Am-Be Neutron Irradiator Used for Nuclear Instrumentation Training

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***Abstract*- A neutron irradiator was assembled at IPEN (Nuclear and Energy Research Institute) facility to perform qualitative-quantitative analysis of materials, using thermal and fast neutrons. In order to determine the ^{116m}In decay constant, a thermal flux obtained experimentally by Monte Carlo N-Particle Transport Code-MCNP, in a previous work, was used in the nuclear experiment. The activity calculated from the activation parameters was 13.51±0.17 kBq and the activity determined experimentally was 12.51± 0.36 kBq. The decay constant determined by the pulse height analyzer (PHA) measures was 211.4 $\mu\cdot s^{-1}$, and that determined by fitting the data using a Multichannel Scaler (MCS) system was 200.3 ± 1.6 $\mu\cdot s^{-1}$. The half-life of ^{116m}In found in the literature is 3256.8 s, which corresponds to a decay constant of 212.8 $\mu\cdot s^{-1}$. The present experiment does not intend to establish a new value for the decay constant: it solely aims students' practical exercises in nuclear properties of elements. This experiment is part of the nuclear experimental course.**

Key Words: Neutron Irradiator, decay constant, nuclear course

I. INTRODUCTION

A neutron irradiator was assembled at IPEN (Nuclear and Energy Research Institute) facility to perform qualitative-quantitative analysis of materials, using thermal and fast neutrons. This facility is made up with a 0.5cm thickness aluminum cylinder, 120cm long and 98.5cm diameter, filled with paraffin and two perpendicular cylindrical cavities, with the same diameter (~ 12.5cm) and intersecting the geometric center. Inside the longitudinal metallic cavity (with 8.0 cm internal diameter), a sample positioning ruler passes through the longitudinal direction: thus, the material may be placed in different positions for irradiation. In the transversal position, the two AmBe neutron sources of 592GBq each are placed symmetrically, at the same distance from the geometric center, opposite to each other, as seen in Fig. 1. In order to determine the ^{116m}In decay constant, a thermal flux obtained experimentally and by Monte Carlo N-Particle Transport Code-MCNP in a previous work [1], was used in the nuclear experiment. The activity calculated from the activation parameters was 13.51±0.17 kBq and the activity determined experimentally was 12.51± 0.36 kBq.

The decay constant determined by the pulse height analyzer (PHA) measures was 211.4 $\mu\cdot s^{-1}$, and determined by fitting the data using a Multichannel Scaler (MCS) system was 200.3 ± 1.6 $\mu\cdot s^{-1}$. The half-life of ^{116m}In found in the literature [2] is 3256.8 s, which corresponds to a decay constant of 212.8 $\mu\cdot s^{-1}$. The present experiment does not intend to establish a new value for the decay constant: it solely aims the students' practical exercises in nuclear properties of elements. This experiment is part of a nuclear experimental course. The course: "Theoretical and practical fundamentals of the instrumentation used in nuclear data acquisition" seeks to teach students how to use the laboratory nuclear instruments and carry out experiments to obtain nuclear parameters. It is one of the courses offered by the Nuclear and Energy Research Institute (IPEN–CNEN/SP) postgraduate programs.

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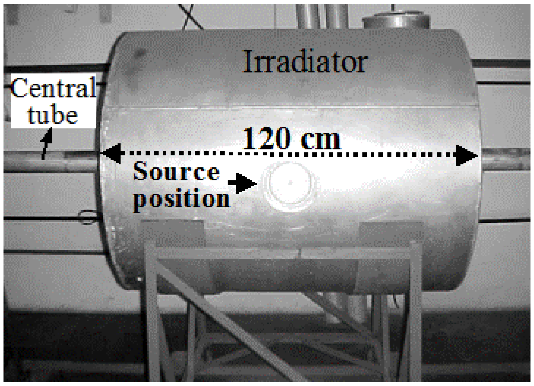


Fig. 1. Irradiator Photo with details of neutron source position

II. MATERIALS AND METHODS

In a previous work [1], to establish the prototype specifications, the neutron flux distribution was determined experimentally using the gold foils technique and the calculation with the Monte Carlo technique, for two conditions: (a) with a polyethylene block, (b) without a polyethylene block. The polyethylene block is a cylinder positioned between the neutron source and the sample, Fig. 2. Fig. 2 also shows the MCNP simulated geometry. This irradiator presents a thermal flux around 2.5×10^4 $n.cm^{-2}.s^{-1}$. Today this facility is used to train students in activation and nuclear decay studies.

