Dose Calibration and Track Diameter Distribution for [241]Am-Be Neutron Source, Using CR-39 Nuclear Track Methodology

J. S. Bogard[1], J. I. Golzarri[2], G. Espinosa[2*]

[1]*Oak Ridge National Laboratory (ORNL), Oak Ridge, TN 37831-6480, USA*

[2]*Institute of Physics, National Autonomous University of Mexico (UNAM), 04520 Mexico City, Mexico*

*Email: espinosa@fisica.unam.mx

ARTICLE INFORMATION

ABSTRACT

In neutron detection, the more common method is using electronic instrumentation associate with Bonner spheres, however, currently the Nuclear Tracks Methodology (NTM) is coming popular because of the simplicity, flexibility in size of the detector, no requirement for sophisticated instrumentation and installation, and low cost. In this work, a preliminary result of the dose calibration and track diameter distribution of Americium-Beryllium ([241]Am-Be) source using Nuclear Track Methodology is presented. As material detector, CR-39 polycarbonate, cut in 1.8×0.9 cm^2 chips was chosen, and two step chemical etchings after neutron exposure was used to develop the tracks. The irradiations were made in environmental normal conditions, in the ORNL neutron calibration facilities. The CR-39 chips were placed in a phantom, with 3mm plastic (Lexan) sheet in between the source and detectors to increase the proton generation. The total track density and track diameter distribution was performing in a Counting and Analysis Digital Image System (CADIS), developed at the Institute of Physics of the University of Mexico UNAM. The results are compared with a standard survey instrument and energy reference spectra of the International Atomic Energy Agency (IAEA).

1. Introduction

The neutron detection is not a simplest issue: a) first neutrons are indirectly ionizing radiation, they need to have an interaction with the mater to produce ionizing particles; b) very different reaction can be produced by the neutrons with the matter, as (n,a), (n,p) and (n,g), dealing with the detection of the reaction particle; c) the neutron energy distribution from epithelial to fast neutrons; d) the cross section for each particular reaction ; and e) the generation of strong field of betas, X-rays and g radiations [1-2]. All these considerations, plus some more experimental problems makes hard the neutron detection and very complicated to have a good accuracy in the characterization of neutron radiation fields. The most common detection method is the use of electronic instrumentation, but no mater this system will require the change of sphere of different materials and sizes. Since the introduction of CR-39 polycarbonate as detection material, other option for the neutron measurements is the use of the Nuclear Tracks Methodology (NTM). The main advantage of using NTM in fast neutron dosimetry and measurements is the insensitivity to photon and beta exposure, low energy threshold, no changes in a considerable variation of environmental conditions as temperature, humidity, barometric pressure and altitude, plus a wide range of neutrons energy and considerable low cost compared with the electronic systems [3-4]. In this work, a preliminary results of dose calibration, efficiency detection and diameter distribution for [241]Am-Be neutron source, using CR-39 Nuclear Track Detectors (NTD) are present. In collaboration between the Oak Ridge National Laboratory, and Dosimetry Applications Project group (DAP) of the Physics Institute of the University of Mexico (UNAM), important results were found, providing a very promising basic experimental methodology for future developments on the neutron detection, neutron dosimetry and energy analysis.

2. Experimental

2.1 Material

After several studies of different polymeric materials [5-7], it was founded that most of the plastic materials shown: a) low sensitivity; b) small cross section to produce recoiled nuclei; c) large critical angles for detection; and d) inhomogeneity

through the material by self, for the fast neutron detection. But most of these no desired characteristics for the neutron detection, was solve with the appearance of CR-39 as detection material [8-10]. Since the 80's was choosing as the material for neutron detection using the NTM [11-15]. This development was so important that these days the use of NTM and the use of CR-39, is consider as basic method for neutron dosimetry inside of the European organizations [16]: CENDOS (the Co-operative European Research Project on Collection and Evaluation of Neutron Dosimetry data), and EURADOS (The European Radiation Dosimetry Group). For this work, CR-39 polycarbonate was chosen as neutron detection material, cute in small chips for the producer Landauer®, of 1.8×0.9 cm^2 [1,11].

2.2. Irradiation

The plastic detectors were irradiated in normal environmental conditions, using the ORNL neutron calibrated facilities, under very high controlled conditions. The CR-39 chips were placed in phantom at 50 cm from the [241]Am-Be source, following the IAEA recommendations [17-19], using a 3 mm Lexan (plastic) sheet in between the neutron source and CR-39 detectors. With the Lexan sheet the proton generation will increase, obtaining better sensitivity in the detection. In Figure 1, is show the experimental arrangement for the neutron irradiation. The CR-39 chips are overlaid with a thin sheet of PMMA for enhanced charged-particle production at the detector surface.

