Fusion Based Neutron Sources for Security Applications: Energy Optimisation

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Abstract

There is a growing interest in the use of neutrons for national security. The majority of work on security focuses on the use of either sealed tube DT fusors or fission sources, e.g. Cf-252. Fusion reactions enable the energy of the neutron beam to be chosen to suit the application, rather than the application being chosen based on the available neutron beam energy. In this paper we discuss simulations of fusion reactions demonstrating the broad range of energies available and methods for adapting the neutron beam energy produced by target/projectile combinations.

INTRODUCTION

Large scale neutron facilities using either spallation or reactors are the mainstay of neutron work. There are numerous applications of neutron beams in science, medicine and industry many of which are not suited to large scale facilities.

In national security there is increasing interest in the use of neutrons for container inspection. Approximately 90% of freight passes through seaports [1] and the majority of inspection is performed using X-Ray interrogation. X-Ray scanners can be fooled relatively easily by either shielding or disguising contraband [2].

Two types of compact neutron source are typically considered for security applications. Sealed tube devices which direct deuterons onto a deuterated or tritiated target are used. The sealed tube devices are not suited to mass deployment due to the radiotoxicology concerns of tritium. There are also fission based sources which use a small sample of fissionable material (e.g. ^{252}Cf) to produce a white spectrum but these are also not ideal as they are uncontrolled and have very long lived by-products.

An alternative to the sealed tube and fission sources is to use a low energy accelerator to initiate fusion reactions with other low-Z targets. In this paper we show how the energy of a neutron beam can be varied and the spectral distribution chosen to suit the application.

NEUTRON SOURCE

Low energy fusion reactions are a reliable source of neutrons, sealed tube fusors provide reliable off the shelf neutron sources by fusing deuterons with either deuterium or tritium. These sealed tube devices use the $T(d,n)^4He$ (DT) and $D(d,n)^3He$ (DD) reactions which produce neutrons of $E_n \approx 14MeV$ and $2.5MeV$ respectively.

The presence of tritium in the DT fusors and the production of tritium in DD fusors through the $D(d,p)^3H$ reaction means they are unsuited to mass deployment. Using alternative targets and projectiles offers the potential to avoid the production of tritium and other intermediate life isotopes.

An important consideration when considering a combination is the Q of the reaction, given by:

$$Q = (M_p + M_{TN}) - (M_n + M_{DN})$$

In which M_p is the projectile mass, M_{TN} is the target nucleus mass, M_n is the neutron mass and M_{DN} is the decay nucleus mass.

The Q can be used to approximate the energy of neutrons produced in a fusion reaction. In the center of mass frame the neutron kinetic energy E_n is approximately given by:

$$E_n = \frac{E_k + Q}{1 + \frac{M_n}{M_{DN}}}$$

In which E_k is the projectile kinetic energy in the CoM frame. As the neutron emission is approximately isotropic in the CoM frame a distribution of energies is inevitable when returning to the lab frame which, when coupled with the potential for additional decay channels and meta-stable decay nuclei, prevents a perfectly mono-chromatic source being possible.

PROJECTILE ENERGY VARIATION

In this section we show how varying the projectile energy can be used to tune the energies of the neutrons emitted in a fusion reaction. The Monte-Carlo code MCNPX has been used to simulate the $^{26}Mg(p,n)^{26}Al$ reaction, amongst others, with various proton beam energies to study the effect.

Figure 1 shows the effect of beam energy variation on the neutron spectrum produced by Magnesium under proton irradiation. The increasing proton energy can be seen to increase the neutron energy and the total neutron yield. The increased neutron energy is due to the increased Lorentz boost of the CoM frame and energy available in the CoM frame. The increased yield is due to the cross-section for the $^{26}Mg(p,n)^{26}Al$ reaction increasing over the energy range simulated.

