

**13<sup>th</sup> INTERPOL Forensic Science Symposium, Lyon, France, October 16-19 2001**

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**EXPLOSIVES REPORT**  
**1998 - 2001**  
**Detection and Characterization**  
**Of Explosives and Explosive Residue**  
**A Review**

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## ACKNOWLEDGEMENTS

Ms. Adiva Sotsky, Librarian at the Bureau of Alcohol, Tobacco and Firearms Laboratory in Rockville, Maryland, obtained most of the literature citations and journal articles that were necessary to prepare this survey report. Her many hours of work are greatly appreciated.

The author would like to thank his laboratory colleagues and management at ATF for allowing the time away from other duties to complete this task. Elliott B. Byall, Laboratory Chief, San Francisco Laboratory, Center Bureau of Alcohol, Tobacco and Firearms.

## INTRODUCTION AND COVERAGE OF THE LITERATURE

In the process of compiling a review of recent work in explosives detection and identification, several factors complicate an accurate depiction of current efforts. While it appears to be a relatively narrow field, the work actually encompasses several different, but often overlapping, areas of interest. One of these involves criminal misuse of explosives, i.e. law enforcement. Closely related are security concerns in safeguarding facilities from potential explosives entry, either on individuals or in containers. This generally involves detection of bulk explosives whereas law enforcement activities may involve amounts from post-blast traces to kilogram quantities. A third area involves work in connection with potential liability in the production, use and disposal of explosives. The latter includes environmental testing and analysis, and may constitute primary areas of developmental efforts for laboratory detection and identification of low levels of explosives related materials. Motivation for efforts in this area is the increased environmental concerns and resulting legal requirements for the measurement of explosives, their production byproducts and compounds resulting from degradation of explosives. These analytes are frequently present at extremely low levels and may be in complex mixtures containing significant amounts of contaminants, thus the interest in more sensitive instrumentation and improved methods for sample separation, concentration and cleanup.

The diversity of interests within the field of explosives detection and analysis, and no clearcut major journal in any of the areas described, leads to publication of results and reports of new developments in a broad spectrum of the periodical literature. Thus, in any survey, pertinent articles are easily overlooked. In addition, the long lead time for publication in peer-reviewed journals means that they alone do not provide an up-to-date portrayal of areas of activity and progress. Papers presented at major meetings during the past three years but not, as yet, published indicate topics of current research or development and merit inclusion in this survey report. While these papers may eventually appear in the Proceedings of the meeting at which they were presented or in a widely circulated journal, in many instances only the abstract may be available for some time and a significant fraction of presented papers are never published. As a result, abstracts from major meetings and symposia proceedings are essential to an overview of current work in the field.

In the period covered by this review, mid-1998 through mid-2001, papers from three symposia devoted to explosives analysis and detection appeared. The first of these was the 6<sup>th</sup> *International Symposium on the Analysis and Detection of Explosives*<sup>1</sup>. This symposium is held every 3 years, bringing together scientists from worldwide forensic laboratories. At the 6<sup>th</sup> International Symposium, hosted by Petr Mostak of the Czech

Republic, 45 papers were presented dealing with the forensic aspects of explosive incidents. In 1999, a *Workshop on Explosives Trace Analysis Methods* took place at the Forensic Explosives Laboratory, DERA, United Kingdom. Summaries of the strengths and weaknesses of methods used for trace explosives analysis were presented, as well as a comparison of the methodology and experiences of the representative laboratories. Abstracts from this workshop, attended by representatives from 8 European countries, were published in the open literature<sup>2</sup>. A third symposium, the *International Workshop on Forensic Aspects of Low Explosive Devices*, took place in February 2000 at the Forensic Explosives Laboratory, DERA, United Kingdom, and was attended by delegates from 15 countries<sup>3</sup>. Summary reports on the types of low explosive devices encountered in the UK, France, USA, Sweden, Australia, Northern Ireland, Canada, Italy, South Africa and the Netherlands were presented, as well as research efforts underway to further characterize components of low explosive improvised devices.

