ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRO111

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. Traditional X-Ray scanning measure the attenuation of an X-Ray beam between source and detector. Over the area of a container the attenuation can be used to produce a 2-Dimensional image of the average density between source and detector. The addition of a second energy of X-Ray enables discrimination between metallic and organic cargo through the differences in their attenuation characteristics.

Neutron techniques can be loosely grouped into neutron in/neutron out and neutron in/photon out techniques. Neutron in/neutron out techniques use a beam of neutrons and measure some change between the initial and final beam. Neutron in/photon out techniques measure the γs produced though interactions between the impinging neutron beam and the target. Additionally combinations of neutron in/neutron out and neutron in/photon out techniques 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. We then focus on the neutron in/photon out technique Pulsed Fast Neutron Analysis (PFNA) and potential improvements to it.

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. The neutron capture cross section is strongly element and energy dependant therefore a peak in the capture ratio at specific energies can be used to infer the presence of certain elements and therefore identify materials.

The source requirements of neutron transmission imaging are comparatively simple. The simplest form can be performed with any spectrum available, a high flux of white neutrons can be readily supplied. If the addition of energy dependant attenuation is desired it is necessary to either have a well characterised and variable spectrum entering the container or efficient neutron spectrometry after.

Fast Neutron Scattering Fast neutron scattering represents a viable way of inferring the elemental composition of an unknown material. The double differential cross section with angle and energy is measured. The presence elastic and inelastic peaks in the angle and energy distributions, and the relative differences in their heights, allows for material identification [3]. A quasi-monochromatic beam of fast neutrons is necessary for fast neutron scattering and the ability to use more than one energy could further enhance the technique.

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 and subsequent decay of produced radionuclides for material recognition [3]. 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.

Thermal neutron capture is effective but only suited to near surface interrogation. Contraband hidden far from the surface of a container would not be detectable and therefore limits the usefulness of this technique.

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

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 14 MeV $T(d,n)$ fusors. By using simulations we are able to consider any energy of beam and therefore the energy dependence of PFNA. Under 14 MeV neutron irradiation pure samples of C, N, O and Cl give the spectra shown in Fig. 1, these spectra show multiple characteristic peaks which can be used for material identification.

Some of the dominant peaks visible in Fig. 1 can be used to show the influence of neutron energy. Figure 2 shows the variation in γ multiplicity of some spectral peaks; 4.44 MeV for C; 2.32 MeV and 5.11 MeV for N; 6.13 MeV and 7.12 MeV for O; and 1.73 MeV and 0.52 MeV for Cl.

There are large resonances in the γ multiplicity visible if Fig. 2 especially in the 4 → 10 MeV region. As these peaks are relatively close together a higher neutron energy would be beneficial. Avoiding significant resonances in the γ emission cross-sections will enable a reduction in the uncertainty and therefore an increase the reliability of material identification.

Trial systems using PFNA have been demonstrated at international ports and airports and shown to be effective. Rapiscan International demonstrated a system at Houston Airport, Texas and were able to show threat detection significantly superior to traditional X-Ray systems [5]. The upper image of Fig. 3 shows an X-Ray scanner of an air-freight container, the lower image shows the same container imaged with PFNA. The use of post-processing to identify materials allows the benign components to be subtracted from the image so the operator is shown a 3-Dimensional image containing only the possible threats.

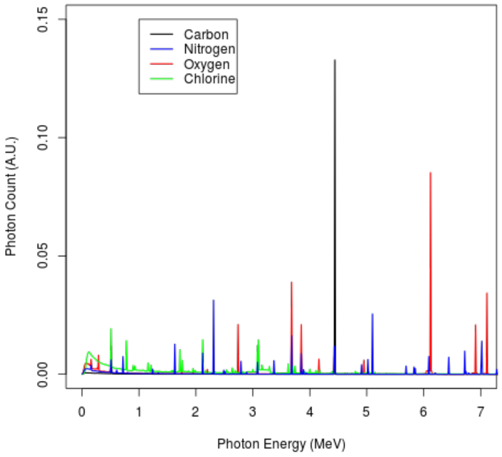

Figure 1: γ spectra emitted by pure samples of C, N, O and Cl under monochromatic 14MeV neutron irradiation.

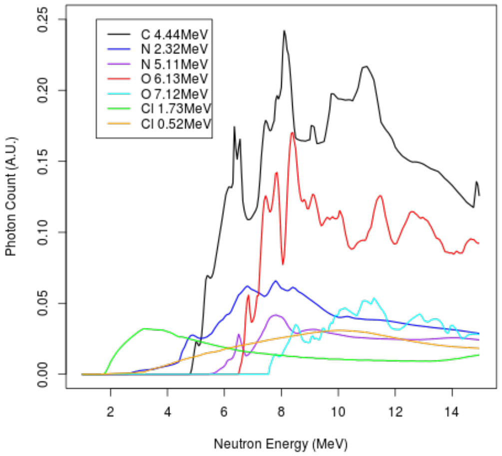

Figure 2: Energy dependance of some of the dominant spectral lines for C, N, O and Cl.

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 able to provide the requisite neutron beam in an affordable, compact and radiotoxicologically safe way.

Of particular interest is the neutron in/photon out technique Pulsed Fast Neutron Analysis (PFNA). The majority of research performed on PFNA has used 14.1 MeV $T(d,n)$

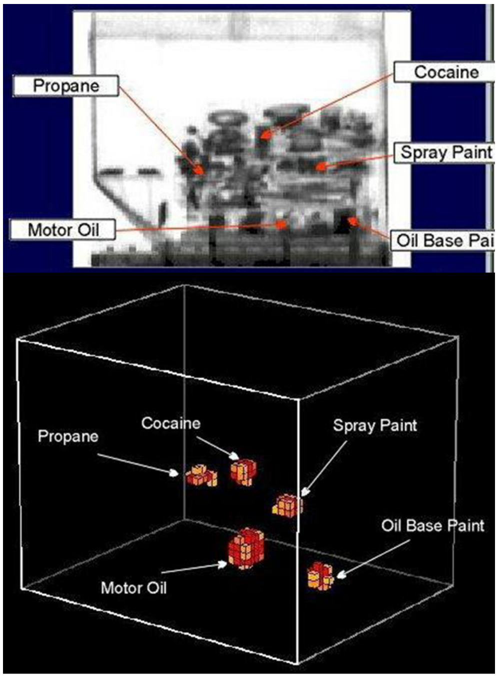

Figure 3: Two images of a container containing possible threat objects. X-Ray interrogation shown top, PFNA interrogation shown bottom.

fusors. 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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