coiling. A systematic irradiation program is underway that allows study of total fluence, fluence-rate, and neutron spectral effects. Samples have been exposed to neutron fluences as high as 2×10^{16} cm^{-2}.

Introduction

In support of the Hybrid Central Tracking Chamber (HCTC) concept, we undertook initial neutron radiation damage studies of straw tubes and a glue, of avalanche photodiodes (APD's), and of plastic scintillating fibers (PSF's). The HCTC is expected to occupy a cylindrical annular region extending in radius, r, from approximately 40 cm to almost 200 cm and over the pseudorapidity range $-1.6 \leq \eta \leq 1.6$. Citing the work of several investigators, Groom [1] estimates that the neutron albedo from an uranium scintillator calorimeter would vary, at a radius of 200 cm, between about 4×10^{11} and 5×10^{12} cm^{-2} yr^{-1}, over the pseudo rapidity range $\eta = 0$ to 1.6. Scaling by $1/r^2$, we estimate the maximum annual fluence (at $\eta = 1.6$, $r = 40$ cm) to be approximately 10^{14} cm^{-2} at design luminosity of 10^{33} cm^{-2} s^{-1}. Thus, assuming a ten-year active lifetime, the total annual neutron fluence within the HCTC volume is expected to vary over the approximate range 4×10^{12} to 10^{16} cm^{-2} (the latter figure accommodates a possible order of magnitude increase in luminosity).

The anticipated albedo neutron energy spectrum has been shown [1] to exhibit an approximately gaussian peak in its $E\, d\Phi/dE$ versus logE behavior (where E is neutron kinetic energy and $d\Phi/dE$ is energy-dependent flux), peaked near E = 1.3 MeV. This, combined with the fact that the silicon elastic scattering cross section exhibits a marked increase above E = 0.15 MeV, has led to considerable interest in "fast" neutron damage effects. However, we have chosen to study effects of both thermal and fast neutrons, for three primary reasons: (1) not all HCTC components will contain silicon (although electronic devices typically do); (2) early studies [2] suggest that the *number* flux of neutrons at thermal energies is comparable to that at the 1.3 MeV peak; and (3) thermal neutron interaction mechanisms (*e.g.*, absorption) are typically different in character from those for fast neutrons (primarily scatter).

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Facility Description

The PULSTAR reactor is a 1 MW swimming-pool type reactor operated at North Carolina State University for teaching, research, and service. The reactor operated 2,400 hours in calendar year 1989 and is available on a near full-time basis. The facility has four vertical exposure ports (VEP's), six horizontal beam tubes, and a bulk irradiation facility. The irradiations reported here utilized VEP Y, which has maximum full-power flux levels of 1.3×10^{13} cm^{-2}-sec^{-1}, thermal, and 2×10^{12} cm^{-2}-sec^{-1}, fast. Provision can be made for pneumatic transport and for specimen rotation (to enhance exposure uniformity). The reactor pool temperature is normally between 105°F and 109°F.

A water-tight outer irradiation capsule was designed and constructed that allows the simultaneous or sequential irradiation of PSF, straw tubes, and electronic devices. The capsule was machined from high purity aluminum and contains a cylindrical active irradiation volume, with a length of approximately five feet and a diameter of two inches. Both aluminum-tube and plastic-rod central supports were constructed. Circular plates surrounding the central supports serve to position them in the center of the capsule and to accommodate samples. A cadmium sleeve can be inserted in the space between the capsule wall and the guide plates, to remove thermal neutrons. Thermal and fast neutron fluxes were measured at 3-inch separations along the capsule tube length using indium and cadmium-covered indium foils, respectively (the "fast" flux is that above the cadmium threshold of 0.15 eV). The neutron dosimetry results are summarized in Fig. 1.

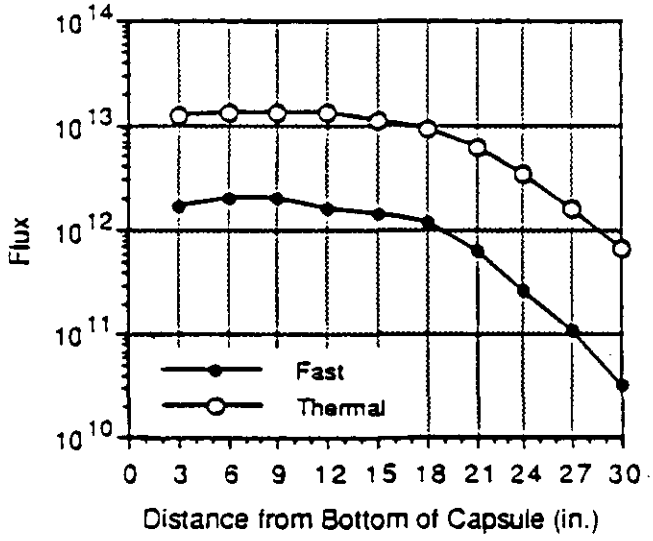

Figure 1. Measured full-power fast and thermal flux profiles at the capsule center in PULSTAR VEP Y; flux values are in units of $cm^{-2}\,s^{-1}$.

