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Performance studies of boron lined proportional counters for reactor applications

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ABSTRACT

Boron lined proportional counters of standard cylindrical geometry were developed and characterized for reactor applications. It is observed that the life of boron lined proportional counters is significantly lower if irradiated in high neutron flux keeping the HV bias "ON" compared to the irradiation with HV bias "OFF". When operated in gamma radiation, the boron lined proportional counters suffer count rate loss and underestimate the neutron flux. The loss in the count rate in gamma radiation is attributed to the space charge effect. The space charge effect is theoretically calculated for a known gamma radiation. The estimated values compared well with the experimentally observed values. Neutron sensitivity is estimated by modeling the boron lined proportional counters in FLUKA Monte-Carlo simulation code. The estimated neutron sensitivity values are comparable to the experimental and theoretical values.

1. Introduction

^{10}B lined proportional counters have attracted increased attention in the recent years because of renewed interest in nuclear reactors for power generation and also because of short supply of ^{3}He gas to develop neutron detectors. Boron lined proportional counters of neutron sensitivities ranging from 1 cps/nv to 20 cps/nv are widely used in nuclear reactors for reactor control. The detectors are used for monitoring thermal neutron flux in the start-up range. Recently extensive work has been published [ref. [1–11] and references within] on the development of boron lined proportional counters. A lot has been discussed regarding modeling of boron counters for efficiency and performance characteristics. However, not much information is available regarding design and performance issues from a reactor application point of view. Important parameters such as long term operation of boron counters in reactor environment, effect of gamma radiation on the detector count rate in mixed field and neutron sensitivity estimation are required to be studied. In the present article nvt life (thermal neutron flux nv (neutrons $cm^{-2}\,s^{-1}$) multiplied by duration of irradiation (t)) of boron lined proportional counters with HV bias "ON" and "OFF" conditions have been studied. The nvt life of boron lined proportional counters with HV "ON" conditions is being reported for the first time. The neutron sensitivity loss in gamma radiation due to space charge effect is evaluated. Neutron sensitivity is estimated theoretically and by using FLUKA Monte Carlo code.

2. Life test of boron lined proportional counters

Boron lined proportional counters are filled with argon and a small percentage of polyatomic gas. Argon provides adequate avalanche multiplication at low voltages but generates photons in multiplication process near the anode wire. An energetic photon may be reabsorbed elsewhere in the gas by photoelectric absorption, creating a new free electron. Alternatively, the photon may reach the cathode wall where it could release a free electron upon absorption. Therefore a quenching agent in the filled gas is required to prevent these photons from generating non-proportional effects in the detector output. The polyatomic gases have the ability to absorb the photon and dissociate. Dissociation of the polyatomic gas prevents the photons generated during the gas multiplication process, which leads to non-proportional outputs. Trenholme [12] showed that CO_2 gives stable performance compared to methane as quenching gas. Dauphin and Jean [13] and Todt and Carpenter [14] give experimental results of long irradiation of boron lined counters filled with various percentages of CO_2 gas as quenching agent. The reports showed that for a standard geometry boron lined proportional counter filled with 5% CO_2 gas as quenching agent, no significant change in the detector performance is observed up to 10^{14} nvt irradiation. However, both the reports discuss high flux irradiation of boron counters with the HV bias "OFF". In the reports, the detectors performances were checked before irradiation in high flux. During irradiation, HV bias to the detector was switched "OFF" and after completion of irradiation, the detector performance was checked by switching "ON" the HV bias of the detector. In the present article, life of boron lined proportional counters is studied with both HV "OFF"

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Table 1
Main specifications of ^{10}B lined proportional counters.

Type of detector	Detector no. 1	Detector no. 2	Detector no. 3	Detector no. 4
Cathode dimensions	57 mm ID × 732 mm length	51.3 mm ID × 700 mm length	23.8 mm ID × 378 mm length	9.0 mm ID × 190 mm length
Anode	25 μm tungsten	25 μm tungsten	25 μm tungsten	50 μm tungsten
Neutron sensing material	92% ^{10}B	94% ^{10}B	94% ^{10}B	94% ^{10}B
Neutron sensitivity (cps/nv)	20	15	4	1

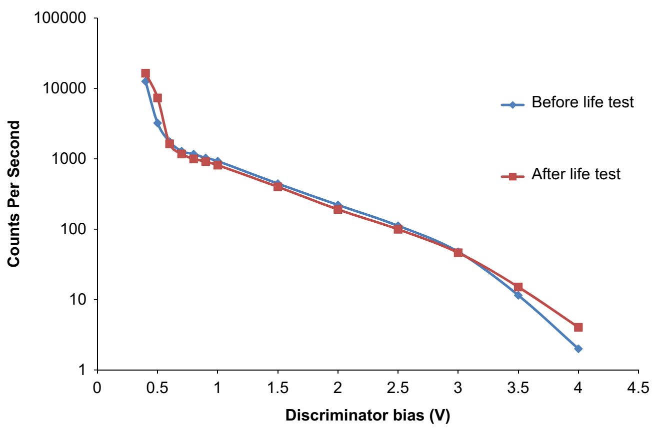

Fig. 1. nvt Life test of detector no. 1 up to 5×10^{14} nvt with HV "OFF" condition.

