

Insensitive Munitions Development for General Purpose Bombs

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ABSTRACT

The Air Force requires a 1.6 hazard classification of general purpose bombs to reduce restrictions posed by current quantity distance criteria, minimize storage hazards and to increase combat readiness. There has been a concerted effort by industry and Air Force explosive development teams to provide an energetic material which meets these requirements without compromising performance levels. Wax desensitized formulations, nitroguanidine-based formulations and, most recently, NTO-based formulations have been studied in melt-cast and polymeric systems. The relatively large critical diameter of many insensitive candidate formulations has generated a requirement for larger subscale evaluation techniques and practical means of predicting behavior in full-scale hardware. The eight-inch diameter gap test and modified expanded large-scale gap test have been calibrated. A relatively inexpensive technique for measuring casewall fragment velocities and deriving Gurney characteristic velocities has been developed. Experimental results are provided for the in-house candidate material currently in advanced development, TNTO. Hydrocode methods for predicting full-scale pressure and energy profiles in realistic storage configurations are ongoing. A comparison of experiments and calculations for MK-82 bombs in various geometrical arrangements is presented. These technologies and procedures are essential to accomplish the task of arming the services with insensitive munitions. Future munitions must be safe to handle and store while performing as required upon demand.

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Introduction

This is an overview of the Air Force advanced development program for insensitive munitions (IM) technology. The Air Force program focuses on desensitization of the explosive fill for the MK-82 general purpose bomb.

The discussion begins by reviewing the formal requirements documentation upon which this program is structured and by contrasting Hazard Classification Reduction and Joint Service Insensitive Munitions policy. The process used by the High Explosive Research and Development (HERD) facility to study new explosives for insensitive systems is explained. The balance of the paper provides a status report for the Air Force insensitive explosive candidate being developed in-house, TNTO. Finally, an in-depth look at the efforts to marry experimental results for prediction of sympathetic detonation with computational hydrocodes is also presented.

Requirements Documents

The US Air Force requirement for munitions exhibiting reduced hazards was first stated formally by the Air Force Logistics Command (AFLC) in their Statement of Need (SON)-02-83 (Reference 6) for Insensitive High Explosives in Air Munitions in 1983. Later, the Air Force Tactical Air Command (TAC) presented their requirement in TAF SON 309-88 (Reference 5). A Joint Service Insensitive Munitions (IM) policy was ratified in 1987.

AFLC and TAC-SONs

The constraints imposed by AFLC and TAC are severe and include:

- 1) Munition effectiveness must not be compromised;
- 2) Warhead configuration changes must be minimal;
- 3) The life cycle cost of a GP bomb system meeting reduced classification requirements must be no greater than that of existing items;
- 4) The main charge must be reliably initiated with existing fuzes and boosters;
- 5) The system must meet the requirements for Insensitive High Explosives (Hazard Class Division 1.6, Insensitive Articles).

AFLC SON 02-83 and TAF SON 309-88 address the fact that Air Force munitions are subject to the Department of Defense (DoD) hazard classification system which is derived from the United Nations (UN) Organization system. The number one priority for reduced hazard classification cited by AFLC, the general purpose (GP) bomb (see Figure 1), is included in Class 1 of this system reserved for explosives.

