A CONTRABAND DETECTION SYSTEM PROOF-OF-PRINCIPLE DEVICE USING ELECTROSTATIC ACCELERATION *

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Abstract

A new Contraband Detection System (CDS) Proof-of-Principle (POP) device is nearing completion at Northrop Grumman's Advanced Technology and Development Center. We employ gamma resonance absorption (GRA) to detect nitrogen or chlorine in explosives and certain forms of illegal drugs. Using tomography, 3-D images of the total density and selected element density are generated. These characteristics together may be utilized with considerable confidence in determining if contraband is present in baggage or cargo.

The CDS employs a high current (10 mA) DC electrostatic accelerator that provides a beam of protons at either 1.75 or 1.89 MeV. These high energy particles impinge upon a target coated with ^{13}C or ^{34}S. The resultant resonant gamma rays are preferentially absorbed in either ^{14}N or ^{35}Cl. Because of the penetrating power of the gamma rays, this approach can be utilized for inspection of fully loaded aircraft containers such as the LD3.

Our current program calls for testing of the POP CDS by late 1996. This paper presents the overall design and characteristics of the CDS POP.

Introduction

The interrogation of man-portable containers through the GRA process has been found from previous work [1] [2] [3] to be a potential candidate for determining the presence of explosives. As a result of the work in this project, we have further developed the GRA approach into a system design that offers the potential for detecting a significant portion of illegal drugs. The contracted CDS POP mission is to examine the range of available parameter space for the GRA technique and for drug and explosives detection applications, provide a technical data base sufficient to assess the practicality for use with man-portable luggage. We have found during the conduct of this effort that the CDS approach may also be effective for the interrogation of medium sized containers such as the LD3. In addition, the development of a high current electrostatic accelerator for the CDS breaks new ground using state-of-the-art technology that will be beneficial to other applications such as radiography or medical therapies.

Technical Approach

There are two primary characteristics that can be used to identify explosives and illegal drugs among common materials; they are material total density, and individual selected element density [4]. Due to the overlap in total density of many materials, X-rays alone, which can determine total density if used with tomography, may not be sufficient to separate contraband from common materials or materials deliberately used for concealment. If nitrogen density imaging is employed in addition to total density imaging, the detection of contraband can be significantly improved, resulting in lower false alarms with a higher probability of detection.   Separation between contraband and common materials is performed using the available multi-dimensioned density space (nitrogen and total densities).   The addition of chlorine density imaging can provide a valuable means of detecting chlorine based explosives.

After surveying all of the possible reactions for generation of resonant gamma rays from energetic protons, we selected the best reaction, ^{13}C(p,)^{14}N, for nitrogen.   This resonance occurs at a proton energy of 1.75 MeV. Of the next best resonant reactions there are two for chlorine (^{34}S(p,)^{35}Cl) that occur at proton beam energies of 1.89 MeV and 2.79 MeV. We selected the lower proton energy to minimize the accelerator requirements for the POP. The performance figure of merit for this reaction is about 5% of that for nitrogen which results in longer inspection times. If the POP shows the chlorine reaction is usable, then the higher proton beam energy would improve CDS performance by a factor of 2 for chlorine detection.

The cross section for generation of resonant gammas gives rise to a proton beam requirement on target having small energy spread (12 keV). This in turn leads to the selection of an electrostatic accelerator. The need for fast inspection time drives the accelerator current upward toward the survival limits of the gamma generating target. We have found that proton currents of 10 mA or more are required. For the CDS POP a tandem configuration is chosen which requires an electron stripper at the high voltage terminal. The development of such an accelerator pushes the state of the art and opens the possibility for use in other applications such as neutron radiography or medical therapies.

The proton beam target for the GRA technique is identified as the highest risk in the system. There is limited experience about the lifetime of the target coating from constant bombardment by energetic protons; however, a parallel test program has been underway for some time at Northrop Grumman which addresses this issue. A rotating target design is employed to maximize lifetime by spreading the effects of beam sputtering and heating.

Another risk area for the CDS POP is in the performance of a suitable electron stripper. At the beam current densities of interest, a conventional foil stripper would burn up quickly. Simulations for a gas stripper channel indicate that the required performance should be achievable; however, the issue of proper gas confinement in the stripper region to mitigate HV accelerator breakdowns is being addressed with an off-line test program at TRIUMF.

