A PHOTONEUTRON SOURCE FOR BULK MATERIAL STUDIES

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ABSTRACT

Neutron diffraction and scattering provide valuable tools for probing the structure of bulk materials. Neutron scattering facilities throughout the world generate neutrons either with a nuclear reactor or with high energy particle accelerators through (p,n) spallation reactions. We suggest a photonuclear-based neutron source, using an electron linear accelerator, which may provide an inexpensive method to perform neutron scattering and diffraction experiments. This paper reports the results of calculations using Monte Carlo computer code (MCNPX) to optimize the neutron conversion targets and to study the properties of the obtained neutron source. Measurements and calculations for the neutron yield and the energy distributions of the neutrons are presented. As a preliminary experiment we have used a 20 MeV electron linear accelerator at the Idaho Accelerator Center (IAC) to generate neutrons using lead and tungsten targets.

INTRODUCTION

A charged particle, electron or positron, does not travel far through solids or liquids before its trajectory loses any correlation with the original beam. This makes them unsuitable for looking inside bulk materials. Neutrons can penetrate matter far better than charged particles because they have no charge, and their magnetic moments are able to couple to magnetization and spin phenomena. Additionally the momenta and energies of neutrons can be matched with phonon energies in bulk materials to probe interatomic phenomena by coherent scattering.

Neutron-scattering facilities throughout the world generate neutrons either with nuclear reactors or with high-energy particle accelerators. However, the cost of producing neutrons in any of these facilities is expensive. We suggest a photonuclear-based neutron source, using an electron linear accelerator, which may provide an inexpensive method to perform neutron scattering and diffraction experiments. In the photo neutron process the electron beam, from an electron linear accelerator, incident on a thick target generates a cascade shower of bremsstrahlung photons and lesser energy electrons. The absorption of a photon leads to the formation of a compound nucleus which decays by the emission of one or more neutrons.
MEASUREMENTS AND CALCULATIONS

We have performed calculations using the Monte Carlo computer code (MCNPX) to optimize the neutron conversion targets and to study the properties of the obtained photo neutron source. The calculations assume beams of monoenergetic electrons are incident perpendicularly on a target.

We have simulated the photo-neutron production for different electron energies and different target materials, shapes and dimensions. The total neutron yields from targets bombarded by electrons were calculated as a function of the incident electron energy, for the range from 15 to 60 MeV. Figure 1 shows the calculated photoneutron yield (Neutrons/Sec.KwMeV) as a function of the incident electron energy, for lead and uranium targets having the same dimensions. It can be seen that electron beam energy of around 40 MeV is optimum as higher energies increase the accelerator size, complexity and cost without a commensurate increase in yield.

![Figure 1. Neutron yield as a function of incident electron energy for Pb and U targets](image)

Calculations were then made to give the photo-neutron yields as a function of the accelerator power, for incident electron energy of 40 MeV on two different target materials, Pb and U, having the same geometry. The results are shown in Figure 2. It is clear that increasing the accelerator power results in a significant increase in the neutron yield but requires a large accelerator size.
The generated neutrons have energies up to mega-electron volts, and the corresponding neutron wavelengths are far too short for investigating condensed matter. Also, neutrons whose energies are above a few electron volts tend to damage solids by knocking atoms out of their positions, producing vacancies and interstitials. So, for scattering
experiments, neutrons must be moderated with a large scattering cross section material such as water or liquid hydrogen. Neutrons enter the moderator and lose energy to recoiling moderator atoms. After a few tens of collisions, the energies of the neutrons are similar to those of the atoms of the moderator.

We simulated the energy distribution of the moderated photo neutrons by using a 40 cm heavy water moderator around Lead and Uranium targets. The simulation was done for incident electron energy of 40 MeV and assuming the accelerator power to be 5 kW. The energy spectrum of the moderated neutrons is shown in Figure 4.

![Figure 4. Neutron yield as a function of energy for the moderated neutrons from the photo-neutron source](image)

The graph shows that the average energy of the neutrons from a heavy water moderator is about 25 meV. The wavelength of a 25-meV neutron is 1.8 Å, which is of the same order as typical interatomic distances and, therefore, is quite suitable for diffraction experiments[1]. Another advantage of these photo neutrons is that they are generated in pulses. So, by measuring the time of flight of each detected neutron, its velocity can be determined, and consequently its wavelength. This means that there is no need for the monochromator crystal used in reactor-based neutron sources because all the neutrons can be used.

In order to benchmark some of the calculations, measurements were carried out using a small electron linac whose electron pulse width was 2 µs with 60 Hz repetition rate. The particular accelerator used delivered electrons with energy in the range 15 to 22 MeV. The electron peak currents were in the range 30 to 80 mA, thus the average beam power was a few hundred watts. The experimental set up has been described in a previous paper[3]. The target was a lead cylinder with a 5 cm diameter and 10 cm length. Lead foils were used to find the generated neutron yield from the target. The photonuclear reaction, \( ^{204}\text{Pb} \ (\gamma, \text{n}) \ ^{203}\text{Pb} \), on the isotope \(^{204}\text{Pb}\), produces \(^{203}\text{Pb}\), which can be detected by...
its characteristic $\gamma$-ray of 279 keV. By using the measured 279 keV $\gamma$-ray yield, the neutron yield can be calculated by taking into account the detector efficiency, the abundance ratio of the lead isotopes and the volume ratio between the foils and the target. Figure 5 shows the measured spectrum from a lead foil counted after irradiating the target with the 20 MeV electron beam for 20 min.

![Gamma Spectrum](image)

Figure 5. The gamma spectrum showing the 279 keV $\gamma$-ray emitted from a Pb foil sandwiched in the target.

The measured neutron production rate from 20 MeV electron Linac was $10^{11}$ n/s with an error of about 20% which is in good agreement with the calculated value from the simulation.

By using the new accelerator facility at the IAC, which has an output energy of ~ 40 MeV with a beam power of up to ~5 kW, neutron yield is expected to be up to ~$10^{13}$ n/sec. This facility is now undergoing operational tests at the IAC.

CONCLUSIONS

A photo neutron yield of $\sim 10^{13}$ n/s can be obtained for 40 MeV incident electron beam on a solid target. The average energy of the generated neutrons from a heavy water moderator is 25 meV. The corresponding wavelength of these neutrons is 1.8Å, which is of the same order as typical interatomic distances and, therefore, is quite suitable for diffraction experiments. A photonuclear-based neutron source, using electron linear accelerators, with this reasonable yield, suitable energy spectrum and the advantage of not requiring a monochromator crystal, may provide an inexpensive method to perform neutron scattering and diffraction experiments for bulk materials studies.
REFERENCES

[8] J.P. Schapira; IN2P3, Institute de Physique Nucléaire, Orsay, France