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NEUTRON RADIATION EFFECT ON CARBON-LOADED POLYETHYLENE

Eduardo P. Ervedosa[1,3], Frederico A. Genezini[2] and Luiz A. P. Santos[3]

[1] Departamento de Energia Nuclear
Universidade Federal de Pernambuco
Av. Prof. Luiz Freire, 1000
50740-540 Recife, PE
eduardoervedosa@hotmail.com

[2] Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP
fredzini@ipen.br

[3] Centro Regional de Ciências Nucleares do Nordeste (CRCN-NE / CNEN)
Av. Prof. Luiz Freire, 1
50740-540 Recife, PE
lasantos@cnen.gov.br

ABSTRACT

This work aims to study the changes in the electrical conductivity of carbon-loaded polyethylene after neutron irradiation. The material is a polymer-based semiconductor and it was used to evaluate the neutron flux in a research nuclear reactor. The main advantage with this type of semiconductor concerns about that the composite itself is not a material that bring high neutron activation. Such a feature could allow for measuring the neutron flux in real time with the advantage that it is a low cost material. Samples in triplicate with identical geometries were prepared and irradiated at different time intervals in order to evaluate the material response to neutron radiation in function of its electrical property. The method of measurement is based on the voltage yielded when a high precision ultra-low constant current is passing through the material. The results show that if this polymer-based semiconductor is submitted to a neutron flux from a nuclear reactor it presents a systematic variation in its electrical resistance and one can conclude that this material can be used as a neutron sensor.

1. INTRODUCTION

The neutron radiation has several applications such as in industry, nuclear power plant, nuclear medicine and radioisotope production, and in recent years for the treatment of cancer tumors [1]. Thus, the use of neutron radiation grows increasingly and also the demand for neutron detectors. In addition, concerns about security and illegal transport of radioactive or strategic material in large urban centers, especially after the terrorist attacks in the last decades, have motivated scientific research to develop radiation detectors for use in airports, bus terminals and train stations [2].

In comparison with other areas of nuclear instrumentation, the neutron detection has had modest advancements in recent years. The materials, techniques and electronic equipment most commonly used for that application is the same over ten years [3]. A neutron sensor normally has the operating principle based on the ^{3}He gas, and although its efficiency in detecting thermal neutrons, it has a relatively high cost. Then, the research for neutron detectors more commercially viable has motivated researchers to test other materials for this purpose.

This study aimed to evaluate how the electrical behavior of the carbon-loaded linear low density polyethylene (LLDPE) responds to a neutron flux in a nuclear reactor. Currently, the neutron sensor for this purpose is very costly, and the fact that electrical quantities can be measured in real time with low cost of LLDPE semiconductor type, provides an innovation for monitoring procedure of the neutron flux in nuclear research reactor.

2. MATERIALS AND METHOD

2.1. Materials

About 90 samples of carbon-loaded polyethylene semiconductors were cut in a rectangular shape having 48 mm length and 2.2 mm width. To make proper statistics, a set of 3 samples was submitted to neutron flux each time (Fig. 1). Actually, they are strips of thin plastic films having 72 µm thickness with 0.07 kg/m^2 density. From the manufacture data (Vermason Ltda) we have found that each 1cm × 1cm square of the material has $10^5\Omega$ electrical resistance approximately. The choice for that type of film was purely its low cost, commercial and easy to buy. But there is a technical and scientific reason for that: the composite itself is not a type of material that brings high neutron activation and such a feature is very interesting for nuclear physicists.

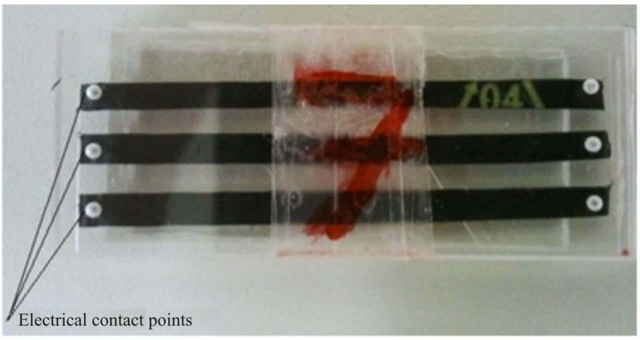

Figure 1: 3 samples of carbon-loaded polyethylene semiconductors into PMMA encapsulation with 6 points access to take electrical measurements.