Discrimination between resonant and non-resonant gamma rays is achieved by exploiting the fact that the resonant gammas are emitted at a specific angle. The detection system is required to be position sensitive (see Fig. 1). This is accomplished using segmented Bismuth Germanate (BGO) detectors much like, but improved over PET systems, which provide good spatial resolution and high detection efficiency. A detector development program is in place and demonstrating positive results.
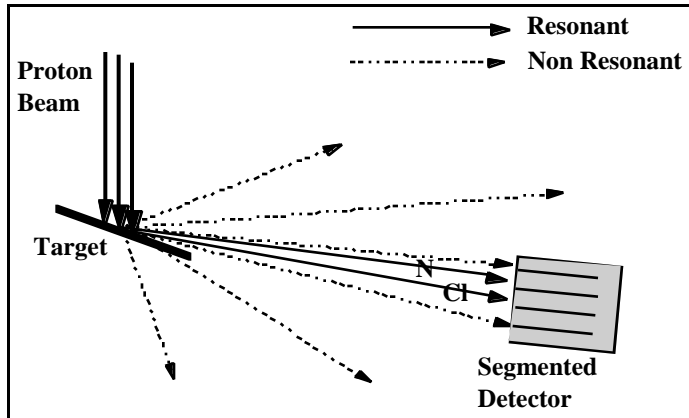

Fig. 1.   Position Sensitive Detection

Camouflage techniques to hide contraband among other materials leads to the conclusion that a tomographic imaging approach should be used. Furthermore, this approach is necessitated by use of density for discrimination. By rotating and elevating a volume to be inspected, the attenuation factor of the gamma rays are recorded at all positions and angles (see Fig. 2). A 3-D image of resonant and normal gamma rays' attenuation factor per unit volume are used to reconstruct 3-D images of both total and elemental densities. An algorithm based upon the multi-dimensioned density data of substances is used to signal the presence and position of contraband.

Description of the POP Device

An isometric view of the CDS POP device is shown in Figure 3. This machine is not optimized for field use. Instead

it is designed for maximum flexibility and ease of access for quick changes and/or modifications. The centerline of the
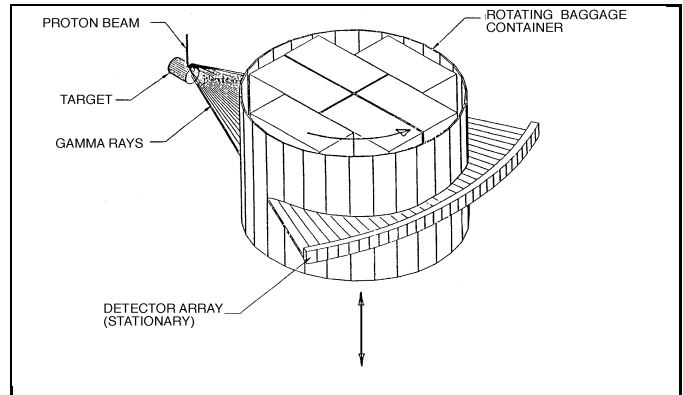

Fig. 2.   Tomographic Inspection Technique

Fig. 3.   View of CDS POP at Northrop Grumman

tandem accelerator is 108 inches above the floor. This configuration provides adequate length in the high energy beam transport section which must be bent at an angle of 80.7 degrees for proper position of the proton beam with the target surface to result in a horizontal gamma ray fan at the area of container inspection. Another choice to have the accelerator at a lower level would require that the target, the detector and container handling equipment be at elevation. We selected the former based upon the anticipation that most of the hands-on time with the POP device will be with the target, detectors and container handling. The POP shown in the figure employs a double decked array of 88 BGO segmented detectors spanning a field of view of 53°. Due to funding constraints on the present program, the initial POP demonstration scheduled to take place in December 1996 will use a scaled down set of detectors (single layer of 7 BGO detectors) and a smaller baggage handler than as shown in the figure. The proton accelerator will demonstrate full CW output, but the gamma production target will be a low-cost/low-duty factor interim design. The POP will demonstrate key principles that are scaleable to a fieldable CDS including; (1)high current DC tandem accelerator

operation and long term stability at the required beam conditions for resonant gamma production, (2)image resolution and resonant/non resonant gamma ray sorting, and (3)basic 3-D tomographic imaging. Successful operation of the CDS POP accelerator will lay the ground work for higher output tandem accelerators that might be used for BNCT or Neutron Radiography.

