A TECHNICAL APPROACH TO MARKING EXPLOSIVES, PROPELLANTS, AND PRECURSOR CHEMICALS

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ABSTRACT

Techniques for marking or tagging explosives, propellants, and precursor chemicals–chemicals which can be used to manufacture explosives and propellants–are discussed. The history of taggant technology and the effectiveness of various techniques are discussed. Several detection and identification taggant concepts are identified including electromagnetic radiation, immunochemical assays, DNA, rare-earth elements, and isotopic labeling. Detection technologies for detecting tagged and untagged explosives, propellants, and precursor chemicals pre-blast and post-blast are identified. Technical and management issues associated with implementing a taggant program are reviewed. Potential "stakeholder" groups are identified and their positions are discussed in terms of the present direction of taggant work. Projections of the deterrent effect of taggants on the ability of terrorists to inflict their will through the use of lethal force are also postulated.

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Acronyms

ANFO	Ammonium nitrate fuel oil
BATF	Bureau of Alcohol, Tobacco, and Firearms
DMNB	2,3-dimethyl-2,3-dinitrobutane
DNA	Deoxyribose nucleic acid
EGDN	Ethylene glycol dinitrate
EPA	Environmental Protection Agency
FAA	Federal Aviation Association
FBI	Federal Bureau of Investigation
ICAO	International Civil Aviation Organization
IME	International Makers of Explosives
ISEE	International Society of Explosives Engineers
NMA	National Mining Association
NRA	National Rifle Association
OTA	Office of Technology Assessment
o-MNT	Ortho-mononitrotoluene
p-MNT	Para-mononitrotoluene
PETN	Pentaerythritol tetranitrate
PCR	Polymerase chain reaction
RDX	Cyclo-1,3,5-trimethylene-2,4,6-trinitramine
TNT	2,4,6-trinitrotoluene

COUNTERTERRORISM TACTICS

The application of counterterrorism tactics to fight the critical problem of terrorist activity is a concept which has been discussed widely among lawmakers and scientists. In the wake of such tragic events as the World Trade Center (1993) and the Atlanta Olympic Centennial Park (1996) bombings and in direct response to the national outrage over the bombing of the Alfred P. Murrah Federal Building in Oklahoma City (1995), Congress passed the Antiterrorism and Effective Death Penalty Act in April of 1996. The act (P.L. 104-132; S. 735) specifically addresses the subject of tagging plastic explosives, excluding gunpowders and fertilizers, as a countermeasure to terrorist activity (1). Congress mandated the Department of Treasury to conduct a study which would investigate the feasibility and practicality of tagging explosives and their precursor chemicals. In addition, the United States has ratified the International Civil Aviation Organization's (ICAO) "Convention on the Marking of Plastic Explosives for the Purpose of Detection," which addresses the use of one of four possible vapor tags to mark plastic explosives for detection purposes. In 1993 the United States approved the utilization of 2,3-dimethyl-2,3-dinitrobutane (DMNB) as a detection marker for plastic explosives. The National Academy of Sciences has also been asked to independently study the feasibility and practicality of using tracer elements for identification and detection purposes, rendering common explosive chemicals inert, and regulating chemical precursors (2). These study findings have been released.

EXPLOSIVES
Definition and Classes

According to Rudolf Meyer's book entitled *Explosives*, explosives are defined as any solid, liquid, or gaseous materials that are capable of undergoing an almost spontaneous chemical reaction without the presence of an outside catalyst or other external reactant (3). Explosives can be classified as either "high" or "low" and may be classified further within these categories. The distinction between high and low explosives is determined by the rate of the explosive reaction. High explosives detonate and are characterized by fast, high-pressured reaction rates, while low explosives deflagrate and react at lower pressures and slower rates (3). In addition, several chemicals, known as precursor chemicals, have explosive potential when used in combination with other chemical reactants or in industrial quantities. Precursor chemicals are those chemicals that can be utilized to fabricate explosives or propellants. For example, ammonium nitrate is considered to be an explosive material when used in combination with nitromethane; therefore, ammonium nitrate and nitromethane individually are known as precursor chemicals.

