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Warhead Venting Technology Development for Cook-off Mitigation

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Insensitive Munitions (IM) warhead technology is being developed in order to survive unplanned stimuli produced by fires (slow & fast cook-off). The current effort is concentrating on venting design capability development through small scale laboratory hardware experimentation and computer modeling. Small scale venting experiments have been conducted using highly controlled thermal cook-off test fixtures. The small scale test fixtures consist of a small diameter (25mm) explosive pellet, highly confined in a steel housing. One end of the housing has a circular vent with an adjustable diameter. The steel housing is heated using four heating bands and electric current feed-back control based on measured thermocouple temperatures. These experiments characterize the explosive violence for a known venting area and controlled heating rate. From the data to date, PAX-28 and PBXN-109 required less vent area to achieve a non-violent response compared to Comp-B and solid explosives react violently without an IM venting liner that melts before the explosive reaction. Thermal modeling including explosive kinetics has been conducted using ALE-3D. The testing results are also being used to parameterize and develop analytic burn modeling of vented warheads.

INTRODUCTION

The U.S. Army Armament Research, Development and Engineering Center (ARDEC) is developing Insensitive Munitions (IM) warhead venting technology in order to survive unplanned stimuli produced by fires (slow & fast cook-off). Warhead venting for mitigating the violent response to unplanned thermal stimuli caused by fires or other heating sources is not a new concept [1,2,3,4]. However, explosive venting requirements characterization and quantification for different explosives and heating rates is generally lacking. As a result, warheads venting to date has been primarily developed using a purely experimental iterative testing approach for a given warhead and venting geometry. This type of approach can be very expensive and does not assure a well optimized and cost effective venting solution. In addition, each additional munition venting development essentially starts with virtually no information to aid in the venting design process. In order to address these concerns, Insensitive Munitions (IM) warhead venting technology development is being conducted. This effort is providing data and design capability for venting with the objective of reducing explosive violent response to unplanned stimuli produced by fires.

WARHEAD VENTING CONCEPTS

Venting techniques using melt venting and pressure rupture are being addressed. The melt venting techniques use vent plugs or thread adaptors that will soften or melt when heated in cook-off scenarios. The pressure rupture techniques use pressure blow-out plugs or thread adaptors that rely on pressure build-up from the explosive during a cook-off event. Pressure rupture applications must provide sufficient venting area and respond at low enough pressures to prevent explosive high burning rates associated with violent response. Another approach is the use of shape memory alloys to provide a mechanical venting response at a desired temperature. Warhead IM liner technology using melting materials is also part of the development. Such a liner is applied around the explosive billet between the explosive billet and the warhead case material. This liner is incorporated in order to provide a path for explosive products release to the vent positions, as well as to provide some initial volume for burning products in order to prevent extreme rapid pressurization. The liner melts in a cook-off event, before the explosive billet initiates burning. The melted liner material then flows and allows explosive products a path to the body vent positions, regardless of the ignition position. The concepts outlined are primarily passive venting techniques. Active venting techniques include some separate sensing, safe and arm, and activation technique in order to produce venting. One such active venting approach being pursued is the application of shaped charges to create a vent and promote explosive burning in order to produce a controlled munitions response. In order to have design capability for these warhead venting concepts, explosive burning and venting requirement characterization is required. Initial efforts are concentrating on laboratory scale experimentation for venting requirements characterization, as well as thermal modeling for the ignition onset.

