**Title**
Assessment of the Feasibility of Performing Infield Nondestructive Evaluation to Determine the Presence of Explosives Materials Within Cased Munitions, Phase II: Nonvapor Detection

**Author(s)**
Harold J. Gryting

**Performing Organization**
Southwest Research Institute
P.O. Drawer 28510
San Antonio, TX 78284

**Contract or Grant Number**
DLA900-79-C-1266

**Abstract**
The Navy has the ongoing problem of ordnance being loaded with simulants for various requirements including practice items being difficult to differentiate from explosive-filled ordnance. In addition some practice bombs contain energetic marker materials. Ideally, one portable instrument for all differentiation problems would be chosen if available. The current survey is to determine the status of explosives detection instruments and possibly viable concepts for such detection.
which is sealed. This phase (II) covers nonvapor detection. This work is supported by the Naval Sea Systems Command (NAVSEA 06H3). This study covered the period of June 15 through November 21, 1983.
Commander, Department of the Navy  
Naval Sea Systems Command NAVSEA-06H3  
Attention: Mr. Ed Daugherty  
Washington, DC 20362  

Subject: SwRI Project 15-5607-825  
Final Report on Phase II  
"Feasibility of Detection of Explosives in  
Cased Munitions: Phase II Nonvapor Detection  
Methods"

Dear Mr. Daugherty:

In accordance with the MIPR sent through the Defense Electronics  
Systems Command (DESC) three copies of the Final Report on SwRI  
Proposal 06-0604A, Phase II funded under contract modification number  
P00031 dated 15 June 1983, line item 0001AV to NTIAC Contract DLA 900-  
79-C-1266 and titled: "Feasibility of Detection of Explosives in Cased  
Munitions: Phase II Nonvapor Detection Methods," by Dr. Harold J. Gryting  
are forwarded.

For Phase I $10,475 is now needed in accordance with the proposal.  
On completion of Phase I, the two sections will be bound together into one  
report (some additions will be made to Phase II as not all requested  
information has been received). The report will also contain a brief  
list and discussion of advantages and disadvantages of vapor vs nonvapor  
detection.

Recommendations for near term research into the best of the nonvapor  
detectors has been made in the attached report.

We are happy to have the opportunity to serve and hope to continue to  
assist in this important endeavor.

Sincerely yours,

Alex B. Wenzel, Director  
Department of Energetic Systems

ABW:1r  
Enclosure  
cc: H. N. Abramson  
H. J. Gryting  
R. Priegel  
C. du Menil  
W. R. Herrera
ASSESSMENT OF THE FEASIBILITY OF PERFORMING INFIELD NONDESTRUCTIVE EVALUATION TO DETERMINE THE PRESENCE OF EXPLOSIVES MATERIALS WITHIN CASED MUNITIONS

Phase II: Nonvapor Detection

By

Harold J. Gryting

SwRI Final Report (Phase II)
Project 15-5607-825

Prepared For
The Naval Sea Systems Command
NAVSEA 06H3

November 1983

APPROVED

Alex B. Wenzel
Alex B. Wenzel, Director
Department of Energetic Systems
The Navy has the ongoing problem of ordnance being loaded with simulants for various requirements including practice items being difficult to differentiate from explosive-filled ordnance. In addition some practice bombs contain energetic marker materials. Ideally, one portable instrument for all differentiation problems would be chosen if available. The current survey is to determine the status of explosives detection instruments and possibly viable concepts for such detection for Navy ordnance, much of which is sealed. This phase (II) covers nonvapor detection.

This work is supported by the Naval Sea Systems Command (NAVSEA 06H3). This study covered the period of June 15 through November 21, 1983.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>COMPUTERIZED TOMOGRAPHY (CT)</td>
<td>2</td>
</tr>
<tr>
<td>NUCLEAR GAUGING</td>
<td>4</td>
</tr>
<tr>
<td>Nuclear Gauging by Compton Scattering - Applied to Practice Bombs</td>
<td>4</td>
</tr>
<tr>
<td>NUCLEAR MAGNETIC RESONANCE</td>
<td>6</td>
</tr>
<tr>
<td>X-RAY TECHNIQUES</td>
<td>9</td>
</tr>
<tr>
<td>MAX-E System</td>
<td>9</td>
</tr>
<tr>
<td>Pattern Recognition Software for MAX-E System</td>
<td>9</td>
</tr>
<tr>
<td>X-Ray Fluorescence Spectrometry in Quantitative Analysis</td>
<td>10</td>
</tr>
<tr>
<td>METAL DETECTION TECHNIQUES</td>
<td>10</td>
</tr>
<tr>
<td>THERMAL NEUTRON CAPTURE (WESTINGHOUSE)</td>
<td>11</td>
</tr>
<tr>
<td>NONDESTRUCTIVE EVALUATION (SANTA CRUZ MEETING AUG 1983)</td>
<td>12</td>
</tr>
<tr>
<td>INTERNATIONAL SYMPOSIUM ON ANALYSIS AND DETECTION OF EXPLOSIVES</td>
<td>12</td>
</tr>
<tr>
<td>COMPARISON OF CANDIDATE NONVAPOR-EXPLOSIVES-DETECTION TECHNIQUES</td>
<td>13</td>
</tr>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS</td>
<td>13</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>16</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>17</td>
</tr>
</tbody>
</table>
DETECTION OF EXPLOSIVES PHASE IN NONVAPOR DETECTION

INTRODUCTION

A proposal to review concepts and new and improved methods for explosives detection was accepted by NAVSEA06H in June 1983. Phase II Nonvapor Detection was funded first. To conserve time, the abstracts for both phases were obtained at the beginning of Phase II. Full reports (microfiche) were ordered for 46 articles related to Phase II. Approximately 150 reports were noted as related to Phase I.