Several books of interest to forensic scientists conducting explosive analysis have been published during the past three years. The most comprehensive is *Forensic Investigation of Explosions*, edited by Dr. Alexander Beveridge<sup>4</sup>. This is a definitive multi-disciplinary reference book, with chapters written by internationally renowned authors, and covers the full range of chemistry of explosives, investigation at the scene, identification methods, forensic pathology and presentation of expert testimony. Dr. Jehuda Yinon published the book *Forensic and Environmental Detection of Explosives*, which dwells heavily on mass spectrometric techniques<sup>5</sup>, as well as a chapter in *Handbook of Analytical Separation-2* that describes extraction, clean-up and analytical techniques used in the analysis of explosives<sup>6</sup>. The U.S. National Institute of Justice published a monograph titled *A Guide for Explosion and Bombing Scene Investigation*, developed by the Technical Working Group for Bombing Scene Investigation, in 2000<sup>7</sup>.

As is customary, this review will focus primarily on publications and papers dealing with analytical laboratory examinations. Section II deals with approaches that may be useful in improving the quality of samples collected for laboratory examination. These include concepts ranging from sample clean-up and concentration to newer approaches for sampling of surfaces, clothing, soil, etc. Sample clean-up procedures become more significant as the amount of explosive in the analytical sample declines and sample complexity/contamination increases. The third section of the report describes improvements in analytical instrumentation and techniques to enhance sensitivity and selectivity, resulting in reliable detection at lower levels and increased confidence in results and conclusions. Section IV will examine characterization of specific explosive samples, as well as reports on physical evidence from small and large scale detonations. The final section will include articles and reports providing general information in the explosives area useful to the examiner, but not fitting neatly into the categories previously mentioned. A bibliographic listing of references to the presented papers and articles mentioned in the review is included.

#### **SAMPLING AND CONCENTRATION OF EXPLOSIVE TRACES**

When attempting to characterize explosives or explosive residues at low to trace levels, the most critical step in the analysis is the location, whether at the scene or in the laboratory, of materials likely to contain either intact residual explosive or residues characteristic of a particular explosive material. Once collected at the scene, the sample must be packaged so that its evidentiary value is not lost and that it does not contribute to contamination of other samples. When the sample arrives in the laboratory, separation and concentration of the target analytes becomes crucial. The objectives of this step are separation of the analyte from the sample matrix and potential interferants and, if feasible, at the same time, concentrating the material of interest for analysis.

Efficient sample collection, whether involving vapors or particulates, is essential to detection of materials present at low levels. Two promising techniques for the removal and concentration of an analyte in a matrix are Solid Phase Microextraction (SPME) and Supercritical Fluid Extraction (SFE). SPME utilizes a coated fiber housed inside a syringe needle as an adsorbent. The needle is inserted directly into the aqueous or organic extract of the sample and the fiber then exposed for collection. Once collected, the sample can be desorbed either thermally or by solvent extraction. A number of articles on this technique have been reported, and SPME appears to have considerable potential for the analysis of explosives, combining speed and simplicity<sup>8-12</sup>. One study used cotton swabs to remove potential organic explosive residues, followed by aqueous extraction and collection on the SPME fiber. They report that water extracted the explosive as effectively as acetone, and did not co-extract interfering materials<sup>13</sup>.

SFE is attractive for the removal of explosives from complex matrices using liquid CO<sub>2</sub> or another supercritical fluid as solvent. SFE provides the penetration of liquids, but has advantages in analyte concentration and solvent disposal<sup>14</sup>. Modification of the fluid with additives can increase selectivity and decrease co-extraction of potential contaminants. Presently, the major limitation of SFE is its inability to handle samples larger than a few mL. While not applicable to large debris fragments, the technique appears attractive for materials such as soil, fibrous materials, etc. Organic solvent extraction of soil, for example, is time consuming and produces complex, highly contaminated solutions that create problems with analytical instruments. SFE is fast and the extracted samples may be nearly neat solids.

