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A Basic Neutron Howitzer

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Abstract

The design and construction of a neutron howitzer using a 0.5 Ci Am-Be source is described in detail. The purpose of this device is to serve as an educational tool to get insight of the experimental nuclear physics. A 200 liters stainless steel tank filled with a refined wax constitutes the shell of this device; inside it has an arrangement of four perpendicular stainless steel experimentation channels placed horizontally, plus one vertically and centered tube for the positioning of the neutron source. The five tubes can be refilled if necessary with a moderating element, polyethylene in our case. The measured external and internal levels of radiation fulfill the maximum permissible radiation levels accepted internationally for this type of apparatus. This neutron howitzer has the mechanical resistance required by the nuclear international organisms.

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1 INTRODUCTION

The analytical methods used to study materials with X rays and electrons are well known in several engineering and scientific areas. Methods of analysis like Mössbauer and neutron spectrometries use gamma and neutron nuclear radiation.

Neutrons of low energy, called thermal or subthermal, are of singular importance in the study of molecular dynamics in solids and liquids. The molecular rotations and the vibrational modes of the lattices can be studied with a certain ease and detail, by means of inelastic scattering; neutrons have energies in the order of magnitude where these movements occur, typically between 10^{-3} and 10^{-1} eV. The neutron's wavelength is approximately 10^{-8} cm and can probe a molecular system at intervals between 10^{-14} and 10^{-10} s. There are published articles that use this technique, for example: water adsorption in silica and alumina powders, and presence of hydrogenic molecules in zeolites and molecular sieves [1].

Another technique based in the use of neutrons is the Neutron Activation Analysis NAA)[2], which has been found to be important in the study of an enormous quantity of samples of materials, where the presence of elements in important and intermediate quantities is evaluated in no more than a few parts per million. A worldwide estimate reports that about 100,000 samples are annually analyzed using the NAA technique[3]. Judging by the results, the metallic elements are conveniently analyzed by means of NAA but are not the only elements that can be studied with this technique.

A well known and easy method for obtaining metal activation is through the activation of indium; the reaction that occurs can be expressed as follows:

$$^{115}\mathrm{In} \rightarrow {}^{116m}\mathrm{In}(0.9\mathrm{h}) \rightarrow {}^{116}\mathrm{Sn},$$

as a result of this process it is possible to observe gamma lines produced by excited states of ^{116}Sn.

Another example that is important from a didactic point of view is the activation of silver which presents a content of 51.83% of ^{107}Ag and a 48.17% of ^{109}Ag. The activation by neutrons produces either

$$^{107}\mathrm{Ag} + {}^{1}\mathrm{n} \rightarrow {}^{108}\mathrm{Ag} \rightarrow {}^{108}\mathrm{Cd} + \beta^{-}$$

or

$$^{109}\mathrm{Ag} + {}^{1}\mathrm{n} \rightarrow {}^{110}\mathrm{Ag} \rightarrow {}^{110}\mathrm{Cd} + \beta^{-},$$

where two isotopes with beta emitters having half-lives of 2.41 min and 24.6 s respectively are obtained.

There are many applications based in neutron physics, ranging from energy production to medical applications, but the description of such topics is outside the scope of this paper. Our aim is to show that a neutron howitzer is easy to make and is well suited for training nuclear technicians and undergraduate physics students.

This article is organized as follows. The general characteristics of the Am-Be neutron source employed are depicted in Section 2. In Section 3 the design and construction details of the neutron howitzer are described. The results of the measurements of gamma and neutron fields around the irradiator are presented in Section 4, and the conclusions of the performance of this device are described in Section 5.

