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This paper was prepared for submittal to the
5th International Symposium on Analysis and Detection of Explosives
Washington, DC, December 4-8, 1995

January 1996

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Development of Non-Hazardous Explosives for Security Training and Testing (NESTT)

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Abstract

A series of materials has been prepared that have authentic properties of explosives but are non-hazardous. These NESTT materials are prepared by coating a few micron thick layer of an explosive on a non-reactive substrate. This produces a formulation with an authentic vapor and molecular signature. Authentic x-ray and oxygen/nitrogen density signatures are obtained through the appropriate choice of a substrate. The signatures of NESTT TNT and NESTT Comp. C-4 have been verified by instrument and canine (K-9) detection in a Beta Test Program.

Introduction

The security force at the Lawrence Livermore National Laboratory (LLNL) routinely used canines to search for explosives and other contraband substances. The use of threat quantities of explosive for realistic training in populated or sensitive Laboratory areas has not been permitted because of the hazard. To overcome this limitation a series of non-hazardous materials with authentic signatures have been prepared and evaluated.

Two classes of materials were made; one for K-9 detection studies and another for instrument detection studies. Authentic signatures were obtained by coating a small quantity of the parent explosive onto especially selected organic/inorganic substrates. The materials were non hazardous if the concentration of the parent explosive remained under approximately 15%.

Preliminary results were so successful that NESTT versions of two commonly used explosives were prepared in larger quantities for a Beta Test Program. The testing program involved both United States and foreign instrument companies and K-9 explosive detection units. This report describes the preparation, properties and preliminary test results obtained for NESTT versions of TNT and Comp. C-4.

*This work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-Eng-48.
Material Preparation

NESTT materials for use in the training and reinforcement of explosive detecting canines must have no additional odors present than those found in the parent explosive. To insure this, high purity fused silica was used as the substrate. NESTT materials for use in instrument detection studies used appropriate organic and inorganic substrates to match the parent explosive's x-ray signature and nitrogen/oxygen densities characteristic of explosives. The compositions of the three NESTT materials used in the Beta Test Program are listed in Table 1. They are preliminary versions of an "instrument" NESTT for Comp. C-4 and "K-9" NESTTs for TNT and Comp. C-4.

Table 1. NESTT Compositions Use in the Beta Test Program

<table>
<thead>
<tr>
<th>Name</th>
<th>Compositiona (wt %)</th>
<th>Density (g/cm³)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTN-01-AA</td>
<td>8% TNT 92% silica</td>
<td>0.97</td>
<td>This material has the K-9 odor &quot;signature&quot; of TNT</td>
</tr>
<tr>
<td>KTN-04-AA</td>
<td>8.0% RDX 9.2% DOA  2.7% PIB 3.6% oil 76.5% silica</td>
<td>1.54</td>
<td>This material has the K-9 odor &quot;signature&quot; of Comp. C-4.</td>
</tr>
<tr>
<td>IN-04-AA</td>
<td>7.4% RDX 78.5% cyanuric acid 8.3% DOA 3.3% PIB 2.5% oil</td>
<td>1.42</td>
<td>This material has the same effective atomic number as Comp. C-4; the oxygen/nitrogen density characteristic of explosives; and contains RDX. Its density is about 10% lower than that of Comp. C-4.</td>
</tr>
</tbody>
</table>

a TNT = 2-methyl-1,3,5-trinitrobenzene
RDX = hexahydro-1,3,5-trinitro-1,3,5-triazine
PIB = polyisobutylene
DOA = dioctyl adipate
Estane = polyurethane binder, (C₁₄H₂₈N₆O₁₉H₇₆)n

KTN-01-AA was prepared by dissolving TNT in acetone and then adding silica to this solution in a high shear mixer. The acetone was stripped off while mixing and the remaining solid was dried in an oven. This resulted in a granular material with a bulk density of about 1 g/cm³. Microscopic examination showed that some areas of the silica were coated and some had very small crystals of TNT adhering to the surface. Samples for testing were packaged in containers similar to those used for military demolition charges and also in plastic bags.

KTN-04-AA was prepared by first dissolving RDX in acetone and then adding silica to this solution. The acetone was removed using a rotary evaporator and the
granular product was then dried in an oven. Next, PIB, DOA, and oil were dissolved in pentane and combined with the granular RDX/silica material in a high sheer mixer. The pentane was stripped while mixing and the resultant putty like material was then oven dried. Bars measuring 2.5 x 5.0 x 30.5 cm were molded and encased in plastic. (Packaging was identical to the M 112 Comp. C-4 demolition bars produced by the Army.) Both bars and putty material supplied in plastic bags were used in the Beta Test Program.