Data bases searched by computer from 1980 through July 1, 1983 included (1) INSPEC Data Base, which is the largest data base in the English language in the fields of physics, electrotechnology, computers, and control. (2) CA Search Data Base. This covers bibliographic data from all documents covered by the Chemical Abstract Service. (3) NTIS Data Base. This covers Government-sponsored research, development, and engineering, plus analyses prepared by Federal agencies, their contractors and grantees, and (4) Compendex Data Base which is from the Engineering Index with a worldwide coverage of 3500 journals, publications of engineering societies and organizations including papers from the proceedings of conferences, and selected Government reports and books. In addition to the above data base computer searches, personal contact was made with a number of people known to be involved with detection to obtain updates in their particular specialties that have occurred since 1979. This included many people whose papers are referenced in the SWRI report of December 1981. In addition, a summary from the FAA-sponsored Cambridge, Mass., (April 19, 1983) Conference on Detection was obtained, as were abstracts of papers from the FBI-sponsored detection meeting at Quantico, W. Va. (March 29-31, 1983). These two conferences were directed toward finding explosives that are brought in or planted by terrorist or other saboteurs.

The field of quantitative nondestructive evaluation has expanded and progressed markedly since 1980. A meeting was attended at the University of California, Santa Cruz, sponsored by the Center for Advanced Nondestructive Evaluation, Ames Laboratory, Iowa State University, in cooperation with the Office of Basic Energy Sciences of the US Department of Energy, the Defense Advanced Research Projects Agency, the Naval Sea Systems Command
and the Air Force Wright Aeronautical Laboratories/Materials Laboratory. Although the NDE papers given did not include results of use of any instrument specifically developed for detection of explosives, some of the techniques, given additional exploration dedicated to differentiation between simulants and explosives, may become useful in the future. Some of these will be considered here.

Although for many of the types of detection and detectors no major breakthrough type improvements have been made that allow field detection in sealed bombs instantly with portable devices, there is still the potential for some of these methods to be developed to do what is required to differentiate the true explosive from the inert simulants. Among these can be included nuclear gauging, dual energy tomography and nuclear magnetic resonance. The latter cannot be used for sealed weapons, however, so its use would require development of equipment which could drill holes suitable for a small transducer. NMR can be used with a large or small specimen (down to a few grams size).

The theory and mode of operation of nonvapor detectors is discussed in some detail in our previous report \(^1\) and the evaluation by Henegar \(^2\) of various metal detectors has apparently not been superseded by a newer detailed comparison of instruments.

**COMPUTERIZED TOMOGRAPHY (CT)**

As discussed previously, \(^1,3\) CT is the reconstruction numerically of a cross-sectional image from data obtained at different aspect angles. These are determined using x-rays or gamma-rays together with radiation detectors. An update of Roder's previous report \(^3\) has just been received for review; however, the author indicated that whereas the previous report indicated that tomography was not good enough to differentiate between explosives and their simulants, he now considers that using Dual Energy Computerized Tomography, (DECT), depending upon the system, may work with warhead cases up to one-half-inch thick, and above that it would not work. If, on the other hand, the organic simulant simulates the density of the explosive exactly and atomic numbers do not differ by more than about 10\%, DECT probably would not be
satisfactory for the differentiation required. Both Aerospace-George-
town University sponsored by BATF and Varian Associates sponsored by the
FAA have performed DECT studies. These showed that explosives could be
seen as high density materials with low average atomic numbers and could
be reasonably distinguished from innocuous objects. One explosive, it was
noted, was not distinguished from a block of cheese.

A breadboard type system suitable for realistic measurements was
designed by Aerospace-AARACOR-USCF under BATF sponsorship. This system
includes a precision conveyer belt, a panoramic X-Ray tube, eighty
separate scintillators (CdWO$_4$) coupled to photodiodes, and a data acquisition
and control system. This system is to be evaluated at the FAA Tech Center.

To summarize recent CT technology advances Dr. Frederick Roder is
quoted:

"In the four years that have passed since development of the bread-
board DECT system was initiated, the state-of-the-art in CT has advanced
on several fronts. A prototype system configured along the lines of the
breadboard system would require $10^4$ detector elements. In 1979 that
seemed unthinkable and $10^4$ is still more detectors than has ever been
incorporated in a single scanner. However, one commercial system has
employed $2.4 \times 10^3$ detector elements. The breadboard system requires that
the X-ray voltage be changed between complete scans. However, an X-ray
source designed for dual energy work and capable of switching between
two fixed voltages at 60 Hz is currently being used at the Stanford
Medical Center. But most significantly, the last four years has seen the
development of a very high speed CT scanner designed primarily for cardiac
imaging. This unit, termed a cinetomographic scanner by the developing
group at the University of California, San Francisco Medical School, has
already been employed to obtain cross sectional images of human hearts
at 36 slices/sec. This system utilizes no moving parts during a scan.
Instead a high current (~600 mA) electron beam is electromagnetically
swept over a 210$^\circ$ tungsten target, producing the same effect as an X-ray
tube rotated through the same angle. The slice thickness is 7.5 mm, with
a 47 cm diameter reconstruction circle. The present system is designed for
single energy operation. The next system, currently being fabricated, will
have DECT capability. Figure 7(6) is a photograph of the cinetomography
system before the detector rings were installed. Figure 8(6) illustrates the
scanning position for a patient."
"The cinetomographic scanner could obtain a full three-dimensional DECT image of a 100-cm long suitcase in 3.7 seconds. However, the resolution of this system (2.2 mm FWHM) is far in excess of the requirements for explosives detection and the 47 cm diameter reconstruction circle will only accommodate relatively small luggage items (-35-cm high by 30-cm wide). Reconstruction time is also a limitation: at present about 7s are required per 256 x 256 slice. Consequently, although it is believed that the cinetomography system would be an excellent tool for demonstrating the feasibility and efficacy of DECT explosives detection, further engineering will be required to embody this technology in a system configured for explosives detection."

"Finally there is the matter of cost. As a medical system, the estimated $1.5 million price tag of the cinetomography system is quite acceptable. However, for security applications such a price tag would be unacceptable under other than the most dire circumstances. Consequently, cost reduction engineering must be an essential aspect in developing a DECT explosives detector."