An accelerator of this type offers lower capital and operating cost than RF driven linear accelerators of the same output. The cross section view in Figure 4 shows the two accelerating columns extending from the high voltage center terminal. The center terminal contains two sets of triplet magnets, a vapor stripper subsystem, a series of collimators and associated diagnostics. The whole assembly fits within a corona cage and sits on top of a 1 MV power supply. The external containment vessel provides an enclosure for SF_6 (dielectric) at 60 psi.
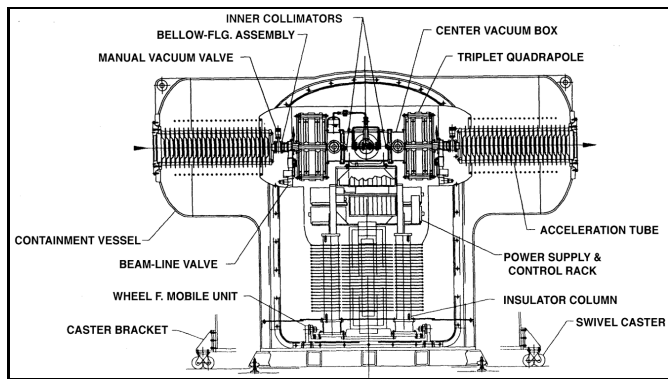

Fig. 4.   Side View of Tandem Accelerator

Performance

The counter-drug mission differs significantly from explosives detection in that the volumes of contraband involved are usually larger when compared to high explosives, relaxing the need for high resolution. The larger volume of contraband associated with drug trafficking permits integration of the 3-D scan information over larger slices, thereby enhancing the signal to noise and allowing separation and detection of the relatively low nitrogen densities. On the other hand the amount of nitrogen in most high explosives makes detection less difficult. The ability to detect thin sheet forms of high explosives is actually easier than bulk drugs in similar quantities.

The key parameters for a fieldable CDS device which are being used as goals for the CDS POP are presented in Table 1. To provide the capability for dual element detection, the energy of the accelerator must be variable. The proton current is a compromise between technical capability and production yield per proton. A 10 mA proton beam is adequate for detection of nitrogen in high explosives while proton current between 10-20 mA is required for chlorine imaging because of the lower gamma yield. For small or loose baggage, the carrousel can be sized for an optimum volume to maximize throughput and still maintain sufficient transmission of gamma rays for high probability of detection. For suitcase size containers it is estimated that the CDS could process 430 bags/hr with a detection probability of 90% for a 1 pound quantity of thin sheet high explosive. We have also performed simulations of fully loaded containers as large as the LD3 that indicate inspection times on the order of 10 to 15 minutes per container are possible.

Table 1
CDS System Parameters

CHARACTERISTIC	VALUE	
Element Detected	Nitrogen	Chlorine
Nuclear Reaction	$^{13}C(p,)^{14}N$	$^{34}S(p,)^{35}Cl$
Target Type	segmented surface	
Beam Current (mA)	10	10/20
Beam Energy (MeV)	1.75	1.89
Energy Spread (keV)	25	12
Detector FOV (degrees)	53	53
Container Dia. (inches)	56	56
Container Height (inches)	44	44
Container RPM	60	6
Detector Height (cm)	10	10
Detector Radius (m)	2.14	2.14
Resolution (mm)	5 to 50	50
Est. Q (bags/hr)	430	25/50
Sensitivity (kg)	0.5	4.0
Detection Probability	0.9	0.7

Conclusion

The requirements for a GRA based detection system have been defined and a device to demonstrate the achievability of the required performance is nearing completion. Although there are some areas of the device that may not be completed to the full potential due to limited funding at this time, the planned demonstration will suffice to show whether the GRA approach is practical for either or both drug and explosives detection. The POP device will benchmark our models and facilitate accurate prediction of fieldable CDS performance. Development of the high current tandem accelerator may have other applications.

References

[1] T. Gozani, "Nuclear Based Techniques for Cargo Inspection - A Review", Proceedings of Contraband and Cargo Inspection Technology International Symposium, Washington D.C., October, 1992, pp. 9-19.
[2] D. Vartsky, et al., "A Method for Detection of Nuclear Explosives Based on Nuclear Resonance Absorption of Gamma Rays in 14N", Nuclear Instruments & Methods in Physics Research, Section A 348, 1994, pp. 688-691.
[3] NIS6-94:341SDG, Status Report, Nuclear Resonance Fluorescence Study, March 1994.
[4] Sredniawski, "A New Proof-of-Principle Contraband Detection System", ONDCP Conference, Nashua, NH, October 23-27,1995.