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On the behavior of spallation neutrons from extended Pb targets plus moderator: A comparison between SSNTD measurements and calculation

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Abstract

Thick Pb targets of different lengths were irradiated by 1 GeV protons at the Nuclotron accelerator of the High Energy Laboratory, JINR, Dubna. To favor transmutation via (n, γ) reactions a paraffin moderator is used. Solid-state nuclear track detectors (SSNTDs) measured neutron distribution. A comparison of experimental results with calculation on the moderator surface is given.

Keywords: Neutron detection; Spallation sources

1. Introduction

Spallation reactions have been studied on various thick targets in the last decade because of their applications in transmutation experiments (Pienkowski et al., 1997; Hilscher et al., 1998). Most of these experiments were performed by high-energy proton irradiation of lead targets, which have good neutron multiplication and low neutron absorption. The results are useful for transmutation of nuclear waste (Letourneau et al., 2000; Wan et al., 2001). The neutron spectrum produced by spallation sources is a hard spectrum extended practically up to 250 MeV neutrons. A neutron spectrum softening enhances the performance of a spallation source to (n, γ) reactions and therefore to transmutation of fission products. A good moderator material with low neutron absorption can be used as a spectral shifter. In this work a paraffin moderator is used. The neutron distribution along the moderator surface was studied for two cylindrical targets of different lengths. The results were compared with the calculation.

2. Experimental

The installation consists of a cylindrical Pb target of 8 cm diameter surrounded by 6 cm paraffin (Zamani et al., 2005). Pb targets of length 20 and 50 cm were irradiated with 1.0 GeV protons at the Nuclotron accelerator (JINR, Dubna). Neutron distributions were measured along the paraffin surface using CR-39 detectors. A converter of $Li_2B_4O_7$ produces alpha particles from the $^{10}B(n, \alpha)^7Li$

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reaction. Neutron densities were obtained by counting alpha particle tracks developed in a CR-39 detector. Recoil events revealed from neutron elastic scattering with the constituent nuclei in the detector were also counted. The conversion of track number to neutron number was obtained by using the converter mass and the effective cross section (Stoulos et al., 2004). The detectors were positioned along the outer moderator surface, parallel to the target axis and to the beam direction.

3. Results and discussion

Measured neutron distributions along the paraffin moderator surface are presented in Fig. 1 for target lengths of 20 and 50 cm. The shapes of both distributions are very similar to those observed on the target surface (Carpenter et al., 1999). A maximum at 10 cm upstream the target (15 cm from the beginning of the moderator) can be observed corresponding to about one mean free path of 1 GeV protons in the Pb target. The longer target produces more neutrons (about twice) at the moderator surface, as it was also observed in previous studies concerning the target length (Pienkowski et al., 1997; Hilscher et al., 1998). Backscattered emitted particles as well as multiple scattering in the moderator can explain this behavior. The experimental results were fitted by using the empirical relationships of physics around high-energy accelerators (Sullivan, 1992). In the first step of the calculation proton and neutron production arising from primary and secondary interactions along the target was considered. The average particle energy as well as the angular distribution of secondary particles was calculated (Sullivan, 1992). Exponential proton beam attenuation along the Pb target as well as exponential attenuation of secondary protons with constant interaction length, λ, were taken into account. For this calculation the same λ, of about 16 cm, was used. The λ variation with energy was not significant (this is related to inelastic cross section which is almost energy independent for this energy region). In the second step interactions of secondary particles produced in the target with the moderator were calculated. In this step the angular distribution of particles was also taken into account. The calculation fit very well to the experimental results as shown in Fig. 2. Neutron distributions are normalized to the total neutron production on the moderator surface. It is concluded that the main part of neutron production occurs upstream the target independent of the target length, at about one mean free path of the beam protons in the target (which means that all types of reaction products contribute to the secondary particle production). As the target length increases the neutron distribution decreases indicating that the beam attenuation competes with the particle production.

4. Conclusion

The study of neutron distributions along the outer moderator surface shows a similar behavior as in the target surface. The main neutron production takes place in about the first mean free path of the proton beam interaction with the target. This behavior is independent of the target length. On the moderator surface higher neutron fluxes were observed for longer targets.

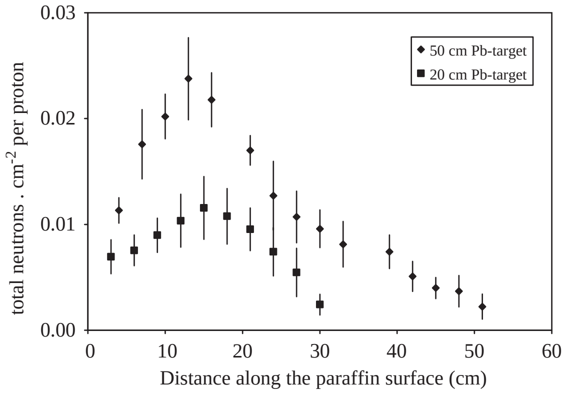

Fig. 1. Neutron distribution along the paraffin surface for Pb targets irradiated by 1 GeV protons.

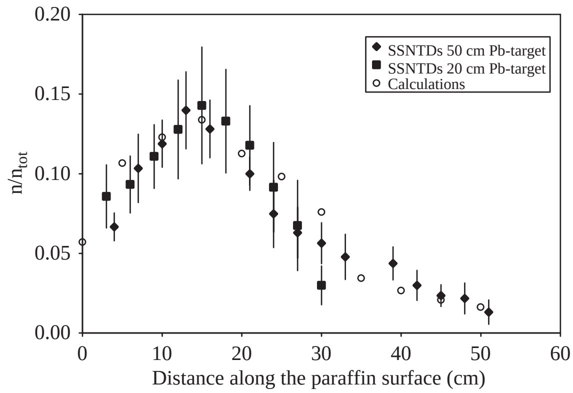

Fig. 2. Normalized neutron distribution to the total neutrons produced along the paraffin surface. The calculated distribution is also shown.

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