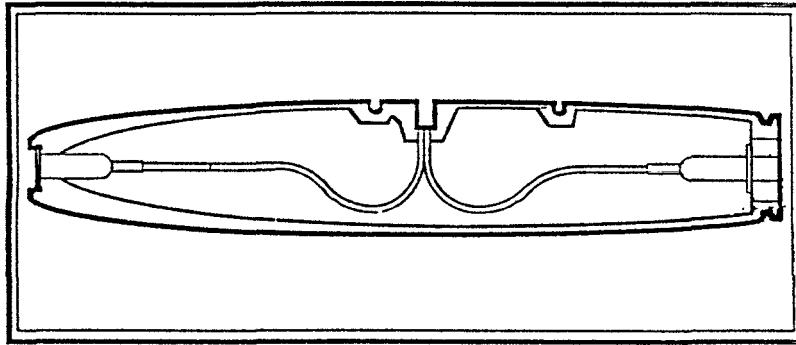


Figure 1. MK-82 500-Pound Bomb with 190 Pounds of Tritonal Explosive

Within this class, GP bombs are designated as Division 1.1, mass detonating (Reference 1). GP bombs are positioned based on the assumption that propagation of a detonation from a small portion of any stack will occur so rapidly that the combined shockwave has the damage-yield characteristics of a single, simultaneous event. This classification places severe restrictions on the number of GP bombs which may be stored near inhabited buildings and critical assets. As a result, only a small fraction of the available storage capacity is currently realized.

Department of Transportation (DOT) regulations impose constraints on transportation routes and carrier frequency for these 1.1 articles. The impact to operational readiness is severe. Munition assets are not available at forward air bases in USAFE or PACAF. If required, these items would need to be shipped from centralized storage depots, making them vulnerable and jeopardizing the Air Force Mission.

Besides the readiness factor, the additional cost of storing and transporting 1.1 munitions is prohibitive. The real estate required to provide clear zones for additional munitions must be purchased along with storage igloos. Potential savings of 263 million (1983) dollars for new construction existed in USAFE alone when AFLC SON 02-83 was penned. An additional 50 million dollars was available in PACAF.

Joint Service IM Policy

The policy statement outlining the joint service requirements for insensitive munitions were provided in a Memorandum of Agreement (MOA) approved in 1987 (Reference 7). This MOA was established as a result of individual service studies, including a report by the Scientific Advisory Board ad hoc committee confirming the urgent Air Force need. The IM policy is intended to make munitions systems and delivery systems more survivable. It is distinctly separate from the requirements in the Department of Transportation (DOT) storage and transportation regulations which the Air Force is attempting to meet.

1.6 Hazard Classification Requirements

The protocol for achieving the newly-created hazard classification, 1.6-insensitive articles, has been defined in Test Series 7 of the United

Nations Recommendations on the Transport of Dangerous Goods Tests and Criteria (Reference 3). In addition to the screening tests outlined in the DOD Ammunition and Explosives Safety Standards (DoD 6055.9-STD), Series 7 requires the tests shown in Table 1. Classification division 1.6 is reserved for articles containing only Extremely Insensitive Detonating Substances (EIDS), which "demonstrate a negligible probability of accidental initiation or propagation under normal conditions of transport" (Reference 4). EIDS are those materials which have passed the substance tests in Table 1. The blasting cap requirement makes 1.6 Hazard Classification of a fused system with conventional detonator/lead/booster initiation trains impractical. Initiation systems will:

- 1) continue to be stored separately;
- 2) be incorporated into systems where a Hazard Classification between 1.6 and 1.1 is acceptable; or
- 3) become electronic/mechanical with no sensitive materials in line. The 1.6 Hazard Classification requirement may be contrasted with the Insensitive Munitions test requirements also shown in Table 1.

**TABLE 1. 1.6 Hazard Classification
and Insensitive Munitions Testing Requirements**

<u>1.6 Hazard Classification Tests</u>	<u>Insensitive Munitions Tests</u>
<u>Substance</u>	<u>Substance</u>
Blasting Cap	Not required
Gap Sensitivity	
Susan Impact	
Bullet Impact	
Fast Cookoff	
Slow Cookoff	
<u>Article</u>	<u>Article</u>
Fast Cookoff	Fast Cookoff
Bullet Impact	Bullet Impact
Sympathetic Detonation	Sympathetic Detonation
Slow Cookoff	Fragment Impact*
	Slow Cookoff*
	Shaped Charge Jet*
	Spall Impact*

* Service specific based on a threat hazard analysis of the munition system being evaluated.