2.2. Instruments

A 8508A FLUKE multimeter, which is metrological standard, was used to take measurements of the electrical resistance in each sample before irradiation. This multimeter inject a constant electrical current and the resistance readout is based on the voltage yielded in the film following Webster [4]. In order to avoid any waste of time after irradiation procedure, an 189 FLUKE multimeter, with the correction factor f_c=0.9999, was used to take measurements.

2.3. Irradiation procedure and methodology of analysis

First of all, 21 strips (7 assemblies of 3 samples) were selected from the 90 samples to be irradiated in the IEA-R1 nuclear research reactor at IPEN/CNEN. These 7 assemblies of strips were separated in order to have their resistance values with low variability before irradiation procedure. The samples were placed into the *EIRA* position (Fig. 2). The neutron flux at this position is about 10^{13} $n{\cdot}\text{cm}^{-2}{\cdot}s^{-1}$ for thermal neutrons and 10^{10} $n{\cdot}\text{cm}^{-2}{\cdot}s^{-1}$ for fast neutrons.

The methodology of analysis consisted in verify how the electrical resistance of the strips vary after be exposed to the neutron flux in the nuclear reactor. Then, the measurements were taken before and after irradiation procedure. The exposure times were choose to be from 6 min up to 24 min, in 3 min steps, and the set of strips were systematically enumerated as be seen in Table 1.

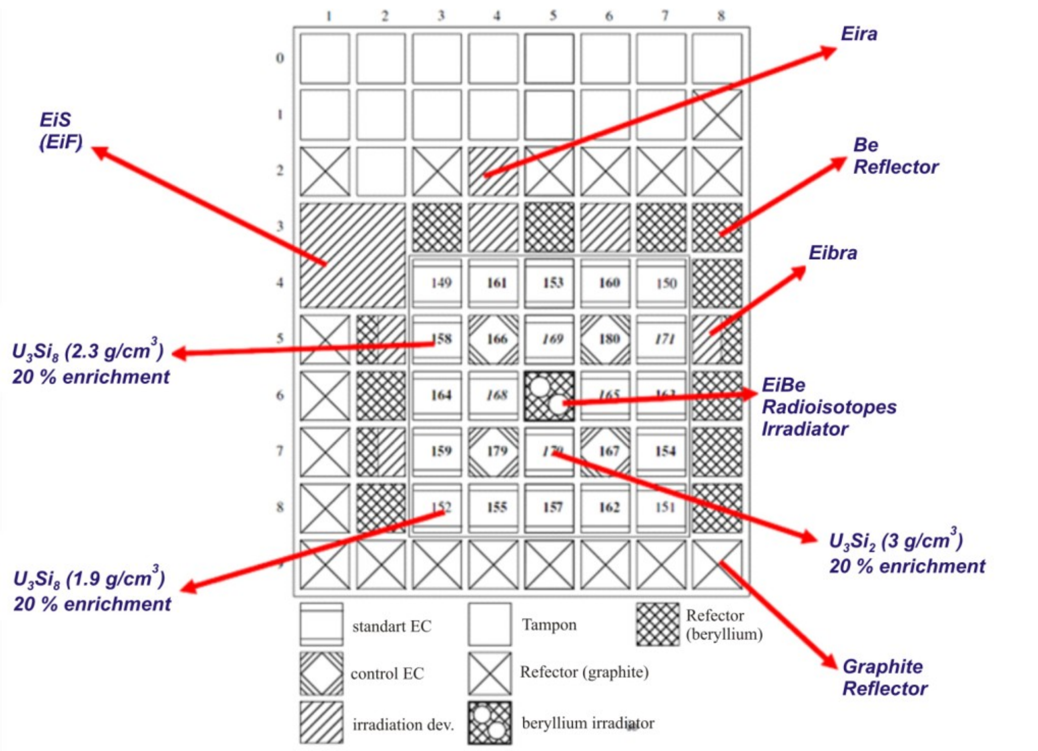

Figure 2: Scheme of irradiation procedure at the IEA-R1 nuclear reactor.

Table 1: The exposure times of each set of strips in the nuclear reactor.