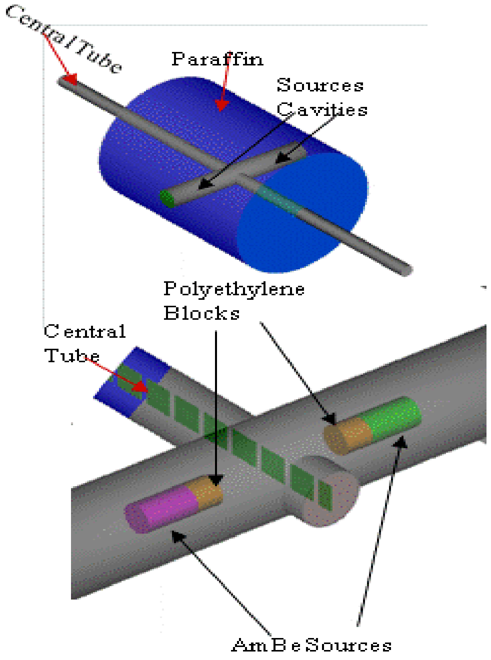


Fig. 2. – Irradiator modeled geometry and AmBe sources using MCNP. Cut at the irradiator center. [1]

Fig. 3 shows the neutron flux distribution along the Irradiator axis with a polyethylene block; this situation is used in this work.

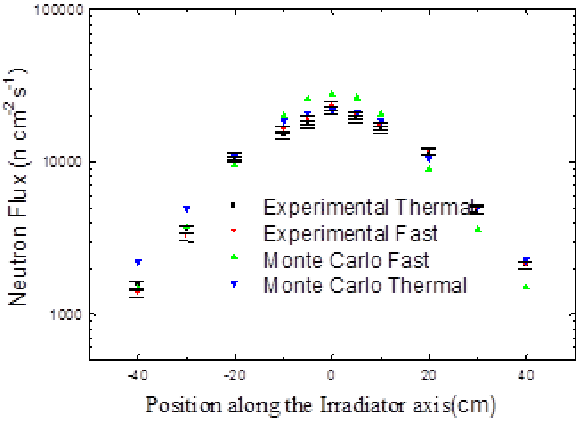
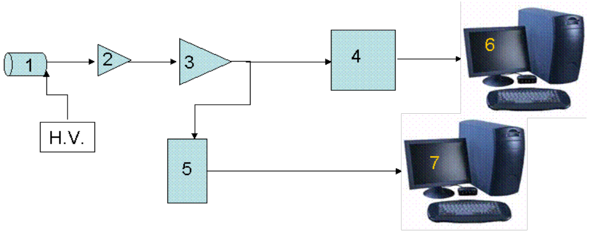


Fig 3 - Neutron flux distribution along the Irradiator axis, with the polyethylene block. [1]

After the indium foil activation, the induced activity was measured using a high purity germanium detector (HPGe) and the necessary electronic instruments to obtain the data. Two multichannel analyzers were used: one in pulse high analysis (PHA) function and the other in multichannel scaler (MCS) function. Pulse Height Analysis (PHA) pulses are selected and stored each channel, in accordance with its height, forming a histogram of pulse height. Used in together with a detector with a signal is proportional to the incident radiation energy, the case of hyper-pure germanium (HPGe) and with the aid of a standard radioactive source, it is possible to convert the histogram into an energy spectrum.

A Multi-Channel Scaler (MCS) records the counting rate of events as a function of time. When a scan is started, the MCS begins counting input events in the first channel of its digital memory. The time interval of a channel **i** is **ti** + **dt**, called dwell time. At the end of the preselected dwell time, the MCS advances to the next channel of memory to count the events. This dwell and advance process are repeated until the MCS has scanned through all the channels in its memory [3]. Fig. 4 shows the block diagram.



1 – HPGe Detector,
2 – Preamplifier,
3 – Amplifier
4 – Spectrum Master Ortec Model 919, PHA
5 – Monochannel analyzer,
6 – Computer with Ortec Maestro software
7 – Computer with MCS Plate and Ortec MCS-32 software.

Fig. 4 – Measurement system detector and electronic instrument.

