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Optimization of fast neutron flux in an irradiator assembly using Monte Carlo simulations

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ABSTRACT

When carrying out experimental work related to neutron interactions with the matter, it is important to get an accurate knowledge about the angular distributions of neutron beam. Descriptions of the neutron source assembly as well as the irradiator design are discussed. A sealed tube neutron generator is used to produce 14 MeV neutrons through deuterium (^{2}H) - tritium (^{3}H) reactions. Monte Carlo simulations have been carried out for optimizing 14 MeV neutron flux distribution around a tritium target. Simulation was also tested by experimental measurements using a foil activation method. The discrepancy between two methods is due to sample preparations, irradiation facility and geometry.

1. Introduction

Neutron sources are used in nuclear physics research and different practical applications such as neutron activation analysis, nuclear power stations and neutron physics. The basic essentials required of a neutron source are characterized by several factors such flux, energy and angular distribution, polarization, and mode of emission [1–2].

In contrast to the funding requirements, radiological safety support, governmental regulation and often-negative public interest associated with nuclear reactors, one finds the compact neutron sources from accelerators can produce fast mono-energetic neutrons. Sealed tube neutron generators are small particle accelerators which produce fast neutrons use the deuterium (D) and tritium (T) gases. Neutrons can be produced by creating ^{2}H ions and accelerating these ions either by $D + T \rightarrow n + {}^4He$, $E_n \sim 14.2$ MeV or by $D + D \rightarrow n + {}^3He$, $E_n \sim 2.5$ MeV fusion reactions[3–4].

Different elements are applied for measuring neutron flux distribution which depend on the activation foil technique. In case of thermal neutrons ^{197}Au foil is recommended for this purpose. In case of monoenergetic fast neutrons, Al, Ti, Fe, Cu, Ni, Zn, Zr, Nb, and In are recommended[5–9].

This work aims to evaluate angular distributions of 14 MeV neutron flux using the activation foil technique and compared these with Geant 4 Monte Carlo simulations. It is important to involve the modeling of the neutron irradiation facility. By this way the viability of the irradiation facility can be checked to fit any another experimental set up for other different arrangements.

2. Material and methods

In the present study, a sealed tube neutron generator with 14 MeV neutrons produced via $H^3(d,n)He^4$ reaction is used with an average current 200 μA and 250–300 KV accelerating voltage. It consists of four main parts: the accelerator, the cooling and vacuum units, the power supply and the remote control console as shown in Fig. 1. Deuterium gas is moved through a palladium leak assembly into the ion source. All these parts are under vacuum of about 10^{-8} mbar. A pneumatic system was installed to transfer irradiated samples from irradiator to detection system within a few seconds so it can treat all kind of applications that need detecting of short half-life isotopes.

The foil activation technique has been adopted for measuring the 14 MeV neutron yield around a tritium target. Aluminum foils (99.9% purity, 1 cm^2 size and weight around 0.25 g) were used via the neutron reaction $Al^{27}(n,p)Mg^{27}$. Samples were distributed in a

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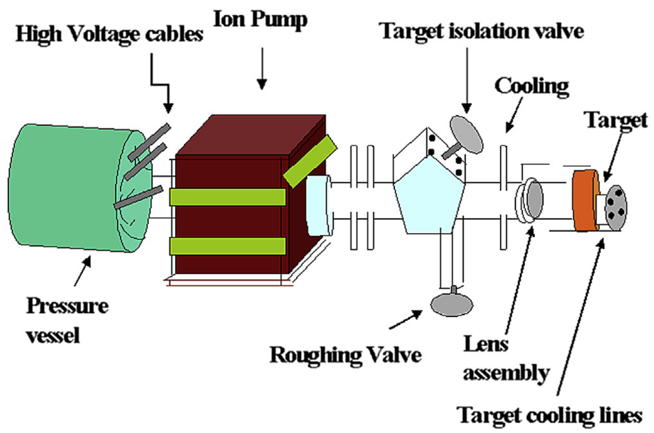


Fig. 1. Main parts of a sealed tube neutron generators (D + T) reaction.

wooden holder in which its plane is perpendicular to the plane of the tritium targets in a range of angles 0°–180°. Much more detail of the experimental arrangements is shown in Fig. 2. The measurement was tested also at angle 0° at different distances and repeated by using Cu^{63} (n, 2n) Cu^{62} reaction. The nuclear data used for two reactions is listed in Table 1.