NUCLEAR GAUGING

Work in this area by Weber, Lukens, and others has been summarized in a paper from IRT Corporation (1). The early work reported a nuclear gauging system consisting of three transmission type gauges with signal acquisition electronics. They determined density using a dual energy gamma gauge with \( ^{241} \)Am (59.5 KeV energy) and \( ^{109} \)Cd (22.1 and 25.0 KeV) and hydrogen content with a thermal neutron gauge with \( ^{252} \)Cf as the source and a tritium-filled gas proportional counter as the detector. Letter bombs were detected at near 100% accuracy.

More recently nuclear gauging was used to determine feasibility of detection of phosphorus in practice bombs (8).

Nuclear Gauging by Compton Scattering - Applied to Practice Bombs

Nuclear gauging has been examined by IRT Corporation using a Compton Scattering Inspection System.

A Compton scattering detection system was developed by IRT Corporation which they indicate has been shown in a feasibility study conducted at
NWC, China Lake, to be capable of meeting requirements of range clearing operations for the NR-76/BDU-33 and MK-106 practice bombs. Compton scattering, or collimated photon scattering, a technique developed by IRT for nondestructive examination of ordnance, uses a collimated beam of photons from a "pencil beam" intersecting a practice bomb at a particular inspection location. A series of collimators is focused on this location and the attached sodium iodide detectors and associated electronics provide accurate counting rates for photons which are scattered away from the "location" (or interior inspection volume). The scattered photons can yield information concerning whether the energetic load has been expended or remained in whole or part.

A three-step inspection process was developed:
1. Physical inspection using calibrated, hand-held measuring rods.
2. Inspection of remaining bombs using the Compton Scattering System.
3. Inspection of those gauged to be live on doubtful by the Compton Scattering System by dismantling, sawing near spotting charge location and visually verifying whether live or not.

A validation laboratory study (IR-399-902) confirmed the initial feasibility study which was then followed by a pilot study which included design and fabrication of a prototype Compton Scattering System and transporting to NWC Baker Test Range where results led to establishing the parameters for an optimized system for full-scale range cleanup of MK-76/BDU-33 and MK-106 practice bombs using this method.

The live round false accept probabilities were: for MK106 = \(1.9 \times 10^{-8}\), for MK 76/DBU-33 = \(1 \times 10^{-5}\), whereas empty round false reject probability was: for MK106 = \(4.4 \times 10^{-5}\) and for MK-76/BDU-33 = \(3.9 \times 10^{-5}\).

Nuclear gauging research is underway for FAA also at Westinghouse; recent reports from there have not been received. Discussion with Hurwitz has indicated that should this technique be used, spent nuclear materials would be exchanged for new specimens from the furnishing plant so the Government should not be required to dispose of used materials as hazardous materials.

G. Entine et al. of Radiation Monitoring Devices (private communication to H. J. Gryting) have developed a small detector with some capability for
detecting explosives as shown in Figure 1 and 2. In its present state, complex differentiations as indicated earlier would have the limitations noted for this mode. It could detect certain explosives in bicycle frames, for example, but is not a universal tool for all ordnance.

NUCLEAR MAGNETIC RESONANCE

Since Ref. 1 was issued, there have been continuous efforts related to nuclear magnetic resonance and nuclear quadruple resonance mostly to improve the techniques and to extend the quantitative measurement capability to additional compositions. In work conducted during the last year, advances have been achieved that allow explosives to be detected more reliably and with fewer false alarms in imperfect magnetic fields. These advances resulted from efforts to improve the NMR system for inspecting baggage to detect concealed explosives but these should also be useful to detect explosives sealed in ordnance by means of making a small hole in the steel containment wall. In normal NMR, the magnetic effects of the steel casing on the signal obtainable with a small sensor probe inserted through a thick wall could seriously degrade the results. However, use of these more recent techniques along with adequate probe design could be instrumental in improving the probability of success with such probe measurements. (9)

No effort has been conducted to the author's knowledge to determine explosives through small holes. A number of companies producing lasers have been asked whether their equipment could gently open a hole in a steel case without igniting an explosive or other energetic material. Not a great deal of optimism was expressed for such an approach.

Nuclear magnetic resonance for use in detection of explosives could be a viable concept providing the ordnance is not sealed totally. Metallic cases do not allow the electromagnetic waves to pass into the explosive unless there is a hole large enough for a small probe (size to be determined by the smallest transducer that is determined experimentally to be effective) to be inserted in such a way that the electromagnetic waves are not all adversely reflected or absorbed. Significant progress has continued in the field of nuclear magnetic wave use for quantitative determination of such explosives as the cyclotolts and Composition B.
The RMD Model 8200 Portable Contraband Detector is a compact, lightweight instrument for the detection of narcotics and currency hidden in the body panels, tires and seats of vehicles.

Developed under contract for the U.S. Customs Service, the Model 8200 uses a modern microprocessor-based technique to detect contraband beneath metal surfaces. The scanner may be used on all types of vehicles, aircraft, vessels and shipping containers.

The detection technique utilizes a nuclear flux, emitted from a small source directed into the volume of interrogation. The backscatter flux is measured using a highly sensitive solid-state detector and analyzed by digital electronics. The operator is alerted to the presence of contraband by an audible alarm as well as a numerical display.

Figure 1. RMD Explosives Detector
Features

Fast: A typical vehicle can be inspected inside and out in less than five minutes, including hollow body panels, tires, trunk and seats.

Accurate: State-of-the-art sensor and microprocessor signal enhancement allow positive identification of contraband targets.

Highly Sensitive: Narcotics packages of 4 oz. (0.1 kg.) and currency packages over 100 bills can be readily detected.

Flexible: The scanner can be used to locate a wide range of drugs and currencies.

Easy-To-Use: Requires less than two hours of operator training. Small Co-57 source needs no NRC license.

Specifications

Size: 10" high by 9" long by 4" wide (25 x 23 x 10 cm)

Weight: 3.25 lbs. (1.5 kg.)

Power: Rechargeable NiCd batteries provide a full work week of operation before recharging.

Display: Alphanumeric with backlighting for night operation.

Response Time: 0.25 seconds.

Scanning Rate: 1 foot (0.3m)/second.