A 2.54 cm diameter and 1.2051 g mass foil of indium was activated with a neutron flux of 2.5×10^4 $neutrons/cm^2.s^{-1}$ [1] from an irradiator composed by two AmBe sources, each source of americium, with 592 GBq activity. The ^{241}Am radioactive source is alpha emitter, with particles emitted with greater probability (84.8%) of having energy of 5485.56 keV [2]. The production of neutrons, with mean energy of 4MeV [4], occurs by the reaction $^{9}Be\ (\alpha,\ n)\ ^{12}C$ [5]. The natural indium owns 95.7% of ^{115}In, whose cross-section for thermal neutron capture is 202.2 b [2], generating ^{116m}In with a half-life of 54.29 minutes [2]. The activity induced by the irradiation can be determined using the activation parameters [6]:

$$A = \emptyset \frac{mN_0}{M} \sigma F (1 - e^{-\lambda t_i}) \quad (1)$$

where:

Φ = neutron flux;
N = Avogadro number;
M = Atomic mass of Irradiated element
σ = Cross section for radioactive capture of ^{115}In neutrons;
F = Isotopic abundance of ^{115}In;
λ = decay constant of ^{116m}In;
t_i = irradiation time

The main energies emitted by ^{116m}In are presented in Table I.

TABLE I. ^{116M}IN MAIN GAMMA EMISSIONS [2].

Energy (keV)			Gamma yield (%)		
416.90	±	0.02	27.2	±	0.4
818.68	±	0.02	12.13	±	0.14
1097.28	±	0.02	58.5	±	0.8
1293.56	±	0.02	84.8	±	1.2
1507.59	±	0.02	9.92	±	0.13
1752.50	±	0.02	2.36	±	0.03
2112.29	±	0.02	15.09	±	0.22

III. RESULTS AND DISCUSSIONS

The measurement system was calibrated, in energy, using standard sources: ^{137}Cs, ^{60}Co and ^{152}Eu. The system calibration line was determined by the method of least squares, using the Origin 8.5 software and is given by:

$$Energy(keV) = a + b \cdot channel \quad (2)$$

where: a= 175.44±0.26 and b=0.77537±0.00023
with R^2=1

The irradiation time was t_i= 3960s and the time between the end of irradiation to the start of the counts was t_e = 81s. Data acquisition with the two multi-channel analyzers was simultaneous. During the decay measurement of the source with MCS, twelve spectra pulse heights of 300 s each (live time) were acquired. For the energy of 1293.56 keV, resolutions of photopeak were determined to measure their variation with the source decay. Also, for this energy, the count rate through the ratio of the total areas and time of the spectrum acquisition was determined, to calculate the decay constant through the curve of counts in function of time.

The detection system efficiency curve was determined as:

$$\eta(\%) = 2.1 + 20.1e^{\frac{energy}{393}} \quad (3)$$

Using this relationship to determine the efficiency for the energy of 1293.56 keV and the number of counts at the end of irradiation, C_0 (t=0), obtained by the exponential adjustment of counts versus time, the activity induced by the indium foil irradiation was estimated as:

$$A = \frac{C_0}{F\eta G} \quad (4),$$

were G = geometry factor.

Considering that the radioactive source and the detector window are circular, with the former being approximately punctiform, the geometric factor may be approximated up to 0.5 [3], because the source was placed on the detector window.

The channel corresponding to the maximum intensity, called peak centroid of the photopeak (or full energy peak), acquired in the Maestro computational analysis program, was determined. Each centroid channel was associated with one of the energies from gamma emissions of sources found in the literature [7].

The activity induced by irradiation was 13.51 ± 0.17 kBq, calculated using the neutron flux source AmBe. Considering that 81s were spent between the end of irradiation and the start of the measures, the initial activity was 13.30 ± 0.17 kBq. The first and last pulse height spectra measured, already calibrated in energy, are shown in Fig 2.

For data obtained using the MCS, an exponential curve was adjusted with the Origin 8.5 computer program, to determine the disintegration constant and the initial counts. Thus, using the initial count value, the system efficiency was concluded as [5]:

$$\eta = \frac{C}{A \times G}$$

With A, the radioactive source activity immediately before the start of the counts (calculated using the induced activity).

