Chapter III

TAGGANT RESEARCH REVIEW

Chapter 111.–TAGGANT RESEARCH REVIEW

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Chapter III

TAGGANT RESEARCH REVIEW

INTRODUCTION

Research into methods to control criminal bombings has been going on for a number of years. One aspect of this research has been concerned with methods of detecting explosives before their detonation, and thus preventing bombings of protected targets. A second aspect has involved the development of procedures and equipment to identify the source of explosives, from either undetonated bombs or from the postdetonation debris, and thus provide information that might aid in the capture of criminal bombers.

Early work in the field was sponsored by the Law Enforcement Assistance Administration (LEAA), the U.S. Postal Service, the Bureau of Mines, the Bureau of Alcohol, Tobacco, and Firearms (BATF), the Federal Aviation Administration (FAA), the Energy Research and Development Administration, various Department of Defense agencies, and a number of companies. The primary efforts in the past 2 or 3 years have been sponsored by the Department of Energy, FAA, and by BATF, with the Aerospace Corp. acting as the BATF project contractor. The BATF/Aerospace work is concerned primarily with the development of tagging materials to aid in the predetonation detection of explosives and in the postdetonation identification of the source of the explosives. The DOE and FAA work has been devoted to the detection of explosives without the use of taggants; some effort has also been expended on that approach by the BATF/Aerospace team.

The purpose of this chapter is to briefly review the research conducted on the detection and identification of explosives. The review will include the development history of the research, a description of the current BATF/Aerospace taggant development program, and a discussion of the survival and recovery of identification taggants. The issues of the safety of adding taggants to explosives, the potential cost impact of a taggant program, and the utility of a taggant program to law enforcement personnel, are discussed in detail in the following chapters.

TAGGANT DEVELOPMENT HISTORY

The idea of adding material to explosives to enhance the predetonation detection and the postdetonation identification of explosives has been considered by various military and civilian agencies for at least 15 years. Some of the suggested material, such as radioactive isotopes, would perform both functions, some could only perform one. A number of the concepts which have been proposed during that time are briefly described in the following subsect ions.

Identification Taggants

Ideas for tagging materials to be used for identification of the source of explosives used in criminal bombings and bombing attempts can be generally grouped into the following four classes:

1. addition of materials that would not survive the detonation, but which would provide information if a bomb were recovered undetonated;

2. addition of materials that would physically survive the detonation and be recovered intact;
3. addition of materials to the explosives that would be detected in an assay of the debris; and
4. addition of radioactive isotopes.

Predetonation Only

Since 1970, the date, shift, manufacturer, and product have been printed on the cartridge of cap-sensitive high explosives. The manufacturer keeps records, by that date-shift code, and can tell to whom each batch of material was sold; distributors also are required to keep records of sale. It is possible, from the date-shift code, to compile a list of last legal purchasers of explosives from a lot with the same date-shift code. In fact, BATF maintains a National Explosives Tracing Center, whose function is to coordinate that activity. A typical trace would start with the recovery of an undetonated bomb by a BATF special agent. He would call into the tracing center with the information, and the data would be forwarded to the manufacturer who would provide the list of consumers or distributors; if explosives from that lot were sold to a distributor or distributors, they would be contacted for a list of retail purchasers.

The date-shift code information has proven useful in investigations of criminal bombings, although its utility is limited to instances where the explosive is recovered before detonation, or in some cases, where a low-order detonation does not destroy the cartridge. In addition, the information is only on cap-sensitive high explosives, and on the packages of detonators, black powder, and detonating cord. No trace data is available for other explosive material, such as smokeless powder, individual detonators, or even cap-sensitive high explosives that have been removed from the cartridge.

Smaller amounts of information are given by other systems that do not survive the detonation. For instance, all dynamite legally coming into New York must be red. If dynamite is recovered that is not red, it indicates a purchase not legally usable in New York. This data is not helpful to police in tracking bombers but does assist in control of legal uses of dynamite within New York.

The English apparently use a method somewhat better than the date-shift code in that the identifying code consists of colored threads within the explosives. The threads do not survive the detonation, but the information content is not lost by discarding the cartridge, as is the case with the date-shift code; it may not be possible, however, to encode sufficient information for U.S. needs by that method.

Radiological Tracers

Addition of small amounts of radioactive isotopes to explosives during the manufacturing process is particularly attractive as it provides a mechanism for both identification of the explosive materials from the postdetonation debris and a simple detection mechanism. There are a large number of radioisotopes, so an identification scheme could certainly be developed that would provide sufficient unique code species.

The two primary objections to this often-proposed solution are public reaction and safety. Given the present widespread antipathy to anything involving radioactivity, it is doubtful if the public would accept such a solution, even if there were no safety hazards.

Two potential safety hazards exist, one having to do with sensitization of the explosive materials, and the other with the effects of low-level radiation. Addition of foreign materials to explosives poses a potential sensitivity hazard. However, the amount of radioisotopes required would be far smaller than the material necessary for other tagging mechanisms, so explosive sensitization would probably be no more of a problem than with other types of taggants.

The hazards of low-level exposure to radiation are not well-defined; the current trend is toward severe limitation of exposure. Thousands of people come into direct contact with explosives every day at the manufacturers, distributors, and users level, so a large number of

people would have some exposure. Primary concern would be at the manufacturing level, where workers would have more continuous exposure than, for instance, a user. Aside from the adverse psychological effect the use of tracers might have on such workers, and the possible long-term effects of low-level exposure, there would be a large cost impact due to the need for specially trained personnel, as well as storage, handling, and decontaminating equipment. If it were necessary for the Nuclear Regulatory Commission to control the shipment of the explosives and to license and otherwise supervise all explosive users, additional major costs and inconvenience would occur.

A final drawback is that reading of the information encoded in the postdetonation debris would be a fairly complicated laboratory procedure involving sample preparation, radiation counting, and radioisotope identification. Only a limited number of laboratories in the country have the trained personnel and facilities; police forensic laboratories are not among them.

Chemical Assay

A number of approaches have been proposed that have in common the addition of chemicals to the explosives that would be recovered from the postdetonation debris and be identified by a laboratory assay of the debris. While the number of chemical materials is almost limitless, a successful chemical taggant must have the following properties:

- inertness,
- nonsensitization of the explosives,
- not present in background material,
- able to survive the detonation,
- long-term stability,
- not a health hazard, and
- sufficient variation must be possible to form a large number of unique codes.

The chemical taggant with which the greatest amount of research has been conducted was developed by the Ames Laboratories in the early 1970's, In this method, rare earths were added to explosives as oxides or as nitrates in ethanol solutions. By using several rare earths and by varying concentrations, a sufficient number of unique codes could be constructed. The taggants were recovered from the debris with ethanol-dampened cotton swabs. The swabs were then assayed in the laboratory by ion-exchange methods; analysis was accomplished by X-ray excited optical luminescence techniques.

Drawbacks to the Ames taggants included sensitization of the explosives by the ethanol carrier, a high background level, particularly for detonations taking place near or on the ground, and a rather specialized laboratory procedure necessary for the taggant assay and identification.

