Fusion Based Neutron Sources for Security Applications: Neutron Techniques

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Abstract

The current reliance on X-Rays and intelligence for national security is insufficient to combat the current risks of smuggling and terrorism seen on an international level. There are a range of neutron based security techniques which have the potential to dramatically improve national security. Neutron techniques can be broadly grouped into neutron in/neutron out and neutron in/photon out techniques. The use of accelerator based fusion devices will potentially enable to wide spread application of neutron security techniques due to the potential for much safer operation than that offered by fission or sealed tube sources. In this paper we discuss some of the neutron security techniques available and the advantages they present.

INTRODUCTION

Approximately 90% of the worlds freight passes through seaports annually [1]. Current security focuses on combining intelligence gathering with X-Ray interrogation however it is relatively easy to shield/disguise contraband such that it goes undetected [2].

A number of techniques based on neutrons exist which have the potential to greatly improve threat detection currently available with X-Ray technology. Neutron techniques can be loosely grouped into neutron in/neutron out and neutron in/photon out techniques, though combinations are also viable.

In this paper we discuss some of the neutron interrogation techniques available and the neutron sources they would require. We do not present an exhaustive list but seek to give a flavour of the technologies available.

TECHNIQUES

Neutron In/Neutron Out

Neutron Transmission Imaging Neutron transmission imaging operates on the same principle as a traditional X-Ray image. A flux of neutrons is applied to the volume under interrogation and detected on the far side . As with X-Ray imaging this provides a 2D reconstruction of the target giving the line-integral of the attenuation through the volume [3]. As neutrons have very different attenuation characteristics to X-Rays combining the two would provide an advantage as the metallic bodies which are opaque to X-Rays are transparent to neutrons with the reverse being true for organics.

Neutron transmission can be further enhanced by using a source with a range of energies and counting the number at each energy which reaches the far side of the container. As the capture cross-section is strongly energy dependant this can be used to infer the composition of material as well as measure the attenuation.

Fast Neutron Scattering Fast neutron scattering represents a viable way of inferring elemental composition of an unknown material. The neutron energy at certain angles is measured, the angle and energy composition is then unique to the element under interrogation [3]. The presence of both elastic and inelastic peaks in the scattered spectrum and the relative differences in their heights allows material identification. Neutron scattering techniques are hindered by the need to use neutron spectrometry however this is not an insurmountable problem.

Neutron scattering techniques would benefit from a source with variable energy. In particular using two quasi-monochromatic spectra would allow for different scattering resonances to be excited and combined with Time-Of-Flight.

Neutron In/Photon Out

Thermal Neutron Capture Low energy neutrons impinging on a target can be used for elemental identification. Suited to near-surface objects neutron capture techniques use the photons emitted through neutron capture for material recognition. The energies of the γs emitted in neutron capture are unique to the element interrogated allowing direct correlation between the γ spectrum and the composition.

Whilst useful for threats near the surface of containers neutron capture has limited use due to the requirement for threats to be near the surface.

Fast Neutron Scattering An alternative use of fast neutron scattering is in the neutron in/photon out regime. Fast neutrons can excite the emission of prompt gammas from materials with the photon energy unique to the element. Unlike thermal neutron capture this technique can be used to investigate the entire volume of a container.

In particular the technique Pulsed Fast Neutron Analysis (PFNA) is growing in popularity and has been demonstrated to be effective [4]. PFNA uses a rapidly pulsed beam of fast neutrons to excite the emission of prompt gammas. Pulsing the neutron source then allows Time-Of-Flight information to be included which gives 3D imaging within the container.

Combination

A very promising option which has received some interest is to combine a neutron in/photon out technique with a neutron in/neutron out technique. The elemental recognition and 3D reconstruction of PFNA combined with neutron transmission imaging to cross-check for shielding will provide substantial improvement.

PULSED FAST NEUTRON ANALYSIS

Pulsed Fast Neutron Analysis (PFNA) is a Neutron in/Photon out technique with growing international interest. The PFNA technique requires short pulses of fast monochromatic neutrons with $E_n \approx 8$MeV or higher. As the pulse propagates through the container being inspected prompt γ emission is excited. Based on the neutron Time-of-Flight the distance from the source at which the γs were emitted is known therefore allowing full 3-Dimensional imaging of the container.