Explosives Subclassifications

Most explosives used in bombing threats are high explosives (4). They can be categorized further into three classes: military, commercial, and improvised. Military explosives are chemicals or mixtures such as TNT, RDX, PETN, etc. Commercial explosives are chemicals or mixtures such as gelatins, powders, ANFO, slurries, etc. (3). Improvised explosives usually refer to "home-made" explosive recipes. Most of the explosives used for terrorist activity are either stolen or self-manufactured (4).

TAGGANTS
History and Use

Although the idea of tagging explosives appears to be a novel concept, its origins date back to the early 1970's. On August 24, 1970, at the University of Wisconsin Madison campus, an ammonium nitrate-fuel oil (ANFO) bomb exploded in Sterling Hall. This bomb was set as a direct and offensive political stance against the United States' involvement in the Vietnam War. Three people were injured and one person died. Outraged by the violent action, Richard G. Livesay, a former 3M research chemist, began contemplating the possibility of tagging explosives with a material which would survive the thermal blast of a detonation and be retrievable for detection and identification purposes (5). Livesay hoped this material would serve as a criminal deterrent and aid law enforcement officials in evidence recovery and analysis. His solution is known today as the Microtaggant particle. Microtaggants, manufactured by Livesay's parent company Microtrace, were tested nationally in 1978 by the Bureau of Alcohol, Tobacco, and Firearms (BATF)/Aerospace Corporation Pilot Study and served as prosecutorial evidence in a Baltimore truck bombing. However, enraged by the possible liability issues involved, explosive companies began lobbying against their use. Today, Microtrace is the only commercial company that manufactures tags for explosives. Switzerland is the only country using explosive tags, having tagged their explosives since 1980. The Microtaggant particulate is just one of three tags currently authorized by the Swiss government (5). The tag's primary purpose is to help solve potential criminal offenses involving explosives.

Taggants, as they have become known, are tiny tracer elements used to mark explosives and their precursor chemicals. Taggants have previously been added to explosives; however, for political, product safety, and product performance concerns, the issue of adding taggants to powders (gunpowder and smokeless powder) has been left unresolved. Each taggant has a unique systematic code which can provide such information as the manufacturer and distributor, date of production, and last legal purchaser (4). Several code variations exist, which make it possible to distinguish between explosive lots. Between the late 70's and early 80's, Aerospace Corporation conducted a pilot taggant testing program for the BATF specifically testing the Microtaggant particulate. Testing evidence indicated that potential safety and explosive compatibility problems existed. For example, a specific smokeless powder was discovered to undergo a chemical reaction under high temperatures and high concentrations of taggant material (4). This suggested product incompatibility. The Office of Technology and Assessment (OTA) reported in 1980 on the study results, discussing the potential of taggants as a useful law enforcement tool; however, they also reiterated relevant safety problems and suggested further research and testing.

Utility of Taggants

Taggants could be useful in increasing the solve rate of criminal bombing cases; however, implementation of the idea has prompted several important and critical attacks. The capability to locate the information identifying the last legal purchaser of an explosive could lead to important prosecutorial evidence. This capability also raises new liability issues for large explosives manufacturers, as well as other critical concerns. Questions about taggant safety, stability, ease of detection and identification, explosive compatibility, shelf life, contamination potential, liability issues, and cost all remain unanswered. Several organizations and individuals also possess a stake in the outcome of this issue. No one wants the cost to outweigh the benefit. If powders are not compatible with taggants, is a taggant program worth implementing? The idea behind taggant use is technically feasible, but the practicality of implementing such a program has both positive and negative aspects. At this point, the only real conclusion which can be drawn is that further extensive research, testing, and general analysis must be conducted.

