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The Development of a Walk-through Portal Detector for the Identification of Contraband Explosives

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Abstract: Recent worldwide events have shown that explosives are the weapon of choice of terrorists in a variety of situations. For this reason, the need exists to develop a walk-through explosives detector that can be used at airports, government buildings, and other sites requiring both high security and the rapid screening of large numbers of people. In this paper, we discuss on-going efforts at Sandia to develop a walk-through explosives detection portal for the Federal Aviation Administration (FAA). We present a brief overview of detectors and detection methods currently utilized in this field, and discuss the special challenges associated with the development of portal detectors. Preliminary results obtained with the portal system at Sandia indicate that the overall portal concept is viable for the detection of contraband high explosives.

Introduction

The repeated use of high explosives by terrorists in recent years has made the development of ever more sensitive and reliable explosives detectors a research area of utmost importance. A number of technologies have been utilized in developing commercial detection units, and such units have been proven to function very well under certain conditions. However, for some applications, especially those involving personnel screening in high traffic areas, present generation commercial detectors are often inadequate because the sampling methods employed (typically swiping) are too time consuming to be applied uniformly. There is thus an immediate need for a walk-through system that can detect explosives vapor on the time scale of a few seconds per person screened.

In this paper, we discuss the current status of a project at Sandia to develop a walk-through portal explosives detector for the FAA. While the research is still in progress, there is little doubt that the basic portal concept is viable and that such units will be produced and marketed within the next few years. The prototype portal at Sandia has been shown to be very sensitive to certain high explosives, with the ability to detect nanogram (ng) quantities of molecules such as TNT and RDX. It is also capable of detecting plastic explosives such as a threat quantity of the RDX-based military explosive C4.

Current Methods of Explosives Vapor Detection

Detection of high explosives can be divided broadly into the areas of bulk and vapor detection, or in layman's terms into the arts of "looking" and "sniffing". While this paper

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focuses on vapor detection, bulk detection is also an active area of research and some facts are worth noting. These two research areas are to a large degree complementary, since bulk detection works best for explosive samples with large volume relative to surface area, while vapor detection works best for samples with large surface area-to-volume ratios. Bulk detection is often used for baggage or package screening. The main drawback of bulk detection for personnel screening is that the incident radiation that is traditionally used (e.g. x-rays, gamma rays) is potentially harmful to humans, and thus vapor detection is the more attractive alternative from a public health viewpoint. Passive bulk detectors that use no incident radiation but rather rely on detection of the body's emission of millimeter wavelength radiation are currently being developed, but none have yet been marketed. A combined bulk/vapor detector would be extremely useful, and we anticipate the development of such instruments in the future. For the present, however, we focus on the development of a walk-through vapor detector.

Current methods of vapor detection include animal olfaction as well as the technologies of gas chromatography(GC)/electron capture, GC/chemiluminescence, tandem mass spectrometry (MS/MS), and ion mobility spectrometry (IMS) (1). Animal olfaction is currently used in many police and military applications where trained dogs have proven successful at detecting a variety of contraband materials. However, this technique suffers from the fact that both the dog and the handler need to be regularly retrained; it is too time intensive to be used in high traffic areas; and dogs (like their human handlers but unlike machines) are subject to fatigue and distraction. Hence, there is a need for technology-based detection instruments in many circumstances.

The technologies listed above for vapor detection of explosives all have distinct advantages and disadvantages (1). Electron capture detectors (ECDs), in which a reduction in standing current from a beta-emitter due to capture of electrons by vapor phase explosives molecules is detected, represent the simplest such technology. This makes ECDs convenient for hand-held detectors, and as a result there has been much commercial development of this technique. However, the sensitivity is rather poor (2-3 orders of magnitude less than chemiluminescence or IMS), and this technique cannot identify the type of explosive or related compound present and thus requires coupling with a GC. Chemiluminescence, in which an explosive molecule is decomposed to produce ultimately excited NO_2 molecules that emit detected photons, is more sensitive but is also non-specific and thus also requires GC coupling. Tandem mass spectrometry, in which the analyte is passed sequentially through two different mass spectrometers and the resulting ions are analyzed, offers potentially unrivaled specificity for a large variety of compounds, but this technique is still in the developmental stage and hence is largely untested commercially. Ion mobility spectrometry (2) involves the formation of negative molecular ions of explosives using a beta-source, and these ions are then identified by their drift times traveling through a region with an applied electric field. This technique offers very high sensitivity with the capability of detecting a few parts per trillion (ppt) of some explosives in air, and the specificity is sufficiently good that coupling to a GC is not required in most applications. There are a number of commercial instruments that employ this technology, and it has become one of the most widely used techniques for vapor

detection of explosives. Nevertheless, this technique also has drawbacks: the chemistry of the ionization process is complex and varies with atmospheric conditions, the database is much less developed than in the case of GC or MS, and clustering of ions can greatly complicate spectral analysis.