IN-04-AA was prepared by dissolving PIB, DOA and oil in pentane. This solution, RDX and cyanuric acid were added to a high sheer mixer. The pentane was removed while mixing. The resultant putty material was dried in an oven and then was packaged like KTN-04-AA for use in the instrument portion of the Beta Test Program.

**Hazards Testing of NESTT Materials**

NESTT materials have been tested both in small scale laboratory safety tests and the larger scale United Nations (UN) approved hazards classification tests. In addition a large number of tests have been carried out by the Department of Defense (DoD) on both TNT and RDX mixtures with sand and other inert materials. As a result, Department of Transportation (DOT) has concurred that all mixtures of 8% or less of TNT or RDX with an inert are not classified as explosives (not Class 1 materials).

The small scale impact and thermal tests are summarized in Table 2. No positive reactions were observe on the drop hammer or spark sensitivity tests. The thermal stability results were similar to those of the parent explosive (TNT or RDX).

<table>
<thead>
<tr>
<th>Name</th>
<th>Impact Sensitivity</th>
<th>Spark Sensitivity</th>
<th>CRT Gas Evolution</th>
<th>DSC Exotherm</th>
</tr>
</thead>
<tbody>
<tr>
<td>KTN-01-AA</td>
<td>&gt;177 cm</td>
<td>no reaction</td>
<td>32 (cm³/kg)</td>
<td>&gt;200 C</td>
</tr>
<tr>
<td>KTN-04-AA</td>
<td>&gt;177 cm</td>
<td>no reaction</td>
<td>100 (cm³/kg)</td>
<td>&gt;200 C</td>
</tr>
<tr>
<td>IN-04-AA</td>
<td>&gt;177 cm</td>
<td>no reaction</td>
<td>50 (cm³/kg)</td>
<td>&gt;200 C</td>
</tr>
</tbody>
</table>

a 2.5 kg Type 12 anvil.
b 1J with 510Ω in line resistance.
c Chemical reactivity test. Gas produced during 22 h at 120 degrees C.
d Differential scanning calorimetry. 10 degrees C/min.

The NESTT materials containing TNT or RDX were submitted to UN large scale sensitivity tests. The materials did not react in the shock sensitivity tests or the fire tests. Similar results were obtained by the DoD when testing mixtures of 15% or less of TNT or RDX mixed with sand in the UN zero-gap shock test or the DDT test.
NESTT Instrument Test Results

The Naval Research Laboratory (NRL) is developing methods to detect explosives using nuclear quadrupole resonance (NQR). They were provided samples of both of the RDX-containing NESTT materials. They found a $^{14}$N NQR resonance at 3.41 MHz for RDX in NESTT identical to that determined for RDX in Comp. C-4. The line width of this resonance is in the range of those seen for RDX in actual explosive compositions (Figure 1). These results for NESTT Comp. C-4 and real Comp. C-4 were obtained by Quantum Magnetics¹ using a prototype detector made under NRL license.

NRL has also made preliminary measurements with NESTT TNT. Eleven $^{14}$N NQR lines were observed. The frequency of the lines agree with the literature values for the monoclinic phase of TNT. Their report indicates that the non-hazardous NESTT materials are "extremely useful in the laboratory and in conducting on-site demonstrations".

Figure 1. Nuclear quadrupole resonance spectra (amplitude in microvolts) for explosive Comp. C-4 and NESTT Comp. C-4.

Both TNT- and RDX-containing NESTT materials were tested by Thermedics Inc.² using their EGIS detection system. Vapor and particulate samples are collected and explosives are identified by analysis of selected decomposition products. The NESTT materials were carried to the Thermedics' laboratory in a brief case. The results indicated the presence of explosive, not only in the NESTT sample itself, but also on the courier's hands and the briefcase containing the materials (Figure 2). The following day an explosive detecting K-9 being trained by the Connecticut State Police also reacted positively to the then empty but still contaminated briefcase.
Figure 2. Thermedics' chromatographic analysis (in arbitrary units) of the samples obtained from: the courier's (author's) hands prior to opening the briefcase and from the briefcase containing "sealed" NESTT samples. Note: DNT (dintrobenzene) is present in TNT as a normal contaminant.