Physical Taggants

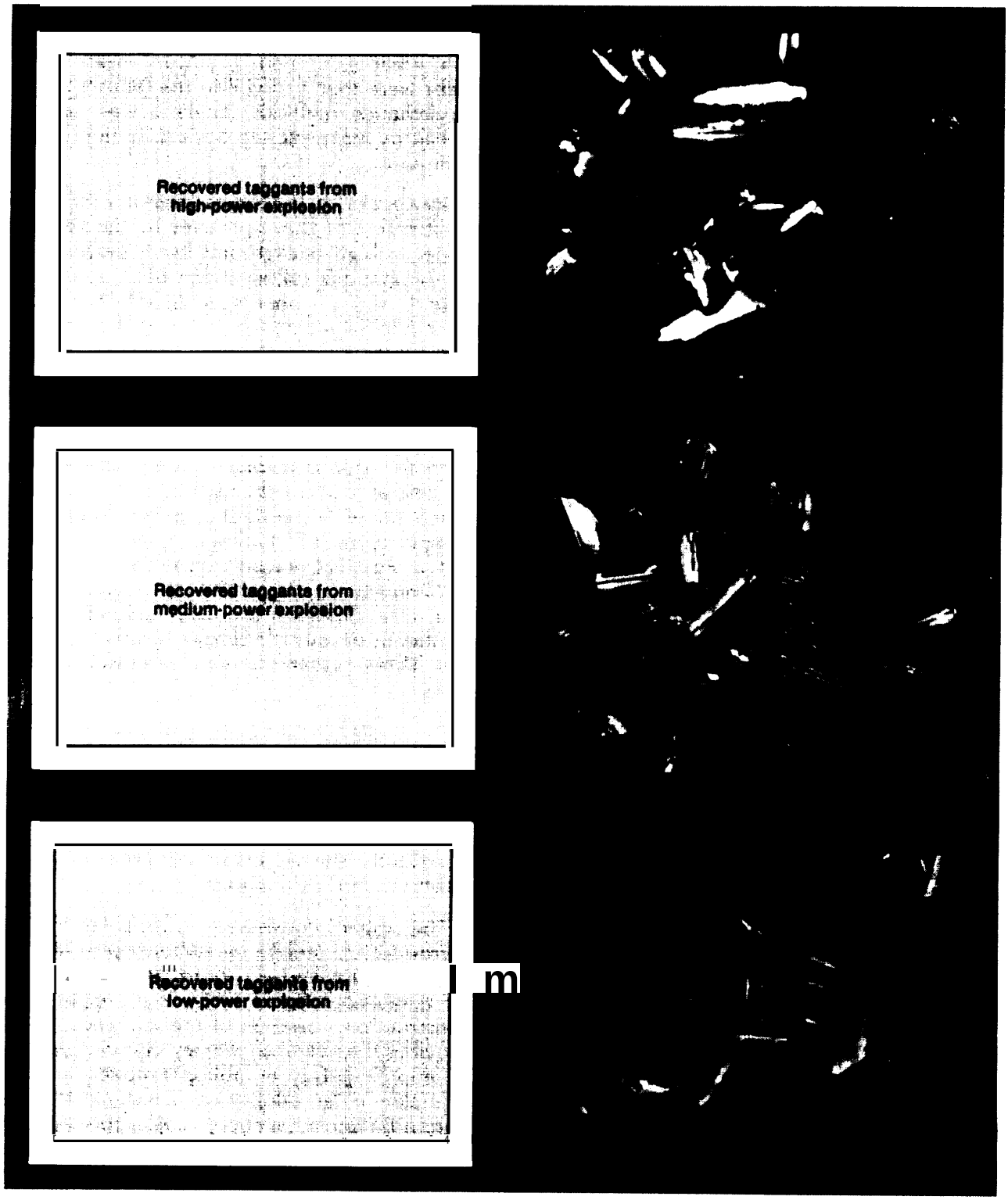
This class of taggants is designed to survive the detonation in its original physical form, to be separated from the debris, and to be decoded, either in the field or in the laboratory. Several types of materials have been suggested. Physical taggants must meet the same requirements as the chemical taggants, however, in addition to physical survival, so the number of serious candidates is somewhat limited. Three taggants remain promising candidates.

3M COLOR-CODED TAGGANT

More research has been conducted with the 3M identification taggant than with any other. It is the baseline taggant proposed by BATF for implementation if a taggant program is legislated, and is the taggant used for the OTA cost, safety, and utility analyses.

The taggant consists of an irregular chip of thermosetting melamine alkyd, approximately 0.12 mm thick and about 0.40 mm in its greatest dimension. Figure 6 shows the eight-layer construction; variation of the sequence colors provides the necessary library of codes. A total of approximately 6 million unique codes is available, when al lowances are made for certain forbidden adjacencies (colors too difficult to distinguish) and other restrictions. One face of the taggant visably fluoresces when illumi-

Figure 6.—3M Color-Coded Identification Taggants



nated with black light (366 nanometers) as an aid in recovery, either in the field or laboratory. The other face contains iron powder, allowing the taggant to be picked up by a magnet, another recovery aid.

In theory, the taggant can be recovered from the debris by use of a magnet and a black light, read in the field by a low-power microscope, and traced through the BATF tracing center. In fact, laboratory separation may be needed in most bombings; the recovery and laboratory procedures are quite simple, however, and can be performed in the field with little equipment and training.

Several variations of the basic concept have been tried, some including a polyethylene encapsulant and some including Slightly different chemical and physical properties of the individual layers. The safety, survivability, utility, and cost aspects are discussed in great detail elsewhere in this report.

WESTINGHOUSE CERAMIC TAGGANT

The Westinghouse taggant consists of a mixture of rare-earth compounds, bound together into a ceramic-1ike particle, whose appearance is similar to a grain of sand, and whose largest dimension is approximately 0.2 mm. Each of the rare-earth compounds fluoresces at a characteristic wavelength when illuminated by ultraviolet radiation (325 nanometers). A scanning monochronometer is used to read the wavelength of the various rare-earth compounds, and thus to identify the taggant code. The 10 rare earths that have been evaluated, and their characteristic emission wavelengths, are:

	Nanometers
Strontium chlorophosphate. europium	447
Yttrium vanadate thulium.	476
Yttrium phosphate cerium, terbium	546
Yttrium vanadate erblum	555
Yttrium vanadate: dysprosium	575
Yttrium vanadate: samarium	608-648
Yttrium vanadate: europlum	618
Yttrium oxy sulfide europlum	626
Strontium fluoroborate. europlum, samarium	687
Strontium fluoroborate europlum	375

As in the 3M taggant, the Westinghouse taggant incorporates a spotting phosphor which fluoresces in the visible range when illuminated by shortwave ultraviolet radiation (254 nanometers) and magnetic particles, both of which assist in the recovery process.

Due to the limited number of rare-earth compounds available, and the fact that the individual components are not ordered like the 3M taggant layers, the library of possible codes is only approximately 3,000, even with three distinct spotting phosphors. Use of different concentrations or pairing of two different taggants to form a unique species can significantly increase the library, with approximately 600,000 codes available for the paired taggant variation.

A significant number of compatibility tests have been conducted with the taggant, as have a small number of survivability-recoverability tests. Due to the ceramic nature of the taggant, it is extremely survivable and does not thermally degrade in high-energy explosives (such as boosters), as does the 3M taggant. In addition, since the rare-earth doping is homogeneous throughout the material, the full code can be read from even a small recovered taggant chip. The Westinghouse taggant is extremely gritty, and has been shown to sensitize explosives if not encapsulated in a polyethylene coating.

No additional effort is currently underway with the Westinghouse taggant, due to a Westinghouse concern over liability should some taggant not be fully encapsulated and thus cause sensitization of an explosive material. From the limited data available, it would appear that the Westinghouse taggant shows interesting potential, particularly due to its high survival rate, although solutions must be sought to ensure 100-percent encapsulation. In addition, some further limitations are imposed by the relatively small code library available and by the rather complex laboratory identification procedure required.

CURIE POINT TAGGANT

The Curie point taggant consists of a collection of five distinct ferrites, packaged with an ultraviolet sensitive spotting phosphor in a binder of potassium silicate. Ferrites exhibit

the property that their ferromagnetism disappears when the temperature of the ferrite is raised above a specific temperature, designated the Curie point temperature. identification of a particular taggant is thus accomplished by placing the recovered taggant in a temperature-controlled chamber and recording the magnetism as a function of temperature.

Approximately 50 ferrites have been identified whose Curie point falls in a laboratory practical temperature range. The 50 ferrites, used in combinations of s at a time, yield a library of approximately 2 million unique species.

As the taggants are ceramics, their survivability in high-energy explosives, such as boosters, should be good. Very preliminary tests have demonstrated the survivability of the taggant in boosters and high-power commercial explosives such as Power Primer.

The Curie point taggants share the potential sensitization problem of the Westinghouse taggants, and must therefore be encapsulated with 100-percent certainty. The Curie point taggants have another serious drawback: magnetic separation from powdery materials such as gunpowders and powdery dynamite would be an obvious simple countermeasure.

Summary

The 3M taggant, which has been the most thoroughly researched identification taggant, appears to be the most viable candidate, although the Westinghouse taggant exhibits a good deal of promise at this early stage of development. The other candidates exhibit technical, cost, countermeasure, or public acceptance problems, or require elaborate laboratory separation and analysis to yield the identification code. However, as other sections of this report make clear, the 3M taggant is not yet fully developed or tested, and could not be generally used unless and until several remaining problems are resolved.

Detection Taggants

Four general types of detection tagging approaches are described in the literature, including:

1. radioisotopes,
2. vapors,
3. electromagnetic (E/M) taggants, and
4. activation of nonradioactive isotopes

Radioisotopes for use as detection taggants possess the same drawbacks as they do for use as identification taggants; the above discussion need not be repeated here.