Explosives detectors can play a role in locating evidence at the scene and improving the quality of evidence submitted for examination, or for screening bomb scene debris in the laboratory. A great deal of the work with explosive detectors has been directed toward aviation security. The Canadians have carried out a study of five different trace explosive detectors, both in the laboratory and in place at airport security locations<sup>15</sup>. Malotky provided a discussion of current technology for explosive detection in luggage<sup>16</sup>.

The EGIS chemiluminescence detector is used for baggage screening, and two reports were given which discuss improved methods for removing vapors and particulate matter prior to directing the air stream to the EGIS detector<sup>17,18</sup>. These involve mechanisms to vibrate, bash and subject the object to pressure changes. Additional potential luggage inspection techniques use angular dispersive x-ray diffraction<sup>19</sup>, nuclear quadrupole resonance<sup>20,21</sup>, and surface acoustic wave devices<sup>22</sup>.

The handling and transportation of explosives has been shown to generate traces of explosives on surfaces, which may subsequently be detected<sup>23</sup>. The traditional methods of dry wiping, solvent wiping and vacuuming have been insufficient, and studies have been carried out regarding the adhesive forces of explosives and other particles to the surface of luggage and how best to remove them to a detector module<sup>24-26</sup>. In related work, Calisti and co-workers reported on the deposition of an explosive (pentrite) by transfer from a hand to the surface of an object<sup>27</sup>, and Phares and co-workers used an ion mobility spectrometer (IMS) to determine if explosives could be detected on fingerprints left by an individual who had handled explosives. They reported that less than 1 ng of RDX was collected from fingerprint transfers<sup>28</sup>.

The above explosives detector work, while not having significant laboratory applications at present, could result in simpler and more specific laboratory instruments in the future. And a wider application for using these instruments for screening of bomb debris in the laboratory is encouraged.

The use of effectively trained dogs as explosive detectors continues to expand throughout the world. Overall, canines represent the fastest, most versatile and reliable real-time explosive detection device available. A review of the use of dogs as chemical detectors, their reliability in this regard, and a comparison with analytical instrumental techniques was presented by Furton and Meyers<sup>29</sup>.

## DETECTION/IDENTIFICATION OF EXPLOSIVES AND RESIDUES

Approaches to the detection and identification of explosives range from the "alert" of a trained explosives detecting canine, to the results from one or two simple chemical tests, to a carefully detailed analytical protocol. Each of the former two must be recognized as "presumptive" and is, in that regard, more nearly equivalent to detection than identification. The extent to which even a protocol involving use of sophisticated instrumentation "identifies" an explosive depends on the rigor of the protocol and conduct of all tests required. For purposes of discussion, a further distinction will be made between detection/identification and characterization. As in previous reports, detection will encompass an alert indicative of a "target-type material" such as an explosive or a presumptive "group-type" analysis. Identification will be considered as incorporating the results of additional confirmatory testing beyond the initial tests. Typically, subsequent testing would involve a conceptually different approach to the test conduct than that used in prior testing. Identification thus requires independent confirmation of the preliminary results.

An overview of recent developments in explosives analysis was presented at the 6th International Symposium<sup>30</sup>, and the experiences of individual laboratories in how they approach explosive analysis in their country were presented in the previously mentioned workshops<sup>2,3</sup>. In recent years, explosive examination schemes or protocols are becoming much more formalized. This is dictated not only by technical considerations, but also the recognition that the procedures must meet the requirements of the legal system. The European forensic community discussed the question of which and how many techniques are required for confirmation of an explosive identification. The problem is complex, and there is no single answer. The techniques to be used must all be acceptable to the scientific community and the main errors associated with particular methods must be eliminated. It was accepted that a single analysis is insufficient to make an identification, but the number required depends on how mutually exclusive the techniques are<sup>31</sup>.