Set of strips	S1	S2	S3	S4	S5	S6	S7
Exposure time (min)	6	9	12	15	18	21	24

3. RESULTS

Table 2 presents the electrical resistance values before the irradiation procedure for each set of strips and the variation in percent after irradiation. Some strips have been damaged at the moment of measurement with the probes of the multimeter because the material undergoes degradation in its mechanical property after the neutron irradiation [5-6]. One can observe that the results present certain variability and such an effect could also be attributed to the damage of the material although a more deeply study is underway.

Table 2: Electrical resistance of each set of strips before and after irradiation.

Set of strips	Sample	Resistance before irradiation (kΩ)	Variation after irradiation (%)
S1	1	995±4	7.7
	2	766±10	19.3
	3	840±9	10.7
S2	1	1037±19	18.1
	2	1010±25	-
	3	821±6	-
S3	1	1007±18	8.5
	2	1270±10	18.6
	3	1016±11	40.1
S4	1	813±3	-
	2	985±17	16.1
	3	969±11	16.8
S5	1	1092±21	16.0
	2	1167±43	8.4
	3	846±16	24.6
S6	1	1324±17	-
	2	786±5	77.8
	3	1040±10	22.5
S7	1	1161±9	38.0
	2	1105±19	59.3
	3	869±2	62.3

The graph in Fig. 3 displays the tendency of the behavior of the electrical property for the carbon-loaded polyethylene semiconductor proportionally to the neutron radiation exposure time. The y-axis corresponds to the electrical resistance variation of each set of strips. One can note that all samples have an increase in the resistance and this effect may be due to deformities that neutron bombardment causes within the composite structure although studies are underway to definitively reach this conclusion.

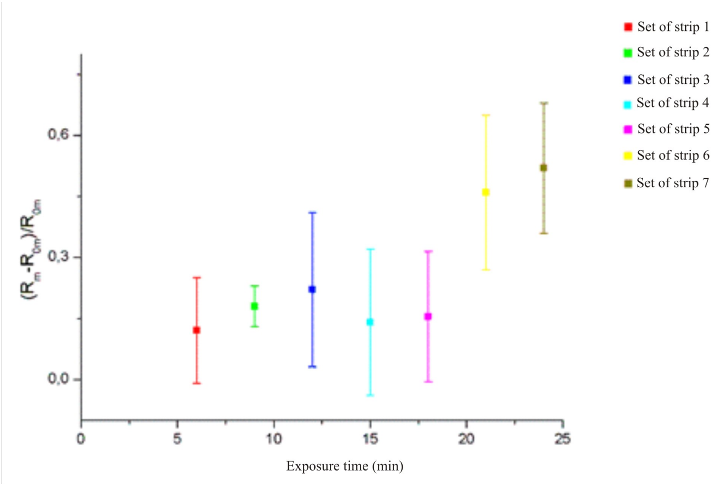

Figure 3: Tendency of the behavior of the electrical property of this carbon-loaded polyethylene semiconductor with the neutron radiation exposure time.

4. CONCLUSIONS

Carbon-loaded polyethylene semiconductor material, in form of thin film, was irradiated in a neutron flux from a research nuclear reactor. The samples were cut in a rectangular shape to be considered an electrical resistor, and their responses have demonstrated that the electrical property was changed systematically in function of the neutron flux exposure time. Although the variation does not appear perfect linear, the tendency can be viewed and deeply studies are underway to verify the physics behind the phenomenon. Furthermore the result shows that one can try to develop a plastic semiconductor material which is optimized for real-time measurements in a nuclear reactor.

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REFERENCES

1. NIU, Institute for Neutron Therapy at Fermilab, http://www.neutrontherapy.niu.edu/neutrontherapy (2011).
2. B. Fishbine, *A modular neutron detector*, Los Alamos Research Quarterly (2003).
3. G. Kaminski, *Neutron detection array based on stilbene scintillators*, Flerov laboratory of nuclear reactions, Moscou (2010).
4. J. G. Webster, *The Measurement, Instrumentation and Sensor Handbook*, CRC and IEEE Press, New York (1999).
5. D. W. Clegg & A. A. Collyer, *Irradiation effects on polymers*, Elsevier, London (1991).
6. A. Rivaton & J. Arnold, Structural modifications of polymers under the impact of fast neutrons, *Polymer Degradation and Stability*, **93**, pp. 1864–1868 (2008).