Testing procedures for the four tests common to both protocols are interchangeable. Fuel fire testing may be substituted for the external wood fire in the fast cookoff, although the latter is the method preferred by the United Nations.

Development Process

Figure 2 shows a flow chart of the Air Force in-house development process for candidate extremely insensitive detonating substances. Insensitive molecular materials are studied and then incorporated into

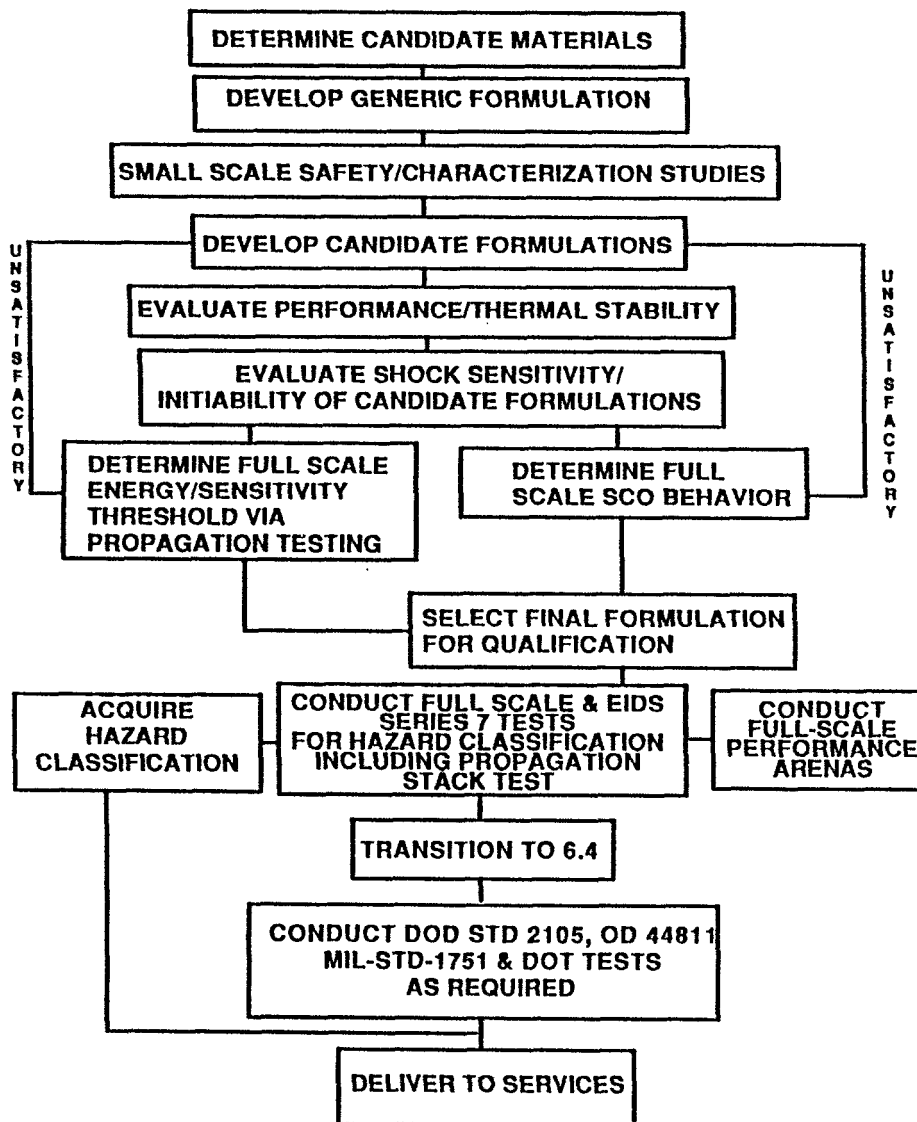


Figure 2. Air Force Insensitive Explosive Development Process

explosive formulations for further evaluation. The safety characterization and material compatibility studies shown in Table II are conducted prior to optimizing the formulation.