The Ideal Taggant

Ideally, a taggant should possess the power to enhance the forensic tools available to investigate criminal activities involving explosives without any additional complications. Ideal characteristics which should be met by a worthwhile taggant concept include the following:

- Ease of retrieval
- No contamination of the environment or food-chain
- No potential for cross contamination
- Ease of incorporation into the explosive processing production without altering the stability and sensitivity of the explosive's nature
- Economical production
- Biodegradability to help prevent cross-contamination and environmental waste
- Safety (in handling and use)
- Minimal added expense for record keeping and distribution
- Lack of susceptibility to countermeasures
- The ability to satisfy the public and manufacturer's concern of liability.

These ideal circumstances would best serve the public perception, the lawmakers' demands, and the law enforcement position.

Taggant Classification

Taggants may be classified into two categories: detection taggants or identification taggants. A detection taggant is any material which may be added to an explosive or explosive material for pre-blast detection using modern instrumentation. An identification taggant is any material added to the explosive or explosive material which can be detected post-blast and provides crucial information which can be utilized by law enforcement personnel (4).

Detection taggants can be further subcategorized as either passive or active. A passive detection taggant is any material which will respond to a query. A material which on electromagnetic excitation absorbs or emits due to a change in energy state can be used as part of a passive detection system. An active detection taggant constantly emits a signal which would indicate the presence of an explosive. An example would be a radioisotope emitting gamma radiation. (Refer to Table I).

Identification taggants may be further subclassified as either physical or chemical. A physical identification taggant is categorized at the macro level. An example would be a vehicle identification number or a date-shift code. A chemical identification taggant is categorized at the micro level and can be any coded molecule or mixture of chemicals that are incorporated into the explosive. An example of a chemical identification taggant would be the use of a strand of DNA which may be detected with the use of a polymerase chain reaction (PCR) and biological detection instrumentation. (Refer to Table I)

TABLE I. Taggant Detection Methodologies

<u>Electromagnetic Radiation</u>

Electromagnetic radiation is an energy wave which is made up of both an electric and magnetic field component. Both field components are orthogonal to each other and to the direction of propagation of the energy wave. Spectroscopy is often used to detect qualitatively and quantitatively the absorption, emission, or scattering of this electromagnetic radiation. For explosives tagging, an electromagnetic particulate material could be incorporated into the explosive or explosive material (i.e. detonator) and upon excitation could be detected via spectroscopic methods.

<u>Immunochemical Techniques</u>

Immunochemical techniques utilize protein assay techniques which are highly sensitive and discriminatory. This process employs the use of antibodies which when introduced to a foreign protein will specifically bind to this foreign protein (specificity leads to sensitivity). Spectroscopic absorption or fluorescence can then monitor the antibody-antigen reaction. For explosive detection, an inert foreign material, which is antibody specific, could be incorporated into an explosive for detection purposes.

<u>DNA Techniques</u>

Deoxyribose nucleic acid possesses a unique code which is created by its base-pair sequences (A-T, C-G). A specific deoxyribose nucleic acid sequence can be detected and amplified using the polymerase chain reaction (PCR) methods whereby small strands are cut and analyzed under specified temperature mediated enzymatic/molecular reactions (4). For explosive detection purposes, a unique and specified DNA sequence could be synthesized and incorporated into the explosive material and detected post-blast via PCR and associated biological instrumentation techniques.

<u>Rare-Earth Elements</u>

Rare-earth elements have electronic transitions of their f-electrons which are responsible for the absorption process and their characteristic wavelengths. As an explosive identification tag, rare-earth elements could be incorporated into the explosives as mixtures of salts or oxides. These “tags” can then be recovered by certain assay techniques and analyzed by x-ray fluorescence spectroscopy. For explosive detection, rare-earth mixtures can be incorporated into the explosives as micro-spherical particulates which could be detected due to their fluorescence under ultra-violet radiation (4).

<u>Isotopic Labeling</u>

Radioisotopic labeling is the technique which uses common isotopes and induces them into an “unstable” state (spontaneous disintegration which leads to a stable isotope) which causes the emission of gamma rays that can then be detected. For explosive detection, small amounts of radioisotopes can be added during the manufacturing process for detection purposes (i.e. Cobalt 60). Another possibility is to actually incorporate the “heavier” isotope into the explosive chemical formula, such as replacing hydrogen with deuterium.