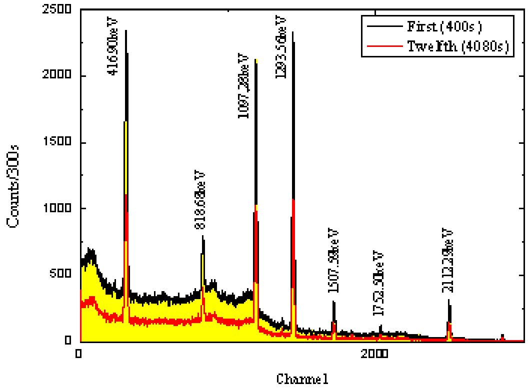


Fig. 5 - Spectra energy from ^{116m}In. The time refers to the interval between the completion of irradiation and the end of the spectrum acquisition

Only the results corresponding to the first and last measured spectra were presented, since similar values were obtained for intermediary spectra. The error rate was less than 0.2% for all energies studied in the spectra obtained.

The resolution of the 1293.56 keV photopeak was determined as the ratio of the width at half height (FWHM - Full Width at Half Maximum) and the centroid channel for all spectra of pulse height [5].

The resolutions observed vary around the average value, due to the decay of the source and consequent reduction of the rate of events in the detector, but there was no significant change in the photopeak centroid channel, or in the resolution. Using the total area under the energy peak of 1293.56 keV, a graph was plotted with the count rate in function of time, to determine the disintegration constant of ^{116m}In (Fig. 6).

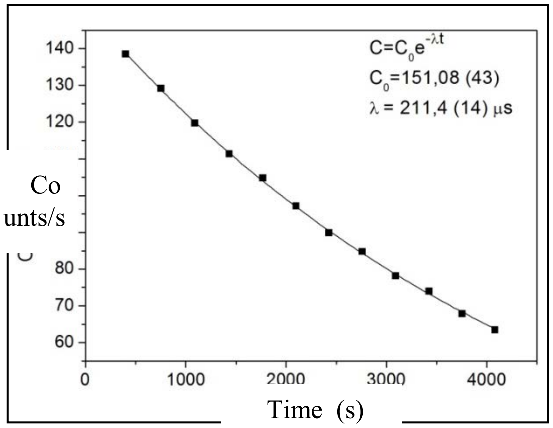


Fig. 6. Decay curve of the ^{116m}In source, considering the total area under the energy peak of 1293.56 keV.

The activity induced by the indium foil irradiation, calculated using the initial count (4) obtained in Figure 4, was 12.51 ± 0.36 kBq, near the theoretical value calculated from the activation equation (1). The constant of the determined disintegration in Figure 4, with data obtained by PHA, was $211.4 \pm 1.4\mu s^{-1}$.

Using the data obtained with the MCS (dwell time=450.00ms), it was possible to adjust an exponential curve, determining the number of initial counts and the constant of the ^{116m}In disintegration (Fig.7).

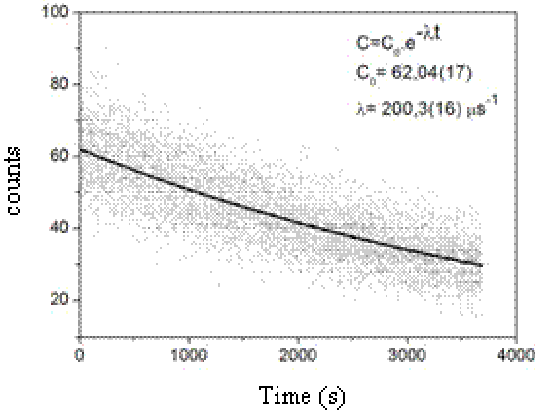


Fig. 7: ^{116m}In decay curve measured in the MCS.

The decay constant determined by the adjustment of the data obtained with the MCS was $200.3 \pm 1.6\mu\ s^{1}$. The ^{116m}In half-life found in the literature [2] is 3257.4s, which correspond to a disintegration constant of $212.8\mu s^{-1}$. This value is within the uncertainty range 1σ of the constant determined in Fig. 3, whose data were obtained by the PHA method. Nevertheless, the value obtained by the MCS method, Fig. 5, even with a 3σ interval does not include the expected value.

IV. CONCLUSION

The activity determined experimentally, using (4) (12.51 ± 0.36 kBq), showed an approximate value to that calculated using (1), with activation parameters (13.51 ± 0.17 kBq). These results validate the method for calculating the activity from (1). The decay constant determined by the PHA method ($211.4 \pm 1.4\ \mu s^{-1}$) is nearer the value found in the literature ($212.8\ \mu s^{-1}$) than that obtained with the MCS ($200.3 \pm 1.6\ \mu s^{-1}$). The problem may be the poor statistic count in function of a detection short time by channel (dwell time=450.0ms).

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