Straw Tube Component Tests

The work by Zhou, et al. [3] indicates that straw tubes can be expected to operate at neutron fluences up to at least 1.1×10^{13} cm^{-2}. Our initial tests examined the mechanical integrity of the straw tubes themselves, and of a glue used in fixing the straw tubes, before and after irradiations to neutron fluences as high as 2×10^{16} cm^{-2}. Four irradiations of 4-mm diameter straw tube samples were conducted. The straw tubes were fabricated by Stone Industrial of College Park, MD, from a spirally wrapped ribbon of 50 μm thick mylar film. The overlapping seams of adjacent spiral windings were bonded with a polyester adhesive.

A single 49-cm straw tube was irradiated for thirty minutes at full power. The straw received a neutron fluence profile that varied from about 1.1×10^{15} to 3.7×10^{15} cm^{-2}, fast, and from about 1.0×10^{16} to 2.3×10^{16} cm^{-2}, thermal. The gamma-ray dose was estimated to be between 0.1 and 0.5 Mrad. In order to test the integrity of the seams after the irradiation, the 49-cm long straw was pressurized to determine its burst strength. The straw was able to sustain a gauge pressure of 40 psi, which was the maximum to which it was subjected and represents many times the expected gas flow pressure in the tubes.

We have been assembling straw tube arrays by gluing adjacent tubes at 10 – 20 cm intervals with a cyanoacrylate adhesive (super glue). To test the ability of the adhesive to withstand the radiation environment anticipated at the SSC, pairs of 1 cm straw tube segments were glued together. Forty pairs were stressed to measure the load necessary to cause the glued joint to fail. The average failure load was 520±175 gm. In two separate ten-minute runs at reactor full power, thirty eight 1-cm straw tube section pairs were irradiated such that nineteen received neutron fluences of approximately 2×10^{14} cm^{-2}, fast, and 2×10^{15} cm^{-2}, thermal, and the other nineteen received fluences of approximately 10^{15} cm^{-2}, fast, and 8×10^{15} cm^{-2}, thermal. The straw sections received approximate gamma-ray doses between 30 and 150 krad. The average failure load of those irradiated to a thermal fluence 2×10^{15} cm^{-2} was measured to be 450±150 gm, while those irradiated to a thermal fluence of 8×10^{15} cm^{-2} failed at 430±100 gm.

Finally a collection of 25 straw tubes, which had been glued together into a trapezoidal array of 5 rows (7 straws in the bottom row, 3 straws in the top row), was irradiated for 30 minutes at full power. The array received nearly uniform neutron fluence distributions which varied between about $2.5\text{-}4.0\times10^{15}$ cm^{-2}, fast, and $1.5\text{-}2.5\times10^{16}$ cm^{-2}, thermal, and approximately 0.1-0.5 Mrad gamma-ray dose. In order to determine whether the exposure to which the straw tube array was subjected would result in a measurable dimensional change, the array was surveyed before and after irradiation with a traveling microscope that has a measurement precision of better than 20 microns. The width of the 40-cm long array of straws was measured at 5-cm intervals. Comparison of the measurements before and after irradiation show that to within the accuracy of the measurements no variation was observed. It is noted that the irradiated straw tube samples were mounted on $\frac{1}{8}$-in. diameter lucite rods to facilitate handling. After the radiation exposures, the lucite rods showed noticeable yellowing and had become brittle. In contrast to this, the mylar tubes showed no visible effects from the irradiations.

Scintillating Fiber Component Tests

Ten GE Electro Optics modified C30921S APD's were radiated in the reactor at low power (1 watt) for various times from 10 to 240 sec. The following data were collected before and after irradiation: breakdown voltage (V_B), dark count rate at V_B+10 V, and dark current at V_B-10 V. Room temperature at the time of data collection was 72±1°F. An ultra-stable power supply and a high-precision voltmeter were used to record the variation inherent in dark count rate as the bias was varied by ±0.5 volts about the nominal V_B+10 V. This variation, and the statistical count-rate variances, were used to estimate the uncertainty in the ratio, R, of dark count rate after irradiation to that before.