Table II. Safety Screening Tests

<u>Test</u>	<u>Criteria</u>
Differential Scanning Calorimetry	No exotherm at 250°C
Impact (Drop Hammer)	Sensitivity less than Explosive D
Electrostatic Discharge (spark)	No reaction at 0.25 Joule
Friction	No reaction
Vacuum Thermal Stability	Maximum 2 cc/g
Chemical Reactivity Test	Maximum 2 cc/g
Critical Temperature (Henkin)	

Thermal stability, shock sensitivity, critical diameter, performance and initiability are evaluated in small-scale and engineering scale units (8-inch diameter, 1/2 inch thick steel cylinders). If a formulation exhibits promising features, it is evaluated in the two most severe full-scale environments -- sympathetic detonation and slow cookoff. Acceptable cookoff behavior allows further sympathetic detonation testing to optimize the performance/sensitivity balance. Unacceptable cookoff behavior returns the developer to the formulation stage of the process. Once a final formulation is selected, it is subjected to the remaining environments prescribed by the United Nations for Hazard Classification.

Full-scale performance tests are conducted to obtain fragment velocity, size and spatial distribution and air blast in the warhead configuration of interest. Final qualification of explosives for Air Force application is accomplished in accordance with MIL-STD-1751 (USAF), Safety and Performance-Tests for Qualification of Explosives (Reference 8). This document supersedes NAVORD DD 44811 of the same title.

In parallel with in-house efforts, the Air Force has stimulated commercial industry involvement in explosives research and development. The output from this effort has been the development of several promising plastic bonded explosive (PBX) formulations.

Technological Challenges

To date, none of the formulations developed by the Air Force (in-house or via contract to industry) have met all the performance, sensitivity and initiability requirement simultaneously. These parameters, coupled with the necessary cost constraints for general purpose bomb fills, have made the challenge of developing insensitive high explosives seemingly insurmountable. Less sensitive forms of existing molecules, formulation desensitizers, alternate storage configurations and improved package designs along with new, less sensitive energetic molecules are a few of the technologies which have emerged from efforts by Department of Defense (DoD) and Department of Energy (DoE) laboratories as well as commercial research groups to meet this challenge. The background and test results for the insensitive explosive candidate developed in-house by the Air Force, TNT0, are presented in the following section of this report. This formulation shows promise of striking the proper balance to meet the requirements stated above.

TNTO

Desensitization of formulations with inert binders compromise performance parameters. It is preferable to employ less sensitive energetic molecules. One such molecule is 3-Nitro-1,2,4-Triazol-5-one, commonly called nitrotriazolone or NTO (see Figure 3).

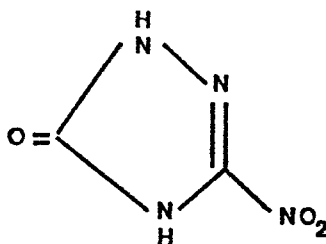
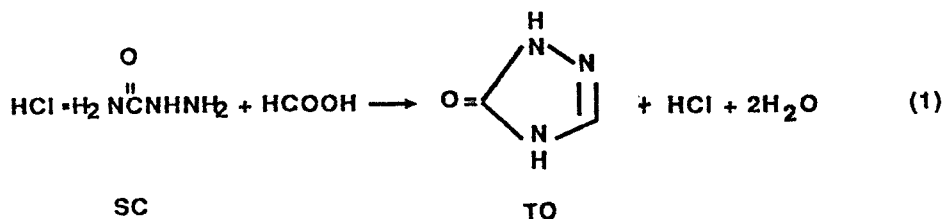


Figure 3. Structural Formula for NTO

It was first synthesized in 1966 (Reference 13). However, not until 1985 did Lee and Coburn (Reference 14) recognize its potential as an explosive. It was first synthesized and incorporated into insensitive explosive formulations for the Air Force by the Energetic Materials Branch of the Air Force Armament Laboratory in 1988. It is synthesized by a two-step process. Semicarbazide hydrochloride (SC) is reacted with formic acid to form 1,2,4-triazole-5-one (TO), followed by nitration in 70% nitric acids at 50-60°C. These reactions are shown in equation 1 and 2. NTO may be recrystallized from hot water (References 14, 15). Particle size is controlled by adjusting the precipitation rate. The stability of NTO is believed to result from resonance and tautomerization.

