MDNT: IM MELT PHASE ENERGETIC BINDER

Omar Abbassi, Philip Samuels, Paul Anderson, Daniel Iwaniuk, Christopher Choi
US Army ARDEC
Picatinny Arsenal, NJ

ABSTRACT

As the push for Insensitive Munition (IM) compliancy in munition systems continues, the maturity of DNAN-based High Explosive (HE) solutions have contributed to significant improvements over their legacy counterparts. However, a technology gap still exists as the output of the DNAN-based IM HE formulations limits their ability to meet the lethality requirements of several munition systems. A promising high-output melt-phase energetic binder that has been evaluated in recent years is 1-methyl-3,5-dinitro-1,2,4-triazole (MDNT). In screening tests MDNT was demonstrated to have detonation velocity similar to that of Composition B, while simultaneously having shock sensitivity below that of TNT. Follow-on testing confirmed the performance output of MDNT, and additional shock sensitivity testing illustrated very promising trends. Pushing the envelope for high-output formulations capable of being utilized in shaped charge applications, formulations with HMX demonstrated exceptional performance; comparable to PBXN-9 and approaching LX-14. Characterization and demonstrations included a side-by-side comparison to LX-14 in testing utilizing a 3.2" Generic Shaped Charge Testing Unit (GSTCU). Although ARDEC views MDNT as an energetic melt phase material capable of bridging the technical gap between performance and sensitivity, it is no longer being pursued due to repeated dermal sensitization occurrences.

INTRODUCTION

MDNT was first synthesized in lab scale quantities by one of the national lab partners of the Army, and was selected for further evaluation under an OSD joint funding program. Further quantities of MDNT were produced by ARDEC synthetic chemists and BAE Holston supporting small scale performance and sensitivity characterization. A subsequently funded effort focused on a scalable synthetic process to produce MDNT. That process was developed and matured at the lab scale at Nalas Engineering, and subsequently demonstrated at intermediate and pilot scales at BAE Holston. A total of approximately 45 lbs of MDNT was produced to support the latter phases of the effort; the development and characterization of a meltable IM formulation for anti-armor warhead (AAW) applications.

Formulation efforts with HMX demonstrated a melt-cast explosive with performance properties rivaling legacy explosives such as PBXN-9 and LX-14. However, due to the limited quantities of MDNT available, a processing method was never fully realized to achieve high quality casts. Shock sensitivity and performance remained un-optimized due to the relatively low casting densities achieved and it was anticipated that similar un-optimized results would be observed in larger-scale IM and performance demonstrations without a formal casting study and analysis.

RESULTS AND DISCUSSION

MDNT Melt-Phase Characterization

MDNT has been characterized via several sensitivity and performance tests, and although the casting density was not optimal, the results illustrate benefits to sensitivity without drawbacks to performance.

Diameter (inches)	Type	% TMD	DV (km/s)	CJ (GPa)
0.50	Cast	90.0	> TNT < Comp B	> TNT < Comp B
0.75	Cast	94.7	> TNT < Comp B	> TNT = Comp B

Table 1 – Detonation Velocity Comparison

Formulation	TMD%	Gap (in)	Shock (kbar)
MDNT (IHE)	83%	= TNT	= TNT
MDNT (LSGT)	89%	< TNT	> TNT

Table 2 – Shock Sensitivity Comparison

Although the samples that were cast for testing were lower than 95% TMD (Table 1), the output for detonation velocity and detonation pressure resulted in values at or exceeding predictions. Additionally, the 0.50" diameter test resulted in a high order detonation. This indicates that the critical diameter is below 0.50 inches. This also validates the result of the LSGT below that of TNT (Table 2), and allowed for shock sensitivity evaluation in an IHE gab tube as the diameter of 0.50 inches for that test is larger than the critical diameter of MDNT.

