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Reactor Power Monitoring Using Silicon Carbide Fast Neutron Detectors*

Frank H. Ruddy[**1], John G. Seidel[1], Thomas E. Blue[2], and Donald W. Miller[2]
[1] *Westinghouse Electric Co., 1332 Beulah Road, Pittsburgh, Pennsylvania 15235-5081, USA*
[2] *The Ohio State University, Columbus, Ohio 43202, USA*

Abstract

Silicon Carbide semiconductor detectors have been demonstrated for fast fission-neutron monitoring in a nuclear reactor. A linear response of the fast-neutron response to reactor power has been demonstrated over a factor of twenty in power range. The relative precision of the Silicon Carbide response compared to the reactor power monitors was better than 0.6% and was 0.2% compared to a Silicon Carbide thermal neutron detector over this power range. Initial current-mode thermal neutron response measurements also showed a linear response to power.

KEYWORDS: Silicon Carbide; semiconductor; detector; neutron, reactor, power

1. Introduction

Silicon Carbide (SiC) semiconductor neutron detectors offer advantages for nuclear reactor power monitoring applications. SiC detectors can be operated in changing and high temperature environments [1,2] and are resistant to the effects of neutron [3,4] and gamma irradiation. [5] SiC thermal neutron detectors have been shown previously to have a linear response to fluence rate over a range of more than seven orders of magnitude [6,7] and have been proposed for ex-core reactor power monitoring in Pressurized Water Reactors. [8]

In the present paper, we describe the results of power monitoring measurements using SiC fast-neutron detectors

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** Corresponding author, Tel. 412-256-1064, Fax. 412-256-1007, E-mail: ruddyfh@westinghouse.com

2. Measurements

Three sets of SiC detectors mounted on standard TO-46 headers were used for the measurements. Each header contained two 500-µm diameter SiC diodes with 3-µm thick depletion regions when fully depleted. Previous tests of similar diodes showed a capacitance of about 9 picofarads when fully depleted at -7 volts bias. Biases in the range from zero to -20 volts were used for the measurements.

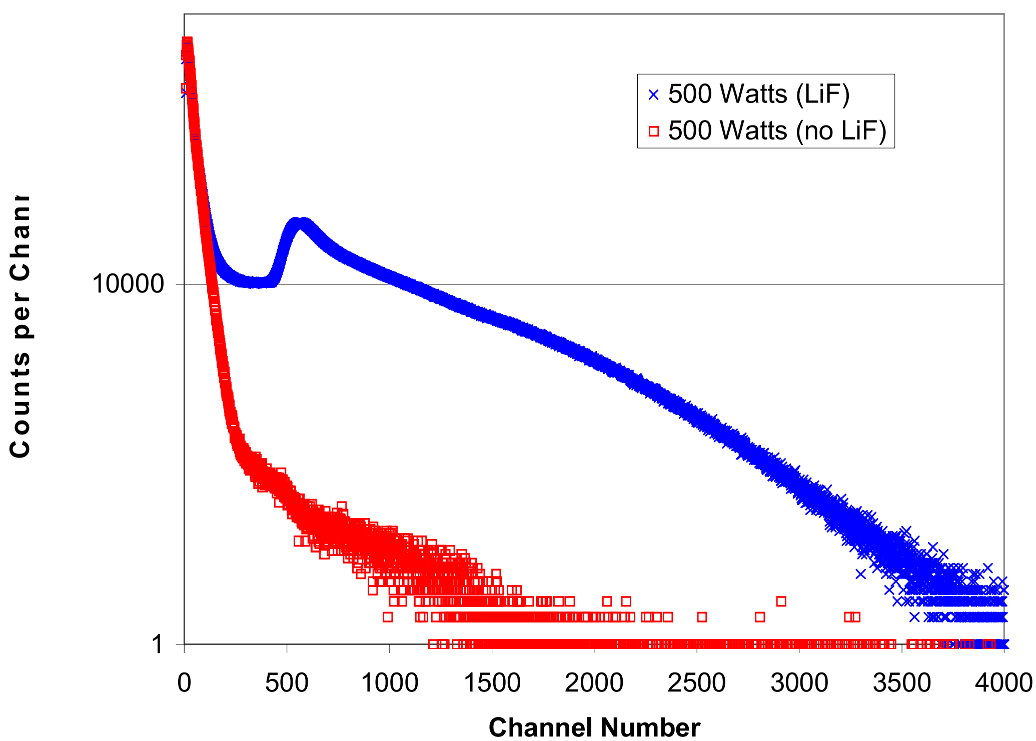
Each TO-46 header was mounted into an empty MHV connector housing. One diode lead was soldered to the case of the connector along with the ground lead. The other diode lead was soldered to the center pin of the MHV connector. The diode headers were mounted so they faced the back of the MHV connector (cable end). A cap was screwed into the back of the connector to shield the diodes from electromagnetic interference. Small aluminum disks coated with ^{6}LiF were placed over two of the open faced TO-46 headers. When exposed to thermal neutrons, the LiF produces tritons and alpha particles via the ^{6}Li(n,α) reaction. The nominal ^{6}LiF converter foil thicknesses used for the two detectors were 24.2 µm and 2.5 µm. Since no aluminum foil covering was placed between the diode and the LiF to absorb the reaction α particles, (as has been done in past measurements), the SiC diode response is to both tritons and alpha particles. No ^{6}LiF converter foil was placed in the third diode assembly. Therefore, the signal from this diode comes primarily from fast-neutrons reactions within the SiC diode.