Electromagnetic taggants incorporated into a detonator, such as the passive harmonic radar taggant investigated by the Aerospace Corp., offer the possibility of detection at a distance with a relatively low rate of false alarms. All of the concepts so far proposed, however, can be easily defeated by wrapping explosives in metal foi1. In addition, inclusion of such devices would probably have a significant effect on the procedures used to manufacture detonators, on detonator cost, and significant false alarms could be caused by common diodes from radios, calculators, and other electronic instruments.

A variation of the idea of electromagnetic taggants has been proposed, called detonator deactivation. In this concept, a reed switch is connected in series with a detonator bridge wire. illumination of the detonator by a switchable electromagnetic source would cause the reed to open. A number of methods are possible to ensure that the reed could not be subsequently closed. The advantages of the concept are twofold:

- the necessary illuminator could probably be made quite inexpensively, allowing it to be used to protect far more targets than would be possible with other detector concepts; and
- the deactivator process is passive — no operator is necessary.

Disadvantages include the fact that deactivation rather than detection of bombs would offer no help in finding the would-be criminal

bombers; significant (and possibly costly) impacts on current processes of manufacturing detonators; and the risk of accidentally deactivating detonators, resulting in their failure for normal use. No research beyond initial conceptualization has been conducted for this concept.

An interesting taggant concept has been suggested by the Franklin Institute, based on the idea of using Moss bauer active isotopes as taggants. The technique involves the addition of nonradioactive trace taggants to explosives, followed by the gamma ray excitation of the Mossbauer isotopes and the measurement of the characteristic absorption spectrum of those taggant isotopes. The Mossbauer effect has been measured in numerous common elements, including iron, tin, and nickel. In a Mossbauer isotope, gamma rays, whose energy corresponds to the transition energy between nuclear levels, may be resonantly absorbed upon excitation, producing a sharp absorption spectrum characteristic not simply of the Mossbauer element, but of the chemical compound of the element. This effect is due to the small perturbations of the nuclear levels by the surrounding electrons. For use as a taggant, a chemical compound not found in nature or used in industry would be manufactured. Due to the low excitation level required, little shielding of the source would be necessary.

Mossbauer taggants are simply a concept at this stage, however, so little judgment can be made of its practicality, cost, or safety in explosives An Aerospace Corp, analysis questions the practicality of the technique. A significant l imitation to the use of the Moss bauer and other activation techniques is that they cannot be used to search people, due to the activation radiation

A number of other activation taggant techniques have been suggested, including the doping of explosives with material that would enhance the effectiveness of X-ray or similar devices These concepts al l lack specificity, however, and could cause the X-ray to be triggered by many common items, resulting in an unacceptable false a l arm rate

Vapor Taggants

vapor taggants have received the bulk of the research on detection taggants. vapor taggants share the common taggant requirements of stability, inertness, compatibility with explosives, and absence from normal materials. In addition, they must have a vapor pressure sufficient to produce enough molecules to be sensed, but not so high that a large initial mass would be required to ensure continued operation when placed in explosives that have a shelf-life of several years. They must have a relatively steady molecule emission rate over a 5- to 10-year shelf-life, must not produce an environmental hazard, and must not readily adhere to surfaces with which they are likely to come into contact.

Several hundred different vapor sources have been considered, with almost 200 having been investigated in the laboratory. Avenues of approach have included the use of disproportionating salts, the direct adsorption of vapor taggants into the elastomeric plug material of detonators, and the microencapsulation of taggant materials.

DISPROPORTIONATING SALTS

A number of the salts of weak acids and bases, such as boron trifluoride adduct compounds, disproportionate or separate into two or more constituent parts, some of which sublimate at room temperatures, theoretically providing a possible stable vapor emission source. Tests conducted by the Aerospace Corp. indicated that no compounds investigated had the proper balance of vapor pressure, emission rate, desired lifetime, and projected detection limit by a sensor to allow the use of a sufficiently small amount of taggant material. It is possible to control the emission rate of a high vapor pressure salt by the use of a microencapsulation membrane; use of such a membrane allows the consideration of a large number of more easily handled liquid taggants, however, as described below.

ELASTOMERIC ADSORPTION OF VAPOR TAGGANTS

The adsorption of the vapor detection mat e-rial directly into the elastomer used to fabri-

cate the end plug of detonators offers a number of advantages, including removal of the necessity for additional steps or changes in the detonator fabrication process. Research has therefore been conducted to evaluate the effectiveness of various elastomer/taggant pairs. Taggants evaluated include sulfur hexafluoride, and hologenated alkanes, amines, aerobatics, esters, and ketones. A number of combinations appear feasible, although useful lifetimes may be shorter than the 5-year minimum desirable. A more severe limitation, however, is that the elastomerically adsorbed taggants would be useful only on detonators, and possibly with detonating cord. None of these taggants appears to be as successful as other candidates when microencapsulated for use with other explosive materials. Use of separate taggants for detonators for other explosives would lead to the development of two sensors or to the requirement for dual-mode sensing in a single sensor, an unnecessary sensor development constraint.

MICROENCAPSULATED VAPOR TAGGANTS

Approximately 180 vapor materials have been screened in the laboratory as candidate microencapsulated vapor taggants. **In** addition, several hundred other materials were rejected after a thorough analytical review. Five candidate perfluorinated cycloalkane compounds have been extensively tested, and have successfully completed barrier penetration, mutagen, toxicity, and atmospheric impact testing. The five candidate vapor taggants and their chemical properties are shown in table 16.

A parallel research effort has been underway to find an appropriate microcapsule material. The optimum material would be inexpensive, easy to use with the candidate taggant materials, compatible with the explosive materials, and form membranes that account for only 10 to 20 percent of the microencapsulated taggant weight. Figure 7 shows a photograph of a canadidate microencapsulated vapor detection taggant, with a needle to indicate relative size.

Emission rate studies are currently underway with a number of membrane materials. Early tests were very encouraging; a number of more recent test results show variations in emission rate from lot to lot and as a function of ambient relative humidity and temperature. Tests have not yet started on long-term emission behavior, especially in the presence of explosives. Tests have only recently started on the compatibility of explosive materials with either the taggant vapors or the membrane materials.

Summary

Although a wide range of detection taggant materials have been proposed, the need for long life, stability, specificity, and absence of easy countermeasures has caused the bulk of these to be rejected, at least given the current state-of-the-art. The most promising concept is the microencapsulation of perfluorinated cycloalkane compounds, although the direct adsorption of taggants into the detonator plug elastomer appears promising for that application. A number of preliminary tests have been conducted with five candidate taggants; compatibility testing has just been initiated. Detonator deactivation is a possible alternate approach, although little research has been accompl i shed.

Table 16.–Candidate Vapor Taggant Properties

Chemical name	Abbreviation	Empirical formula	Molecular weight	Boiling point “ c	Melting point “ c	Specific gravity (300° K = 27° C)	Vapor pressure
Perfluoro-1 1-2-dlmethyl-cyclobutane	PDCB	C, F,,	300	45	-32	1.67	390
Perfluoromethylcy clohexane .,	PMCH	C, F,,	350	76	-37	1.79	106
Perfluoro-1,3 3-dimethylcyclohexane	PDCH	C, F,,	400	101-2	-70	185	35
Perfluorodecalln	PFD	$C_{o}F_{1_{8}}$	462	141-2	0	193	6.6
Perfluorohexylsulf sulfur-pentafluonde	L-4412	CSFI,SF,	446	118	-31	1.89	195