2 ^{241}AMERICIUM-BERYLLIUM NEUTRON SOURCE

In order to justify the design of the irradiator it is convenient to recall on the relevant properties of neutrons and to list the specific parameters of the neutron source. The neutron is an elementary particle without electric charge with a mass of $1.6748\text{x}10^{-24}$ gr, very close to the proton's mass; the neutron produces a proton, an electron and one antineutrino as a result of its disintegration. Neutrons are usually classified according to their kinetic energy as follows: (a) relativistic, with energies greater than 20 MeV; these can be produced through nuclear reactions, their primary interaction with matter being elastic; (b) fast, having energies above several tenths of keV. Neutrons with these energies (200 keV) are typically associated with fission neutrons, and (c) slow or thermal, named so because they are in thermal equilibrium with their surrounding medium, and have energies of about 0.025 eV. In nuclear reactors and cyclotrons it is possible to produce neutrons with fluxes up to $1.5\text{x}10^{15}$ neutrons/cm^2/s. It is also possible to produce neutrons with a radioactive source through a nuclear reaction. There are two types of neutron sources: those produced by spontaneous fission and those produced by (α,n) and (γ,n) reaction. The most common neutron sources are of the second type with an (α,n) reaction because there is a greater neutron production per Ci, and have long half-lives. The target materials usually employed with (α,n) sources are ^{7}Li, ^{11}B, ^{19}F and ^{18}O; the most frequently utilized is Beryllium. This material and the alpha emitter are prepared as an alloy or as a compound with the advantage that the reaction Be(α,n) produces a great quantity of neutrons, about 1 neutron each 10^4 α particles. The most common α emitters employed in the (α,n) sources are: ^{239}Pu, ^{238}Pu, ^{210}Po, ^{226}Ra and ^{241}Am. The neutron energy spectra of the last source show sharp peaks at 3.5 and 5 MeV and two more at 8 and 10 MeV [3-6].

The ^{241}Am-Be source that was positioned in the irradiator has a half-life of 458 years and was prepared with AmO$_2$ packed with Be; the mean energy of the emitted neutrons is 4.5 MeV. This source was manufactured by Amersham Ltd., an English company and is contained in an X.3 capsule with the classification code AMN19. The specific characteristics of this Am-Be source are: nominal activity of 0.5 Ci and the emission of $1.1\text{x}10^6 \pm 10\%$, n/s. The source container is a double stainless steel cylinder with the following dimensions (mm): length 30.0, diameter 22.4, thickness of each cylinder 1.2. The top of the container has an internal screw (M6 type) to be used on a rod. This source was subjected to security proofs set by the IAEA: GB/9/S. The source classification of ISO (International Organization for Standardization) is E.66545. Figure 1 shows a diagram of the described radioactive source.

3 DESIGN AND OPERATION OF THE IRRADIATOR

One of the motivations that led to the design and construction of the howitzer is the high cost that represents buying a commercial irradiator and the scant budget available (in our country) to acquire devices oriented to teach nuclear physics at the undergraduate level. We designed and constructed a neutron howitzer employing quality materials and elements of easy acquisition, fulfilling the radiological protection regulations. The neutron howitzer or irradiator is basically a container filled with a moderating (or absorbing) material to neutrons. These materials must have abundant quantities of hydrogen atoms, such as water, wax, and polyethylene [10]. A frequent design feature is a tube arrangement embedded into this device in order to: position the source, install the detectors, as well as the experimentation channels.

3.1 IRRADIATOR STRUCTURE

The primary structure constituting the irradiator is a 200 1 cylindrical steel tank, 80 cm high and 55.6 cm of inner diameter. A stainless steel arrangement of five tubes was fixed in the interior of the tank. Four identical tubes were placed 15 cm of the lower end of the tank, perpendicular to each other (in a cross arrangement), in a horizontal plane[7] constituting the experimentation channels; each tube has the following dimensions (in cm): 0.40 thickness, 3.80 of inner diameter and 55.00 of length. A vertically oriented tube perpendicular to the cross arrangement, was assigned as a guide tube with the purpose of moving the radioactive source. This tube has a 6.20 cm inner diameter and a length of 55.00 cm; in the lower end there is a 0.30 cm thick lead welded cap. This lower cavity was used as a chamber to lodge the source. The upper extreme of the guide tube was fixed with a flange to a metal sheet used as a cover of the absorbing material (wax in this case) and to fix the neutron source. This cover is 0.30 cm thick, 56.50 cm of diameter and a drilling of 6.50 cm of diameter. A third part of the total area of this cover is permanently welded to the tank and the rest can be closed or opened by means of a hinge. The cover has a pair of clamps placed 12.00 cm in each side of the central aperture. Padlocks were placed to these clamps in order to permit the access to the neutron source only to authorized personnel. The rod that fills the guide tube can be placed in seven positions, one to insert the source in the lodge and the other for irradiation, one of them is to set the source to the height of the experimentation tubes. The details are shown in a longitudinal view of the irradiator in Fig. 2.