In the US, similar discussions are taking place within the Technical Working Group on Fire and Explosives (TWGFEX), a group composed of government, forensic laboratory personnel and academic scientists<sup>32</sup>. TWGFEX expects to produce formal explosive examination protocols within the next year. In one laboratory in the United Kingdom an analytical scheme for examining swabbings for explosives traces was described which dealt with both organic and inorganic components. Swabs were extracted with ethanol/water and the extract passed directly through a simple column

containing an acrylonitrile/styrene copolymer adsorbent. The adsorbent retained common organic explosives, which were recovered as a relatively clean ethyl acetate solution and could be analyzed using gas chromatography with chemiluminescence (TEA) or mass spectrometric detection. The unretained inorganic ions and sugars were recovered as an ethanol/water solution, and could be directly analyzed using ion chromatography and/or capillary electrophoresis <sup>33</sup>.

### Organic Explosives - Applicable Techniques

For a variety of reasons, TLC techniques remain attractive both in the laboratory and in the field. One reason is that, in some instances they can be inexpensively and readily performed at a scene as, for example, to demonstrate explosive product contamination of soil at a site with greater validity than that offered by other simple presumptive tests <sup>34,35</sup>. HPTLC offers improved performance and is an integral part of some laboratory protocols <sup>36</sup>. Another laboratory reported using TLC as a fast screening technique, which was then followed by gas chromatography. They also use TLC for looking at sugar in improvised explosive mixtures <sup>37</sup>. One limitation of TLC for explosives analysis is the number of systems using halogenated mobile phases. These pose hazards to laboratory personnel and are becoming a problem in disposal.

Raman spectroscopy has always had potential for explosives analysis, but its application was severely limited by the instrumentation available. The Raman effect is inherently weak, but by using UV-excited resonance Raman the band intensities were increased and allowed for identification of explosive species in complex mixtures <sup>38</sup>. New instrument designs have greatly improved spectral quality and the analysis is non-destructive so reexamination of the sample by another sensitive technique is feasible. If a portable version could be developed, it would be useful in processing the bomb scene or in searches of a suspect's vehicle, premises, etc.

Ion Mobility Spectrometry (IMS), once considered a technique of great promise for both field and laboratory, continues to receive moderate attention <sup>39,40</sup>. With clean samples, rapid and sensitive examinations can be done, but sensitivity declines with dirty or complex samples <sup>41</sup>. The RCMP reports the use of an IMS instrument at bombing scenes to rapidly screen those exhibits that will be further examined in the laboratory, and also use it to screen work areas, tools and equipment that are involved with explosive processing <sup>42</sup>.

Instrumental chromatographic techniques are stalwarts in the detection/identification of trace amounts of organic explosives. Gas chromatography is widely used in explosives laboratories, and the ability to examine thermally labile explosives such as nitrate esters (e.g. nitroglycerine) and nitramines (e.g. RDX) can be improved by taking certain precautions. Of major importance is cleanliness and deactivation of the injector port liner, as well as short capillary column length and increased carrier gas velocity <sup>43</sup>.

There is considerable variation in detectors used with the gas chromatograph, but the major ones used for explosive analysis are the electron capture detector (ECD), the thermal energy analyzer (TEA) and the mass spectrometer (MS). Electron capture detectors have good sensitivity and have been used for three decades. Walsh describes the examination of soil, contaminated with TNT, DNT, RDX and HMX, using GC/ECD with a deactivated port liner and wide bore capillary column, and detected these explosives at levels of less than 1 microgram/kilogram of soil <sup>44</sup>.

The TEA detector, which may be used with both gas and liquid chromatography systems, is based on infrared chemiluminescence and has excellent sensitivity for nitro and nitroso compounds that pyrolyze to produce NO or NO<sub>x</sub>. It has good selectivity and has become a standard method in a number of large laboratories. The Northern Ireland laboratory found GC/TEA to be more sensitive and selective than GC/ECD <sup>45</sup>. Using packed capillary columns and carbon dioxide as the mobile phase, GC/TEA was used to detect nitroglycerine in sub-microgram/mL concentrations <sup>46</sup>. The EGIS portable explosives detector, incorporating a vacuum sampler, high speed GC and chemiluminescence (TEA) detector is a fast, sensitive and selective instrument used in both laboratory and field situations <sup>15,17-18</sup>, and is comparable to a conventional laboratory GC/TEA system.