SMALL SCALE LABORATORY FIXTURE

Venting design capability development through venting requirement characterization is being conducted using small scale laboratory hardware experimentation. Figure 1 presents a diagram of the small scale testing hardware configuration and photograph of the assembled test fixture. The small scale venting experiments use a highly controlled thermal cook-off test fixture very similar to non-vented experimentation conducted at Lawrence Livermore National Laboratories (LLNL) [5]. The small scale test fixtures consist of a small diameter explosive billet, highly confined in a steel housing. The inner chamber of the test fixture measures just over 25mm in diameter by 100mm long. The high explosive billet is either melt cast directly into the test cylinder or pressed/cure cast and than machined. All explosive billets are x-ray inspected for voids and cracks, and only used for testing if determined to be acceptable from the inspection. One end of the housing has a circular vent disc with an adjustable vent diameter. The vent disc, two o-rings, and sixteen bolts were inserted and assembled in the fixture. The bolts were torqued in a star pattern and the entire fixture is normally placed vent side up on a ceramic tile inside of the heavy steel cylinder located in the test chamber. Ceramic tiles were used as insulation between the fixture and steel floor to make it easier to control the fixture temperature. A mirror and light are then aligned to allow a camera to remotely record the vented side of the fixture through a viewing port located on the side of the test chamber. Normally, two test fixtures, with different vent diameters, are loaded into the chamber for each test. This is done simply to increase the testing through-put. Figure 2 presents the assembled test fixture in the chamber ready for testing. The steel housing is heated using four heating bands and electric current feed-back control based on measured thermocouple temperatures. Standard digital video cameras (30 fps) output images directly to the hard disk drive of a Panasonic DMR E-500H DVD video recorder via S-video cable. The hard disk drive feature of this recorder provided the opportunity to capture hundreds of hours of video at full resolution and frame rates without any risk of running out of recording space. A pair of cameras and Panasonic recorders are operated so that the reactions of both assemblies can be recorded simultaneously. These experiments characterize the explosive violence for a known venting area and controlled heating rate. Figure 3 presents an example of the inside of the chamber after one of the experiments in which one round exhibited a violent reaction and the other round did not. The standard test procedure is to increase and decrease the vent size in order to bracket a non-violent/violent reaction threshold. Normally, this can be done fairly quickly with a set of 8 test fixtures. To date, all tests have been conducted with a heating rate of a constant 28ºC (50ºF) per hour temperature increase. The choice was made to use a heating rate of 28ºC (50ºF) per hour, rather than a much slower cook-off rate of 3ºC (6 ºF) per hour commonly used, because it was considered to be a more realistic heating scenario for slow cook-off to be seen by U.S. Army ordnance [6]. Explosives tested to date include the melt cast compositions Comp-B and PAX-28, as well as the cast cure composition PBXN-109.

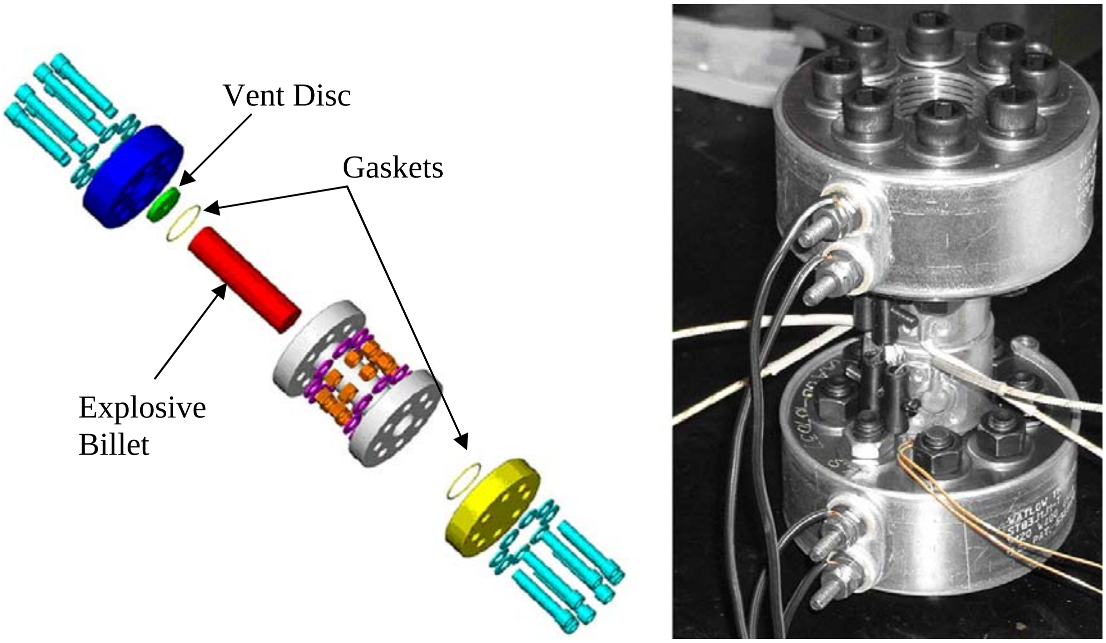


Figure 1: Small scale cook-off venting laboratory hardware configuration.

Figure 2: Assembled test fixture in the chamber ready for testing.