3.2 SHIELDING ELEMENTS

The irradiator was filled with American type wax, with a low content of oil, that serves as a moderating material [8]. This type of moderator offers well known physical characteristics and a simpler way to handle the tank because it does not melt at room temperature. In the hypothetical situation where the tank temperature were higher than the fusion temperature of the wax, there would be no leaks of material. The interior of the tank was uniformly polished and covered with noncorrosive paint, before the mechanical parts depicted in the last section were welded. The wax was melted into the tank in wax layers of 5 cm of thickness, to obtain uniform layers without bubbles and cavities into the wax bulk to solidification. During casting, the tank was maintained in a site without air currents and dust in order to hinder the incorporation of impurities to the wax bulk. A total volume of $V_p = 185058.35\ cm^3$ corresponding to a mass of 149.9 kg of wax was used; the container was filled 11.5 cm below the upper tank edge. The experimental channels, as well as the guide tube were filled with high density polyethylene bars to moderate the fast neutrons emitted by the source. The metallic rod introduced in the guide bar is prevented to move with a pair of pitchforks, one in each extreme, so the polyethylene bar is not supported by the neutron source. Each of the polyethylene bars inserted in the experimentation channels has a brass flange screwed to it. When the bar is inserted, this flange can be coupled to bridles mounted on the tank surface. These pieces can be fastened with padlocks. For irradiation experiments, the polyethylene bars are substituted with adapted tubes that include the detectors or samples depending on the particular experiment.

3.3 LABORATORY DETAILS

The neutron facility requires the same control and protection as any other type of radioisotope laboratory [9]. The neutron howitzer was installed in a room in the second floor with the following dimensions (expressed in cm): 560 length x 197 width x 310 height. The neutron howitzer was placed in the North end near the wall, which is the recommended and permanent position of the neutron irradiator. The characteristics of the room and the occupation level (indicated by τ) in the adjacent areas are: to the North there is refractory brick wall with a window of 109 cm high and 107 cm from the floor, that is facing to an unoccupied garden area ($\tau = 0$). To the South there is a study room separated by a wall similar to the one in the North ($\tau = 1$). There is a warehouse adjacent to the East side separated by a refractory brick wall ($\tau = 1/16$). To the West the irradiation room has a refractory brick wall that separates it from the Modern Physics teaching laboratory ($\tau = 1/2$). A concrete floor and ceiling separates the lower and upper levels; above and below the irradiation room there are warehouses ($\tau = 1/16$). Moreover, there is a spacing of 12 cm between the irradiator and the floor due to the wheels fixed to the irradiator structure.

4 NEUTRON AND GAMMA FIELDS MEASUREMENTS

The general regulations of Radiological Security [5] governing for students and personnel exposed to radiation by occupancy, demand an annual limit for the equivalent dose of 50 mSv, that is, equivalent to a dose of 25 μSv/hr. For general public the regulations order an annual limit of 5 mSv, that is, 2.5 μSv/hr. The measurements must be corrected (multiplied) by the occupation factor τ in each case. The index takes a $\tau = 1$ value when the considered area is occupied continuously by personnel during a day's journey. In our case, the measurements have the correction by the occupation index. The monitoring routines for both gamma and neutrons were realized for several distances to the irradiator[10]. The detectors used were calibrated by the ININ (National Institute on Nuclear Research of México). The background radiation was measured first and then several series of measurements were taken at different points of interest. All the measurements were made at a height of 100 cm above the floor. A Geiger-Müller (Victoreen, Mod. Thyac III) was employed to detect the gamma radiation and then corrected measurements for the exposition rate, expressed in Roentgen (R) were obtained. This quantity is defined as the resulting exposure for the electrostatic charge generated by 1 cm^3 in standard conditions of air pressure, such that $1R = 2.58 \times 10^{-4}$ C/kg. The results are shown in Table 1.