Equation 1.



Equation 2.



NTO has been incorporated into an H-6 analog called TNT0 (see Table III). H-6 is the explosive used to load Navy GP bombs.

Table III. H-6 and TNT0 Compositions

H-6	%	TNT0	Mod I %	Mod II %	Mod III %	Mod IV %
RDX	45	NT0	42	42	42	40
TNT	29	TNT	34	32	30	30
Wax	5	Wax	5	7	9	10
Al	21	Al	19	19	19	20

TNT0 is a melt castable formulation made by emulsifying wax in molten TNT and adding aluminum powder and NTO. Processing is accomplished in standard steam-jacketed kettles with anchor blades. The mixture is stirred under vacuum for approximately 20 minutes. Vacuum is slowly removed and the product is cast under ambient conditions, achieving charge densities of 94-95% of theoretical maximum density.

As shown in Table III, several modifications of this formulation have been studied. Each demonstrate unique sensitivity, performance and initiation characteristics.

Shock Sensitivity

The shock sensitivity of various formulations has been measured using the modified expanded large scale gap test (MELSGT) configuration shown in Figure 4.

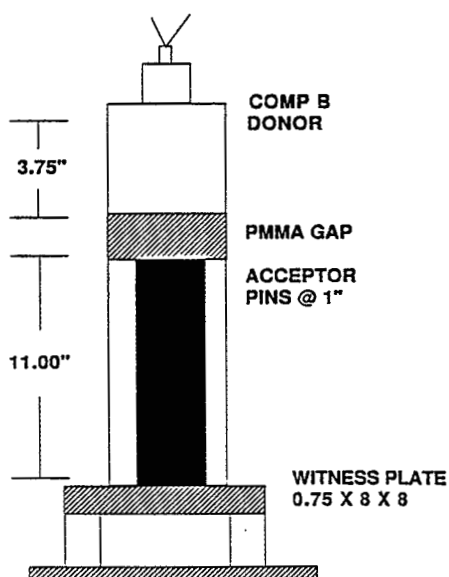


Figure 4. Modified ELSGT Set-Up

Results are provided in Table IV. Tritonal (TNT/Al - 80/20) and PBX-9502 (TATB/KelF binder - 95/5) results are provided for comparison. An RP-83 boosted detonator is used to initiate a 1-inch long by 1 inch diameter A-5 pellet. This, in turn, initiates a 3.75 inch by 3.75 inch diameter cast composition B donor charge. Varying thicknesses of polymethylmethacrylate (PMMA) are used to alleviate the pressure from the donor charge. Pressure vs. PMMA thickness for this configuration has been calibrated by the Armament Laboratory (Reference 17).

Table IV. Shock Sensitivity of Explosive Formulations

Con- figuration	Formulation	Go/No Go PMMA Thickness (in.)	Go/No Go Pressure (Kbar)
MELSGT	TNT I	2.44/2.50	58.4/56.5
MELSGT	TNT II	2.19/2.25	66.7/64.5
MELSGT	TNT III	2.03/2.06	72.3/71.2
MELSGT	TNT IV	1.91/1.94	76.7/75.6
MELSGT	Tritonal	4.00/4.13	20.7/18.6
MELSGT	PBX-9502	2.00/2.06	73.4/71.2

The acceptor charge is contained in a steel cylinder and machined to accommodate the placement of piezoelectric pins for measurement of the shockwave or reaction wave velocity. The charge is supported above a 0.75-inch thick, 8-inch by 8-inch square, mild steel witness plate.