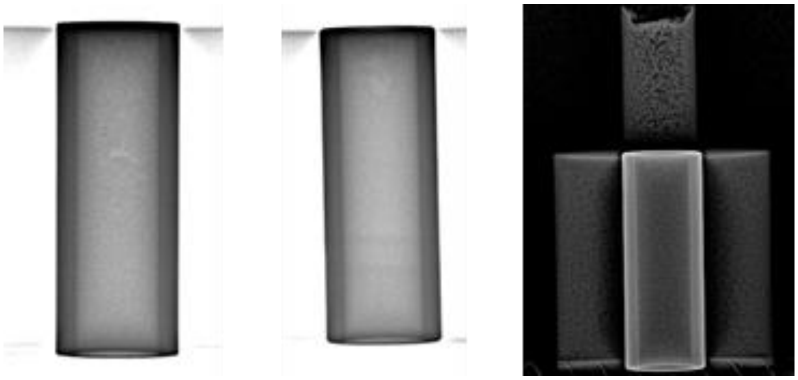

Figure 1 – MDNT IHE Tube X-Rays

The IHE tubes had a lower than desired density at only 83% of TMD. Generally this has a negative effect on shock sensitivity; however, the testing proceeded forward. Testing showed a shock sensitivity on par with that of TNT. The LSGT data previously showed more favorable results with a TMD of 89%. Although the IHE shock sensitivity is higher than preferred, it was not unexpected given the density and porosity in the test assets.

Figure 2 illustrates that for multiple materials or formulations, density/TMD is a critical parameter to reduce shock sensitivity. The increased slope for MDNT and TNT illustrate that this effect is more pronounced for melt-phase casted samples. MDNT is in need of a casting study to determine and optimize the processing parameters for all tests and applications. Once optimized, an accurate characterization of the shock density can be performed. Extrapolating the data for MDNT in Figure 2 illustrates that a superior shock sensitivity may be expected at a TMD above 90%.

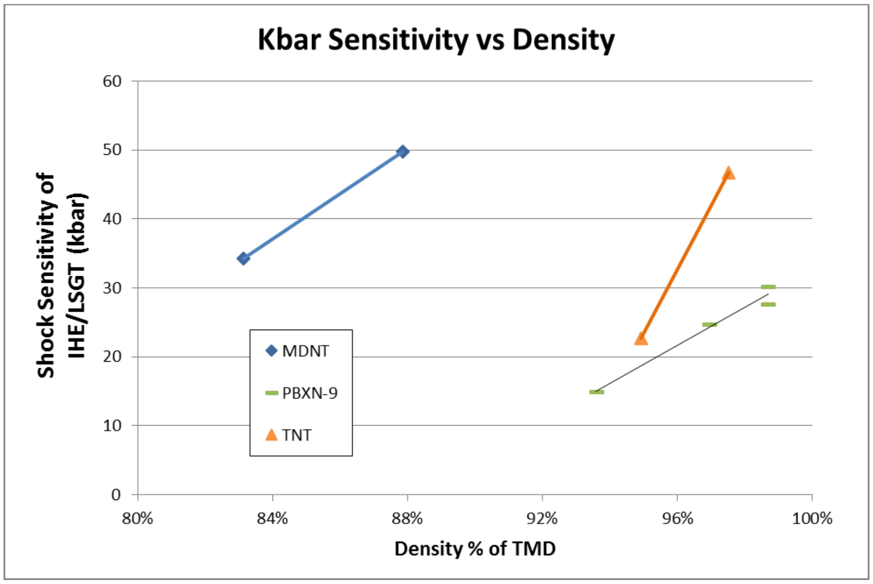

Figure 2 – Shock Sensitivity vs Density

MDNT Melt-Phase Formulation Characterization

Similar to what was observed with casting density for neat MDNT characterization, the formulation test assets for characterization also showed porosity, resulting in casting densities at or below 92% TMD.

