Calculation of Neutron Yields for proton bombardment on Deuterium gas target for Nuclear Energy Applications

R. K. Choudhury, R. G. Thomas, A. K. Mohanty, and S. S. Kapoor
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA

Introduction

Accelerator Driven Sub-critical Systems (ADSS) have been proposed as potential methods for energy production and transmutation of long-lived species produced in the fission process. A high energy (1 GeV) high current (> 5 mA) accelerator alongwith a suitable high Z spallation target (Pb, Pb-Bi) has been suggested to act as an intense external source of neutrons in a sub-critical multiplicative fission reactor assembly. The high proton energy is needed inorder to bring down the energy costs for neutrons, which in case of 1 GeV protons on Pb target is ~ 33 MeV per neutron. Recently, Bowman *et al* [1] have published a few papers on the possibility of using the neutrons from $p + d$ reactions using lower energy protons (~ 100 MeV) arising from a cascade of reaction processes:

$p + d \rightarrow n + 2p$ (break-up)
$p + d \rightarrow p + d$ (elastic)
$d + d \rightarrow 2n + 2p$ (break-up)
$d + d \rightarrow n + ^3$He (fusion)
$d + d \rightarrow n + p + d$ (break-up)
$d + d \rightarrow t + p$ (fusion)
$d + t \rightarrow n + ^4$He (fusion)

The experimental neutron yields measured upto $E_p = 17$ MeV were compared with a first order calculation for the primary reaction, $p + d \rightarrow n + 2p$. The result showed that the experimental neutron yields are higher than the first order calculation. Bowman *et al* have conjunctured that at $E_p = 100$ MeV, and with a Be multiplier surrounding the deuterium target, it is possible to reach the value of 30 MeV for the energy cost of neutrons which compares with the value for a 1 GeV spallation reaction. There is, however, no proper theoretical estimate available for the neutron yields in the $p + d$ reaction including possible cascade of reactions listed above. The present paper discusses the results of the Monte-Carlo based calculation for the neutron yields for bombardment of protons in deuterium gas cell. The calculations are found to explain well the available experimental data up to $E_p = 17$ MeV.

Method of calculation

Proton beam is made to incident on a deuterium gas cell of 120 cm length with internal diameter of 10 cm and at a pressure of 13 atm. As the beam traverses through the gas, it loses energy and also causes the nuclear reactions with the gas target with a certain probability. For the break-up reaction $p + d \rightarrow n + 2p$, the cross sections of Kievsky *et al* [2] were used. The elastic differential crossection data were taken from Ref [2] of Kievsky *et al.* After the elastic scattering, the recoiling deuterium nucleus has certain kinetic energy depending on the angle of scattering. The deuterium nucleus is transported through the gas medium, and this causes the secondary cascade reaction of $d + d \rightarrow n + X$(X=^{3}He, $p + d$ ..). The neutron production crosssection for the $d + d$ fusion as a function of energy were taken from the literature. The calculations were done over a wide range of proton energy and are reported here.

Results and discussion

Fig.1 shows the results of the calculation along with the available experimental data up to $E_p = 17$ MeV. The dashed line corresponds to the calculation for the primary breakup reaction which agrees with the earlier reported calculation by Bowman *et al* and

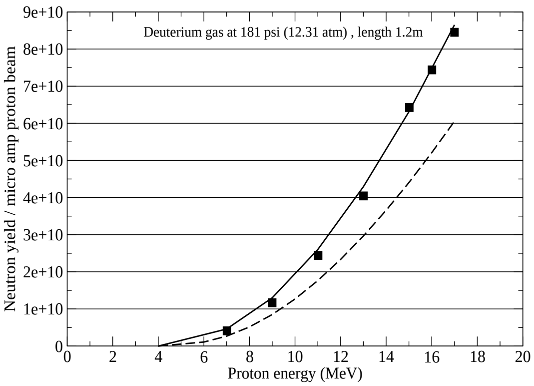

FIG. 1: Results of the calculations along with the available experimental data (solid squares) up to E_p =17 MeV.

under predicts the neutron yields at higher energies. The full line corresponds to calculations which includes the elastic scattering, fusion and higher order breakup channels. It is seen that with the inclusion of the secondary reactions, the calculated yields agree very well with the measured data.

The present Monte-Carlo framework for the calculation of neutron yields can be extended to various target geometries including Be blanket and admixture of deuterium and tritium gases. Since the cross section for the d-t reaction are order of magnitude larger than d-d reaction and extend to much lower energy, the neutron yield for the d-t gas mixture is expected to be significantly higher than the pure deuterium gas. Similarly, it is expected that like p+d break-up, d+d break-up channel may have significant effects on neutron productions at higher bombarding energies. These calculations are in progress and will be reported later. It may be mentioned here that the reactions $d + d \rightarrow n+^3$He and $d + d \rightarrow t + p$ have equal probability. Therefore, the tritium built-up and subsequent neutron production from the reaction, $d + t \rightarrow n+^4$He may have some effect on the total neutron yield. These effects are being incorporated in the Monte-Carlo calculations and will be reported later.

References

[1] C. D. Bowman et al, Nucl. Sci. and Eng. **161**, 119 (2009).

[2] A. Kievsky, M. Viviani and S. Rosati, Phy. Rev. **C64**, 024002 (2001).