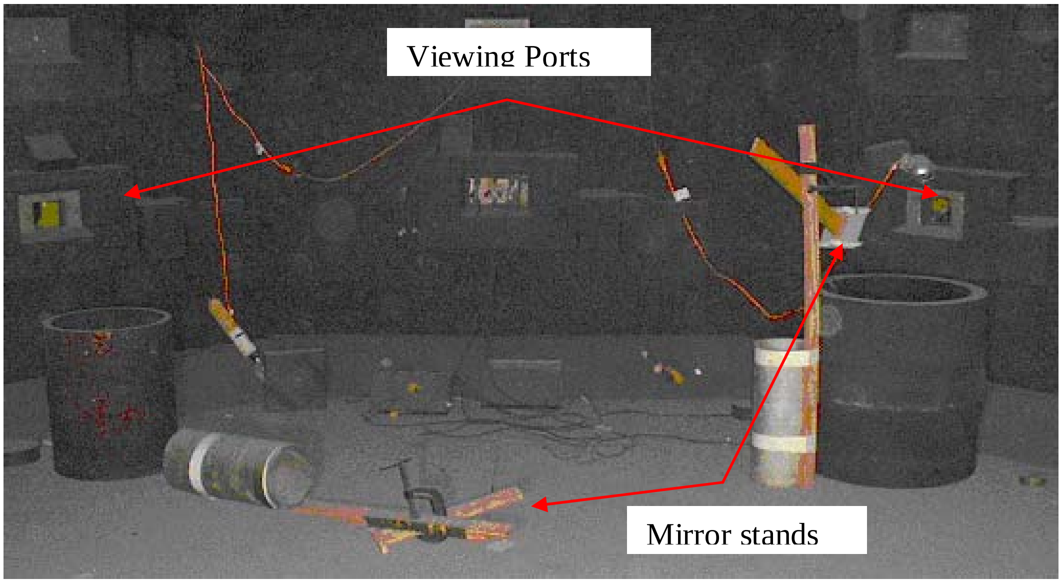


Figure 3: Test chamber post test – violent reaction on left, benign reaction on right.

SMALL SCALE LABORATORY TESTING

For melt cast formulations, the largest vent diameter reactions proceeded from melting with liquid formation at the top of the vent hole through bubbling to vigorous boiling and smoking and then on to burning. All hardware for large non-violent vent diameters has showed evidence of burning. For the non-violent tests, videos and surrounding evidence did indicate that burning had occurred, but the reactions were relatively benign resulting in no damage to both the test fixtures and the ceramic insulating tiles. Figure 4 shows the two largest vent diameters for PAX-28 during the vigorous bubbling and smoking phase. For these large vent diameters, the point of ignition appears to be somewhere in the center of the boiling pool of molten HE. Although the cameras used to record the event only operated at 30 fps, on a few occasions, initiation was captured early enough to indicate an approximate ignition location. Figure 5 presents photographs of the PAX-28 ignition. The burning period for the three largest vent diameter test cases extended for greater than thirty seconds, for the 7.6mm case, and over one minute for the 10.2mm and 12.6mm cases. Figure 6 presents the resulting test fixture from the PAX-28 7.6mm vent diameter case. Some amount of the melt cast explosive boils up and over the top and down the side of the test fixture, ending up in a molten but otherwise unreacted puddle next to and on the fixture.

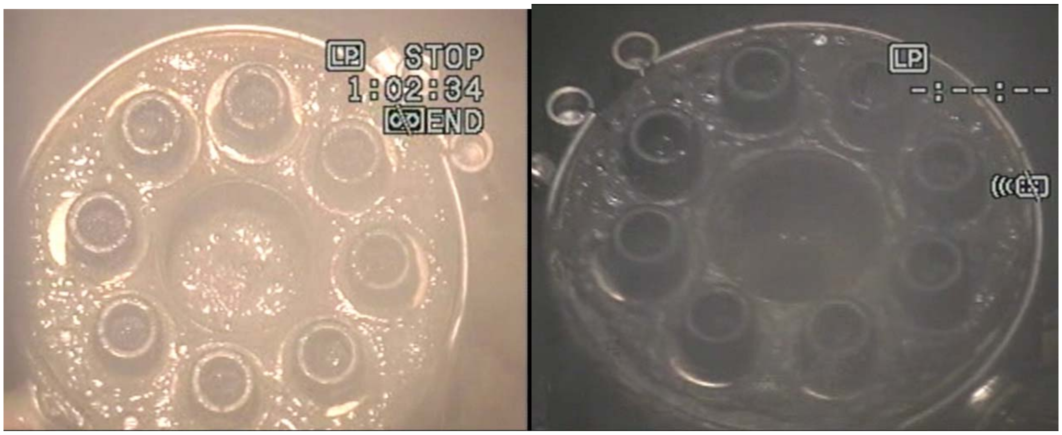


Figure 4. 10.2mm and 12.6mm vent diameters before ignition for PAX-28.