The spectra of the activated foils were detected using"3. ×3". NaI (Tl) crystal for Cu and HPGe detector for Al with power supply (+750 voltage). The principle source of errors for measurements is listed in Table 2.

The uncertainties were supposed to be uncorrelated and the total uncertainty could be in quadratic form. Standard corrections were made and neutron flux at each angular position was estimated.

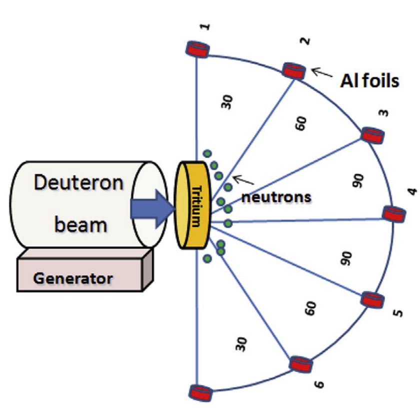
3. Theory and Monte-Carlo simulation

GEANT4 (GEOmetry ANd Tracking) is a simulation tool kit written in C++ that simulates accurately the passage of elementary particles through the matter. Originally it is designed for high energy physics experiments; it has found many applications in different fields especially in nuclear science and engineering. GEANT4 offers the possibility to include a complete description of an experiment: materials used a detailed characterization of the detector, collimator system and the radioactive source. It also provides several sets of physics models (the so-called Physics Lists) which simulate interactions of neutrons with atomic nuclei. In this study the model of the entire neutron activation process of foils is modeled. The standard electromagnetic physics package of Geant4 which accounts for the stochastic nature of the energy loss (energy and range straggling) was used in simulations together with each option of nuclear reaction models [10–12].

The modeling of installations and geometry with the concept of solids, logical volumes and physical volumes was coded in the mandatory class (Detector Construction). So, all foil, dimensions and the relative positions of target must be known and material compositions are incorporated into the Detector Construction. The materials of the detector simulation are implemented using of the NIST (National Institute of Standards and Technology) database, which has its own Geant4 utility class G4NistManager for the implementation of materials. The G4EmStandard Physics_option3 package was designed for extend the capabilities of thetoolkit of describing neutron interactions in Al and Cu foils with higher accuracy.

The incident 14 MeV neutron beam enters foil nucleus and interacts with nucleons via multi body collisions. When the kinetic energy of the particles falls below some threshold, the cascade is stopped and the residual excited nucleus is treated by de-excitation models until statistical equilibrium is reached. The G4BinaryCascade class is used to primary neutrons which were used in the predecessor setup. Each interaction can be described by a binary collision between a nucleon of the target material and component of the projectile. Secondary particles produced in these collisions enter the cascade interface leading to an intra-nuclear cascade.

GEANT4 includes the so-called neutron HP (High Precision) for the simulation of neutron physics processes at low energies (below 20 MeV). It uses the G4NDL neutron data library, which contain information such as Point-wise reaction cross-sections, energy, angular and multiplicity distributions and sometimes correlated of the secondary particles. The G4NeutronHPCaptureFS class has been modified in order to include energy distribution and amount of the neutrons transmitted through a spherical shell made of standard detector/shielding. The G4NeutronHPContAngularPar class has been also used for the secondary particle production. Registration of interaction processes is made in Stepping Action class. Generating a primary event was used primary generator action algorithm. Further classes of some importance are used in Geant4, such as



Reaction	Abundance (%)	Cross-section (mb)	Energy (keV)	Intensity (%)	Half-live (min)

Fig. 2. Experimental arrangement of Al foils distribution around tritium target.