Neutron response measurements were carried out using the Ohio State University Research Reactor (OSURR). In initial measurements two diode assemblies were placed together in a reactor beam port and mounted adjacent to the face of a polyethylene plug. One diode assembly contained the 24.2-µm converter layer, and the second diode contained no converter layer. In a second set of measurements, two diodes containing 24.2 µm and 2.5 µm ^{6}LiF converter layers were mounted side-by-side in order to compare their thermal neutron responses as a function of reactor power. In both cases, the diode pairs were connected to a 5 meter long RG58 (50 ohm) coaxial cable, having a cable capacitance of about 450 picofarads

3. Results and Discussion

The pulse-height response spectrum for a measurement where a ^{6}LiF converter foil was present is compared with the fast neutron response spectrum in Figure 1. The low-amplitude pulses are due primarily to gamma-ray interactions, which produce secondary electrons, which in turn

Figure 1: Comparison of the SiC Detector Responses With and Without ^{6}LiF at 500 Watts. The ^{6}LiF thickness was 24.2 μm.



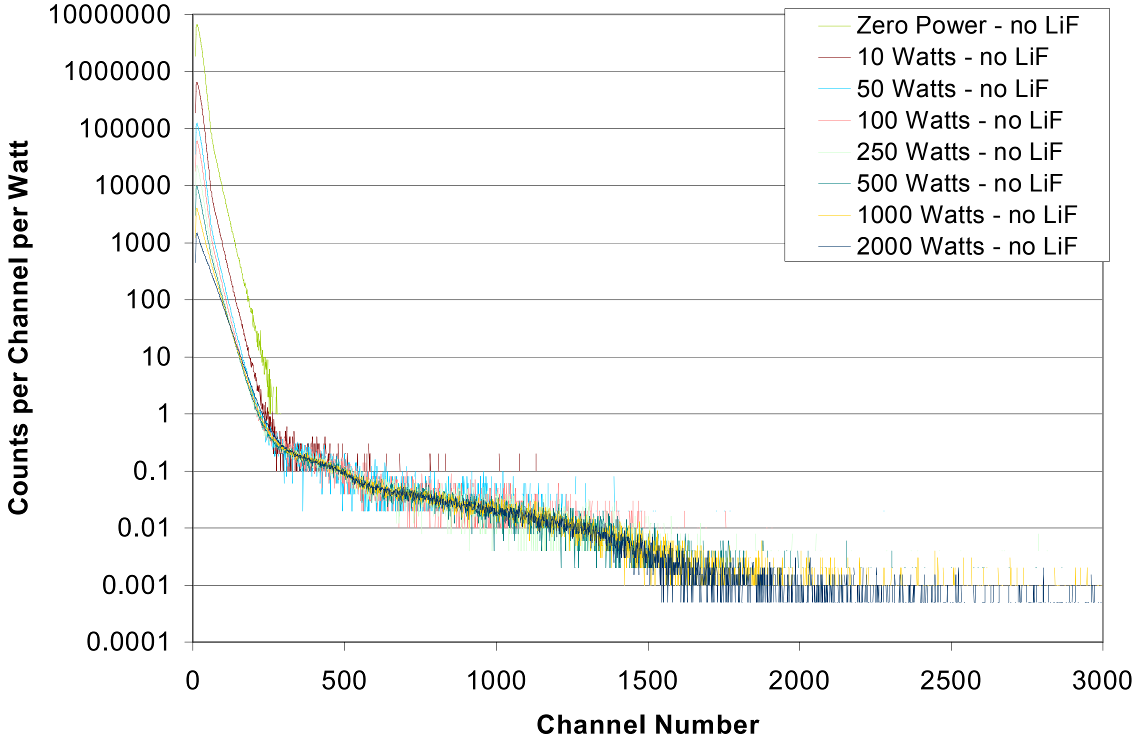
produce ionization in the SiC detector active volume. Because the ranges in SiC of these secondary electrons are large compared to the dimensions of the SiC active volume, only a very small fraction of the energy of each gamma ray can be recorded as ionization by the detector, resulting in the gamma-ray response being limited to extremely low pulse heights. In the ^{6}LiF case, the higher pulse height portion of the spectrum results from energetic tritons and alpha particles from the $^{6}Li(n,\alpha)^{3}H$ reaction. Most of the gamma-induced pulses are confined to channels less than 300.