Fragment Velocity

A technique for measuring the velocity of fragments from 8-inch diameter cylinders has been developed here at AFATL by J. D. Corley and J. G. Glenn (Reference 10 and 19, Figure 5).



Figure 5. Casewall Fragment Velocity Measurement System

As in the 8-inch diameter gap test, an 8-inch long by 8-inch diameter section of schedule 40 pipe containing a charge of cast Composition B is used to initiate the acceptor charge. The acceptor charge is contained in a 16-inch long section of schedule 40 pipe capped on one end with a 0.5 inch thick steel endplate. Piezoelectric pins are inserted into the acceptor charge at precisely machined intervals ($2.00 \pm .005$ inches) to measure time of arrival of the detonation wave thus obtaining a velocity profile. This ensures steady state detonation velocity has been achieved in the region where fragment velocity is measured.

Fragment velocity is determined in a plane approximately 4 inches from the rear surface of the acceptor charge using a radial array of piezoelectric pins to measure time of arrival. The pins are positioned normal to the charge using a template machined to $\pm .005$ inches. They are supported by a plexiglass arch and glued into place. The terminal fragment velocity, V_T , is determined by curve fitting the velocity profile and extrapolating to a point 90 mm from the original casewall position. The Gurney Method is used to determine the metal accelerating characteristics of the candidate explosive from energy and momentum balances (Reference 18). The parameter for quantifying the portion of the explosive's total energy (E) is the characteristic velocity (Vc) given by Equation 3 for cylinders.

Equation 3.

$$V_C = (2E)^{1/2} = V_T (M/C + 1/2)^{1/2} \quad (3)$$

Where, M is the mass per unit length of the metal case
C is the mass per unit length of the explosive charge

Representative values of characteristic velocities obtained in this manner are provided in Table V. They are useful for comparison purposes but are meaningless in an absolute sense. As is shown, the values for the TNTO formulations are nearly equivalent with that of Tritonal.

Table V. Gurney Characteristic Velocities
(km/sec)

Formulation	$(2E)^{1/2}$
Tritonal	2.32
Comp B	2.67
TNTO II	2.52
TNTO IV	2.34

Initiability

TNTO formulations have critical diameters ranging between 1 to 1.5 inches (Reference 22). Booster tests were conducted in 8-inch diameter cylinders with standard fuzewell liners attached to the inside of the forward baseplate (see Figure 6).



Figure 6. Booster Test Cylinder

The initiation trains are inserted into the fuze well for testing. These items are preconditioned to -65°F to confirm reliability at this extreme service condition. The units are placed above rolled homogeneous armor (RHA) witness panels and instrumented with piezoelectric pins as in the 8-inch gap test. The booster configurations used in the TNTO initiability studies are shown in Figure 7. Configuration 1 consists of an RP-83 boosted detonation, followed by a small piece of Detasheet (Dupont) and the crescent-shaped FZU-2B (45 g tetryl) booster from the FMU-81. This is used to initiate the T-147 auxiliary booster (284 g tetryl) from the M-905 tail fuze. In Configuration 2, the T-147 auxiliary booster is replaced with a 500 g PBX-9503 prototype booster. Configuration 3 consists of an RP-83 inserted into 74 g of C-4 which has been packed into the housing above a 1/4-inch thick piece of Detasheet and the M-148 auxiliary booster (182 g tetryl). The results of the TNTO initiation tests are summarized in Table VI.

Table VI. TNTO Initiation Test Results

<u>Formulation</u>	<u>Booster Configuration Required at -65°F</u>
TNTO II TNT/NTD/D2/Al (32/42/7/19)	M-148 (configuration 3 in Figure 7)
TNTO IV TNT/NTD/D2/Al (30/40/10/20)	T-147 (configuration 2 in Figure 7)

TNTO II was initiated by the M-148 booster while TNTO IV required the PBX-9503 prototype booster.