Additional source: Skoog, Douglas A. and Leary, James J. 1992. *Principles of Instrumental Analysis*. Saunders College Publishing: New York.

Drawbacks

Some potential drawbacks to the taggant concepts exist. A primary concern for all taggant concepts is the effect on the explosive's sensitivity. One of the key characteristics of the ideal taggant is to not directly alter the stability or sensitivity of the explosive it is being added to. Another key drawback is the public's perception of the hazards of radioactivity. The general population does not have a full understanding of the exposure limits of radioactive materials, and although radioactive materials are safely used in hospital settings, the public still believes they are hazardous. This misinformed belief could hamper the potential use of radioisotopes as explosive taggants. For some explosive detection methods, characteristic background levels might be too high, making the technologies insensitive and non-discriminatory for their intended purposes. These potential drawbacks must be examined and carefully reviewed.

Examples

The most well-known commercial identification taggant, the Microtaggant, is a microscopic (~ 44 • m), polymeric, color-coded particulate with fluorescent and ferromagnetic properties (5). It is directly incorporated in the explosive product during production. Introduced in high concentrations (250 to 500 p.p.m.), a small percentage of the particulate material has been proven to survive the heat of an explosive blast and is retrievable using a magnet or detectable using an ultra-violet lamp. The unique, systematic particulate code (0 = black, 1 = brown, 2 = red, etc....) can be read on-site using a portable light microscope (100X magnification).

Another example is the date-shift code which is used on sticks of dynamite and other explosive paraphernalia. A vehicle identification number can also be considered to be an example of a taggant if used for terrorist activities where explosives are used. These latter examples are forms of identification taggants at the macro level; however, because the general population often associates the 3M Microtaggant, with the word taggant, examples such as these are often overlooked. Several other companies have been investigating other methods including immunoassay techniques, microencapsulated particulates, DNA, upconverting phosphors, and rare-earth mixtures. Most of these ideas are still in the development stages when applied to marking explosives and explosive materials.

Estimated Cost

The estimated cost of implementing a taggant program is dependent upon several factors. These include, but aren't limited to -

- Cost of materials for both identification and detection purposes
- Detection technology costs (instruments, operation, maintenance, false alarm costs)
- Recurring and non-recurring explosive and powder manufacturing costs (record keeping, waste control, inventory, tooling, storage, product safety testing, etc.)
- Markup costs (manufacturer and distributor)
- Distributor costs (record keeping and storage)
- User costs
- Additional miscellaneous costs (technological development, government administration, etc.)(4).

A current cost estimate would be inaccurate based upon the present state of research and development. In addition, quoted figures are often based on past research. When OTA conducted upon several cost elements they concluded that a baseline cost estimate for a taggant program would be $45.37 million per year (4). This cost estimate included the price of identification taggants, detection taggants, sensor technology, and manufacturer/distribution added costs. OTA also separated this cost into two separate programs, one for identification and one for detection. The cost estimate for an identification program alone was $24.8 million, while the cost for a detection program alone would be $25.4 million (4). Each program when dealt with separately has capital and labor costs which could be shared if both were implemented; therefore, the total of the separate programs does not equal the estimated total for an all encompassing taggant program. It must also be noted that this cost data are from OTA's 1980 taggant evaluation and so are outdated. The Institute of Makers for Explosives (IME) estimated a cost on the order of $700 million per year, while the Aerospace Corporation estimated a cost of $48 million a year (4). IME's estimate factors in taggant material cost, library maintenance fees, and record keeping costs; however, it does not include general overhead costs, any markup costs, or general manufacturer/distributor costs. It should be noted that one of the explanations for the huge difference in cost is the differences in the estimated taggant price per pound of explosive that the respective agency used in its cost analysis. In comparison to OTA's $55/lb., IME's was $200/lb. (4). The Aerospace Corporation's estimate includes ANFO and other blasting agents which are not directly tagged. Aerospace's estimate is more in line with OTA's general baseline cost analysis.