In the case where no ^{6}LiF converter layer is present, the detector neutron response is primarily a result of ionization caused by silicon and carbon recoils produced by fast fission-neutron scattering. The power-normalized fast-neutron response spectra at various reactor power levels are shown in Figure 2. For channel numbers greater than 300, the data form a universal curve. For channels less than 300, the different gamma intensities cause discrepancies between the spectra.

Integrated spectrum counts for channels greater than 300 are plotted as a function of reactor power level in Figure 3. It can be seen that the fast-neutron count rate response is highly linear over the entire range of the measurements. The high degree of linearity observed indicates that both the SiC fast-neutron response and the compensated ion chambers used to monitor OSURR power are linear to better than 0.6% in the 100 watt to 2000 watt range.

As an alternative to comparing the SiC fast neutron response to the OSURR reactor power monitors, the SiC fast neutron response can be tracked against the thermal neutron response at the same relative detector locations. Provided the thermal-to-fast neutron flux ratio remains constant as a function of reactor power, the SiC thermal neutron response can be used to monitor the fast neutron response. Only the thermal neutron measurements at 1000 and 2000 watts with a 0.8 μsecond resolving time were not affected by resolving time losses. The

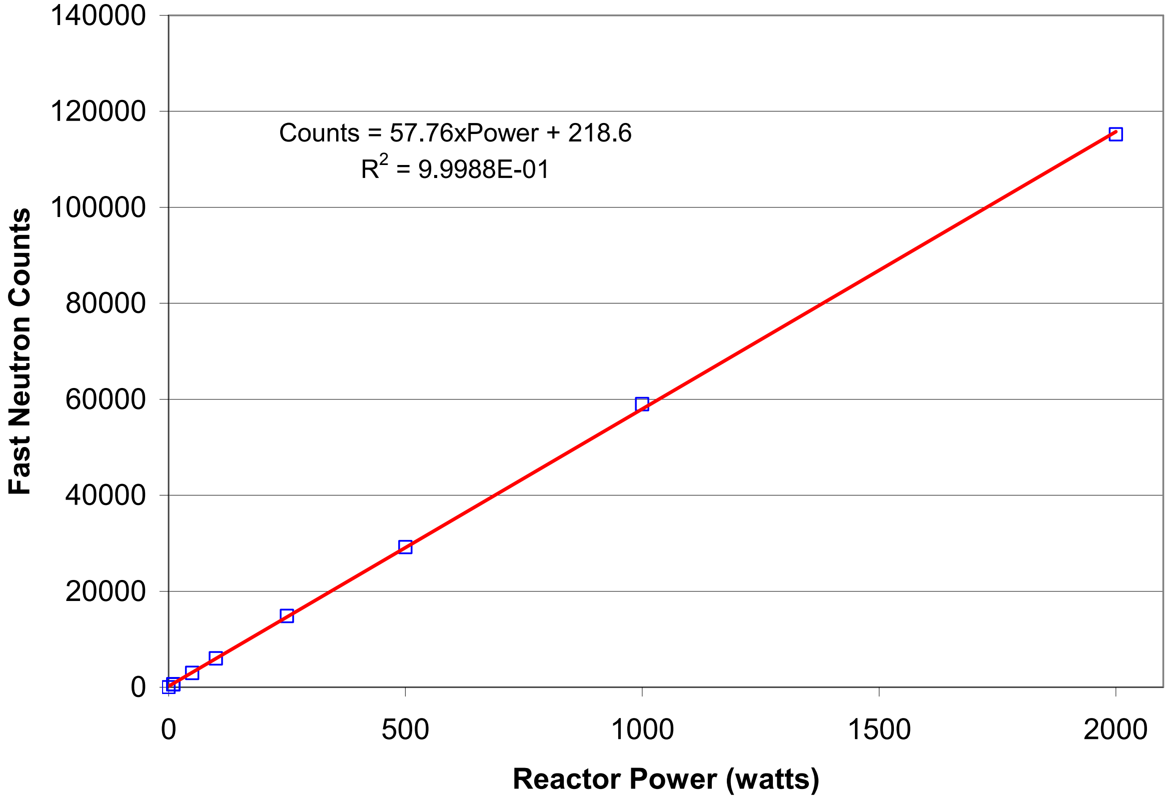
Figure 2. Power-Normalized Fast-Neutron Response Spectra.