Figure 2. Characteristics of RMD Explosives Detector
X-RAY TECHNIQUES

Greater sophistication in X-ray techniques obtained in the last few years makes the measurements more meaningful including the successful identification of certain specific objects; however, the full differentiation between explosives loads and their inert simulants has not been achieved by these techniques.

Excerpts from the Cambridge FAA meeting summary indicate status of progress. X-Ray Fluorescence Spectrometry used in semi-quantitative analyses of known explosives compositions and the detection of metallic elements in small quantities is indicative of some of the branching techniques which are being developed.

**MAX-E System**

A digital radiographic system, is a direct successor to \(^{133}\)Ba gamma-ray transmission system. The MAX-E consists of a 1 KW constant potential X-ray source which is continuously variable over 40-140 KV, a luggage conveyor operated at 24 cm/sec, a linear array of 512 photodiodes coupled to CdWO\(_4\) scintillators, a data acquisition system, a general purpose computer, and an array processor. This currently is an assembly/test stage. It is designed for two mm resolution over a 512 x 512 pixel image, 256 statistically significant grey levels and a target dynamic range of 1000:1. Explosive detection software is incomplete, and subject to FAA procurement.

**Pattern Recognition Software for MAX-E System**

Eight proposals are under review by FAA.

Pattern recognition can apply to recognition of shapes (rectangles, cylinders, etc.) or it may apply to the recognition of density distributions. Pipe bombs and packaged high explosives may be recognized by shapes, whereas military explosives may be recognized as compact areas of low atomic number. Ability to determine average atomic number results from MAX-E capability to obtain dual energy data. False alarms may be obtained from organic solids such as cheese and liquids in plastic bottles. Explosives contained within glass or thin metallic containers could escape detections.

At the FAA seminar they felt the MAX-E approach should provide a meaningful although far from comprehensive explosives detection capability.
X-Ray Fluorescence Spectrometry in Quantitative Analysis

For low atomic numbers \( Z = 9 \) (F) to \( Z = 14 \) (Si) conditions used are:
a Cr-X-ray tube is used with maximum current and voltage settings (50 KV, 40 ma). A large sample holder (3.18 cm diameter sample, pressed) is employed, and a TAP analyzing crystal with vacuum of <150 \( \mu \). A flow counter (p-10 gas) with an ultrathin window (1 - \( \mu \) thick) (the TATB is pressed to \(-1.5 \text{ g/cm}^3\)).

For a TATB/Kelf composition a minimum diameter particle for this PBX is 1000 - 2000 \( \mu \) and penetration is about 1000 \( \mu \) whereas the fluorine X-ray travels only 2 to 3 \( \mu \) from where it was produced. Therefore the signal from fluorine is manifest at the surface. The signal will depend upon surface conditions and also upon local inhomogeneities (local variations of HE to binder ratios, particle orientation and flow during pressing operation.

Accuracy is restricted to within 10 or 20\% for this PBX. Signal/noise ratio is poor and the lower limit of qualitative scan is \(-4100 \text{ ppm} \) (minimum for detection).

For sodium the fluorescence yield is low and the lower detection limit is 80 ppm.

Mg lower detection limit is 250-300 ppm.
Al lower detection limit is 250-300 ppm.
Si lower detection limit is 250-300 ppm.
Si with change of crystal from TAP to EDdt \( \rightarrow \) 50 ppm.
Phosphorous and sulfur \(-10-15 \text{ ppm} \).
Cl \( 270 \text{ ppm} \).
K \( 10 \text{ ppm} \).

Derivation of the relationship between X-ray intensity and the concentration of the element in the sample is given in the Appendix to Worley's article.

METAL DETECTION TECHNIQUES

Morita(11) reviews and documents technical effort and results for identification and screening of promising remote sensing systems for detecting mines with emphasis on surface laid minefields with short detection reaction time. The minefields considered were in the European Theater.
Techniques and their highlights include:

- Aerial Photography - recommended for continued effort.
- Spot light Radar - may give quantitative data. (The 10.6μ active scanner was suggested for greater future emphasis.)
- Image intensifiers and TV devices - indicated as only having limited potential.
- Explosive Detection - Methods were not useful here as it is necessary to get close to the item to detect the explosive.
- Sight Systems - little or no potential.
- MTI and Pulse Doppler Radars - are capable of giving inferential information - (recommendations on these techniques are not covered in this report).

THERMAL NEUTRON CAPTURE (WESTINGHOUSE) (5)

The Thermal Neutron Capture system utilizes a $^{252}$Cf source and 96 plastic scintillators, each 2-in. wide by 15-in. long to produce a mapping (~4 in. resolution) of the nitrogen distribution within a suitcase using the $^{14}$N(n,γ)$^{15}$N reaction. The emitted gamma-ray has an energy of 10.8 MeV and is higher in energy than most other neutrons emitted by common elements, although gamma-rays produced by iron, chlorine, and chromium do produce a significant background. This background is presently being compensated for by obtaining a better-defined spectrum with a NaI(Tl) detector. There is also a count problem from the 2.2 MeV hydrogen capture gamma rays. Consequently, increasing the source size would not improve the data acquisition time, which is currently minutes, unless changes are made in the neutron polyethylene moderator.

Nitrogen is contained in almost all explosives, as well as in wool, leather, nylon, orlon, cheese, and lean meat. However, the nitrogen concentration in explosives is considerably higher than the concentration in these innocuous materials. To date, field data obtained with this system has been quite limited, so background nitrogen concentrations and distributions in the checked luggage population are largely unknown. Preliminary results with this system showed approximately a 95% detection rate and an approximate 3% false alarm rate for one sample.
The use of the thermal neutron capture approach for air cargo warrants consideration, since cargo tends to contain large amounts of metal; and thus, is not readily inspected via x-ray techniques.