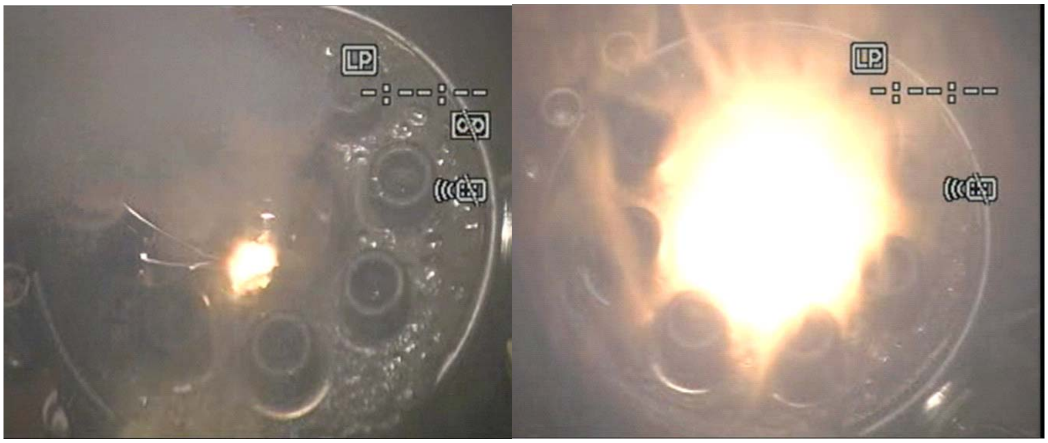


Figure 5. 10.2mm and 12.6mm diameter vent disc ignition for PAX-28.

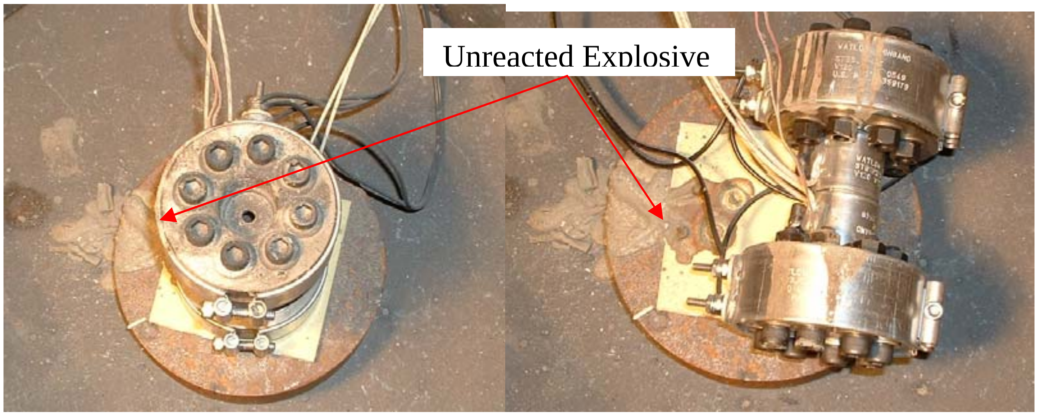


Figure 6. Two views of 7.6mm diameter vent hole test fixture post test

Hardware response for smaller violent producing vent diameters shows varied results from extensively damaging the test configuration to simply blowing off the end fixture. The result of the PAX-28 5.1mm diameter vent test was to blow off the top fixture and peel off three out of the four heating bands while leaving the fixture in its original position as seen in figure 7. However, the PAX-28 6.4mm diameter vent test yields a more typical violent result where the test fixture is blown open. Figure 8 shows the results of this test.

Figure 7. 5.1mm diameter vent test result for PAX-28.

Figure 8. 6.4mm diameter vent test result for PAX-28.