The $^{26}Mg(p,n)^{26}Al$ reaction shows a fairly narrow spectral distribution which makes it ideal for applications based on Time-Of-Flight however most of these applications require higher beam energies. The Q of $^{26}Mg(p,n)^{26}Al$ is $\approx -5.3MeV$ resulting in the neutron energy being significantly below the irradiating proton energy.

Unlike the $^{26}Mg(p,n)^{26}Al$ reaction the neutrons produced by the $^9Be(p,n)^9B$ reaction has many spectral peaks as shown in figure 2. The large number of spectral

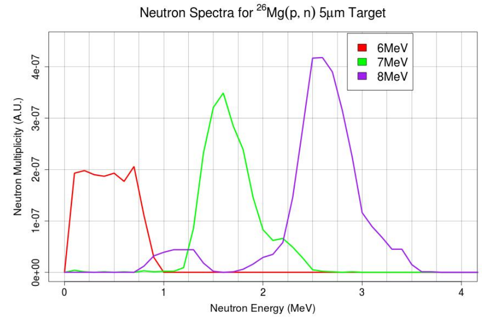

Figure 1: The simulated neutron spectrum produced by a Magnesium target under various energies of proton irradiation.

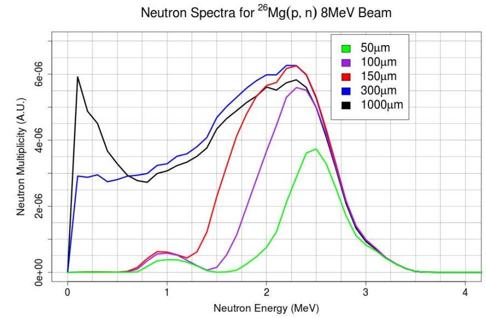

Figure 3: The simulated neutron spectrum produced by a Beryllium target under various energies of proton irradiation.

peaks in the $^9Be(p,n)^9B$ reaction make it unsuitable for any Time-Of-Flight dependant method but for those requiring a white or moderated flux it would be suitable.

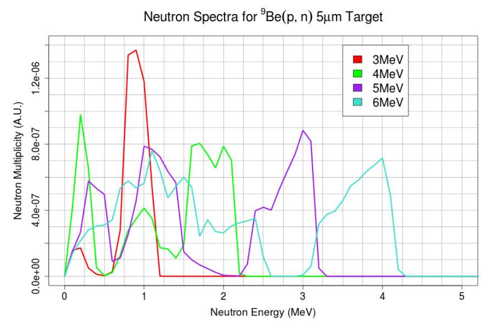

Figure 2: The simulated neutron spectrum produced by a Beryllium target under various energies of proton irradiation.

TARGET THICKNESS VARIATION

Increasing the target thickness has a large effect on the resulting neutron beam. Increasing the target thickness has two effects, an increase in the total neutron production and an increase in the spectral width.

The results in figure 3 show a gradual increase in neutron flux and spectral width with increasing target thickness. The increase in spectral width shown is due to two effects. As the proton propagates through the target it loses energy in a standard $\frac{dE}{dX}$ energy loss resulting in a lower kinetic energy when producing a neutron. If a neutron is produced early in the target there will also be some moderation which will decrease neutron energies.

After the target has become thick enough that the protons drop below the reaction threshold energy the neutron production will not increase however the neutron moderation will continue increasing, this produces the difference which can be seen in figure 3 between the $300\mu m$ and $1000\mu m$ thickness, the total number of neutrons is approximately constant between both thicknesses but there is a significant shift in the spectrum towards lower energies.

CONCLUSION

As the interest in security applications of neutrons grows it is important that the possible source options be well understood. In this paper we have shown how the neutron spectrum produced in fusion reactions can be varied by changing the irradiating beam energy and the target thickness.

Low energy accelerators $E \leq 10MeV$ with variable energy are ideal particle sources. By using targets without significant radio-toxicology concerns it will be possible to significantly vary the neutron beam energy with minimal effort allowing the beam energy to be optimised for the materials under interrogation.

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