Considerations for Portal Development

In developing a portal detector, screening time is a consideration of paramount importance. For example, in a typical airport it is necessary to screen one person every 5-10 seconds in order to avoid unacceptable delays to the traveling public. Commercial explosives detectors typically utilize surface sampling in which a person or item suspected of bearing explosives is swiped with a collection pad. The pad is then inserted into a collection port on the instrument, and the sample is desorbed and analyzed. While often successful in detecting minute amounts of explosive material, this means of analysis is clearly much too time consuming to be used on every individual entering an airport, government building, or commercial center. It is from this time constraint that the need for a portal detector which can rapidly collect and analyze explosives vapor arises.

The need for small collection and analysis times leads to a second requirement for portal detectors, namely very high sensitivity. Lack of sufficient sample is the most common reason for the failure of vapor detectors, and the small time frames involved severely limit the amount of air that can be sampled for vapor. This problem is exacerbated by the very low vapor pressures of many explosives. For example, the equilibrium vapor pressures of RDX and PETN at room temperature and atmospheric pressure are only a few ppt (1). Losses of sample molecules due to adsorption on ducting surfaces also add to this problem. Because of their large size and reactive nitro groups, explosives molecules tend to be very "sticky" and readily adsorb on surfaces of almost any material. The effects of short sampling time, low vapor pressures, and sample loss due to adsorption combine to make high detector sensitivity a vital criterion for any vapor based detection system.

In addition, a portal system needs to have good specificity, i.e. the ability to distinguish different types of explosives from one another and from chemically similar interferences. This is vital in determining whether a threat is really present and in gauging the nature of the threat. Needless to say, compound identification must be carried out on a time scale consistent with the above discussion, a constraint that eliminates traditional GC separation of compounds.

Finally, the detection of explosives by the portal is constrained by the fact that one inevitably needs to screen for the presence of several different explosive molecules simultaneously. Optimal collection and analysis conditions for one particular explosive will likely be far from optimal for another explosive, and may even be inconsistent with detection of the second species. For example, collection of a relatively stable molecule such as TNT can be enhanced by heating ducting surfaces to $\sim 160^\circ\text{C}$, thus reducing losses due to adsorption on these surfaces. However, ducting walls at this temperature will lead to at least some decomposition of less stable explosive molecules such as PETN and

EGDN, which from the point of view of detection may be equally important. Similarly, different operating parameters for operating e.g. an IMS detector would be appropriate for optimal detection of different types of explosives. The result is that there are always trade offs among maximizing detection efficiency for different species, and one must either try to find a "happy in between" or increase the expense and complexity of the system by using multiple detectors.

Portal Development at Sandia

Figure 1 shows a schematic representation of the prototype portal being developed at Sandia. A photo of the portal is shown in Figure 2. The system consists of the main portal structure, a preconcentrator, and an IMS detector. Ion mobility spectrometry has been chosen as the explosive detection technology that, in our view, currently offers the best combination of high sensitivity, specificity, and detection speed discussed above. When an individual enters the portal, air is blown down over his or her body and is drawn out of the portal into the preconcentrator. If any explosive is present on the person's body, vapor from this material will be entrained in the airflow and collected in the preconcentrator. This is followed almost immediately by pulsing of the collected sample into the IMS, where characteristic signals due to any explosives present are detected. The entire collection and analysis process requires less than ten seconds.

The preconcentrator, developed at PCP, Inc.(3), is a key feature of this technology. It contains a number of metal plates, which during the intake of airflow from the portal adsorb substantial amounts of any explosives molecules present. After completion of the air inflow cycle, the plates are heated rapidly to desorb these molecules and a sample of the explosive vapor rich air inside the preconcentrator is pulsed into the IMS. The preconcentrator thus serves to concentrate explosives molecules from a very large air sample (typically 200-250 liters) taken into the preconcentrator into a much smaller air sample (typically ~ 2 liters). While not yet quantitatively measured, this concentration effect greatly reduces the density of vapor that must be present in the portal in order to detect a particular compound.

At this time, only preliminary results can be given concerning the performance of this prototype portal. However, the results obtained to date appear promising for the future development of this technology. Airflow in the portal has yet to be optimized, but under typical operating conditions about 40-50 liters/sec of air are drawn into the preconcentrator for a time period of ~ 5 seconds. Initial experiments have shown that if a vapor coil is used to vaporize explosive in the portal under these conditions, the system is capable of detecting ~ 2 ng of TNT and 5 ng of RDX. While these numbers appear impressive, it must be pointed out that the IMS alone is much more sensitive; e.g. it is capable of detecting 1-10 picograms (1 picogram = 1 pg = 10^{-3} ng) of TNT. Hence there is much room for improvement in the efficiency of the preconcentrator and in the ducting of material from the portal to the preconcentrator. Nevertheless, these detection limits

indicate that the portal should function as a viable detector for TNT and RDX, since ng quantities of vapor can be expected to be produced by explosives being concealed on a person's body. The portal has also proven successful in detecting a threat quantity of C4, a plastic explosive composed mainly of RDX, held at waist height. More systematic testing of the portal system with these and additional explosives is currently in progress.