SOURCE The Aerospace Corp

F gu e M oen apsu a ed De e on aggan s Shown W h a Need e o nd a e S e

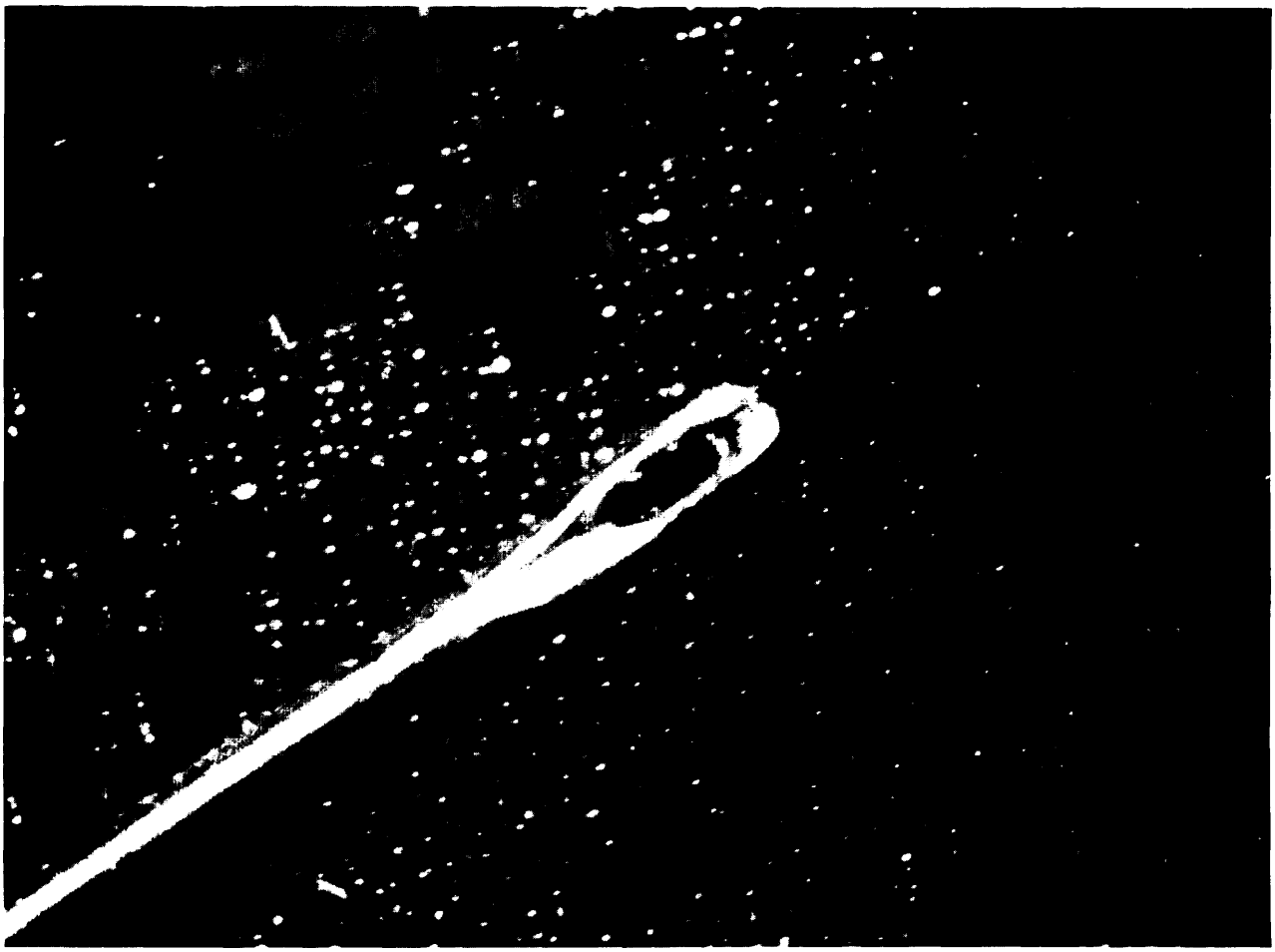


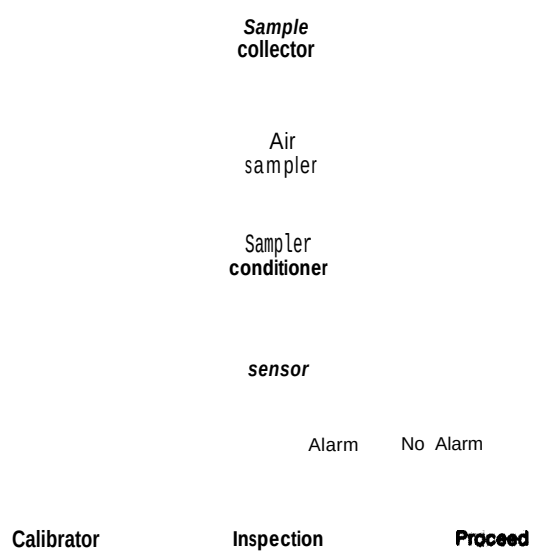
Photo credtt Aerospace Corp

Detect ion Taggant Sensor Systems

The development of a system to detect the emitted vapors is proceeding in parallel with the development of vapor-emitting detection taggants. A schematic block diagram for the operation of such a system is shown in figure 8. Air, from the vicinity of the item being inspected, is collected and delivered to a sensor, after first being conditioned. The sample collector can simply consist of a gust of air for inspection of boarding passengers, or can include a small pressure pulse to a piece of checked baggage to introduce more of the air from the interior of the baggage into the air sample stream. For some of the concepts the free oxygen and water vapor must be removed prior to insertion of the air into the sensor. If the vapor taggant is present, an alarm indication is registered; if none is present, then the item passes through with no delay. A detailed procedure has not been developed to deal with alarms, but the procedure would probably include a recycle through the sensor to eliminate the chance of an equipment transient being responsible, followed by a suspected bomb disposal procedure if the alarm persists.

Work is progressing on three candidate detection sensors. Very little effort has been expended by the Aerospace Corp. on the other elements of the system, although some preliminary design identification work has taken place on the air sampling process and on methods of enhancing the original sample. A U.S.

Figure 8.— Detection Taggant Sensor System Block Diagram



SOURCE: Office of Technology Assessment.

Customs Service device has been tested, for instance, which exerts a gentle force on baggage, causing an exhalation of the baggage interior air into the sampling network.

The three candidate detection sensors are, in order of increasing complexity and cost, the continuous electron capture detector (CECD), the ion mobility spectrometer (IMS), and the mass spectrometer (MS). Figure 9 shows a schematic diagram of the operation of IMS. Gas is introduced from the sampling device into the conditioner. After the free oxygen and water vapor are removed, the sampled gas molecules are drawn into the ionization region where many molecular species, including the taggant molecules if present, form negatively charged ions. The negative ions are then gathered and injected into a drift tube where an electric field causes them to flow against a counter-flowing drift gas stream. By virtue of the ion molecule reactions between the negative ions and the neutral drift gas molecules, the ions are separated into spatial clumps of like species. Each species, depending on the strength of the ion-molecule interaction, traverses the length of the drift tube in a different length of time so that one can turn-on, or gate, the detector to respond only to a specific molecular species or group of species such as the taggant vapors.

The taggant molecules being considered all have long drift times and are easily separated from common gasses in the IMS. Additional specificity is gained by the toughness of the taggants; most other large molecules fragment in processing through the detector.

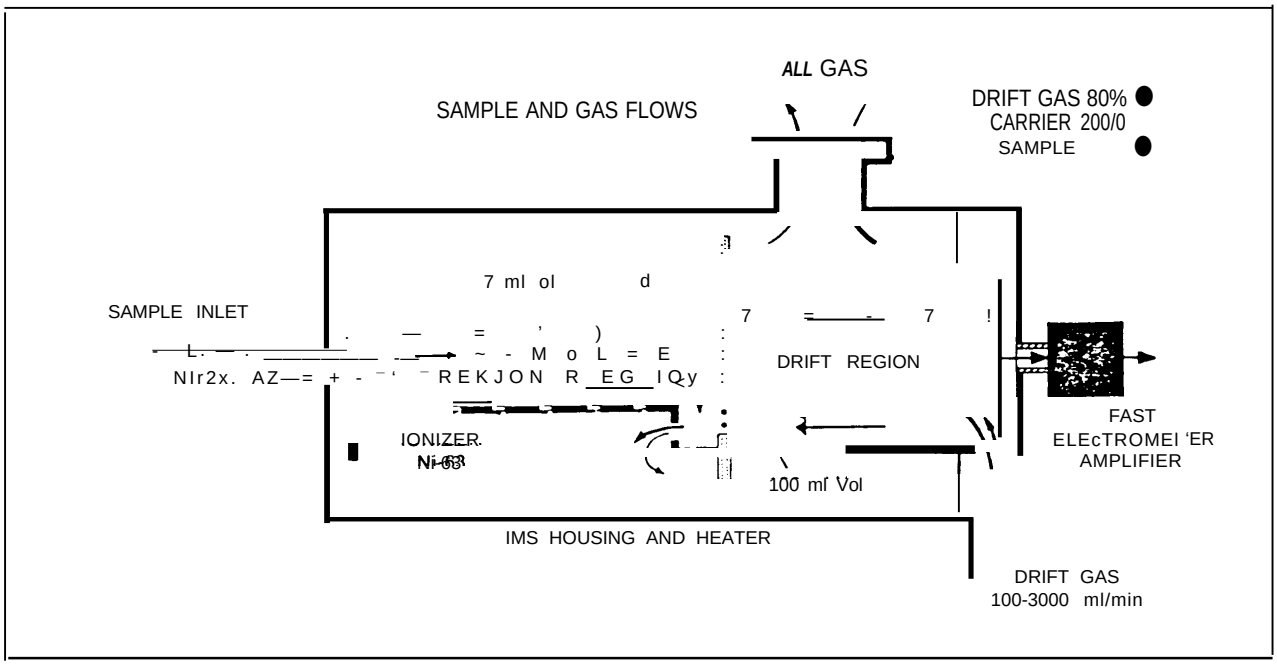
IMS devices have been commercially available for approximatelys years, with about sO currently in use for various applications. Tests have been run with a commercial IMS unit at airports to examine ambient air for the presence of molecules in the critical drift time region; no molecules which would have triggered a false alarm were detected.