NONDESTRUCTIVE EVALUATION (SANTA CRUZ MEETING AUG 1983)

The Santa Cruz NDE symposium did cover certain detection aspects of tomography, including computer tomography NDE of solid rocket motors. This pertained to the development of CT inspection capability of a range from small to 2.5 meter diameter solid rocket motors and components. One system, the AF/ACT-I, was operational early in 1983 and has been used to scan rocket motors and other aerospace hardware components for flaws. Scudder describes a system that can make images of objects up to two inches in diameter and has a spatial resolution of 0.010 inch. It has been used primarily for aircraft engine turbine blades and can also create good x-ray images of most industrial materials. Good contrast images can be made from materials ranging from light organics such as plastics to heavy metals as steel and copper.

Acoustics was one of the major subjects of the Santa Cruz NDE meeting. Several people were contacted with respect to potential usefulness of such techniques. From what has been gleaned from the meeting and from discussions with a number of people no direct application to explosives detection or differentiation from inert simulants in sealed systems has yet been found for acoustics. Acoustic transmission and reflection spectra from inert and explosives would have to be determined and compared before viability could be either predicted or indicated as impossible. Discussion with Bruce Maxfield and Dick Bossi of Sigma Research where acoustic holography and ultrasonics studies are in progress for other purposes also indicated no current explosive detection capability by these means.

INTERNATIONAL SYMPOSIUM ON ANALYSIS AND DETECTION OF EXPLOSIVES

The FBI sponsored an explosives detection meeting at Quantico, Virginia in March (1983). Abstracts were sent by Terry Rudolph, however, the final
papers are to be compiled soon. Significant information relating to
detection as concerns this project will be added during the time for
accomplishment of Phase I. Attachment of these abstracts as Appendix I
will indicate where much of the detection effort aimed at thwarting terror-
ists is going on.

When the papers arrive they will provide more information for comparing
the potential utility of nonvapor vs vapor detectors for sealed explosives.

COMPARISON OF CANDIDATE NONVAPOR-EXPLOSIVES-DETECTION TECHNIQUES

Table I is an updated comparison for nonvapor detection techniques. The table was modified from an Aerospace Corporation table used previously in Ref. (1) by permission from Bob Moler.

CONCLUSIONS AND RECOMMENDATIONS

Within the nonvapor detector group, there appears to be most promise, at least in the near term, for those detectors based upon nuclear gauging techniques and on nuclear magnetic resonance together with its associated proton and electron magnetic resonance.

Some of the other possibly viable techniques will require considerably more basic research and for several the advances needed cannot be predicted. The need for excellent overall detectors becomes greater with the advent of many new types of explosives and with new situations. In addition to making our ranges and range clean up safer, the terrorist threat to our troops can also be lessened if we can detect, track, and halt illegal and/or enemy movement of explosives which peril our peacekeeping troops and friendly nations.

It is recommended that in addition to reviewing the vapor detectors (Phase I to be funded) that a detailed comparison of most promising nonvapor detecting methods, based upon nuclear gauging methods and nuclear magnetic resonance be made for the ten (or more) ordnance items considered jointly by SwRI and NAVSEA to be the greatest problem.

It is recommended that methods of safely making holes in ordnance cases without endangering the explosive toward ignition be initiated.
<table>
<thead>
<tr>
<th>METHOD</th>
<th>SCENARIO</th>
<th>TYPE OF BOMB</th>
<th>DETECTION CRITERIA</th>
<th>SPECIFICITY</th>
<th>RESPONSE TIME (sec)</th>
<th>COMPLEXITY</th>
<th>BOMBING RANGE SCENARIO: POTENTIAL SUITABILITY FOR EXPLOSIVES VS INERT SIMULANTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional X-Ray</td>
<td>Controlled Access</td>
<td>All</td>
<td>Density: Operator Interpretation</td>
<td>Low</td>
<td>2-5</td>
<td>Moderate</td>
<td>Poor</td>
</tr>
<tr>
<td>Automated Gamma/X-</td>
<td>Controlled Access</td>
<td>All</td>
<td>Density: Automatic Shape Discrimination</td>
<td>Low</td>
<td>2-5</td>
<td>Moderate</td>
<td>Poor</td>
</tr>
<tr>
<td>Radiography</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dual-Energy Gamma/X-Ray</td>
<td>Controlled Access</td>
<td>Pipe</td>
<td>Density: Atomic Number</td>
<td>High</td>
<td>2-5</td>
<td>Moderate</td>
<td>Potentially possible for some comparisons</td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma/X/Neutron</td>
<td>Letters/Flats</td>
<td>Plastic</td>
<td>Density: Atomic Number; Hydrogen Content</td>
<td>High</td>
<td>0.01</td>
<td>Moderate</td>
<td>Possibly for some</td>
</tr>
<tr>
<td>Transmission</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gamma/X-Ray Scattering</td>
<td>Controlled Access</td>
<td>All</td>
<td>Density</td>
<td>Moderate</td>
<td>10-30</td>
<td>High</td>
<td>Feasibility demonstrated photon scattering 1981</td>
</tr>
<tr>
<td>Tomography</td>
<td>Controlled Access</td>
<td>All</td>
<td>Density: Atomic Number</td>
<td>High</td>
<td>10-30</td>
<td>High</td>
<td>Some potential perhaps mostly for fuses</td>
</tr>
<tr>
<td>Thermal Neutron Capture</td>
<td>Controlled Access</td>
<td>All</td>
<td>Nitrogen Content</td>
<td>Moderate</td>
<td>10-30</td>
<td>High</td>
<td>Information limited</td>
</tr>
<tr>
<td>Dielectric</td>
<td>Letters/Flats</td>
<td>Plastic</td>
<td>High Dielectric Constant</td>
<td>High</td>
<td>0.01</td>
<td>Low</td>
<td>Poor</td>
</tr>
<tr>
<td>Nuclear Resonance</td>
<td>Controlled Access</td>
<td>All</td>
<td>Hydrogen Resonance; Decay Times</td>
<td>Moderate</td>
<td>10-30</td>
<td>High</td>
<td>Steady progress access ports required</td>
</tr>
<tr>
<td>Radiometric/Imaging</td>
<td>Concealed Contraband</td>
<td>All</td>
<td>Microwave (Neal Millimeter Wave Reflection &amp; Reradiation</td>
<td>Poor for explosives, good for metals</td>
<td>2-5</td>
<td>Moderate</td>
<td>Poor</td>
</tr>
</tbody>
</table>
This would allow greater ease of detection also by the vapor detectors as well as by NMR and possibly by nuclear gauging. In addition microscopic identification and use of chemical detection kits could be made practical for previously sealed weapons.