A formulation with a significant amount of HMX was selected for characterization. Assets were prepared to evaluate detonation velocity, detonation pressure, cylinder expansion, and IHE shock sensitivity. Testing at the low density levels illustrated performance at PBXN-9 and LX-14 levels with similar shock sensitivity. Although the performance should be further optimized, the real advantage with improved casting densities would be the shock sensitivity gains, as the results are likely indicative of the porosity in the test samples.

Formulation	Gurney E (cal/g)	VoD (km/s)	Pressure (Gpa)
MDNT	NA	= Comp B	= Comp B
MDNT-HMX	= PBXN-9 < LX-14	= PBXN-9 < LX-14	> PBXN-9 > LX-14

Table 3 - Performance Comparison to PBXN-9, LX-14

The shock sensitivity of the MDNT-HMX formulation was characterized by the IHE gap test. Testing at a density of 92% TMD had a shock sensitivity equivalent to that of PBXN-9.

Formulation	TMD %	Gap (in)	Shock (kbar)
MDNT	83%	= TNT	= TNT
MDNT-HMX	92%	= PBXN-9 < LX-14	= PBXN-9 > LX-14

Table 4 – Formulation IHE Comparison

Prior to performing full scale engineering FI testing on the MDNT-HMX formulation, samples were subjected to a sub-scale fragment impact testing developed and performed by the Navy. The sub-scale FI test was developed under a Joint OSD funded effort in which the thickness of a cover plate can be varied and is tested against a Self Forming Fragment (SFF).

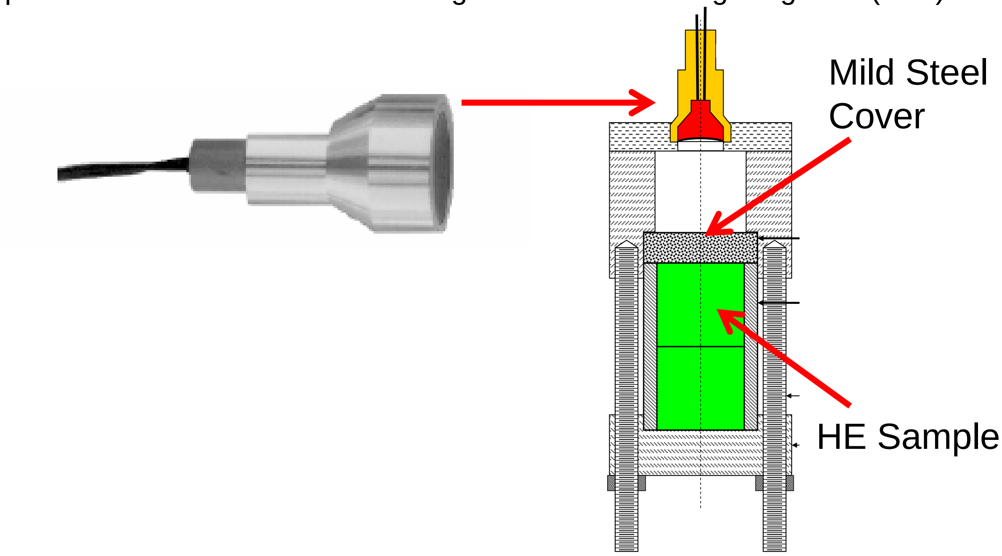

Figure 3 – Sub Scale FI Screening Test Setup

The sub-scale FI test results (Table 5) were performed on MDNT-HMX samples at 92% TMD. The samples (figure 4) had relatively high levels of porosity, which would likely make it difficult to mitigate a penetrating threat. At plate thicknesses of 0.375" and 0.5," the MDNT-HMX formulation reacted similarly to what was observed for LX-14. The data suggests that the formulation was expected to perform similarly to LX-14 in mitigating a fragment impact threat.