Summary

To meet the challenge of detecting contraband explosives using vapor technology in high traffic areas, Sandia National Laboratories is in the process of developing a walk-through portal explosives detector for the FAA. The system is based on the preconcentration of explosives vapor from a large volume of air that is passed over a screened person's body in a few seconds, and an ion mobility spectrometer is employed as the detecting element. Initial experiments with TNT and RDX vapor generation in the portal indicate that the overall concept is sound and that, once optimized, the portal should function as a useful detector for personnel screening.

Acknowledgments

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References

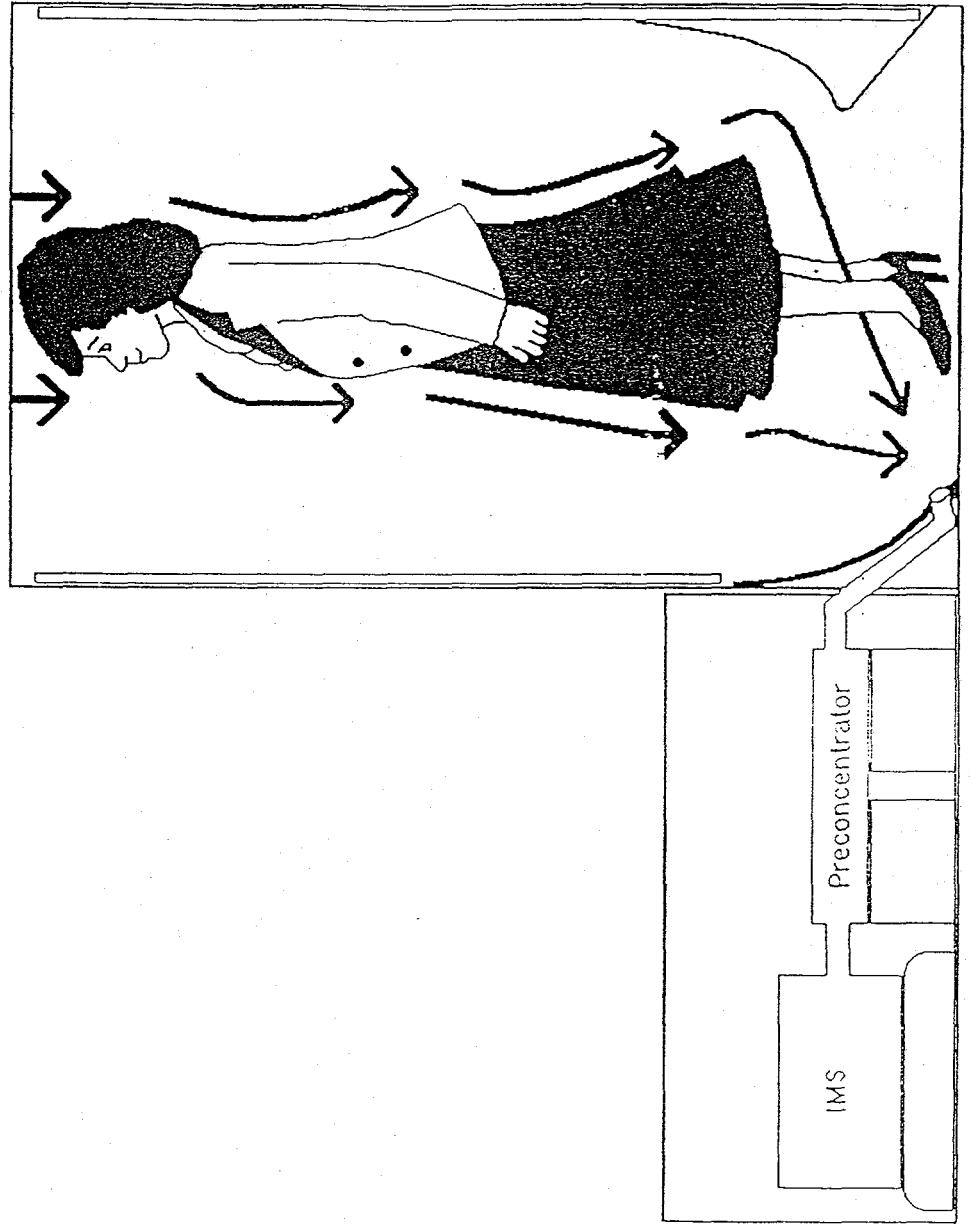
- (1) J. Yinon and S. Zitrin, in "The Analysis of Explosives", Pergamon Press, Oxford, 1981.
- (2) G. A. Eiceman and Z. Karpas, in "Ion Mobility Spectrometry", CRC Press, Boca Raton, 1994.
- (3) Information can be obtained from PCP, Inc., 2155 Indian Road, West Palm Beach, Florida, 33409-3287.

