SHORT NOTE

Effects of Fusion Neutron Irradiation on Photomultiplier Tubes

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Received July 2, 1987

KEYWORDS: coloration, dark current, fusion diagnostics, gain, irradiation, MeV range 10–100, neutron beams, photomultiplier tubes, pulse height distribution, radiation damage, radiation doses, radiation hardening, resolution

Photomultiplier tubes are uniquely sensitive among photosensitive devices currently used to detect and measure radiant energy in the ultraviolet, visible and near infrared region. They also have good performance with respect to fast time response and low noise. Because of these good features, photomultiplier tubes find wide use in nuclear research, industrial applications, medical examinations, space exploration and others. Fusion diagnostics, which is our interest, also requires many high photosensitive detectors such as photomultiplier tubes. However, the photomultiplier tubes have sensitivity to nuclear radiation as well as low energy photons and suffer performance degradation due to radiation damage in a high dose radiation field. Therefore, in order for them to be successfully applied to a fusion diagnostic system, radiation damage, especially that due to high energy neutrons, must be considered.

Radiation effects on photomultiplier tubes have been measured mainly for satellite experiments(1)–(3). Therefore, most reports have described irradiation experiments utilizing a \( \gamma \)-source, an electron accelerator and a high energy charged particle accelerator to simulate the radiation encountered in space. There are few papers on high energy neutron effects on photomultiplier tubes. Irradiation experiments by a D-T neutron source are significant for fusion research, and data on fusion neutron effects and hardness of photomultiplier tubes are directly useful for design of fusion diagnostic systems. The purpose of this paper is to show fusion neutron effects on photomultiplier tubes and to determine how long they can be effectively used in the fusion neutron environments.

Nine kinds of commercially available photomultiplier tubes were irradiated with 14 MeV neutrons from the RTNS-II(4)–(5) at Lawrence Livermore National Laboratory. Table I lists models of the irradiated photomultiplier tubes and summarizes their construction. They were selected to vary in photocathode, dynode and window materials and dynode structure and to allow comparisons of neutron effects and hardness among them. In addition to the photomultiplier tubes, three kinds of glass plates (UV, fused silica and synthetic silica) were irradiated together to consider the coloration of the windows of the photomultiplier tubes. They are the same glasses as are used for the window materials of the following three photomultiplier tubes; R375 (synthetic silica), R760 (fused silica) and R1463 (UV).

The nine photomultiplier tube samples, one for each model, and the three glass plates were set around the rotating target of the RTNS-II and irradiated at room temperature. The glass plates were placed on the windows of the corresponding photomultiplier tubes for irradiation. The neutron fluences, measured with five Nb activation foils for each sample, were controlled by variations of the irradiation time and the distance between the samples and the rotating target. Finally, the photomultiplier tube and glass plate samples underwent five different irradiations and the total neutron fluences for the samples amounted to \( \sim 2 \sim 3 \times 10^{15} \text{ n/cm}^2 \). The irradiated samples were removed from the target room two days after every irradiation and were examined for their per-

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formance degradation. Some typical characteristics of the photomultiplier tubes were measured before irradiation and were compared to those measured after irradiation.

A special dark box equipped with a voltage-divider network to provide enough bleeder currents, a preamplifier and a thermocouple was made for examination of the typical characteristics of the photomultiplier tubes. A constant amplitude light pulser consisting of a small NaI(T1) crystal and an $^{241}$Am $\alpha$-source or a green LED light pulser was set at fixed positions on the windows of the photomultiplier tubes in the dark box. The latter light pulser was used for two photomultiplier tubes sensitive to ultraviolet wavelengths (R166 and R759) and the former for the others. Pulse height response of the photomultiplier tubes to the light pulsers was measured at about the same temperature (room temperature) with a multichannel spectrometry system. An example of the results is shown in Fig. 1. To examine degradation of gain and resolution after irradiation, the positions and FWHMs of the peaks were compared between before and after irradiation. Uncertainty in the light pulser position, temperature and others caused at maximum 4% shift of the peak channel position. Dark current, i.e. anode current of the photomultiplier tubes operated without the light pulser in the dark box was also measured and compared between before and after irradiation. Increase in dark current results in degradation of a signal-to-noise ratio. The irradiated glass plate samples were placed on the windows of the corresponding unirradiated photomultiplier tubes, and their optical transmittance was relatively measured by the same way of using the light pulser. All measurements were made in an air-conditioned laboratory where the temperature was almost constant.