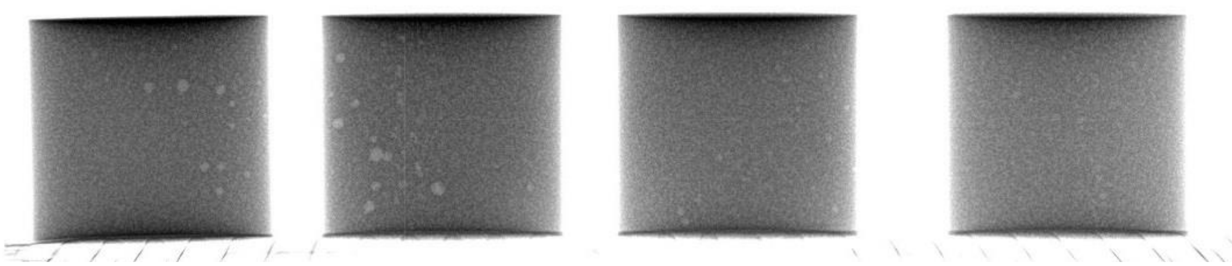

Figure 4 – X-ray of MDNT-HMX samples with visible porosity

Formulation	Results w.r.t. Cover Plate Thickness (inches) for Single Liner in SFF		
	1/4	3/8	1/2
MDNT-HMX		Explosion	Explosion
LX-14	Deflagration	Explosion	Explosion, 17% of sample recovered

Table 5: Sub-Scale FI Testing Comparison

Final testing of the MDNT-HMX formulation was to demonstrate its ability to mitigate FI in a generic shaped charge testing unit (GSTCU) engineering IM test, and to push a 3.2 inch GSTCU. The formulation was loaded into the GSTCU, then encased in both a thin 0.5 mm aluminum liner and a thicker 12.5 mm aluminum outer casing (Figure 5).

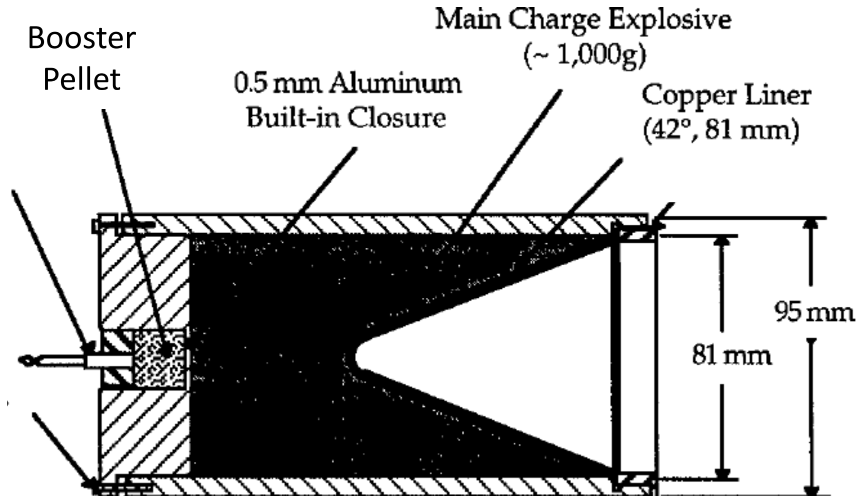

Figure 5 – 3.2" GSTCU encased in 12.5 mm aluminum

The fragment impact testing was conducted at 6000 fps and was performed in a side-by-side comparison to LX-14. Testing was performed with the test assets in a horizontal position, with the shaped charge directed towards a stack of two 2-inch witness plate. Both the MDNT-HMX and the LX-14 test articles initiated high order when impacted by the 6000 fps fragment. In both cases, the shaped charge formed and penetrated through or into the 2nd witness plate. Pressure traces from both tests provided further evidence of a full Type I detonation.