DETECTION TECHNOLOGIES

Vapor Detection

The ICAO has studied one of the technical methods which is today being utilized to detect plastic explosives. Plastic explosives are difficult to detect because of their low vapor pressures and the fact that they can be manipulated into any shape (6). ICAO has identified four chemicals which can be utilized to enhance the detection of plastic explosives by means of vapor detection (7). The four chemicals are ethylene glycol dinitrate (EGDN), 2,3-dimethyl-2,3-dinitrobutane (DMNB), para-mononitrotoluene (p-MNT), and ortho-mononitrotoluene (o-MNT). Each detection material has a minimum concentration at which it is to be incorporated homogeneously into the explosive to aid in detection (7). The Convention was signed in Montreal in 1991, but must be adopted by 35 nations before it can be enforced. The United States has ratified its use and prefers DMNB as its volatile marker (5).

Examples

Several other detection technologies are also in existence. They include dual-energy x-ray, x-ray computer tomography, thermal neutron activation, vapor/particle detection, and the use of canines (5, 8). These are described in Table II. The Federal Aviation Association (FAA) has certified the use of a checked baggage explosive screening system, the CTX 5000 by InVision Technologies, Inc., which is currently being tested in airports to assess its operational function and cost (5). The BATF also uses Thermedics Detection's explosive detection technology known as EGIS, which is based on high-speed gas chromatography. EGIS is a unique system because of its high resolution and real-time response rate. It is made up of a sampler, which is a battery-powered vacuum aspirator, and an analyzer which separates and detects the vapor samples which are collected (5).

TABLE II. Detection Technologies

Dual-Energy X-ray Technology

In Dual-energy or dual-beam x-ray technology, a material, such as a piece of luggage, is subjected to two different x-ray energy levels. Atomic composition, density, and other characteristics of the objects in the luggage can be analyzed by a computer.

X-ray Tomography

In X-ray tomography, the emitted radiation, either in the form of neutrons or gamma rays, is designed to react with different elemental components of the object of interest to produce a reaction particular to the specific detector application. To detect plastic explosives, it is necessary to produce the particular energy that reacts with the subject chemical element in the explosive. In general, plastic explosives contain several elements, such as nitrogen, which have unique characteristics that lend themselves to a host of nuclear detection methods, such as thermal neutron analysis. A radiation of neutrons reacts with the nitrogen nuclei to produce specific detectable gamma-rays (5). The CTX 5000 is a current detection system that uses x-ray tomography to screen checked baggage for explosives.

Thermal Neutron Activation

In Thermal neutron activation, a suspect material is bombarded with pulses of fast neutrons using a radioisotopic source or accelerator. The neutrons react with the nuclei of the suspect material, such as the nitrogen nuclei which are abundant in most explosives, and is detected using its emitted neutron activation. The energy and intensity of the gamma rays are characteristic of the absorbed nuclei.

Gas Chromatography

In Gas Chromatography, a mixture is separated into its individual components. The sample is injected into the instrument port where it is heated and vaporized. A stream of gas carries it along a column that contains a stationary phase. The sample becomes distributed between the mobile gas phase and the stationary phase. The higher a substance's affinity for the stationary phase, the more slowly it comes off of the column. The ratio of the peak sizes gives the ratio of the amounts of the substances in the sample. EGIS is an example of this technology. (This process can also be coupled with a mass spectrometer where the molecules are subjected to a stream of high energy electrons, which fragments them and infuses some with a positive charge. These charged ions are then separated according to mass and counted. Their mass is then plotted versus intensity.) (8).

Nuclear Quadrupole Resonance

In Nuclear quadrupole resonance, nuclei that possess electric quadrupole moments, such as nitrogen-6, are probed using radio-frequency signals. Each compound gives rise to a unique signal which is indicative of the specific nucleus and chemical environment. This technique can be used in luggage screening.