Figure 1. Exposure of CR-39 polycarbonate (centered on PMMA phantom) to a [241]AmBe neutron field.

2.3. Chemical Etching and Reading

Before the irradiation, all the detectors were peeled from the 125 µm protection foil, and pre-etched chemically in KOH 6.25 M solution at 70 ± 1°C for 2 hours, in order to eliminate the surface impurities on the production, scratches and the hardness on the detector material surface. After the pre-etching process, all the detectors were washed in distilled water and dried in air at 32 ± 3°C. Then the detectors are placed in 3mm Lucite, this Lucite arrangement in front of the phantom for the irradiation and in front of the detectors another 3mm Lucite sheet between the detectors and the radioactive source. At the end of the neutron irradiation time, the detectors are taking out and sent to the one-step chemical etching in 6.25M KOH solution to 60 ± 1°C for 8 hours. After the chemical etching, the detectors were again washed in clean running water for 15 min, and each was sandwiched to be dry in a desiccant paper. In Figure 2, are shown a microphotography of the nuclear track detector surface after the etching procedure: a) an unirradiated detector; and b) neutron irradiated detector with formed tracks in the CR-39.
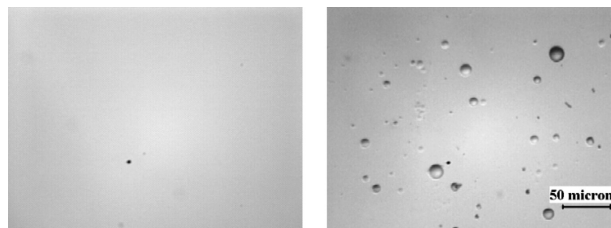

Figure 2. Nuclear track detector showing: a) unexposed; and b) formed tracks.

3. Results and Discussion

3.1 Detection Efficiency Determination

Using the CADIS system, the track density was determinate, as was mentioned before. For this measurement, only the circular tracks or with a relationship of minor diameter d and major diameter D, between 0.8 and 1.0 was consider, to avoid the problem of critical angle of the NTD in each detector. For the efficiency determination, 15 detectors were irradiated at the same time, chemically etched simultaneously, and track density read with the same operational condition on the CADIS. The average value of the track density founded was 3357 ± 70 tracks cm^{-2}. The [241]Am-Be source certificate shows that the radioactive source had 1.2705×10^7 n-cm^{2}s^{-1} at the calibration date (02/May/1966), with a half-life of 432 years, and considering the correction emission rate (n-s^{-1}) at the distance of 50 cm, the fluency rate was 379 n-cm^{-2}s^{-1} (01/July/2005). In four hours irradiation, the total neutron flux was 5.463×10^6 neutrons cm^{-2}. The efficiency E is calculated, resulting a value of: $E = 6.144 \times 10^{-4}$ tracks neutron^{-1}.

This value E is compared with the efficiency reported for other authors [13] and confirm the validity of our detection procedure. The reading of the total track density and track diameter distribution was performing in a Counting and Analysis Digital Image System (CADIS), consisting of an optical microscope with 100X magnification, with electronic ocular USB associate with a PC or lap-top, and a IFUNAM Digital Counting software (registered by UNAM™), following a very well-established protocol. In Figure 3 is shown the automatic counting system used (CADIS), and Figure 4 shows the digital image generated for the analysys.
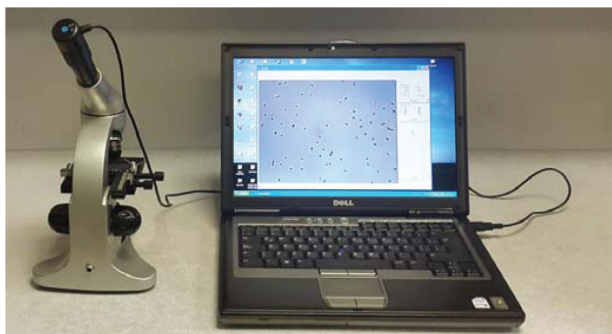