The instrument NESTT Comp. C-4 was tested on both Invision's and VIVID's x-ray explosive detection equipment. Both gave positive results indicating that NESTT had the same effective atomic number and density as a real explosive sample. Figure 3 shows the VIVID instrument's screen display for the NESTT samples to be the same as for their calibration samples.

Figure 3. NESTT Comp. C-4 as viewed by VIVID's x-ray detection equipment.
NESTT K-9 Results

In contrast to instruments, the method by which canines detect explosives is not well understood. There are a variety of explosive storage, explosive packaging and canine training procedures used worldwide. Tests with NESTT TNT (KTN-01-AA) and NESTT Comp C-4 (KTN-04-AA) provided a unique opportunity to gain some insight into the effectiveness of the various procedures since the same material from a single batch was provided to all the participants.

NESTT canine test samples were carefully formulated as described above and packaged to ensure that their "odor signatures" were the same as for uncontaminated parent explosives. Silica fused at high temperature was used as the NESTT materials substrate and also as the packing material for shipping the samples. This minimized the possibility of "odor signature" contamination by other organic compounds. As an "odor signature" check, mass spectrometer analyses showed that the vapor collected from TNT was identical to that from the NESTT TNT.

The test program involved over 150 handler/K-9 teams from the US and foreign agencies listed in Table 3. Over 85% of the teams reported that the canines reacted to the NESTT materials in the same manner as they do to the parent explosive.

<table>
<thead>
<tr>
<th>In the United States</th>
<th>In Foreign Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Force Military Working Dogs</td>
<td>UK Defense Research Agency Dogs</td>
</tr>
<tr>
<td>Navy Military Working Dogs</td>
<td>Israeli Police Dogs</td>
</tr>
<tr>
<td>Secret Service Dogs</td>
<td>German Custom Dogs</td>
</tr>
<tr>
<td>Atlanta Police FAA Dogs</td>
<td>German Police Dogs at:</td>
</tr>
<tr>
<td>Connecticut State Police Dogs</td>
<td>Nordrhein-Westfalen</td>
</tr>
<tr>
<td>ATF-trained Egyptian Police Dogs</td>
<td>Rheinland-Pfalz</td>
</tr>
<tr>
<td>ATF-trained Chilean Police Dogs</td>
<td>Baden-Wurttemberg</td>
</tr>
<tr>
<td>ATF-trained Israeli Police Dogs</td>
<td>Brandenburg</td>
</tr>
<tr>
<td>LLNL Dogs</td>
<td>Munich</td>
</tr>
</tbody>
</table>

A few of the agencies have used only the two NESTT materials to train new canines. In all cases after this training, the canines were able to detect reliably samples of the parent explosives, TNT and Comp C-4.

These results coupled with vapor analysis verify that the NESTT materials have authentic "odor signatures". Studies are now under way to see if the small number of negative results obtained could be due to contamination of the training samples in storage and handling over a period of time. Samples with changing "odor signature" that are used with a repeated reward to reinforce performance could be confusing the canines.
NESTT’s Role in Counter-Terrorism Programs

The beta test program results show that using NESTT materials can benefit explosive detection programs. For canine training, their use would make it economically feasible to minimize the possibility of sample cross contamination. Because of their non-hazardous nature they can easily be stored separately and not, as is now often done, in a centralized explosive magazine.

Realistic sites and scenarios could be used safely and economically for training canines. The NESTT materials could be stored nearby the training sites and not in remote explosive magazines. Moreover, large quantities could be used in training for the detection of car or truck bombs.

NESTT materials would aid in the development of instruments for detecting explosives. Only a limited number of companies now have the ability to use and store realistic threat quantities of explosives in their facilities. NESTT materials eliminate this constraint by providing the developer with “real” materials in sufficient quantity to use in their program.

NESTT materials would play an important role in economically implementing reliable explosive detection systems and procedures in high threat areas such as airports and government facilities. Training personnel and evaluating system effectiveness presents many problems if actual threat quantities of explosives are used in these facilities. The use of non hazardous, yet authentic signature, NESTT materials circumvents this, resulting in more reliable and cost effective explosives detection.

References

1. Quantum Magnetics, 11578 Sorrento Valley Rd., San Diego, CA 92121.
4. VIVID Technologies Inc., 590 Lincoln St., Waltham, MA 02154.