While the laboratory tests are promising, it is not possible to extrapolate to estimates of IMS performance in the field, in a real-life environment, when maintained by normal airport maintenance people, and when using an internal calibration source.

CECD can be conceptually viewed as an IMS device without a drift tube. It simply consists of the conditioner and reaction chamber; the decrease in current in the reaction chamber is a sign that the taggant molecules are present and have been ionized. As described, CECD would have less specificity than IMS, and would probably be triggered by a wider range of interference sources. The key to the device is in the conditioning chamber; the chamber is a catalytic reactor that contains hydrogen gas and palladium metal plated onto a number 5A molecular sieve and operating at 1400 C. The reactor removes oxygen and water vapor, fractures some other potential interference sources, while still others are removed by reduction or combustion. The number of molecules that will survive the conditioning chamber is limited, but the taggants may well not be the only survivors of the passive screening process.

CECD devices have been used as a laboratory instrument by the Brookhaven National Laboratory for the past several years. A bread-

Figure 9.—Cutaway View of the Phemto"Chem 100 Sensor Cell in the Ion Mobility Spectrometer



SOURCE David Williams BATF

board device was recently shown to be quite successful in detecting vapor-tagged dummy blasting caps in baggage on a conveyer belt.

The MS is a standard laboratory instrument, easily capable of resolving the taggant molecules from other species. Current MSS, however, are usually expensive, relatively sensitive laboratory instruments. The challenge is to design and develop a low-cost, field-usable instrument that will detect taggant molecules in a parts-per-tril l ion concentration level.

The limited laboratory testing of detection sensors that has taken place has demonstrated that the technology exists for sensors which could detect the taggant vapors. These tests have not yet demonstrated, however, the ability of the instruments to distinguish between the taggant materials and similar materials which may exist in the environment or may be deliberately introduced into the environment as a countermeasure. It has also not been demonstrated that any of the instruments can successfully detect the taggants in the required parts-per-tri l l ion concentration level under field-use conditions.

The time required to develop instruments of this type is a pertinent subject for discussion, even assuming that the technical problems can be solved. The milestones in a development process include:

- demonstration of technical feasibility,
- generation of specifications for a prototype,
- prototype development,
- generation of specifications for the instrument,
- pilot production of the instrument, and
- ful l-scale production.

None of the detection sensor concepts has yet passed the technical feasibility demonstration milestone. The only time estimate which has been made is an extremely optimistic estimate of 14 months from demonstration of technical feasibility to completion of a prototype. The estimate assumed no technical, contractual, or other problems, and may well be off by a factor of two. Given the fact that these instruments would be produced in quantity (up to several thousand), must be self-calibrating, maintained by routine maintenance people,

and detect at the state-of-the-art parts-per-trillion level, it is unlikely that production could be underway in less than 5 years.

If the instruments can be developed to perform as desired, however, they should be quite effective; the operating costs and false alarm rates would be negligible while the detection rate would ensure essentially no successful penetration of the sensor system.

UNTAGGED DETECTION

Three general methods have been explored for detecting explosives that do not have detection taggants added. These include vapor detection of the characteristic vapors present in the explosives, the use of differential contrast radiography, and the use of excitation induced emissions. Some of the specific techniques investigated are briefly discussed below.

Vapor Detection

A great deal of research effort has been expended in the field of detection of the characteristic vapors emitted by explosives. Table 17 shows the physical properties of the vapor phase of a number of explosive materials, while table 18 shows some of the methods used to detect the explosive vapors. ' Much of the effort has been concerned with characterizing the vapors that are present in explosives, looking for vapors common to a number of explosive materials, and quantifying the problems of vapor detection. While the equilibrium concentrations of the vapors shown in table 17 are within the detection capabilities of much of the instrumentation depicted in table 18, several problems limit the utility of vapor detection.

One of the primary problems is the lack of a common vapor in the various explosive materials. Either nitroglycerine or EGDN is often present in dynamites, and in smokeless powders, but neither are present in the other explosive materials used in criminal bombings, such as gels, slurries, black powder, detonators, and boosters. A detection device would thus have to be able to detect a significant variety of vapors (and thus either be quite slow or expensive) or it would be subject to a high rate of false alarms if it could be triggered by the spectrum of materials that would be spanned by the vapors from the common explosive materials.

A second significant problem is the amount of vapor actually available for detection. While the equilibrium concentrations of the vapors are high enough to ensure detection, the actual amount of vapor present will be significantly degraded by the container that contains the explosive, particularly if an effort is made to create a vapor barrier. The explosive vapors do not have the properties of penetration and nonadsorption of the vapor taggant materials discussed in the previous section. Concentration of the vapors could help alleviate this problem, but that might cause sufficient concentration of ambient interference molecules to generate a high false alarm rate.

These defects must be balanced against the major advantage that detection of the characteristic vapors of explosives has over the detection of taggant vapors—only those explosives that have been tagged can be detected if the sensors are designed to look for the vapor taggant.

As shown in table 18, a large number of physical principles have been used to detect the vapors. The most successful, however, are the ionization mechanisms exploited for detection of taggant vapors. Continued research is primarily devoted to these sensors.

Animal detection deserves a specific comment. Although less sensitive than the other

'From "Explosive Vapor Detection Instrumentation, " by j R Hobbs, prtnted In the *Proceedings of the 1979* Electro Professional *Program, New* York, April 1979

Table 17.–Vapor Pressures of Selected Explosives

Compound	Molecular weight	Temperature °C	Vapor pressure mm Hg	Composition gm/cm³	Mole fraction (V. P./76O)
EGDN–ethylene glycol dmltrate	152	25	2,8 x10-2	23 x 107	37 ppm
NG–nitroglycerine.	227	25	2,4 x1O-s	29 x 10-10	32 ppb
PETN–pentaerythrltol tetranltraie' ., . .	316	25	54 x 10"6	9.2 x10 II	7 ppb
AN–ammonium nitrate	80	25	**5.0** x10"6	2.2 x 1011	7 ppb
DNT–dinitrotluene , .	182	25	1 4 x 10"4	1,4 x 109	184 ppb
TNT–2, 4, 6,-trinitrotoluene. ~	227	25	30 x 10"6	37 x 10"11	4 ppb
R D X	222	25	1.4 x 109	1.7 x 1014	2 ppt

SOURCE J R Hobbs Explosive Vapor Dection Instrumentations`

Table 18.–Explosive Vapor Detection Techniques

Optical	Ionization	Animals	Other
Infrared	Electron capture	Bioluminescence	Plezoelectnc
Ultraviolet	Gas chromatography	Dogs	Thermoionic
Microwave	Mass spectrometry	Gerbils	Condensation nuclei
Fluorescence	Gas chromatography/ mass spectrometry	Enzymes	
Laser- raman	Plasma chromatography		
Two-photon absorption			
Chemiluminescence			
Laser optoacoustical			

SOURCE J R Hobbs Explosive Vapor Detection Instrumentations

sensors (by orders of magnitude), animals have some potential advantages. If small animals such as rats and gerbils can successfully detect explosive vapors, then the cost of an animal backup system would be quite small. Dogs are more expensive to train and work with, but have the advantage of being used for other law enforcement work such as patrols.

Differential Contrast Radiography

Differential contrast radiography takes advantage of the fact that different materials attenuate the strength of a source to a different degree, depending primarily on density and atomic number. Common clinical X-rays and the imaging X-ray detectors used to screen hand baggage at airports work on this principle. Similar devices have been fabricated using gamma radiation and neutrons as the beam source. This method is quite effective for detecting materials whose density is significantly greater than other materials in the environment, such as a steel gun (specific gravity of 7.8) in a briefcase containing books or clothes (specific gravity less than 1,0), but is much less effective in detecting smaller differences in density. Most dynamites have a specific gravity of approximately 1.6; booster materials and military explosives are Slightly higher (up to 1,8); gunpowders have a bulk density of less than 1.0.