As both assets detonated high order, the fragment speed was maintained at 6000 fps for the remainder of the test series rather than increasing to the current standard of 8300 fps. The first series of tests was duplicated, with the inclusion of a plastic 6mm Particle Impact Mitigation Sleeve (PIMS) liner. The PIMS technology was developed under a separate Joint OSD funded effort, using plastic sleeves to mitigate the fragment threat. In this configuration, the LX-14 test resulted in a splatter of high explosive (HE) onto the witness plates with no evidence of the shaped charge liner forming. The liner was recovered, as were several pieces of the casing. For the MDNT-HMX test article, the test was very similar to the baseline test shot with a high order reaction; the liner slug formed and penetrated the 2nd side witness plate, with pressure traces indicative of a high order Type I detonation.

The testing with the 6mm PIMS liner was repeated and the test results were essentially duplicated, with the LX-14 test article resulting in an estimated Type IV reaction and the MDNT-HMX test article displaying a full Type I detonation reaction.

Test Asset	PIMS	Steel Plates	P1/4 20ft (psi)	P2/5 40ft (psi)	P3/6 60ft (psi)	Estimate Rxn
LX-14-581	None	Through Hole	4.73/6.78	2.42/2.44	1.21/1.80	Type (I)
MDNT-HMX-1	None	Slug in 2nd plate	4.22/5.30	2.23/2.45	1.02/1.30	Type (I)
LX-14-587	6mm	HE Splatter	0.46/0.31	0.18/0.21	0.14/0.14	Type (IV)
MDNT-HMX-4	6mm	Slug in 2nd plate	3.44/3.77	1.91/2.03	1.18/1.19	Type (I/II)
LX-14-593	6mm	HE Splatter	0.53/0.35	0.25/0.25	0.17/0.13	Type (IV)
MDNT-HMX-2	6mm	Through Hole	3.40/3.58	2.21/2.13	1.26/1.15	Type (I)

Table 6: FI Testing Summary

The FI testing series illustrated that although the shock sensitivity was reduced as compared to LX-14, the explosive in combination with the PIMS liner did not mitigate the FI threat. As the same combination mitigated the threat with LX-14, the data suggests the Type I detonation results were attributed to the porosity within the test articles.

The final testing conducted was a performance demonstration within the 3.2-inch GSTCU. The generic shaped charge measures penetration through steel at a stand-off distance of a given number of charge diameters (CDs). It is meant to be a down-selection tool that leads into a liner design program for a given HE. The plan was to conduct the penetration performance test at 5 CDs to minimize variability. An in-house LX-14 baseline was conducted as well.

The penetration depth of the MDNT-HMX loaded GTSCUs was approximately 86% of the depth of the LX-14 in-house tests at a stand-off of 5 CDs. This was a positive result considering the formulation contains less HMX by weight, as compared to the LX-14 formulation. It is understood that the liner design is not optimized for the explosives being compared, but it is a good indicator of how well the formulation performed. An MDNT formulation with a higher concentration of HMX, coupled with a proper liner redesign effort, may meet or exceed PBXN-9 and LX-14 penetration.

Explosive	Avg Penetration Depth	Shot 1 Depth	Shot 2 Depth
MDNT-HMX	86% of LX-14	81% of LX-14	91% of LX-14
PBXN-9*	90% of LX-14	NA	NA
LX-14*	91% of LX-14	NA	NA

Table 7: 3.2” GSTCU Penetration Depth at 5CD in Steel as compared to ARDEC LX-14 Results. *PBXN-9 and LX-14 from IMAD Report

With the conclusion of the testing performed, two things were evident. First, the performance output of a MDNT-HMX formulation was approaching LX-14 levels. Second, for the true IM benefits to be obtained, a process to eliminate/reduce porosity to achieve higher density, higher quality assets was paramount.

The MDNT and MDNT-HMX formulation show higher than anticipated shock sensitivities, due to the low density of the samples. Data exists with several explosives where a shift in as little as 3% density results in a 25 to 47 card difference.

Efforts to Increase Density and Eliminate Porosity

The transition to a follow-on effort was to demonstrate an MDNT-HMX based HE in AAW performance applications, against fragment impact and slow cook-off IM threats. The initial focus was placed on methods to increase the density of test assets through improved casting processes.