Mass spectrometry has been used for identification of low levels of explosives for many years, but its applications continue to increase with new spectrometer designs and improved interfaces with either gas or liquid chromatographs. Yinon describes appropriate conditions for obtaining good mass spectra for thermally labile nitrate ester explosives using both electron impact and chemical ionization techniques <sup>47</sup>. The Israel National Police Laboratory reports detection levels of 1-50 ng for nitroaromatics, NG and EGDN, and higher detection levels for PETN, RDX and tetryl using GC/MS <sup>48</sup>. Sigman and Ma studied the GC/MS detection limits for a variety of explosives under electron impact, negative ion chemical ionization and positive ion chemical ionization conditions <sup>49</sup>, and real-time monitoring of explosive vapor samples was described using a diaphragm pump to introduce the sample into an atmospheric pressure chemical ionization (APCI) mass spectrometer <sup>50</sup>. Another study used GC/MS to examine the gaseous and solid products that resulted from the detonation of TNT, composition B, RDX and other high explosives which took place within a containment vessel, to determine completeness of reactions, heat of detonation and other reaction behaviors <sup>51</sup>.

High Performance Liquid Chromatography (HPLC) coupled with mass spectrometry continues to be a useful technique, especially for thermally sensitive explosives. HPLC/MS is used as a screening technique prior to GC/TEA, or a confirmation for GC/TEA results. It was also reported that sample introduction from the HPLC to the mass spectrometer was more effective using electrospray rather than atmospheric pressure chemical ionization<sup>52</sup>. Yinon and co-workers studied the mechanism of ion formation, using electrospray ionization mass spectrometry with a series of explosives including TNT, DNT, RDX, HMX and PETN<sup>53</sup>. Liquid chromatography coupled with a photo-diode array detector (HPLC/PDA) may be used as a screen for explosives, followed by GC/MS confirmation. HPLC/PDA is robust for dirty samples, but does not provide specific identification of the explosive and is not sensitive for some explosives (TATP and HMTD)<sup>54</sup>. Organic explosives were examined by reverse phase HPLC with electrochemical reductive detection at a pendent mercury drop electrode. This is a difficult method, as the liquid samples must be deoxygenated prior to analysis, and considerable expertise is required for running and maintaining the equipment<sup>55</sup>.

#### Inorganic Explosives - Applicable Techniques

Inorganic explosives are widely encountered in many countries, usually as the filler in a pipe, tube, bottle or other container. For example, during the five year period 1993 to 1997 ATF reported over 10,000 bombings or attempted bombings, with over one-third of these being pipe bombs<sup>56</sup>. In spite of the number of these devices, new methodologies for the examination of low explosives have received relatively little attention. Common inorganic explosives include propellants such as conventional or modified black powder, pyrotechnic mixtures and a variety of improvised compositions. Water gel, slurry and ANFO explosives may also be considered in the inorganic category because they are primarily based on ammonium or other inorganic nitrates.

For inorganic explosives, ion chromatography (IC) and more recently capillary electrophoresis (CE) are used to provide sensitive and specific information on the by-products that remain from the rapid deflagration of these materials<sup>57</sup>. Aqueous extracts of debris are analyzed by capillary electrophoresis, allowing separation of chloride, chlorate, nitrate, nitrite and perchlorate anions. The advantages of CE are ease of sample preparation, micro-sampling capabilities and rapid analysis of both anions and cations<sup>58,59</sup>. Hortin and co-workers reported the use of CE for the detection of azide in forensic samples<sup>60</sup>. The use of ion chromatography (IC) for the analysis of anions that are used as oxidizers (nitrate, chlorate, perchlorate) or anion reaction products in post-blast residues (sulfate, thiosulfate and thiocyanate) was discussed in two presentations<sup>61,62</sup>.