The current imaging systems at airports are operator-monitored and therefore dependent on the ability of the poorly trained operator to discriminate small density differences. Most recent research has been concerned with automating the radiographic scannin*g systems.* Due to the wide span in density of explosive materials, and the large density overlap between explosives and other materials, it is necessary to include other means of discrimination in the detection algorithm. Shape is the other discriminant currently used. The pattern recognition algorithm in a computer reacts when the proper density and shape pattern are detected. Such a system is sensitive to orientation, arrangement, and shape of the high explosive as well as to the mass of the high explosive. The breadboard laboratory models so far developed can incorporate only a limited number of shape-density combinations and are able to detect only certain shapes of C-4 explo-

sive and certain shapes of dynamite bombs. While they could detect a 2-lb C-4 charge shaped like a package of butter, they would not detect the same charge shaped as a sphere, cylinder, pancake, or sausage, or even another explosive of slightly different density shaped in the butter package shape. As the devices scan from only one axis, a 2-inch-thick slab with a specific gravity of 0.5 looks much like a l-inch-thick slab of density 1.0. Such a lack of specificity not only generates high false alarms, but explosives arranged in an unusual shape would not be detected.

Two avenues of approach are being pursued to try and alleviate the discrimination specificity problem. The first is to use more than one energy level for the radiation source. Each type of material has a different opacity to different radiation energies. If more than one energy source is used to illuminate the object, then additional information about the material is gained. Some recent work indicates substantial gains in information are possible using two carefully chosen energy levels.

The second approach is to illuminate the package along more than one scanning direction. The information gained can help generate a better idea of both the package shape and its density. In a technique called tomography, the images formed by scanning from several directions are computer processed and used to generate a three-dimensional image of the package in the computer. Any two-dimensional projection can then be generated as well as an accurate density value. This image can be compared to all possible conformations of common explosive materials by the computer, yielding a much higher probability of detection as well as a lower false alarm rate. Aerospace Corp. is currently sponsoring research on dual-energy tomography, which would combine the additional information available from both multiple directional scans and multiple energy scans.

Excitation-Induced Emissions

Many materials absorb radiation of a specific wavelength and subsequently emit an induced radiation whose energy may be a function of the element itself or of the specific compound, due to the interaction of the orbital electrons with the nuclear material. The Mossbauer isotope taggants described in the previous section were an example. Several methods of utilizing induced emissions have been investigated for detection of explosives, including the use of thermal neutrons, X-ray fluorescence, and nuclear magnetic resonance.

The thermal neutron detection concept utilizes the capture of thermal neutrons by nitrogen with the subsequent prompt emission of a 10.8 MeV gamma ray. Explosives are rich in nitrogen and should be easily detected in an unshielded suitcase, but so are a large number of other materials, such as wool, orlon, nylon, and leather. Coupling the system to a pattern recognition computer might be sufficient to discriminate between a solid block of explosives and a couple of orlon sweaters (although test results were marginal), but discrimination between these sweaters and a bomb in which single dynamite sticks are connected by detonating cord, for instance, would be extremely difficult. Processing times for this concept are also rather long for efficient transport of baggage.

Nuclear magnetic resonance (NMR) is a technique with considerably greater specificity. In NMR detection, an applied radio frequency magnetic field, with the correct frequency, induces energy level transitions in hydrogen, with the subseq~ent prompt reradiation of energy in a manner specific to the chemical compound containing the hydrogen. A sensor, tuned to receive the signals that would be emitted by the hydrogen in various explosive materials, could theoretically detect any type of explosive, even when present in small quantities. A major problem with the utilization of this technique for explosive detection would be the fact that metal interferes with the NMR performance, thus shielding the explosive. The unit would also have to be quite large (and thus expensive); the magnet for an NMR unit large enough to scan a suit-

case would weigh several tons. Another problem is the rather slow response cycle time.

Summary

A number of techniques have been described for the detection of untagged explosives. Preliminary testing has been accomplished on most of the techniques discussed; few concepts have progressed as far as the studies on detecting vapor taggants, with the exception of the use of animals to detect the characteristic vapors of explosive materials. Some explosive detection devices are currently on the market, although their performance is not satisfactory. Other techniques have been suggested, and extremely limited testing has been conducted on some of them. All of the untagged detector concepts contain significant problems in terms of adaptation to field use. Instrumentation for many of the concepts would be large and expensive; many are easily countermeasure and none, with the except ion of the vapor detection devices, could be used to screen passengers.

Granting the many problems in nontagged detection, there may still be a significant potential payoff. If an explosive detection instrument or technique could be fielded, it could detect all explosives, not just those to which taggants had been added.

CURRENT BATF/AEROSPACE TAGGANT PROGRAM

I n 1976, the Aerospace Corp. was designated by BATF as the system technical manager of the taggant program. Prior milestones leading to the current taggant program development effort were:

- 1973.–Joint establishment by BATF and FAA of an ad hoc committee on explosives seeding.
- 1973.–Formation of the Advisory Committee on Explosives Tagging chaired by BATF for coordination of Federal agencies involved with tagging and the control of the illegal use of explosives.
- 1973.–Lawrence Livermore Laboratory study to determine feasibility of identification tagging with Aerospace Corp. acting as the program technical manager and LEAA as sponsor.
- 1976.–National Implementation Model and Pilot Test Plan for Identification Tagging developed by the Aerospace Corp. u rider contract to the Bureau of Mines,
- 1977.–Aerospace Corp. designated the system technical manager for the tagging program by BATF.

Since 1977, Aerospace has been engaged in an ongoing program of analysis and testing to develop identification and detection taggants and to demonstrate their use in explosive materials. Details of the taggant and sensor development programs were given above; the status of the compatibility testing program is detailed in chapter IV; the status of survivability and recovery testing is reviewed in the following section and in appendix C; some details of the analysis and pilot testing status are reviewed in chapter V. This information is briefly summarized below, as is a description of the BATF implementation philosophy.

Program Status

The status of the taggant development effort is summarized in table 19 for identification taggants and in table 20 for detection taggants. In the tables, "Technical feasibility" refers to a demonstration or analysis which indicates the concept is feasible, "Technical read i ness" refers to a demonstration or analysis that the concept will work in the manner suggested, and "Practical readiness" indicates that the full spectrum of analyses and tests has been completed which shows that the concept is ready for full-scale implementation.

The ability of the 3M Co, to produce the color-coded taggants has been demonstrated,

Table 19.–Identification Taggant Program Status

Accomplished			Planned or required		
Technical feasibility	Technical readiness	Practical readiness	1 Technical feasibility	Technical readiness	Practical readiness
Color-coded taggant development					
• Initial survivability compatibility testing • Environmental impact assessment • Health impact assessment	• Pilot production compatibility	• Leadyime study			• Tooling-up period/ testing Optimize hues
Cap-sensitive packaged explosives (dynamite, water gels, slurries, and emulsions)					
• Initial compatibihty testing • Initial survivability testing • Manufacturing process reviewed and practicality assessed	• Online tagging demonstrated • Tagging methods selected/evaluated	• Pilot test production-level tagging • Record/tracing methods demonstrated	Comprehensive compatibility testing	• Comprehensive survivability testing	• Analysis/optimization of approach Long-term compatibility
Black powders					
• Initial compatibility testing • Hand-mix survwability testing • Manufacturing process reviewed and practicality assessed	• Online tagging • Additional compatibility (electrostatic) testing • Transport/vibration segregation testing	• Some ballistics testing	Comprehensive compatibility testing	• Comprehenswe survivability testing	• Ballistics testing • Online tagged survivability testing Long-term segregation • Long-term compatibility
Cast boosters					
• Initial compatibility testing • Initial survivability testing • Manufacturing process reviewed and practicahty assessed	• Online tagging • Tagging methods selected/evaluated		Solution of problem posed by reactivity (and presumed incompatibility) with Composition B Comprehensive compatibility testing Recovery testing	• Comprehensive survivability testing	• Pilot testing, production-level tagging • Long-term compattbility • Comprehensive survivability testing • Record/tracing methods demonstrated • Analysis/optimization of approach
Detonating cord					
• Taggants added by hand, initial survwability demonstrated • Manufacturing process studied and tagging practicability assessed			1 ₀ Recovery testing	• Tagging station development • Online tagging	• Comprehensive survivability/compati - bility testing • Pilot testing
Smokeless powders					
• Hand-mix survivability testing			Solution of problem posed by reactivity (and presumed incompatibility) with Herco" powder • Compatibility and hazards analysis . Compatibility and acceptance testing	• Evaluation testing of sequential lots • Production hazard and acceptance testing • Comprehensive survivability testing • Online tagging	• Ballistics testing • Pilot testing
Detonators —			Full range 01 tests and process evaluation required		