Lab pours were conducted on MDNT where the pouring temperature was reduced to the melting point of MDNT, between 94°C and 95°C. Additionally, the metal parts were pre-heated to 90°C to minimize the delta-T in the process. Two sets of pours were conducted: first on neat MDNT and second on MDNT with a processing additive.

Water density measurements were used to determine the density of the casts. A 100% TMD baseline was established by HE pychnometery. Discounting the riser sections, the density of the neat MDNT cast was calculated to be 98.3% of TMD (Figure 6). For the MDNT containing the processing additive, the baseline TMD was also determined by HE pychnometery. The casting disregarding the riser sections had a measured density of 97.6% of TMD (Figure 6). In both scenarios, lab pours illustrated a much high density than previous pours (83-92% TMD).

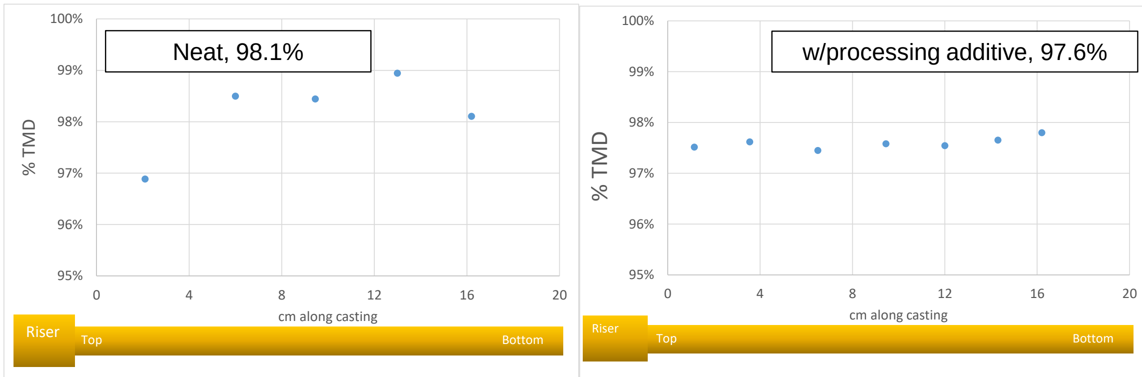

Figure 6 – Density of Lab Pours: MDNT (left), MDNT with processing additive (right)

Vapor Pressure and Dermal Sensitization

Casting quality results in the lab were not able to be duplicated on the pilot scale utilizing similar pouring and metal parts temperatures on the initial trial. Plans were set to continue with a set of experiments varying pouring temperature, metal parts temperature and cooling conditions. However, cases of dermal sensitization and irritation were investigated prior to continuing.

One of the major factors likely contributing to both the poor casting quality and the dermal sensitization is the vapor pressure of MDNT (DNMT in Figure 7). The vapor pressure exceeds that of most other melt phase materials. In previous investigations, efforts with another novel high vapor pressure melt-phase material were terminated as the high vapor pressure was causing crystallization outside of the melt kettle. While MDNT was not crystalizing outside of the melt kettle, operators did note that MDNT was quite volatile as the MDNT fumes were present throughout the melt-pour facility after handling and processing with MDNT. Furthermore, this phenomenon was evident even when opening a bag containing dry powder in preparation for pours.