Figure Captions

- (1) Schematic representation of the Sandia vapor detection portal.
- (2) Photograph of the portal system. The ion mobility spectrometer is visible at the lower left of the photo. The preconcentrator is to the right of the IMS and is largely obscured in this view.

Figure 1

IMS PORTAL DETECTOR



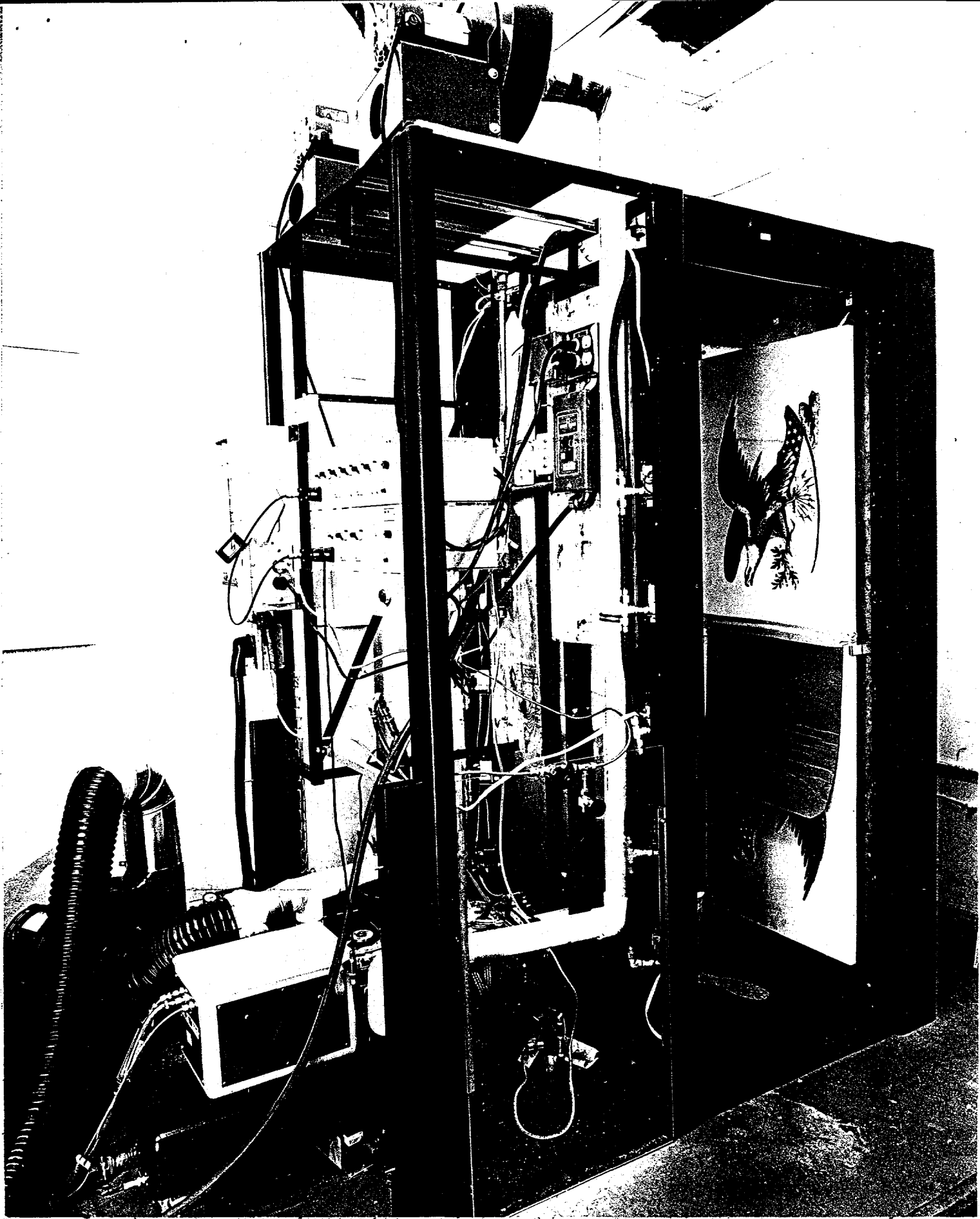


Figure 2