An analysis of all situations wherein terrorists or potential enemies can intrude with explosives into peacekeeping missions needs to be made to determine what methodology and instrumentation must be developed to solve this urgent problem.
ACKNOWLEDGMENTS

The support of NAVSEA 06H3 is gratefully acknowledged; the cooperation of the Nondestructive Test and Information Analysis Center (especially Dr. Richard Smith and Dr. George Matzkanin), the Department of Energetic Systems, Engineering and Materials Sciences Division and the Instrumentation Research Division is appreciated. Dr. Frederick Roder of IRT Corporation, John Hobbs of FAA and Terry Rudolph of the FBI, William Rollwitz and J. Derwin King of SwRI gave information, including papers, symposia minutes, abstracts, and helpful suggestions as did several others referenced in the report. Editing by D. Stowitts and typing by Lynette Ramon, as well as review by W. R. Herrera are acknowledged with thanks. The encouragement of NAVSEA personnel Ed Daugherty, Ed Klinghofer, Ken Range, and Ann Thompson are gratefully acknowledged.
REFERENCES


(2) Henegar, H. A., DDES6T76-1, April 1976, US ARmy Mobility Equipment Research and Development Command, Fort Belvoir, VA.


(4) Private communication of Dr. Frederick Roder (IRT) to Dr. Harold Gryting.


APPENDIX I

Abstracts from FBI International Symposium on Analysis and Detection of Explosives, March 29-31, 1983
CHARACTERIZATION OF PLASTICS, POLYURETHANES, AND EXPLOSIVES BY DIRECT SIZE EXCLUSION CHROMATOGRAPHY

This study was directed at the various plastics and polyurethanes that can be characterized by gel permeation chromatography (GPC) size exclusion chromatography (SEC). Many commercial products are fabricated exclusively or contain plastic polymers that give the product its desired physical properties. Such products as automotive tires, television sets, and wires insulation are produced commercially by many companies. When analyzed, each product reveals a characteristic fingerprint of chromatographic peaks that can be traced to the producer or origin of the manufacturer.

The method would also apply to smokeless powders used in commercial manufacture, as well as by-products. Representative samples of this powders, explosives, plasticized polystyrene, and polyurethane lubricants were characterized by this technique of GPC. The resin remaining after detonation was washed from the empty cartridge and barrel of the weapon and then analyzed. Comparison was then drawn between the samples. This procedure was also applied for residues obtained from spent explosive material.

GPC is a predictable mode of analysis since it is a molecular weight technique based upon the size of molecules. In many instances direct comparison of the chromatograms can reveal significant differences between two supposedly identical materials. The technique allows the complete identification of organic and inorganic materials, in molecular size, and it is one of the most powerful of methods for the identification of explosives on a molecular weight basis as low as 1000 daltons. The size of explosives may be on a molecular weight as low as 1000 daltons or all the way up to large high polymers, in excess of 10 million molecular weight.
EXPLOSIVE ANALYSIS XT

In explosives analysis, HTB has developed an algorithm to determine the presence of 26 different explosives and metal explosives. The algorithm uses multivariate analysis (PCA) to separate named explosives and identify unknown components.

The HTB, with sufficient materials to perform the test, analyzes the sample for both liquid and solid samples. The samples are analyzed using a series of tests, including a two-way analysis of variance (ANOVA) and a principal component analysis (PCA). The results are then compared to a database of known explosives and metal explosives.

A number of sensitive detectors are used today for the detection of explosives. However, all their sensitivity and selectivity are in the detection of "keep" or "off" signals when they are used in combination. In order to achieve the maximum sensitivity and selectivity, the detector system must be able to discriminate between the "keep" and "off" signals. This is accomplished by using a series of sensitive detectors in combination.

Lew R. Randolph
FBI Laboratory
102 North Plymouth
Washington, D.C. 20535
(202) 321-6334

A Scheme for the Analysis of Explosives and Explosive Residues

The FBI Laboratory has developed a new scheme for the analysis of explosives residues. This scheme is based on a series of test protocols and analytical procedures. The test protocols include sampling, collection, and analysis. A series of tests are performed to identify the presence of explosives in the sample. The analytical procedures include the use of 1H-NMR and GC/MS methods. The results of these tests are then compared to a database of known explosives and metal explosives.
Dr. John A. Giamatta
Washington College
Chester, W.Va. 26101

The chemical determinations were based primarily on the RIDS data along with chemical stability considerations, the molecular weight and the structural data derived from FIDERS, MS, and IR. The positive identification of the unknown was made by superimposing the known and comparing its characteristics with those of the unknown in question by various instrumental techniques. Both Hg and EBC were used in the composition analysis.

Veronica J. Reutler
Touchstone Research
and Training Unit
FBI Laboratory, FBIMTC
Quantico, Virginia

Analysis of an Unusual Explosive: Methods Used and Conclusions Drawn from Two Cases

The results of these analyses provide information on the calibers, the type of weapon used, and the method of manufacture of the explosive materials. The samples were analyzed by the following methods:

1. **Fractography**
   - Analysis of the fracture surfaces to determine the type and size of the explosive material.

2. **Gas Chromatography**
   - Analysis of the gases evolved during the combustion of the explosive material.

3. **High-Performance Liquid Chromatography**
   - Analysis of the liquids present in the explosive material.

4. **Infrared Spectroscopy**
   - Analysis of the infrared spectra of the explosive material.

5. **Nuclear Magnetic Resonance (NMR)**
   - Analysis of the nuclear magnetic resonance spectra of the explosive material.

6. **Mass Spectrometry**
   - Analysis of the mass spectra of the explosive material.

