Measuring shielded head for neutron experiment in teaching

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Abstract

The aim of the present work is to design an appropriate measuring shielded head for neutron experiment in teaching. The measuring shielded head has been conceived for a wide range of experiment in nuclear physics and radiation techniques. Also, it can be used as irradiation chamber for neutron activation. Special attention was paid to the radiation protection exigency.

Keywords: Neutrons, experiments.

Resumen

El objetivo del presente trabajo consiste en el diseño de un cabezal de medición apropiado para experimentos con neutrones de carácter docente. El cabezal de medición ha sido concebido para un amplio rango de experimentos en la física nuclear y en las técnicas de radiación. También, puede ser utilizado como una cámara de irradiación para activación neutrónica. Se prestó especial atención a las exigencias de la protección radiológica.

Palabras clave: Neutrones, experimentos.

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I. INTRODUCTION

Since their discovery [1, 2] in 1932, neutrons have played an essential role in basic research and in a range of fields of nuclear applications. Even previous to the properties of the neutrons were fully understood, neutrons served as a potent tool of probing nuclear matter [3]. Neutrons are also of principal significance for fusion energy technology; an area of research which appears to be promising alternative to fission for nuclear energy production in the future [4]. Neutrons in addition have a wide application in others disciplines such as medicine [5], biology [6], materials science [7, 8] and in industry [9, 10, 11, 12, 13, 14, 15, 16, 17], and their importance in these fields is increasing. One of the most notable uses of neutrons in medicine concerns cancer therapy. Radiobiological studies have led to the hope that neutron therapy may contribute to the treatment of some malignant diseases which do not respond to conventional gamma ray treatment [18]. Industrial uses of neutrons presently cover three broad fields of applications: Materials production, materials testing and materials analysis.

In order to meet all the requirements for physics teaching in higher education much effort has been devoted to the development of suitable experiment with neutrons.

The aim of the present work is to design an appropriate measuring shielded head for neutron experiment in teaching. Special attention was paid to the radiation protection exigency.

The measuring shielded head has been conceived for a wide range of experiment in nuclear physics and radiation techniques, which includes: study of the slowing down, thermalization of fast neutrons, neutron flux measurements, fast estimation of neutron removal cross section in hydrogenous and complex materials, determination of hydrogen content in hydrocarbons, determination of moisture content and bound water in minerals, the neutron absorption method and many others. Also, it can be used as irradiation chamber for neutron activation (foils activation techniques, nuclear reactions and nuclear spectroscopy experiments). Detailed information of such experiments can be found in references [19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31] and its characteristics determine the design requirements.

Due to the intended application, the measuring head (MH) has been designed in accordance with following prerequisites: 1) Measuring range of H_2O content 1-15% and reproducibility not worse than 0.8%, 2) Linear behaviour in the measurement range to simplify the calibration, 3) A sampling period of around 3min., 4) Shielding should be light enough to allow for easy movement of the device from one location to other, 5) Volume of the sample around $1000cm^3$, 6) The dose equivalent rate must be below the maximum levels permitted for classified workers, 7) Devices for fastening the source housing and detector housing shall be designed in such way as to facilitate positioning, maintenance and ensure a satisfactory installation in the selected places, 8) Be designed in such way as to prevent it being dismantled by non authorised persons.

II. MEASURING HEAD DESIGN

The measuring head is accomplished by three blocks. The three blocks are rigid assembled through a central bar with a safety lock in one extreme. In this way is prevented MH being dismantled by non authorised persons. Each block is light enough to allow for easy movement of MH from one location to another. It should emphasise that a hand – held device was not intended here; rather a mobile system of a reasonably weight was required. According with this design (transportation of independent blocks of the MH and assemble in the installation place) before any movement from one location to another is necessary to extract the neutron source and put it in storage container.

The lateral blocks are designed for radiation protection purpose only. The central block includes a radioisotope neutron source, a BF_3 proportional counter (a cadmium sheet surrounding the detector except the surface faced to the sample holder) and a drawer with a sample holder. The drawer allows changing the sample avoiding the exposition to radiation also. It has a safety lock to prevent that the drawer could be extracted totally with the consequence radiation risk. A cadmium sheet, surrounding the sample holder (except the surface faced to detector), filters the thermalized neutrons and reduce the background. Source holders and detector holder are placed in two independent drawers with safety locks to facilitate positioning, maintenance and ensure permanent installation in the selected positions. The detector drawer contains also the detector preamplifier.

The associated electronic consists of BF_3 proportional counter, preamplifier and a radiometer that included low voltage supplier, high voltage supplier, amplifier, single channel analyzer and a microprocessor with a program that enable the interaction of the user according to the intended experiment. The electronic was especial design to satisfy all possible experiment with the MH.

There are some basic parameters of the MH that have important influence in the sensitivity: the source – detector distance, the detector length, the energy of the source and finally the moderator and shielding materials employed. To select the values of such parameters to design central block in such a way that a good sensitivity is reached, it was took in account the analysis provided in a previous work [32].