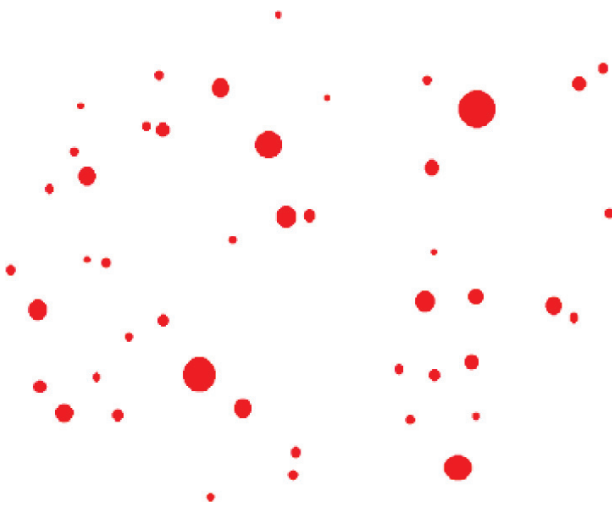**Figure 3.** Automatic counting system used (CADIS-IFUNAM).

Figure 4. Digital image generated by the analysis with the CADIS system.

3.2. Dose Response

For the dose response analysis, the same procedure with the detectors and irradiation system conditions was follow. Doses from 0 to 4.2 mSv was given to the CR-39 detector, using 10 detectors for each dose (0, 1.3, 2.4, 3.5, 4.2 mSv). After the irradiation, the same protocol for the chemical etching and reading was observe. As is shown in Figure 5, the response of the NTD results linear as function of the dose.
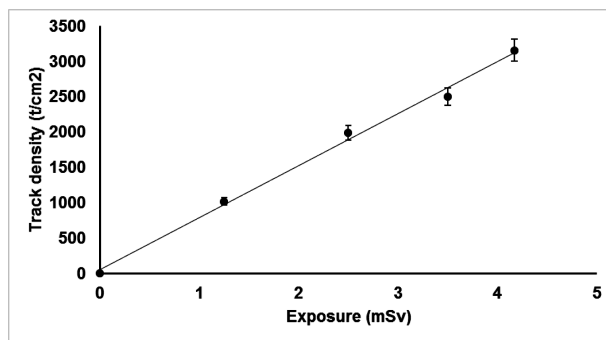

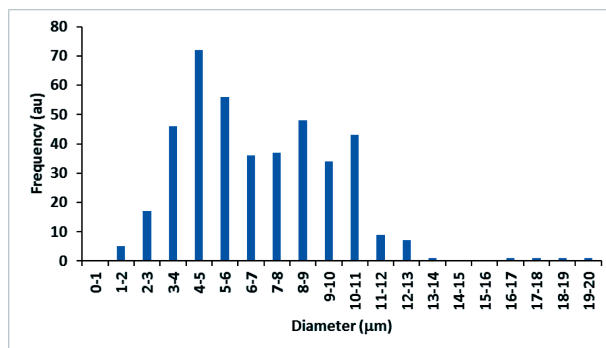**Figure 5.** Dose response of the CR-39 to ^{241}Am-Be neutrons.

Figure 6. Track distribution of ^{241}Am-Be track diameters.

3.3. Track Diameter Distribution

The analysis of the track diameter distribution was done with an automatic system CADIS, always following the same protocols [20-24]. The result histogram is shown in Figure 6. As is very well known, the track diameter is a function of the deposited energy, in this case the energy of the fast neutron in interaction with the Lexan produce recoil protons, and these protons are detected by the CR-39. If the track diameter distribution histogram is compared with the ^{241}Am-Be energy spectra [18, 25], show a good agreement between the electronic and the NTM spectra.

4. Conclusions

The neutron detection is not a simple procedure, the electronic detection system is sometimes the solution, but there are other options for neutron measurements; one is using the NTM and the NTD with polycarbonate materials as detectors. The detection efficiency is not to high then other detection systems, but the neutron flux can be measured with reasonable accurately if the detection efficiency is known. The NTD can be use as fast neutron dosimeters, with high confidence, the neutron spectra can be obtained, giving a fast energy distribution of the neutrons. These

two methods can not compete, but they can be considered complementary using the attributes and characteristics of each one.

Acknowledgements

References

[1] A. M. Abdalla, O. Ashraf, Y. S. Rammah, A. H. Ashry, M. Eisa, *et al., Radiation Physics and Chemistry,* **108**, 24–28 (2015).
https://doi.org/10.1016/j.radphyschem.2014.11.006

[2] M. E. Anderson and R. A. Neff, *Nuclear Instruments and Methods,* **99**, 231–235 (1972).
https://doi.org/10.1016/0029-554X(72)90781-1

[3] K. Becker, *Solid State Dosimetry.* CRC Press (1973).