Pyrotechnic residues may be examined by a scanning electron microscope coupled with an energy dispersive x-ray analyzer (SEM/EDX). This is a rapid screening technique for unknown bulk residues from improvised compositions, and provides an elemental profile of the residue, with further analysis being done by FTIR, IC or CE <sup>63</sup>.

A novel method for identifying inorganic components in post-blast debris involved placing the particles on filter paper and placing one end of the paper in a color test solution. As the solution rises it reacts with certain particles to produce a stain under the particle. The particle is then removed and examined further by GC/MS, FTIR or SEM/EDX <sup>64</sup>.

#### CHARACTERIZATION OF SPECIFIC EXPLOSIVE TYPES

The reaction products from black powder, obtained under different explosive conditions such as confinement, ignition and grain size, were studied by capillary electrophoresis, allowing the simultaneous identification of the more important salts in black powder residue <sup>65</sup>. The results could help determine the grain size of the original black powder, or whether the original powder was commercial or home-made. Linehan reported an HPLC method to examine post-blast residues from Pyrodex, a black powder substitute commonly used in improvised explosive devices in the US. Sodium benzoate and dicyanodiamide could be readily detected, which allows differentiation of Pyrodex from black powder when no intact or partial particles are present <sup>66</sup>.

Wallace described the smokeless powder database maintained by the ATF Laboratory. The different powders, 198 brands represented by 620 lots, are characterized by their physical morphology, colored marking particles and manufacturer information. In addition, the chemical compositions are determined by HPLC. Post-blast residues from selected smokeless powders in pipe bombs were examined and 93% of the post-blast residues could be correctly brand identified <sup>67</sup>. Micellar electrokinetic capillary electrophoresis (MECE) was also used to analyze the organic constituents of smokeless powder. Pipe bomb residues were collected and analyzed by MECE in an effort to match post-blast residue to specific smokeless powder used as the explosive charge <sup>68</sup>.

Triacetoneperoxide (TATP) is a sensitive and relatively easily produced high explosive used primarily by terrorist organizations. Israel has seen an increase in its use in terrorist bombings, and due to its lack of solid by-products upon detonation, TATP has been difficult to identify in post-explosion analysis <sup>69</sup>. Tamiri and co-workers report a method they have used successfully to identify TATP in actual cases, using adsorption of explosive vapors on solid adsorbents, followed by GC/MS <sup>70</sup>. In a study of the impact and thermal stability of TATP as a function of its residual acid contamination, it was found that highly pure TATP was only slightly more sensitive than PETN <sup>71</sup>. Stability was reduced to highly dangerous levels when the sulfuric acid used in the manufacture of TATP was not thoroughly removed. Some additional characteristics of TATP, and how to dispose of it, was reported <sup>72</sup>.

Hexamethylenetriperoxidodiamine (HMTD) is another sensitive high explosive that has occasionally been used by terrorist groups. The Algerian terrorist arrested upon entry to the US from Canada prior to the millennium celebration was found to possess a quantity of HMTD, in addition to RDX, EGDN and over 100 pounds of urea<sup>73</sup>.

Urea nitrate, the suspected explosive in the 1993 World Trade Center bombing, is another explosive made from easily obtained starting materials. Hiyoshi studied the friction and shock sensitivity of urea nitrate, and determined the detonation velocity to be about 4500 m/sec.<sup>74</sup> While a detonator can initiate it, urea nitrate is better initiated by a booster charge.

Semtex and the plastic explosive PE-4 were examined by particle induced x-ray emission (PIXE) analysis to determine if trace element patterns existed. It was found that different batches of PE-4, produced over a 28-year period, showed similar unique trace element distribution patterns, and statistical analysis based on the contamination levels may indicate two distinct populations of PE-4<sup>75</sup>.

