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ScienceDirect

Physics Procedia 66 (2015) 196 – 205

Physics Procedia

C 23rd Conference on Application of Accelerators in Research and Industry, CAARI 2014

Overview of Accelerators with Potential Use in Homeland Security

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Abstract

Quite a broad range of accelerators have been applied to solving many of the challenging problems related to homeland security and defense. These accelerator systems range from relatively small, simple, and compact, to large and complex, based on the specific application requirements. They have been used or proposed as sources of primary and secondary probe beams for applications such as radiography and to induce specific reactions that are key signatures for detecting conventional explosives or fissile material. A brief overview and description of these accelerator systems, their specifications, and application will be presented. Some recent technology trends will also be discussed.

Selection and peer-review under responsibility of the Organizing Committee of CAARI 2014

Keywords: accelerators; homeland security; defense

1. Introduction

Real and perceived threats to homeland security have increased significantly. As a result, innovative active-interrogation methods to detect these threats continue to be developed to protect our borders, airports, and ports. All of these detection methods require a source of energetic particles to induce specific reactions that are key signatures for detecting conventional explosives or fissile material, or to perform imaging. Requirements for the applicable accelerator technology can be directly derived from the requirements of the detection techniques currently in use based on the perceived threats. The most immediate perceived threats and their constituent materials include:

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Selection and peer-review under responsibility of the Organizing Committee of CAARI 2014
doi:10.1016/j.phpro.2015.05.026

- Conventional Explosives – Important elements include N, O, Cl, Na, S, K, P,
- Dirty Bombs – ^{137}Cs, ^{60}Co (medical rad waste), Shielding Materials: Pb, W, Fe, Polyethylene ($(C_2H_4)_nH_2$),
- Special Nuclear Materials – ^{235}U (HEU), ^{239}Pu, ^{237}Np,
- Weapons of Mass Destruction – ^{235}U (HEU), ^{239}Pu, ^{237}Np, Explosives, Tamper Materials,
- Chemical Agents – Sarin Gas ($C_4H_8Cl_2S$), Phosgene (CCl_2O), Mustard Gas ($C_4H_8Cl_2S$),
- Contraband – people, illicit drugs and other illegal cargo.

To detect the associated materials for a particular threat requires a broad range of detection processes. These use primarily photon beams as the source of energetic particles to induce a particular reaction or to do imaging, however, some techniques also use neutrons and high-energy or exotic beams such as protons or muons, respectively. Detection methods that use photons include transmission radiography, neutron resonance absorption, neutron resonance fluorescence, and photon-induced fission. Several of the photon-based detection methods are described in detail in Bertozzi, *et al*. (2011). Detection methods using neutrons include neutron-induced fission, neutron activation, neutron transmission radiography, and (n,γ) reactions involving capture or scattering. Long-stand-off active interrogation requires protons for radiography or muons to generate K muonic x-rays in ^{233}U or ^{238}U, for example, as described in Jason *et al*. (2010). Most integrated active-interrogation systems in use today incorporate several of these methods of detection to broaden the range of use and to provide detection redundancy that helps minimize "false positives" by improving overall detection accuracy. Therefore, most systems incorporate both an x-ray production target and a neutron converter.

The energy thresholds for the reactions involved in each specific detection method ultimately determine the minimum energies of the photons, neutrons or other particles needed. Photons are generated primarily through the bremsstrahlung process by scattering electrons on a high-Z metallic target such as tantalum. The useful photon energy range for homeland security applications is 1-15 MeV, although present US regulations limit the energy to ≤ 10 MeV to protect humans from accidental life-threatening exposures. Neutron beams can be generated through several processes, however the most common uses a D-D or D-T neutron generator, generating 2.5-MeV and 14.1-MeV neutrons, respectively. Required beam energies define the accelerator requirements for these systems.

A review of present homeland security systems reveals that electron linear accelerators are being most widely applied. This comes as no surprise since electrons are easy to accelerate efficiently to high energies in a relatively compact system. Typically, beam energies up to 10 MeV are used with average beam currents up to 1-2 mA and at high beam duty cycle (50%-100%). Proton beams are typically being generated using linear accelerators or cyclotrons. Nominal required beam energies are generally less than 10 MeV (very specific energies and small beam energy spread are required for specific reactions) but can be as high as 500 MeV or greater for long-stand-off active interrogation, with average beam currents also in the 1-2 mA range, as for electrons. Pulsed and continuous-wave (CW) neutron beams can be generated with energies up to using a 4-MeV deuteron linear accelerator through the ^{11}B(d,n)^{12}C reaction. Generally, high average beam currents are desirable to improve detection statistics to speed up the interrogation process. Figure 1 summarizes the detection methods and corresponding beam and accelerator requirements.

2. Accelerator Technology Overview

2.1. General Requirements

While specific accelerator requirements can be derived from the detection method being applied, general accelerator requirements for a practical homeland security system can also be specified that need to be met in order for such a system to be fielded. These general requirements include large beam momentum and/or beam energy acceptance which allows acceleration to a wide range of final beam energies, high beam transmission which limits beam losses, reducing accelerator activation and allows for hands-on maintenance, a small or compact footprint, portability, dynamically-variable beam energy and/or beam current, variable duty factor and output beam current, high reliability and availability, and finally if possible, low cost. As might be expected, many of these requirements are technologically orthogonal and very difficult to meet simultaneously.