[4] L. W. Brackenbenbush, D. E. Hadlock, N. M. A. Parkhurst and L. G. Faust, *Nuclear Tracks and Radiation Measurements,* **8**, 313–315 (1984).
https://doi.org/10.1016/0735-245X(84)90111-X

[5] F. Castillo, G. Espinosa, J. I. Golzarri, D. Osorio, J. Rangel, *et al., Radiation Measurements,* **50**, 71–73 (2013).
https://doi.org/10.1016/j.radmeas.2012.09.007

[6] S. Cavallaro, *Review of Scientific Instrumentations,* **86**, 036103 (2015).
https://doi.org/10.1063/1.4915502

[7] F. D'Errico, D. A. A. Vasconcelos, R. Ciolini and E. Hulber, *Radiation Measurements,* **106**, 607–611 (2017).

[8] F. D'Errico M. Weiss, M. Luszik-Bhadra, M. Matzke, L. Bernardi, *et al., Radiation Measurements,* **28**, 823–830 (1997).
https://doi.org/10.1016/S1350-4487(97)00191-1

[9] A. R. El-Sersy, *Nuclear Instruments and Methods in Physics Research,* **A 618**, 234–238 (2010).
https://doi.org/10.1016/j.nima.2010.02.103

[10] A. R. El-Sersy, N. E. Khaled and S. A. Eman, *Nuclear Instruments and Methods in Physics Research,* **B215**, 443–448 (2004).
https://doi.org/10.1016/j.nimb.2003.08.035

[11] G. Espinosa, *Trazas Nucleares en Solidos,* UNAM, Mexico City, Mexico (1994).

[12] G. Espinosa, R. B. Gammage, K. E. Meyer and C. S. Dudney, *Radiation Protection Dosimetry,* **66**, 363–366 (1996).
https://doi.org/10.1093/oxfordjournals.rpd.a031754

[13] R. L. Fleisher, P. B. Price and R. M. Walker, *Nuclear Tracks in Solids: Principles and Application.* University of California Press.(1975).

[14] R. B. Gammage and G. Espinosa, *Radiation Measurements,* **28**, 835–838 (1997).
https://doi.org/10.1016/S1350-4487(97)00193-5

[15] J. A. B. Gibson and E. Piesch, *Technical Reports Series No. 252, International Atomic Energy Agency,* Vienna (1985).

[16] D. E. Hankins and J. Westermark, *Radiation Protection Dosimetry,* **20**, 109–112 (1987).
https://doi.org/10.1093/oxfordjournals.rpd.a080015

[17] J. R. Harvey, R. J. Tanner, W. G. Alberts, D. T. Bartlett, E. K. A. Piesch, *et al., Radiation Protection Dosimetry,* **77**, 267–304 (1998).
https://doi.org/10.1093/oxfordjournals.rpd.a032322

[18] *Handbook on Nuclear Data for Borehole Logging and Mineral Analysis.* Technical Report Series No. 357, International Atomic Energy Agency (IAEA), Vienna. (1993).

[19] *International Atomic Energy Agency.* IAEA Technical Reports Series No. 403. Supplement to Technical Reports Series No. 318. Vienna, Austria. (2001).

[20] M. Izerrouken, J. Skvarc and R. Ilic, *Radiation Measurements,* **37**, 21–24 (2003).
https://doi.org/10.1016/S1350-4487(02)00131-2

[21] J. Jakes and H. Schraube, *Radiation Protection Dosimetry,* **70(1-4)** 133–138 (1997).
https://doi.org/10.1093/oxfordjournals.rpd.a031928

[22] G. C. Lowenthal and P. L. Airey, *Practical applications of radioactivity and nuclear radiations.* Cambridge University Press, England. (2001).
https://doi.org/10.1017/CBO9780511535376

[23] B. Milenkovic, N. Stevanovic, D. Nikezic and D. Kosutic, *Applied Radiation and Isotopes,* **90**, 225–228 (2014).
https://doi.org/10.1016/j.apradiso.2014.04.008

[24] G. S. Sahoo, S. P. Tripathy, S. Paul, S. C. Sharma, D. S. Joshi, *et al., Applied Radiation and Isotopes,* **101**, 114–121 (2015).
https://doi.org/10.1016/j.apradiso.2015.04.002

[25] K. Turek and G. Dajko, *Radiation Measurements,* **34**, 625–628 (2001).
https://doi.org/10.1016/S1350-4487(01)00242-6