Physical damage resulting from the initiation of an explosive device, such as fragmentation, crater size, structural damage and deposition of explosive residue, is often diagnostic for the type and amount of explosive used. Two studies, one relating to pipe bombs and the other dealing with large explosive charges, are reported. In the pipe bomb study the fragmentation patterns of 56 devices, comprising different explosive fillers, pipe sizes, pipe construction and means of initiation were examined. From the size and number of fragments collected from each test a fragment weight distribution map (FWDM) was developed. The FWDM could be reduced to a single variable, which was found to be reproducible and relatively insensitive to the percentage recovery and to the size of the pipe. This demonstrates the possibility that, even when chemical residues cannot be found, sufficient evidence is present in the pipe fragments to identify the nature of the energetic filler<sup>76,77</sup>.

The three-part study of large improvised bombs, a collaborative project between the Forensic Explosives Laboratory (UK) and the Federal Bureau of Investigation (US), is an attempt to simulate the vehicle bombings that have occurred in these countries over the past 10 years. The explosive charges for these tests ranged from 454 kg (1000 pounds) to 2268 kg (5000 pounds) with a variety of improvised explosive mixtures, TNT and ANFO. By using witness plates, pressure gauges and target vehicles placed at specific distances from the explosive charge, a careful study was carried out of the physical damage as well as chemical deposition of the explosive and its by-products<sup>78-</sup>  
80.

## EXPLOSIVES INFORMATION - GENERAL

Following the Pan Am 103 bombing, the International Civil Aviation Organization (ICAO) worked to have plastic, sheet and flexible explosives marked with a detectable taggant. An ad-hoc study group evaluated many marking agents, and in 1998 the ICAO Convention went into effect<sup>81</sup>. Of the several marking agents approved by the ICAO Convention, 2,3-dimethyl 2,3-dinitrobutane (DMNB) is the most favored and has been the subject of several published reports. The influence of DMNB on the manufacturing and performance of plastic explosives was discussed, as well as efforts to improve the shelf life of the finished product<sup>82,83</sup>. While sheet explosives retain the DMNB marking agent when wrapped, they lose it rapidly when unwrapped. Efforts are underway to reduce the emission rate by encapsulating the marking agent in a thin plastic membrane<sup>84</sup>. Although detonating cord is not covered by the ICAO Convention, a feasibility study of incorporating DMNB into detonating cord was carried out<sup>85</sup>, with the finding that the marking agent had no effect on the explosive performance of the cord, nor on its safety. The detectability of DMNB and other proposed marking agents with an ion mobility spectrometer was reported<sup>86</sup>.

In the US, the government reacted to the 1995 Oklahoma City Federal Building bombing by directing the Bureau of ATF to take a new look at explosive tagging, a concept that was studied in the 1970s but not funded. Switzerland, however, enacted regulations on tagging of commercial explosives in 1980 that involves the incorporation of small polymer particles that survive detonation and can provide manufacturer information in post-blast situations<sup>87</sup>. ATF responded by forming an Explosive Study Group to investigate the tagging of certain explosive materials, the feasibility of imposing controls on precursor chemicals used to manufacture explosives, and state licensing requirements for the purchase and use of commercial high explosives. The Explosive Study Group was also tasked to investigate new prevention technology to detect explosives without taggants or markers. Studies have been funded involving micro-electro-mechanical systems based on microcantilever technology and microcalorimetry. The goal of this work is to develop a small, inexpensive device to detect unmarked explosives. The 1998 Progress Report<sup>88</sup> describes the progress made in the first two years of this study and the research that will continue. The final report of the Explosive Study Group is expected to be published in late 2001.

Finally, mention should be made of the concern and efforts being carried out to prevent explosive contamination of evidentiary materials, not only in the laboratory, but also at the bombing scene and during transportation and storage of the evidence prior to examination. As improved technology allows explosive detection at lower and lower levels, precautions must be put in place to prevent cross contamination and to monitor all aspects of the evidence collection and examination procedures<sup>89,90</sup>. Crowson summarizes an 8-year study of the quality assurance regime in a UK laboratory to determine the best methods to prevent contamination, and provides information on the lessons learned and suggestions for improvement<sup>91</sup>.

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## **Notes**