The APD's were loaded inside the aluminum tube support at one of two selected levels using spacing rods; flux foils were inserted with the APD's. Since exposure times were rather short, the following irradiation procedure was used. The irradiation capsule was allowed to drop by gravity to the bottom of VEP Y; a preset timer was started as the capsule reached the core, as evidenced by the reactivity change displayed on the reactor instrumentation. When the preset time expired, the operator scrammed the reactor, immediately shutting off the neutron supply. The capsule was then withdrawn to the top of the pool and the samples removed.

The results of the ten exposures are summarized in Table 1. Estimates of gamma-ray dose received during the irradiations are 1-10 rads. We plot in Fig. 2 the dark count ratio as a function of fast fluence. The results indicate a damage threshold at approximately 2×10^6 cm^{-2}, as evidenced by a rapid increase in R above the no-damage value of unity, indicative of higher dark count rates due to radiation damage. The dark currents, on the other hand, were unaffected by the radiation exposures. In Test no. 7 the APD was covered entirely by cadmium, which filters out thermal neutrons. The results from tests 7 and 8, in which the same fast fluence was seen, indicate that the damage is due to fast neutrons, as expected. We have seen a modest recovery, of order 10%/mo, over two months of testing four of the damaged APD's. We have also begun PSF irradiations. Two of each of Bicron RH1, Type B, and Type H fibers were irradiated to fluences of about 2×10^{12} cm^{-2}, fast, and 10^{13} cm^{-2}, thermal. These fibers and one unirradiated fiber of each type were sent to Northeastern University for testing. One day after irradiation, no appreciable difference in light output or attenuation length was noticed between the irradiated and unirradiated fibers. Testing of five types of fibers at higher fluences is now underway.

Conclusions

It appears that straw tubes and glues are mechanically sufficiently radiation hard for use in central tracking. We have also shown that the GE APD's – operated in the geiger mode at room temperature – begin to exhibit noticeable radiation damage at fast fluences of approximately 2×10^6 cm^{-2}. If the APD's can be housed outside the calorimeter, coupled to the PSF's by optical fibers, adequate shielding could easily be achieved at modest cost. Damaged APD's appear to be capable of partial, slow recovery.

Table 1. Results of neutron irradiations of avalanche photodiodes

Test No.	Fluence (cm^{-2}) Fast	Thermal	Dark count Ratio, R	Dark current Ratio
1	3.5×10^5	7.3×10^7	1.13	0.86
2	7.0×10^5	1.5×10^7	0.96	1.00
3	1.6×10^6	3.2×10^7	1.30	0.90
4	1.6×10^6	3.2×10^7	3.68	1.00
5	3.3×10^6	6.4×10^7	3.63	1.10
6	5.4×10^6	1.0×10^8	3.16	0.94
7	7.8×10^6	-	7.93	1.00
8	7.8×10^6	1.5×10^8	5.79	0.87
9	1.1×10^7	8.5×10^7	11.04	0.86
10	2.0×10^7	1.6×10^8	13.11	0.83

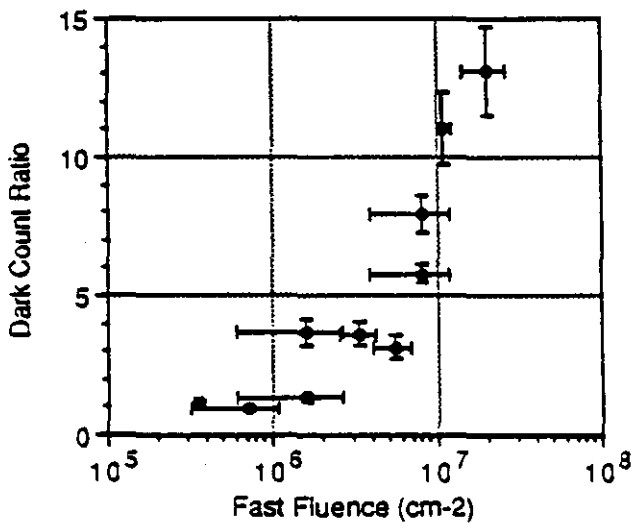

Figure 2. Variation with fast neutron fluence of the ratio of dark count rate after irradiation to that before irradiation.

References

[1] D.E. Groom (Ed.), Radiation Levels in the SSC Interaction Regions, SSC-SR-1033, June 10, 1988.

[2] D.E. Groom, Radiation Levels in SSC Detectors, SSC-201, January 1990.

[3] B. Zhou, D. Warner, J. Rohlf, D. Osborne, A. Marin, W.W. Lu, G. Hopkins, T. Coan, J. Beatty, and S. Ahlen, Performance of Small-Radius Thin-Wall Drift Tubes in an SSC Radiation Environment at the MIT Research Reactor, BUHEP-90-2, December 27, 1989.