Surface Acoustic Wave Sensors

In Surface acoustic wave sensors, an electric field is applied to a piezoelectric material, such as quartz, and a sound wave with a specific frequency is surface generated. The surface can be covered with absorbents which can bind analytes and change the frequency of the surface generated wave. This technology is currently being utilized for the detection of land mines. A specific anti-TNT antibody covers the quartz crystal and when TNT binds to the antibodies a change in frequency occurs (8).

Backscatter Technology

In Backscatter technology, a variation of the dual-energy x-ray technique is implemented. In addition to the two different x-ray energy levels being transmitted, a receiver is used which allows for the x-ray beams to be scattered back for computer analysis. This can also be used for luggage screening.

Ion-Mobility Spectrometry

In Ion-mobility spectrometry, ion-molecule reactions are formed from sample ions which are released into a separation, electric field. The ions move through the field according to their mass until they reach a collector where they register a current peak that may be analyzed by a computer. This technique is being implemented for land mine detection.

Photoacoustic Spectroscopy

In Photoacoustic spectroscopy, a laser beam is used to alternately heat and cool a molecule thereby creating an acoustic wave. This acoustic wave can be detected using a microphone and electrically amplified. The intensity of the wave is directly proportional to the concentration of the molecules absorbing the laser beam energy. This technique is currently under examination as a detection method for explosives.

Reference 8

RESPONSE AND CURRENT DIRECTION

Stakeholder Positions

Aside from the federal, law enforcement, and other agency involvement, several other groups have expressed concern about implementing taggants into explosives and explosive materials. Agencies such as the Institute of Makers of Explosives (IME), International Society of Explosives Engineers (ISEE), and the Fertilizer Institute have all expressed concerns about environmental contamination, safety risks to handlers, the potential adverse effects on the explosive itself, and the economic impact the use of taggants will have on the explosives industry due to manufacturing and record keeping. In addition, the National Rifle Association (NRA) expressed concern for gun owners who load their own ammunition if taggants were used in black and smokeless powders. The NRA would rather support terrorist prevention technologies rather than explosive taggant methods. The National Mining Association (NMA) worries about the effect taggants might have on the mined product and how their use might affect their market competitiveness. Several other public interest groups have also expressed similar concerns (2).

Utility to Law Enforcement

The BATF is the federal agency responsible for investigating crimes involving high explosives. The BATF has been previously involved with taggant research in the past. The Federal Bureau of Investigation (FBI) also has a bomb investigation division, but they normally become involved only at the federal level. The FBI and BATF keep statistics on bombings involved in the United States and analyze the trends in explosive activity. Taggants could be viewed as useful law enforcement aids which could help to increase intelligence information, decrease explosive thefts, increase criminal apprehension and convictions, deter future criminals, and increase bomb detection at potential target sites (4). However, it should be noted that taggants are not the “end all, be all” answer to curtailing terrorist activity. Taggants would most likely serve as just another criminal deterrent. Most law enforcement officials support the use of taggants if they can assist in the bombing investigation. They do, however, show a preference toward pre-blast technologies (2). They are also concerned with possible countermeasures that might arise due to taggant implementation. Most scientists believe that any taggant countermeasure would require a level of technical knowledge and skill that most criminals do not possess. However, there is a fear that criminals will either attempt to remove the taggant from the explosive material or will rely more on the use of “home-made” explosives and incendiary devices (4).

Present Direction

Presently, several private, commercial companies have the existing technology and potential to approach the idea of tagging explosives from a research and development perspective (2). New ideas have sprung forth which might supersede past and present technology. Ideas such as radioisotopic labeling, the use of rare-earth elements, DNA labeling, and the use of upconverting phosphors have all been discussed. The next step is taking these potential solutions and testing them further to see whether or not they have the necessary characteristics. Large-scale tests must be conducted on a variety of explosive materials, and research must include and thoroughly cover safety, environmental, and cost concerns. Until these steps are taken, the idea of a proposed taggant will appear to remain a novel concept.

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