![Fig. 1 Pulse height distributions of R1463 photomultiplier tube for NaI(T1)$-^{241}$Am constant amplitude light pulser](image)

It was ascertained from the irradiation experiments that the photomultiplier tubes suffered the following effects due to the 14 MeV neutron irradiation: (1) Degradation of gain (including optical transmission efficiency of the window, quantum efficiency of the photocathode and secondary electron emission efficiency (gain) of the dynode) and (2) increase in dark current. No significant changes were observed in the resolution. Figure 2 shows the relation between relative gain and 14 MeV neutron fluence for various photomultiplier tubes. The first irradia-
tion (cumulative neutron fluence $\Phi_n: \sim 1 \times 10^{13}$ n/cm$^2$) caused no changes in the gain for any photomultiplier tube. Three photomultiplier tubes (R1463, R2027 and R2558) after the second irradiation ($\Phi_n: \sim 5 \times 10^{13}$ n/cm$^2$) and all after the fourth irradiation ($\Phi_n: \sim 5 \sim 7 \times 10^{14}$ n/cm$^2$) experienced a clear decline in the gain. It is evident from the results that the photomultiplier tubes suffer a gain degradation in the region beyond $\sim 10^{14}$ n/cm$^2$. Also after the third irradiation, brown coloration was obviously observed in the UV glass sample. The fused and synthetic silica samples showed weak purple coloration after the fourth irradiation. The glass plate samples exhibited a similar decrease in transmission of light from the light pulsers in the region beyond $\sim 10^{14}$ n/cm$^2$. It is clear from this that the coloration of the windows of the photomultiplier tubes primarily contributes to their gain degradation. However, irradiated R1463 and R2027 samples evidently showed more gain degradation than expected from the window coloration. Moreover, almost all samples after irradiation indicated change in the relationship between current amplification and supply voltage. This means that the photomultiplier tubes suffered damage not only to the windows but also in other components such as dynodes. As for the other effect, the dark current increased remarkably for every photomultiplier tube sample even after the first irradiation, and finally went over $10^{-6}$ amperes for several samples (R166, R2027 and R375). One or two decades increase in dark current is easily caused by low neutron fluence irradiation below $10^{14}$ n/cm$^2$. Weak light measurements, which are often necessary for plasma diagnostics, may be severely affected by the increase in dark current due to neutron exposure. The pulse height resolution of the photomultiplier tubes for the light pulsers hardly changed even after the fifth irradiation. The irradiated samples were disposed of as radioactive wastes soon after the fifth irradiation and the measurements were finished. Therefore long term recovery from the irradiation effects was not examined.

The limited irradiation experiments described in this paper have given some typical fusion neutron effects and a rough hardness value for photomultiplier tubes. The photomultiplier tubes are composed of a variety of materials, which complicates the interpretation of their irradiation effects. Further irradiation experiments and more detailed measurements, for example, a measurement with a light spectrometer are needed to explain the mechanism of the performance degradation of the photomultiplier tubes.

The present irradiation experiments were performed under the Japan-US cooperative utilization of the RTNS-II facility.

The authors wish to express their gratitude to Dr. H. Moriyama of Kyoto University, Dr. K. Ohba of Hamamatsu Photonics Co., Ltd. and the staffs of the RTNS-II facility for their useful suggestions and discussions in carrying out the irradiation experiments. The photomultiplier tube and glass plate samples for irradiation were supplied through the courtesy of the above company.

REFERENCES