The only cast cure composition tested to date is PBXN-109. Initial testing was conducted using test samples that were machined to fit directly into the test fixture without a melt liner to surround the billet. Testing of this configuration with a large vent hole (12.7mm diameter) had a violent reaction. Subsequent testing was performed using a 0.76mm thick high density polyethylene (HDPE) liner which surrounded the entire explosive billet. The IM venting melt liners were made from HDPE by precision machining of rod material. Figure 9 presents a photograph of and the HDPE melt liner and associated explosive billet. Testing using the HDPE liner resulted in more consistent test results: smaller vent diameters resulted in violent response and larger vent diameters resulted in non-violent responses. Testing with other solid pressed explosives has also required the use of a melt liner to achieve consistent results. Table I presents a summary of Comp-B, PAX-28 and PBXN-109 test results. The results indicate that PAX-28 and PBXN-109 require less venting area than Comp-B to achieve a non-violent response.

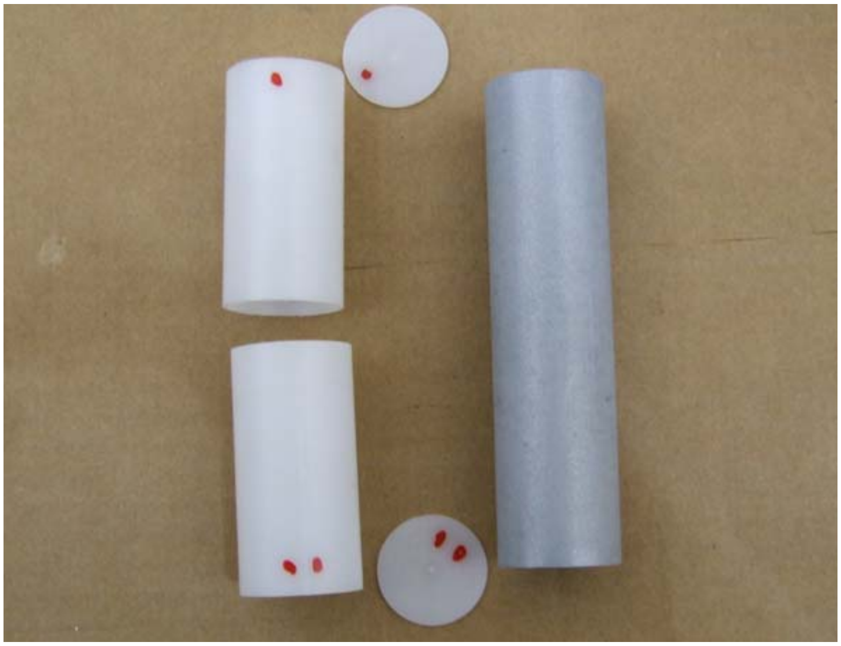


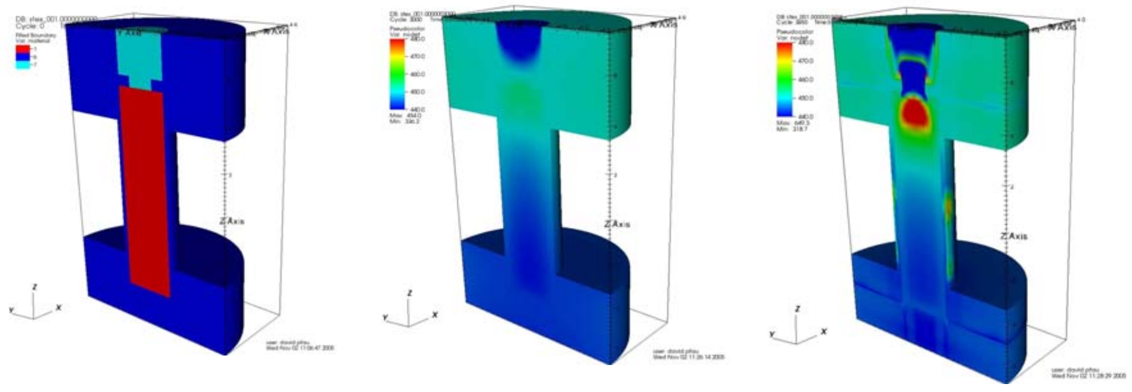
Figure 9. HDPE IM melt liner (left) and explosive billet (right).