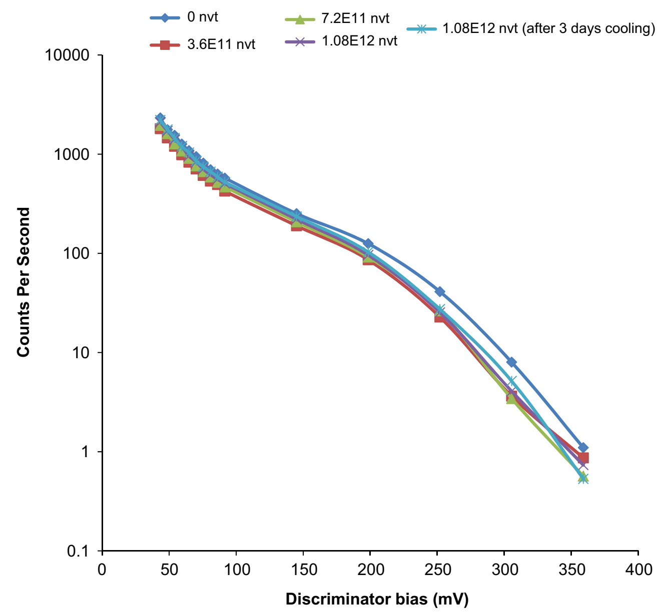

Fig. 2. nvt Life test of detector no. 2 up to 1.08×10^{12} nvt with HV "OFF" condition.

and HV "ON" conditions. Table 1 gives the main specification of the boron lined proportional counters used in the experiments. All the four detectors were filled with Ar(95%)+CO_2(5%) gas mixture at 20 cmHg pressure.

2.1. Life test of detector no. 1

The literature describes various efforts to enhance longitivity of boron lined proportional counters through various patents [15,16]. Some such efforts contain addition of reservoir of the gas mixture. Even though no special design features were incorporated in detector no. 1, great care had been taken while fabrication to reduce the gas impurities to minimum. For this purpose laboratory grade gases were used for filling the detector. The internal surfaces of the detector were honed and smoothened out, chemically cleaned and treated to reduce impurities adsorption to the surfaces. The detector was baked at 100 °C for sufficiently long time to outgas before gas filling. Slow burning long term irradiation over prolonged period was carried out in neutron flux of maximum 10^9 nv flux with the maximum gamma radiation of 956 R/h. For this purpose a test facility was set up at the beam hole no. 8 of Apsara reactor. The thermal neutron flux in the detector location was estimated by gold foils irradiation and the gamma radiation was measured using ionization chamber. The detector was irradiated over a period of 9 years and the detector received 5×10^{14} nvt cumulative neutron radiation. The detector was connected to radiation resistant Kapton cable and facility was provided to take the signal cable out for periodic testing of the detector at lower reactor powers. During irradiation at high flux the HV bias to the detector was kept switched "OFF". The detector was tested at 60 nv thermal neutron flux before and after placing in the beam hole and its neutron sensitivity remained unchanged before and after the tests (Fig. 1). The tests over prolonged time indicates that if sufficient care is taken during fabrication and gas filling, then irradiation in high flux with HV "OFF" conditions gives a stable signal.

2.2. Life test of detector no. 2

The detector no. 2 was tested for signal stability at high neutron flux with HV "OFF" condition and at low neutron flux with HV "ON" conditions. High neutron flux irradiation tests were carried out in a reactor facility. The detector was irradiated at 5×10^7 nv thermal neutron flux for 6 hours to get 1.08×10^{12} nvt neutron fluence. The irradiation duration of 6 hours was split in three cycles of 2 hours each. Detector performance was checked before and after irradiation of each cycle at low neutron flux. For this purpose reactor power was lowered to get 70 nv neutron flux at detector location. After each performance check, the HV bias to the detector was switched "OFF". The reactor power was then raised to get 5×10^7 nv flux in the detector location. Fig. 2 gives the integral bias curves of the detector recorded at 70 nv after irradiations in three cycles. It was observed that the detector showed negligible change in the count rate for 1.08×10^{12} nvt fluence with HV "OFF" condition.

The irradiation experiment was repeated for the detector with HV "ON" condition. However, in the first cycle of 3.6×10^{11} nvt, the detector life was consumed and no measurable signal output was observed. After a cooling period of 3 months again the detector was tested with neutron source and no measurable signal output from the detector was observed. Therefore, the HV "ON" condition experiments were conducted at a lower neutron flux. Another identical detector no. 2 was irradiated at 27 nv thermal neutron flux with HV "ON" condition for 6 hours for 5.83×10^5 nvt fluence and the detector showed stable performance (Fig. 3). The detector was then placed in 1.5×10^4 nv thermal neutron flux with HV bias "ON" and was irradiated for 19 hours to get 1.026×10^9 nvt