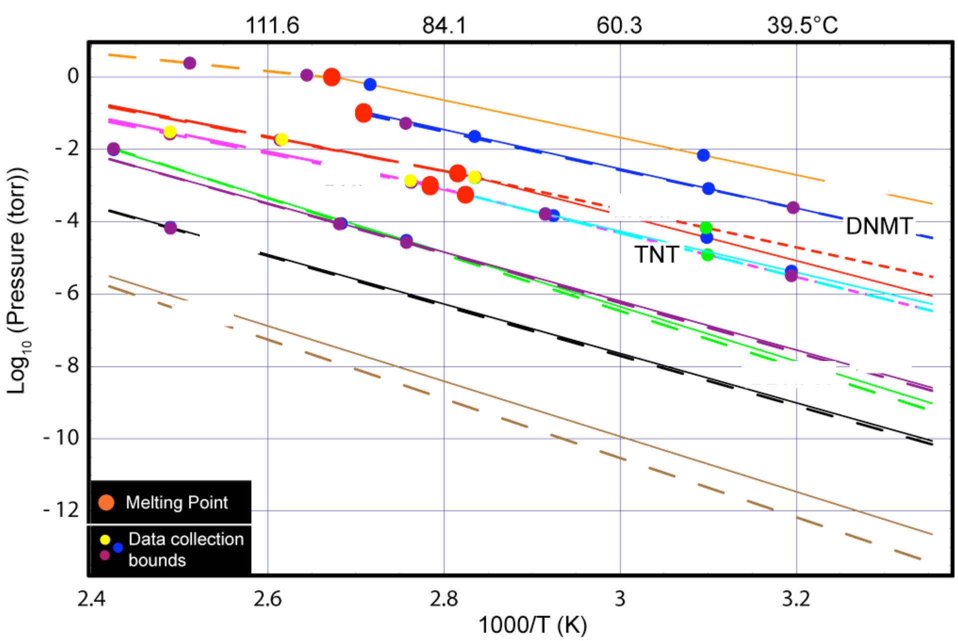

Figure 7 – Vapor Pressure of Explosives

The high vapor pressure of MDNT may explain the difficulty in obtaining high quality casts. As the temperature required for melt casting MDNT is increased, the vapor pressure becomes sufficient to overcome atmospheric pressure, thus, causing the liquid to form vapor bubbles inside the bulk of the material. However, since the temperature for casting is not dramatically increased above the melt temperature of MDNT, and the melt pour was done at atmospheric pressure, the vapor bubble formation is limited to shallow depths within the castings. This could explain the voids and porosity evident in X-rays of testing assets and why the porosity is only seen in the top-half of these assets (Figures 1, 4). Similar materials were cast side-by-side in grenades with similar casting parameters, and the excess porosity of MDNT in comparison to other materials is evident.

In addition to the porosity, multiple cases of dermal irritation had occurred with effects being heightened to subsequent exposures. This is mitigated with proper PPE during processing and handling, however, cases of skin sensitization were evident even during post-inspection procedures. After a visual inspection of the booster cavity of a finished grenade at room temperature, symptoms of skin irritation were present on an employee's neck. The sensitization during such limited exposure raises health concerns during the entire life-cycle of the material in a munition system or application.

SUMMARY AND CONCLUSIONS

MDNT has been demonstrated in several performance tests to have output similar to Composition B. In formulations with HMX, performance testing has demonstrated output rivaling PBXN-9 and approaching LX-14. In addition to performance, the shock sensitivity of MDNT projects well, although it was not realized in the engineering FI testing completed to date.

The major technical challenge and detriment was the processing optimization for preparing test assets with MDNT. Lab pours have illustrated that by controlling and tailoring the temperature of the process, high density casts can be achieved. This was never realized on pilot scale equipment as vapor pressure and dermal sensitization issues were prohibited. Although ARDEC views MDNT as an energetic melt phase material capable of bridging the technical gap between performance and sensitivity, it is no longer being pursued due to repeated dermal sensitization occurrences.

ACKNOWLEDGMENTS

The authors would like to thank the personnel at ARDEC for their efforts in planning, supporting and executing the testing of MDNT and its formulations in this effort. The authors would also like to thank the teams at Nalas Engineering and BAE Systems for their efforts in developing and scaling-up the synthesis of MDNT, as well as the Joint Insensitive Munition Technical Panel program office and the Program Executive Office for funding the majority of this work.