Table 1. Gamma exposition level produced by the irradiator.

Location (referred to the tank)	Dose (mR/hr)
in contact	0.3
at 50 cm	0.1
at 100 cm	0.05
South wall (study room)	0.05
East wall (warehouse)	0.04
West wall (laboratory)	0.04
Lower slab (warehouse)	0.03

On the other hand, the neutron field measurements were made with a neutron detector, Victoreen, Mod. 488A. The measured equivalent dose levels are expressed in μSv (sievert = 1Sv = 100 rem) and are included in Table II.

Table II. Equivalent neutron dose.

Location(referred to the tank)	Equivalent Dose H(μSv/hr)
in contact	3.5
at 50 cm	1.7
at 100 cm	1.3
South wall (study room)	4.3
East wall (warehouse)	0.7
West wall (laboratory)	0.3
Lower slab (warehouse)	1.1

The equivalent doses expressed above correspond to the effective maximum dose to which personnel would be exposed in different points in the irradiation room. Several recommendations and modifications were implemented as a result of the monitoring process with the purpose of making the laboratory and the irradiator a secure zone. In order to diminish even more the radiation levels due to neutrons, primarily the equivalent dose in the South side of the room that has an occupation level $\tau = 1$, a pair of adjustments were instrumented. A wood frame panel with wax blocks was fitted to the South window, moreover a folding screen was constructed with a wood frame and wax blocks, with the following dimensions (in cm): 54 width x 120 height x 6 thickness. The folding screen has wheels and can be pleated giving an external and mobile shielding that attenuates even more the neutron component. It is inserted between the irradiator and the personnel when the latter is preparing experiments; it also supplies an additional protection in the working area. Other measurements of radiation have been realized in the same points. In this case the TLD technique was used, with the TLD-600 and TLD-700 to detect gamma radiation and neutrons. These measurements[10] indicate that gamma radiation is of the order of the background radiation and are in agreement with the results reported here. The measured equivalent doses due to thermal neutrons were lower than the equivalent doses determined in this work for fast neutrons.

5 CONCLUSIONS

A detailed description of the design and construction of a neutron howitzer was presented. Except for the radioactive source, all the other employed materials can be easily and locally obtained. This apparatus has the characteristics required by the international organisms for nuclear science. The gamma radiation level obtained was lower than 0.3 mR/hr and the equivalent resulting dose was below the maximum permitted dose for the personnel that operates the irradiator and lower than the maximum radiation levels permitted for general public. This device offers many possibilities for making a variety of experiments with neutrons.

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FIGURE CAPTIONS

Fig. 1. Diagram of the container with the double encapsulate (stainless steel) of the ^{241}Am-Be neutron source. The top of the source was screwed to a metallic rod for subjection. Dotted region corresponds to the Am-Be mixture. Dimensions in mm.

Fig. 2. Longitudinal section of the irradiator (in cm). Plotted in honeycomb is represented the wax filled zone. Dots and dashes denote the polyethylene bars. In the upper section the handles pass through the crosspiece in order to assure the source position.