SOURCE Office of Technology Assessment

Table 20.–Detection Taggant Program Status

Accomplished			Planned or required		
Technical feasibility	Technical readiness	Practical readiness	Technical feasibility	Technical readiness	Practical readiness
Microcapsule development					
Production and evaluation of test batches • Health and atmospheric Impact assessment			10 Intial compatibility studies 10 Complete health and atmospheric Impact assessment 1 0 Taggant selection	• Pilot production of capsules	• Competitive award /leadtime studies • Development and testing of production • Full-scale production capability
Dynamite, slurries, and water gels					
• Compatibility testing — initiated		—			
Black powder					
• Compatibility testing — initated		—			
Cast Boosters					
● Compatlblllty testing — initiated		—			
Smokeless powder			The full range of analyses and tests detailed for identification taggants must be accomplished for the detection taggants, with the exception of postdetonation ***surivability*** and recovery testing		
• Compatibility testing— initiated		—			
Detonating cord					
—	—	—			
Detonators					
• Compatibility testing Initiated					
Continuous electron capture detector					
• Successful bread- — board demonstration • Instrument characterization (initiated) • Callbration system (initiated)		—	Instrument characterization (in process) 10 Calibration (in process)	• Design prototype • Fab and lab test evaluation • Aerospace lab test	• Prototype field test • Prototype design changes • Final production drawings • Production pilot release • Production pilot complete • Field support function setup • Training and field test
IMS detector					
• Initial feasibility studies			Demonstration (Imminent)	• Design prototype • Fab and lab test prototype • Aerospace lab test Prototype field test	• Prototype design changes • Production drawings • Manufacture and checkout engineering • Production pilot release • Production pilot complete • Support functions setup • Training and field test
MS detector					
• High-cost laboratory system testing • Development and breadboard demonstration—in process			10 Development and breadboard demonstration to be completed	Prototype design, fabrication, and test	• Prototype design changes • Production drawings • Manufacture and checkout engineering • Production pilot release • Production pilot complete • Support functions setup • Training and field test

SOURCE Off Ice of Technology Assessment

although some hue and color code optimization remains, as well as construction of a facility to produce the taggants. Initial compatibility and survival testing has been completed for the cap-sensitive high explosives, as has pilot production of tagged explosives and activation of the tracing network. As chapter IV describes in detail, this initial testing has revealed apparent incompatibilities between the 3M taggant and one type of smokeless powder and also between the 3M taggant and one cast booster material. If and when these presumptions of incompatibility are removed, comprehensive compatibility and survivability testing

must then be completed and decisions made on implementation levels before readiness is demonstrated. A similar level of testing and analysis has been accomplished for black powder, while significantly less has been accomplished for smokeless powder and cast boosters. One of the key remaining booster issues is the recoverability of the taggants when pressed into large pellets (survivability has been demonstrated). Methods of approach have been explored for tagging detonators and detonating cord, but little testing has occurred.

The significant accomplishments in identification taggant compatibility testing which have so far occurred have been made possible by cooperation between the Aerospace Corp. and the explosives and gunpowder industries. Unfortunately, this working arrangement has broken down in the past few months, and the industry has, for a number of reasons, withdrawn its cooperation. The result of this change in the prior working relationship has been a significant delay in the program, particularly with regard to compatibility testing of the detection taggants. The results of these delays, together with an originally planned lag of approximately 1‘A years between the identification and detection taggant development efforts, are evident in the current status of the detection taggant development program, shown in table 20.

Development of candidate detection taggants is continuing. Taggants have only recently been added to explosive materials for compatibility testing and process evaluation. As described previously, development of three candidate sensors is also continuing, with laboratory-type tests showing prom i sing results.

Projected Schedule

As a result of withdrawal of industry cooperation, technical problems which have occurred, and the uncertainty of funding for outyear efforts, a firm schedule for the remaining development effort is not available. An estimate was made by Aerospace of the revised schedule for the remaining development effort; the estimate is shown in table 21. This schedule does not take into account, however, the need for additional compatibility and survivability recovery tests, particularly the resolution of the current smokeless powder and booster material reactivity issues, and the need for the evaluation of long-term effects of taggants on explosive material safety and performance. These efforts would probably add at least 1 year, and possibly more, to the development time. It is unlikely that the effort to demonstrate the use of identification taggants in cap-sensitive high explosives, the type of explosives with which the research effort has progressed farthest, could be completed prior to early 1981. The research on identification taggants in detonators, including pilot-plant tool-up and testing, would not likely be finished before late 1983; the research on other explosive materials would probably fall between these dates. These estimates assume a successful completion of each development stage. Technical problems may occur that add substantially to the estimate delays; continued lack of industry participation could make pilot testing impossible; even resolution of contractual problems could add months of delay.

Table 21 ,–Revised Schedule Estimates for the Identification Tagging Program

Program element	Aerospace preliminary estimated completion date a
Identification taggants	
Color-coded taggant	Early 1983
Cap-sensitive packaged explosives .,	Early 1980
Black powders. ., .,	
Cast boosters ., ., .,	Mid-1981
Detonating cord ... ., ., ., .,	Mid-1980
Smokeless powders . ,	Mid-1983
Detonator ., . ., ., .,	Late 1983
Detection taggants	
Mlcrocapsule development .,	Mid-1981
Cap-sensitive packaged explosives. .,	Mid-1981
Black powder	Not critical
Cast boosters ., .	7
Smokeless powder, ...	Late 1981
Detonating cord ., .,	Not critical
Blastlng caps-micocapsules. .,	?
CECD ., .,	Mid-1982
IMS detector. ., .,	Late 1981
MS detector ., ., . .,	Mid-1982

a Estimated by Aerospace October 1979

SOURCE Office of Technology Assessment

3M has indicated that it would need a lead-time of at least 22 months after receipt of a firm order before substantial quantities of taggants could be delivered. It is unlikely that a firm order would be given before resolution of all technical problems, including uncertainties regarding long-term effects. If a mid-1 983 date is assumed for resolution of al l identification taggant efficacy and compatibility questions, then explosives tagged with the 3M identification taggant could be in full-scale production by late 1985.

A decision could be made to implement tagging as soon as all technical uncertainties are resolved for some portion of the explosive materials, such as cap-sensitive explosives. Under those circumstances, 3M could receive firm orders by early 1981 and tagged explosives could therefore be in full-scale production as early as 1983,

The detection taggant development has lagged that of identification taggants; the development cycle may be shorter, however, due both to the learning experience of the identification taggant tests and to the fact that no survivability demonstration is necessary. The Aerospace Corp. estimates are probably quite optimistic, however, for development and test times of both the detection taggant and the detection sensors, Few compatibility tests have yet been conducted. These tests, particularly the effects of long-term storage, will take at least 2 years. No specific taggant or encapsulation method has been chosen. Pilot-plant production of the taggant is likely to take a considerable time, as the manufacturing processes are complex and the reagents used quite reactive. It is unlikely that solving the technical problems and constructing proper facilities for the large-scale production of detection taggants can be accomplished in a significantly shorter period than that required for the identification taggants. Assuming completion of the compatibility tests, pilot-plant testing of detection taggants in the explosive materials could be accomplished by early 1983, and assuming 22 months from that time to the availability of production quantities of detection taggants, full-scale production of explosives containing detection taggants could probably not be underway until mid-1 982, with sometime in 1984 a more reasonable estimate.

As indicated previously, the estimated development schedule for the detection taggant sensors is extremely optimistic; a more realistic estimate would be that production of the sensors could be underway by late 1984.

In summary, by early 1985 it is possible that all explosives manufactured could be tagged with both identification and detection taggants, and that detection taggant sensors could be in full production. This schedule is realizable only if no major development problems occur and a taggant program is mandated by legislation,

Implementation Philosophy

BATF has publicly stated' that it feels taggants should be included only in those explosive materials that constitute a present or expected threat of use by criminal bombers. They feel that explosive materials that do not constitute a threat could be excluded. Among the materials which BATF considers appropriate for exclusion are:

1. explosives manufactured for U.S. Government agencies other than the military (e.g., National Aeronautics and Space Administrate ion); military explosives are specifically excluded in S.333;
2. special fireworks such as used for 4th of July displays;
3. industrial tools such as explosive bolts, switches, and air bag in flaters;
4. blasting agents. It is the BATF intention to tag the boosters and detonators normally used to initiate the blasting agents. The explosives industry maintains that if cap-sensitive explosives are tagged but blasting agents are not, the use of ANFO by bombers will increase, and BATF will then

Proposed Guidelines for Exemptions to the Requirements for Tagging Explosive Materials Bureau of Alcohol, Tobacco, and Firearms, June 7, 1978

wish to tag ANFO. See chapters 1, 11, and VI for a discussion of this issue; and
5. explosives which are raw materials used in a fabrication process, such as the black powder used infuzes.