relative standard deviation for these two fast-to-thermal response ratios is 0.18%. SiC thermal neutron detectors have previously been shown to have a 0.6% precision relative to a NIST double fission chamber. [1,2]

The same degree of precision was seen in the present thermal-neutron measurements. Initial current-mode measurements were also carried out for the detector equipped with the 24.2 µm ^{6}LiF converter layer resulting in the data shown in Figure 4. Although the current response is linear, more measurements are required with more accurate current monitoring equipment.

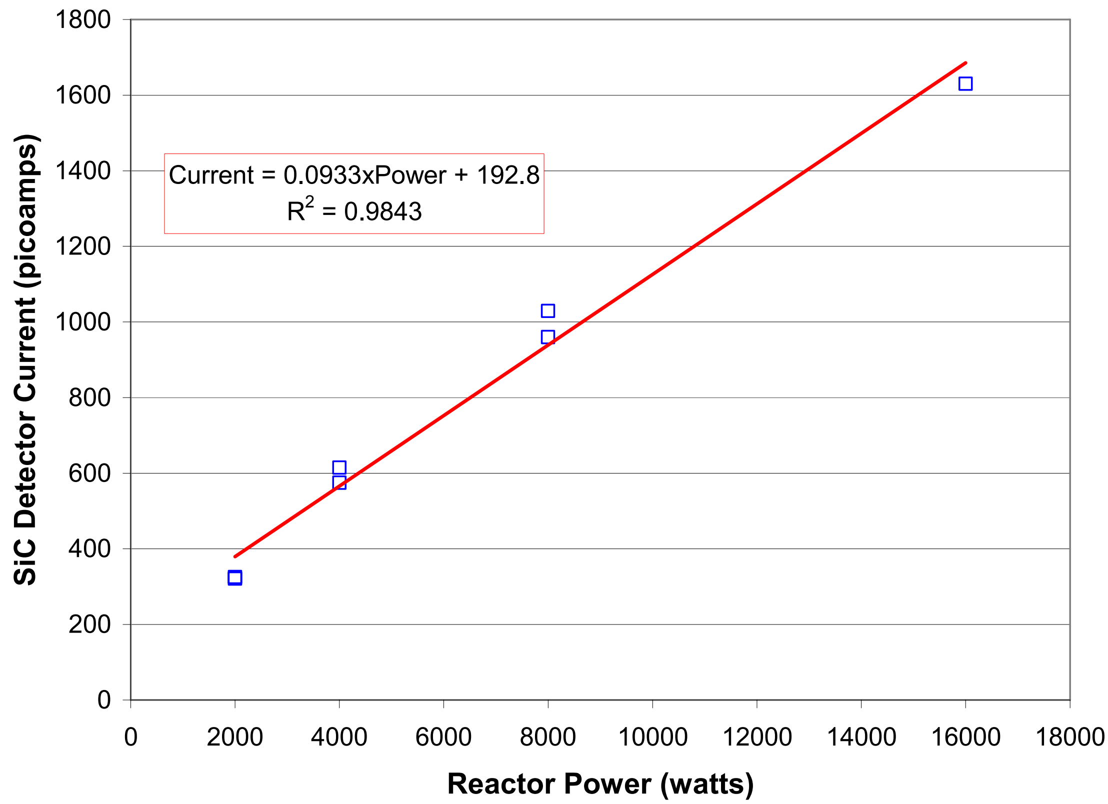
Figure 3 SiC Detector Fast-Neutron Response Count Rate Response as a Function of Reactor Power.



4. Conclusions

The fast-neutron count-rate response of SiC detectors has been demonstrated to be linear with reactor power to a precision of ±0.6%. Initial measurements indicate that the precision of the thermal-to-fast count-rate ratio as measured with SiC detectors is ±0.2%. Current has also been shown to be proportional to reactor power for a SiC thermal neutron detector. Initial current-mode measurements indicate response linearity with reactor power level.

Figure 4 Measured DC Current at Zero Bias for a SiC Detector Equipped With a ^{6}LiF Converter Foil.



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