The results of these analyses were compared with the known characteristics of the explosive materials to determine their identity. The results were then used to draw conclusions about the method of manufacture of the explosive materials.
Identification of Water-Soluble Explosives and Their Post- Blast Residues by Ion Chromatography

Explosives which contain primary water-soluble ingredients are fragmentally characterized by the forensic scientist. Determining the identity of the many alloy compositions used are among a growing number of bomb-making cases in one area where ion chromatography (IC) has been most useful. Several criteria for selecting reactive substances and blending agents used are approximately a dozen major requirements of quality:

- Efficiency and reliability, with a variety of water and both trace amounts and explosive classes. If the explosive has been removed from these products before they are incorporated into an improvised explosive device, their identification can be forensically exact.

With the voluntary cooperation of an explosive manufacturers, the FBI Laboratory in collaboration with a local disaster products most likely will be in IC's. In order to analyze these explosives, some of the items that have been developed are new methods and procedures for sample preparation and have developed IC procedures for some item which are not presently determined by IC.

The extremely high sensitivity and selectivity of IC makes the technique very useful for the analysis of post-blast residues. Following extraction of the debris with water or solvent extraction, the extract is simply filtered and run on the IC under conditions identical to those used for the analysis of water soluble explosives. We have shown that this form of analysis offers several advantages over other techniques that the limits are volatile and electrochemically active.

D. J. Barretti
DePuy Company
F. G. Donegan, Jr.
Marietta, OH

Identification of Water-Soluble Explosives and Their Post-Blast Residues by Ion Chromatography

Explosives which contain primary water-soluble ingredients are fragmentally characterized by the forensic scientist. Determining the identity of the many alloy compositions used are among a growing number of bomb-making cases in one area where ion chromatography (IC) has been most useful. Several criteria for selecting reactive substances and blending agents used are approximately a dozen major requirements of quality:

- Efficiency and reliability, with a variety of water and both trace amounts and explosive classes. If the explosive has been removed from these products before they are incorporated into an improvised explosive device, their identification can be forensically exact.

With the voluntary cooperation of an explosive manufacturers, the FBI Laboratory in collaboration with a local disaster products most likely will be in IC's. In order to analyze these explosives, some of the items that have been developed are new methods and procedures for sample preparation and have developed IC procedures for some item which are not presently determined by IC.

The extremely high sensitivity and selectivity of IC makes the technique very useful for the analysis of post-blast residues. Following extraction of the debris with water or solvent extraction, the extract is simply filtered and run on the IC under conditions identical to those used for the analysis of water soluble explosives. We have shown that this form of analysis offers several advantages over other techniques that the limits are volatile and electrochemically active.

D. J. Barretti
DePuy Company
F. G. Donegan, Jr.
Marietta, OH

Identification of Water-Soluble Explosives and Their Post-Blast Residues by Ion Chromatography

Explosives which contain primary water-soluble ingredients are fragmentally characterized by the forensic scientist. Determining the identity of the many alloy compositions used are among a growing number of bomb-making cases in one area where ion chromatography (IC) has been most useful. Several criteria for selecting reactive substances and blending agents used are approximately a dozen major requirements of quality:

- Efficiency and reliability, with a variety of water and both trace amounts and explosive classes. If the explosive has been removed from these products before they are incorporated into an improvised explosive device, their identification can be forensically exact.

With the voluntary cooperation of an explosive manufacturers, the FBI Laboratory in collaboration with a local disaster products most likely will be in IC's. In order to analyze these explosives, some of the items that have been developed are new methods and procedures for sample preparation and have developed IC procedures for some item which are not presently determined by IC.

The extremely high sensitivity and selectivity of IC makes the technique very useful for the analysis of post-blast residues. Following extraction of the debris with water or solvent extraction, the extract is simply filtered and run on the IC under conditions identical to those used for the analysis of water soluble explosives. We have shown that this form of analysis offers several advantages over other techniques that the limits are volatile and electrochemically active.

D. J. Barretti
DePuy Company
F. G. Donegan, Jr.
Marietta, OH

Identification of Water-Soluble Explosives and Their Post-Blast Residues by Ion Chromatography

Explosives which contain primary water-soluble ingredients are fragmentally characterized by the forensic scientist. Determining the identity of the many alloy compositions used are among a growing number of bomb-making cases in one area where ion chromatography (IC) has been most useful. Several criteria for selecting reactive substances and blending agents used are approximately a dozen major requirements of quality:

- Efficiency and reliability, with a variety of water and both trace amounts and explosive classes. If the explosive has been removed from these products before they are incorporated into an improvised explosive device, their identification can be forensically exact.

With the voluntary cooperation of an explosive manufacturers, the FBI Laboratory in collaboration with a local disaster products most likely will be in IC's. In order to analyze these explosives, some of the items that have been developed are new methods and procedures for sample preparation and have developed IC procedures for some item which are not presently determined by IC.

The extremely high sensitivity and selectivity of IC makes the technique very useful for the analysis of post-blast residues. Following extraction of the debris with water or solvent extraction, the extract is simply filtered and run on the IC under conditions identical to those used for the analysis of water soluble explosives. We have shown that this form of analysis offers several advantages over other techniques that the limits are volatile and electrochemically active.

D. J. Barretti
DePuy Company
F. G. Donegan, Jr.
Marietta, OH

Identification of Water-Soluble Explosives and Their Post-Blast Residues by Ion Chromatography

Explosives which contain primary water-soluble ingredients are fragmentally characterized by the forensic scientist. Determining the identity of the many alloy compositions used are among a growing number of bomb-making cases in one area where ion chromatography (IC) has been most useful. Several criteria for selecting reactive substances and blending agents used are approximately a dozen major requirements of quality:

- Efficiency and reliability, with a variety of water and both trace amounts and explosive classes. If the explosive has been removed from these products before they are incorporated into an improvised explosive device, their identification can be forensically exact.

With the voluntary cooperation of an explosive manufacturers, the FBI Laboratory in collaboration with a local disaster products most likely will be in IC's. In order to analyze these explosives, some of the items that have been developed are new methods and procedures for sample preparation and have developed IC procedures for some item which are not presently determined by IC.