Table I: Venting Experiments Summary

Explosive	*Go/No Go*	*Vent Size*	*Notes*	*T(ºF)*
Comp-B	Go	2.5	Throttle Plate Blown out	370
Comp-B	Go	5.1	Explode	400
Comp-B	Go	5.1	Fixture on Side, Violent, Bolts sheared, center burst	379
Comp-B	Go	10.2	Explode, top end plate came off,	376
Comp-B	No Go	10.2	Burn Off	390
Comp-B	No Go	11.5	Burn off, Fixture in one solid piece	362
Comp-B	No Go	12.7	Burn Off	415
Comp-B	No Go	12.7	Burn Off	375
Comp-B	No Go	12.7	Burn Off	400
Comp-B	No Go	20.3	Fixture on Side, Burn off, Fixture in 1 solid piece	378
PAX-28	Go	5.1	Explode, HE Boiled out, Top Endplate Blew off	375
PAX-28	Go	5.1	Explode, HE Boiled out, Top Endplate Blew off	371
PAX-28	Go	6.4	Explode, HE Boiled out, body banana peeled	352
PAX-28	No Go	7.6	Burn, HE Boiled out of fixture, Smoking, then Burn	376
PAX-28	No Go	10.2	Burn, HE Boiled out of fixture, Smoking, then Burn	365
PAX-28	No Go	12.7	Burn, HE Boiled out of fixture, Smoking, then Burn	345
PBXN-109	Go	12.7	No HDPE Liner, Exploded	390
PBXN-109	Go	5.1	HDPE Liner, Explode, Vent bent outwards	357
PBXN-109	No Go	5.8	HDPE Liner, HE Extruded, Nonviolent reaction	370
PBXN-109	Go	6.8	HDPE Liner, body cavity blown apart	363
PBXN-109	No Go	7.6	HDPE Liner, Burn, HE Extruded through vent	377
PBXN-109	No Go	10.2	HDPE Liner, Burn, HE Extruded through vent	352
PBXN-109	No Go	12.7	HDPE Liner, Burn, Some HE left in Fixture	367

COOK-OFF MODELING DEVELOPMENT

Thermal modeling of the laboratory venting experiments was conducted using ALE-3D. This modeling has been concentrating on the heat flow and predicted self heating due to thermal kinetics of the high explosive. PBXN-109 and TNT have been used for the modeling to date. A description of the LLNL developed ALE3D cook-off modeling methodology and associated explosive characterization has been previously published [7,8,9,10]. Figure 10 presents the 12.7mm diameter vent PBXN-109 ALE3D initial setup, along with color temperature plots just before and just after ignition. The predicted surface temperature at ignition onset was 181°C (358°F), comparing favorably with the actual experimental temperature at ignition of 185°C (365°F). It is interesting to note that the explosive initiation is predicted to occur at the vent position. At first this may seem counter to intuition, as at the relatively low heating rate of 28ºC (50ºF) per hour temperature increase one would expect initiation to occur at the most insulated position within the explosive billet, often near the explosive center. However, as there is no metal contact at the vent position, it is believed that the air acts an insulator, so that the most insulated position is actually at the vent position. The vent testing results are also being used to develop and validate analytic burn modeling.



Initial Pre-ignition Post-ignition

Figure 10. PBXN-109 ALE3D thermal modeling.

SUMMARY

Insensitive Munitions (IM) warhead technology is being developed in order to survive unplanned stimuli produced by fires (slow & fast cook-off). The current effort is concentrating on venting design capability development through small scale laboratory hardware experimentation and computer modeling. Small scale venting experiments have been conducted using highly controlled thermal cook-off test fixtures. These experiments characterize the explosive violence for a known venting area and controlled heating rate. From the data to date, PAX-28 and PBXN-109 require significantly less venting than Comp-B and solid explosives react violently without an IM venting liner that melts before the explosive reaction. Thermal modeling including explosive kinetics has been conducted using ALE-3D. The testing results are also being used to parameterize and develop analytic burn modeling of vented warheads. This new warhead venting technology is being transferred to the U.S. Army PEO Ammunition Insensitive Munitions Initiative, Warhead Venting Thrust. Under the Warheads Venting Thrust effort, the technology is being used for design capability validation on controlled large scale laboratory experiments and full scale venting concepts munitions demonstrations by General Dynamics Ordnance Technology Systems (GD-OTS) and Aerojet. This new technology is applicable to both gun fired and missile munitions (artillery, mortars, large and medium caliber, missiles and rockets).

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