According with the counting period and the reproducibility required the strength was calculated for an AmBe source (10^5 Neutrons/s). The next step was the design of an adequate shielding against neutrons and associated gamma rays. A mixture of polyethylene pellets and paraffin wax was used as shielding materials.

Capture in hydrogen, present in polyethylene pellets and paraffin wax, leads to the emission of 2.22MeV gamma rays which, because of its high energy is particularly undesirable. In order to reduce the gamma background boric acid was used as additive. This additive was chosen to have a high neutron cross section so that the moderated neutrons will be preferentially undergoing absorption within these materials. Therefore the majority of the capture reactions lead to an excited state in the product nucleus, which subsequently decays by the emission of a 0.48MeV gamma rays.

The external surface of the MH was made of steel sheet of 1mm thickness, strong enough to retain shielding materials in appropriate way.

The removal cross method was used to calculate the shielding thickness. The calculations show that the MH designed can provided a good radiation protection for up to 0.25Ci (5.5 10^5 neutrons/s) AmBe source.

III. RESULT AND DISCUSSION

The photo of the MH is shown in Fig. 1.

FIGURE 1. Measuring shielded head for neutron experiment in teaching.

The experimental verification of the prerequisites fixed in accordance with the intended application was carried out.

It was found that the count rate (neutrons/s) depends linearly on the H_2O content W in the range $1<W<20\%$ for different materials (SiO_2, Al_2O_3, gravel, sand and rock). The measurements have a total reproducibility of 0.7%. The measuring time (3min.) ensured that the statistical errors was negligible in comparison with others source of errors. The sample holder volume employed was $1000cm^3$.

To confirm experimentally the adequacy of the shielding designed was used a 1.1 10^6 neutrons/s AmBe neutron source (with the twice of the yield considered in the design) in the experiment.

For the measurement of the shielding properties were used a neutron dose equivalent meter BH3105 and gamma dosimeter Eberline FH40F2 Instrument Gmb Erlangen.

Both instruments were previously tested in a secondary calibration laboratory properly accredited.

Measurements were made so as to take in account the total area of two imaginary surfaces situated at 5cm and 1m from the external surface of the MH. The dose equivalent rate was the sum of the dose equivalent rate from the fluence of the neutrons and from the associated ionising radiation dose rate. The dose rate distribution around the MH is shown in Fig. 2.

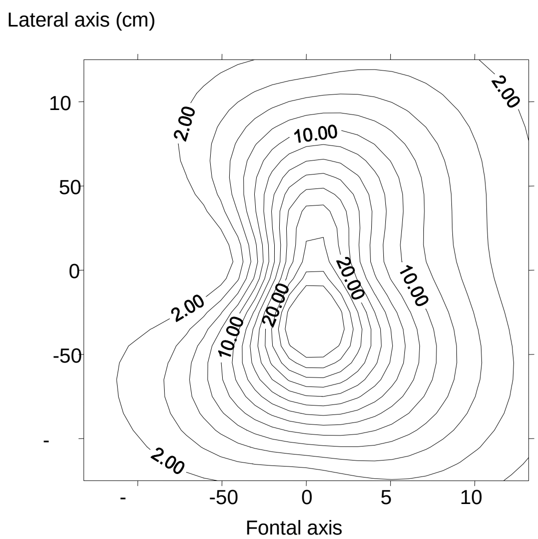

FIGURE 2. The dose rate distribution (μSv/hour) around the MH.

The results of the measurements indicate that a person working 40h/wk, in a normal regime of exploitation of this MH, would not be exposed to a combined dose of neutron and gamma radiation larger than 8.1mSv/y. Considering that the sample changes process required less than 30s and the possibility to used a sufficient long cable (MH – radiometer) is possible reduce the students exposition to a minimum adequate for no occupational persons. The evaluation of dose equivalent rate was made in accordance with International Standard ISO – 7205. The experimental test has confirmed the adequacy of shielding design.

An endurance test according with the standard ISO – 7205 was carried out for drawers of the central block with satisfactory results. The weight of the lateral block is 12Kg each and the central block is 16Kg. Therefore, each block is light enough for easy movement from one location to another.

The design of a central block with a system of drawers and safety lock facilitate positioning, maintenance and ensure an easy installation in the selected place at the same time, the use of a central bar with a safety lock allows that MH can't be dismantled by non authorised persons.

The experimental test has demonstrated that the measuring head developed satisfy the prerequisites fixed in accordance with the intended application.

IV. CONCLUSIONS

It was design a measuring shielded head for neutron experiment in teaching. The device allows a wide range of experiment in nuclear physics and radiation techniques and can be used as irradiation chamber for neutron activation. The experimental test has demonstrated that the measuring head developed satisfy the prerequisites fixed in accordance with the intended application and has confirmed the adequacy of shielding design.

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