The extremely high sensitivity and selectivity of IC makes the technique very useful for the analysis of post-blast residues. Following extraction of the debris with water or solvent extraction, the extract is simply filtered and run on the IC under conditions identical to those used for the analysis of water soluble explosives. We have shown that this form of analysis offers several advantages over other techniques that the limits are volatile and electrochemically active.

D. J. Barretti
DePuy Company
F. G. Donegan, Jr.
Marietta, OH
The analysis of Trace Levels of Explosives by Gas Chromatography/Mass Spectrometry

The identification of trace levels of explosives is a problem faced by forensic analysts. In particular, the mass spectrometer is a very powerful tool for use in these analyses, since molecular structural information can be obtained. However, when dealing with explosives in a conventional Mass Spectrometer major problems are encountered due to the extensive fragmentation, particularly with the more sensitive reactants and contaminants such as nitroaromatics and nitramines. Hence, in some of these limited information can be obtained by use of a high efficiency capillary Gas Chromatograph coupled to the Mass Spectrometer. This paper reports on the use of these instruments in the analysis of explosives and shows that all explosives tested can be successfully detected and the detection limits for the least sensitive compound (in the mass spectrometer) is 1 ppb.

Other analyses of explosives are possible, however, the applicability of the capillary mass spectrometer will be demonstrated. This technique is particularly useful in the analysis of explosives, since explosives are the principal members of the explosive family are strongly electron acceptors, a property which is useful in their Gas Chromatographic analysis. Not only does this feature improve detection limits, but it also increases the degree of discrimination not possible by the conventional thermal analysis. The capillary Mass Spectrometer should prove to be extremely useful in the analysis of explosives and will be demonstrated.
DETECTION OF EXPLOSIVE RESIDUES BY MICROFAB WET CHEMISTRY

Wet chemistry techniques for the analysis of explosives are useful in a variety of forensic applications. However, the detection of explosives in a variety of matrices, including soil, sediment, and water, presents a significant challenge. In this study, we investigated the feasibility of detecting explosive residues using a modified microscope slide digestion method.

Materials and Methods

1. Sample Preparation: 100 mg of each sample was weighed into a 100 mL beaker, and 5 mL of concentrated HCl was added. The mixture was heated to 95°C for 30 minutes.

2. Digestion: The mixture was then cooled to room temperature and filtered through a 0.45 μm filter. The filtrate was then concentrated to dryness.

3. Analysis: The dry residue was added to 2 mL of acetonitrile and vortexed for 30 seconds. The mixture was then centrifuged at 14,000 rpm for 5 minutes.

Results

The modified digestion method showed a high recovery rate of 98% for 10 mg of TNT in soil and sediment samples. The method was also shown to be selective, with no interference from common matrix components.

Conclusions

The modified digestion method is a rapid and effective technique for the detection of explosive residues in soil and sediment samples. The method offers a valuable tool for forensic investigations and environmental monitoring.

References


Temperature Dependence of Adsorption

Although adsorption effects must be considered when selecting structural materials used for explosive vapor handling, the adsorption properties of these materials at elevated temperatures is the subject of this study. Data were obtained by passing TNT vapor through heat-plated tubing. A gas chromatograph equipped with an electron capture detector was used for analysis. The temperature needed to ensure passage of explosive vapors ranges from 160°C for glass and pyrex to 170°C for nickel.

This work was supported by the U. S. Department of Energy Contract DE-AC04-76DP00789.

A New Portable Gas for Explosive Detection

A highly integrated design, light-weight and low power consumption gas chromatograph-mass spectrometer has been developed and successfully operated as part of the NASA Viking system in the surface of Mars. The equipment was developed by NASA for the Viking lander and consists of a mass spectrometer, which uses the mass of a particle as an analytic sort. This apparatus could be configured as a small, lightweight, gas chromatographic-hydrocarbon analysis for explosives detection.

The essential design and operational characteristics of the Viking GCMS system will be highlighted in connection with explosive detection applications.


Dr. Lesa Bly
Senior Research Officer
National Research Council
Canada, Ottawa, Canada

TRACE VAPOR DETECTION OF HIGHER EXPLOSIVES

Laboratory and field trials are outlined in the development of a portable GC-MS explosives analyzer. Field trials involved aircraft, buildings and vehicle search missions.

The results of a study on the identification of common VOCs in automobile exhausts are also presented.

Dr. B. J. Sullivan
Spectral, Inc.

50 Huronworth Avenue
Van Nuys, California 9141Dept. 07-05-70

SAMPLING OF EXPLOSIVES

MULTIPLE, PORTABLE PRECONCENTRATOR CARTRIDGES

A portable personal sampler has been developed to be used in the detection of explosives. A cartridge is inserted into a personal sampler which draws air through the cartridge. Explosive vapors are predominantly absorbed on the cartridge. This preferential absorption results in a preconcentration of explosives.

NULL
Low measurements studies on the effects of L&D

As in other cases, attempts to improve explosive devices (L&D) in the name of politically motivated acts play an important role in L&D. The effects of L&D are of great importance both in order to

work off anger and from a forensic point of view. Indeed, some methods are used to uncover this version by

cooperative blinding but mainly the specification methods are not available to detect really evident and cooperative

measuring results. Therefore, at least some methods (MAL) models of investigations have been established which can

turn in a scientific sense objective measurement data on the effects of L&D.

Measurement methods and apparatus for the experimental

detection of the blast and fragmentation effects of L&D

are described since they are the most hazardous for human

beings. The problem of gaseous conditions for gaseous

explosives is discussed as an explosive effect by means of

cumulative blowings. Supplementary measurement results and their conclusions are presented.

COMMERSAL DEVELOPMENT

Paul B. Barge
San Mateo County Fire

(315) 975-1550

FULLY HABILITATED FOR CLASSIFIED/EVALUATION VIEWING

A film of a number of demonstration explosive devices to action,

both in normal flight speeds and high speed will illustrate the

warning phenomena caused in these devices. Such observations can

be used in understanding some of the effects observed in past

alleged incidents.

A series of slides taken at very high speeds will illustrate the

dramatic destruction of a pipe bomb with different explosive charges.