As with other fast neutron techniques the majority of PFNA research has used 14MeV $T(d, n)$ fusors. By using simulations we are able to consider any energy of beam and therefore the energy dependence of PFNA. Under 14MeV neutron irradiation pure samples of C, N, O and Cl give the spectra shown in 1. A selection of spectral lines are visible.

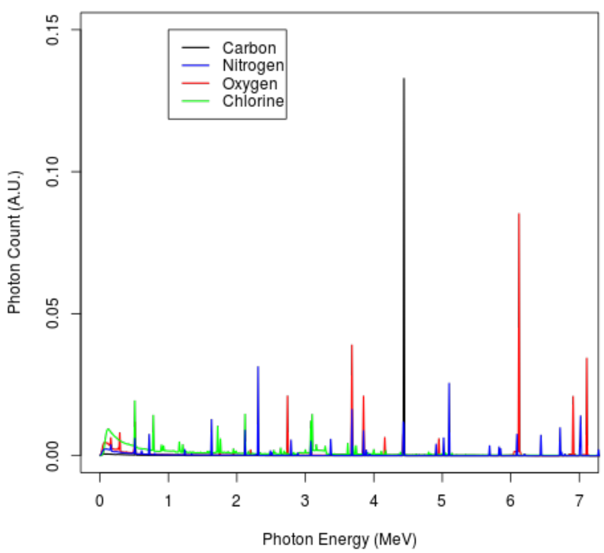

Figure 1: γ spectra emitted by pure samples of C, N, O and Cl under monochromatic 14MeV neutron irradiation.

Considering some of the dominant peaks visible in figure 1 makes it possible to study the energy dependence of PFNA. Figure 2 shows the variation in γ multiplicity from some of the spectral peaks; 4.44MeV for C; 2.32MeV and 5.11MeV for N; 6.13MeV and 7.12MeV for O and 1.73MeV and 0.52MeV for Cl.

The large resonances and multiplicity variations visible in the $4 \rightarrow 10$MeV region of figure 2 would justify higher energies of neutron beam. By avoiding significant resonances in the γ emission cross-sections it will be possible to reduce the uncertainty, and therefore increase the reliability, of material identification.

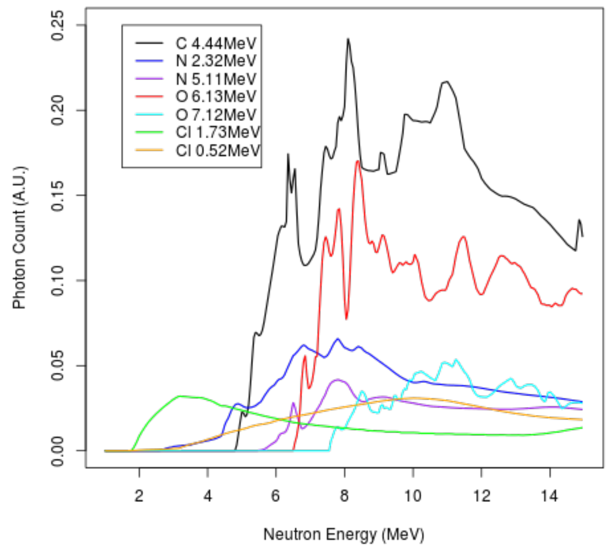

Figure 2: Energy dependance of some of the dominant spectral lines for C, N, O and Cl.

CONCLUSION

There are a variety of neutron imaging techniques currently of interest. Here we have presented a selection of possible neutron imaging techniques and discussed the source characteristics they require. In all cases a low energy accelerator is most suited to providing the requisite neutron beam due to the possibility of them being compact, affordable and having low radio-toxicological concerns.

Of particular interest is the neutron in/photon out technique Pulsed Fast Neutron Analysis (PFNA). The majority of research performed on PFNA has used 14.1MeV T(d,n) fusor neutron sources. We have shown that the energy of the neutron source can have a strong effect on the γ multiplicity both for individual elements and the characteristic γs emitted by each element. As a result future PFNA research should consider ways to either take advantage of, or mitigate the potential disadvantages of, the variation in emission probability.

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