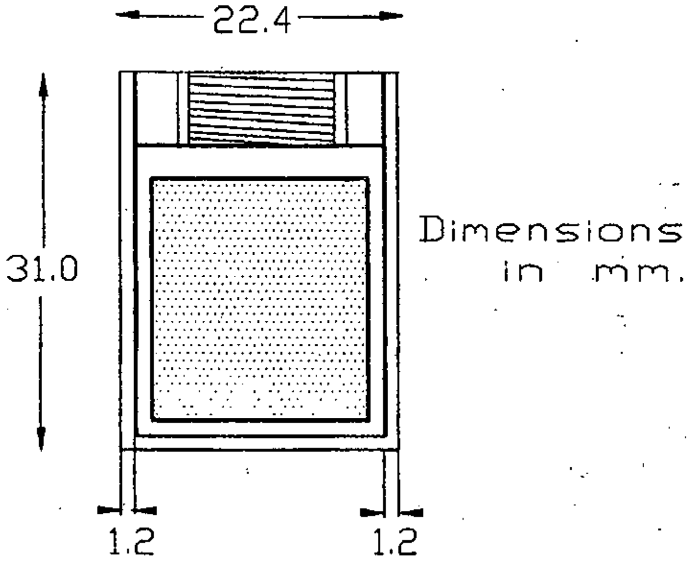

Figure 1.

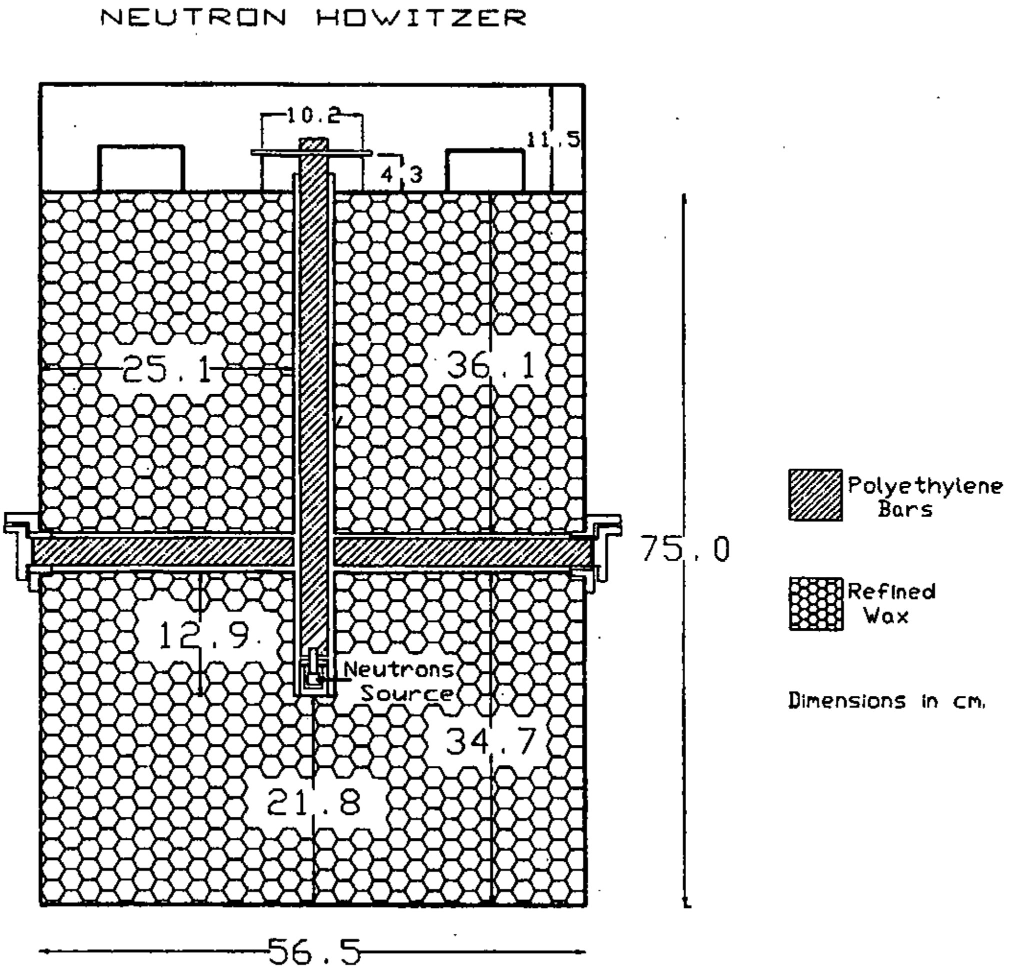

Figure 2.

A Basic Neutron Howwitzer

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