In addition to the categories eligible for exemption, certain types of explosive materials are currently exempted from regulation, and are viewed by BATF as inappropriate for tagging, including:

1. explosives used in medicine;
2. fireworks sold to the public;
3. propellant-activated industrial devices, such as nail guns; and
4. fixed small arms ammunition.

Given that philosophy, the BAT F/Aerospace team has concentrated on taggant research for cap-sensitive high explosives (dynamites, gels, emulsions, slurries), boosters, detonating cord, black and smokeless powders directly consumed by the public (primarily for handloading), and detonators. Blasting agents would not be directly tagged; rather the detonators and boosters normally used to initiate the blasting agents would be tagged.

A strict interpretation of S. 333, at least in the opinion of the Institute of Makers of Explosives, would not allow the Secretary of the Treasury to exempt explosives simply because they do not constitute a significant threat. Resolution of this issue may be facilitated by more specific wording in the final proposed legislation.

IDENTIFICATION TAGGANT SURVIVAL TESTING

The 3M identification taggant would have to survive the detonation of the explosive and be recoverable from the postdetonation debris to be useful in identifying the source of the explosive. It is useful to separate the survival and recovery discussions. Recovery of taggants under real-life conditions is discussed in detail in chapter I I and in appendix C. Survival of the taggant is briefly reviewed here.

To assess the survivability of taggants in explosives, the tests should be carried out so that recovery is maximized. ideally, tests would take place on a large concrete pad or in a very large bunker with steel or concrete walls and floor. Unfortunately, few of the survivability tests carried out by the Aerospace Corp. were done under conditions that enhanced recovery. A majority of the tests were carried out in a 4-ft-diameter steel-walled chamber. For all but the lowest power explosives, the taggants either shattered upon impact or flowed plastically due to the large impact pressure pulse (estimated by Aerospace to be between 10 and 40 kilobars (kb)). Many of the other tests were carried out in a chamber with a cracked rock floor, or in the open on a dirt and cinder floor. I n several cases rain made the open area quite muddy or covered the taggants with a layer of water, severely decreasing the efficiency of the magnetic pickup.

The survival test results for cap-sensitive high explosives, under the varying conditions, are gathered in table 22. That table includes all the survival tests conducted by Aerospace with uniformly tagged explosives. Earlier tests, in which the explosive stick was split down the center and salted, are not realistic and are not discussed here. Some of the tests used unencapsulated taggants (so indicated on the table); as no difference was observed, they are lumped together in the discussion.

Aging time was another variable tested, with the material being aged up to 6 months before testing; again, no effect was observed and all the tests are lumped together.

Given the diversity of test sites and conditions, it is difficult to assess each test. However, several trends appear clear:

1, Under optimum recovery conditions, using small explosive charges, many hundreds of taggants survive, even for Power Primer, the most powerful cap-sensitive

Table 22.–3M Identification Taggant Survival Testing

Explosive	Detonation pressure K bars	Explosive weight, lb	Test site	Number of tests	Tags recovered (average)
Independent K	-10-40	1/2	4-ft diameter steel chamber	2	1,000
Coalite 8S	30-40	1/2	4-ft diameter steel chamber	10	1,000
		10 (part of composite 25-lb charge)	Open air, dirt, cinder floor	1	180
Gel coal	-25-40	3/4	4-ft diameter steel chamber	7	75
		10	10-ft cube concrete chamber, rock floor	1	4
Gel power A-2	- 4 0	1	4-ft diameter steel chamber	8	115
		10	10-ft cube concrete chamber, rock floor	1	10
			12x 20x 8 ft concrete bunker	3	1,450 (unencapsulated)
600/o Extra	50	1/2	4-ft diameter steel chamber	9	1,160
		5 (Part of composite 25-lb charge)	Open air, dirt, cinder floor	1	58
Tovex 800	70	1/2	12x 20x 8 ft concrete bunker	6	1,390 (unencapsulated)
400/o giant gelatin	75	1/2	4-ft diameter steel chamber	5	16 (some tests with encapsulated, some unencapsulated)
		1/2	12x 20x 8 ft concrete bunker	6	545
Specially sensitized emulsion	100	1/2	4-ft diameter steel chamber	12	620
Power Primer	135	1/2	4-ft diameter steel chamber	11	16
		1/2	12x 20x 8 ft concrete bunker	13	510 (unencapsulated)
		1	4-ft diameter steel chamber	6	3
		1	500 x 100 ft concrete pad	6	530
		10 (part of composite 25-lb charge)	Open air, dirt, cinder floor	1	4
		25	Open air, muddy, cinder floor	1	0
		25	500 x 100 ft concrete pad, rainy day	1	26

SOURCE Office of Technology Assessment

commercial explosive (excluding boosters).

2. As the size of the charge increases, the percent of surviving taggants decreases sharply, particularly for the most powerful explosives, Under optimum conditions, however, dozens of taggants still survive; even under rainy conditions 26 taggants were recovered from the 25-lb Power Primer tests.
3. Confinement sharply decreases survival, even under optimum recovery conditions. Only one test has been conducted with explosives confined in a pipe bomb (see chapter I I discussion); in that test scores of taggants were recovered from 60 Percent Extra Dynamite. When that result is compared to the chamber survival tests (in which over 1,000 taggants were recovered from 60 Percent Extra) it appears likely that considerably fewer taggants would survive in pipe born b detonations using one of the more powerful explosives.

Boosters, Military Exp osives

Commercial boosters are normally made from cast TNT or TNT-based explosives. These explosives have higher detonation pressures than even the most powerful cap-sensitive commercial explosives (180-200 kb v. 135 kb). Calculations by the Aerospace Corp. show that taggants will be raised above 4000 C, their decomposition temperature, by booster explosives. Testing showed fewer than two taggants recovered per pound of booster, even for tests conducted under ideal conditions on a large concrete pad. The Aerospace solution to the problem is to press the individual taggants and polyethylene into a large pellet (one-fourth inch). Tests show that approximately 65 taggants survive in a pound booster when pelletized into a one quarter-inch-diameter pellet. Initial recovery tests indicate that the taggants from boosters can be recovered, but far too few tests have been completed to allow a definitive judgment.

Military explosives are generally at least as energetic as boosters, presenting even more severe survival problems for the taggants. Due to the survival issue , the excessive cost of tagging military explos ives and their low frequency of use in criminal bombings, BATF does not plan to include military tary explosives in the taggant program.

Black and Smokeless Powders

Black and smokeless powders are much less energetic than the least energetic dynamite. Gunpowders are normally used as fillers for pipe bombs, however, so the effect of confinement is expected to be considerable, Tests with both black and smokeless powders were conducted in a 20-ft semicircular chamber having steel walls but a sand floor. Due to the poor recovery conditions, only 2 to 3 dozen taggants were recovered for the black powder bombs, and from O to 3 for the smokeless powder. When black powder bombs were detonated under near ideal recovery conditions, using the 8 ‘ x 12 ‘ x 20 ‘ bunker, an average of 1,100 taggants survived 1 lb of the FFFg powder. No ideal recovery tests have been conducted with smokeless powders, but the one pipe bomb test with explosives gives an indication that scores to hundreds of taggants should survive.

Detonators and Detonating Cord

Only the most rudimentary tests have been conducted of the survival of identification taggants when placed on a detonator and none conducted with detonating cord. As the taggants are placed outside of the explosive in both cases, sufficient taggants should survive to enable a positive trace to be made. How likely the taggants are to be recovered in real-world s ituat ions, however, cannot be ascertained without testing.

Summary

In summary, the 3M identification taggants survive the detonation of cap-sensitive high explosives in large numbers for small charges which are unconfined. Survival decreases as the charge size increases, but sufficient taggants should survive even a large charge of the most energetic commercial explosive. The effect of confinement significantly reduces taggant survival, but taggants can probably survive pipe bombs filled with low-energy explosives and gunpowder; their survival in pipe bombs filled with higher energy explosives is uncertain. Individual taggants do not survive booster detonation but pellets made from the taggants do. Taggants wou ld probably survive the explosion of detonators and detonating cord, but there is little or no test data.