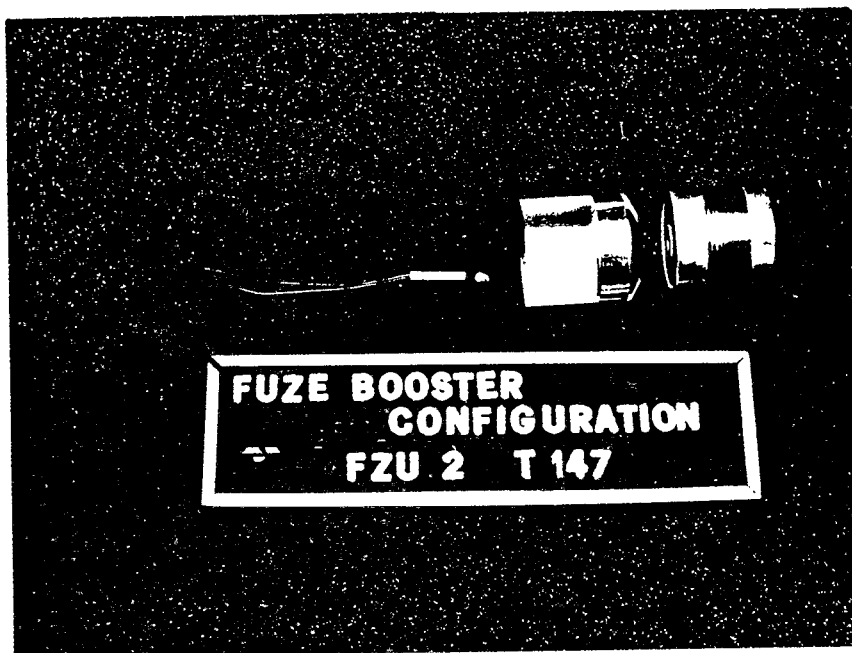


Figure 7a. Initiation Test Configuration 1: T-147 Auxiliary Booster

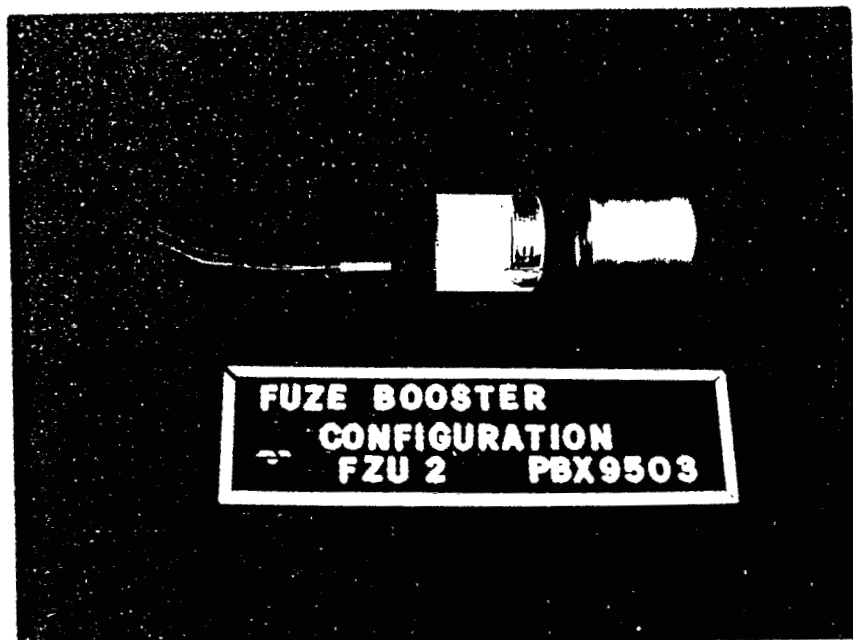


Figure 7b. Initiation Test Configuration 2: PBX-9503 Prototype Auxiliary Booster

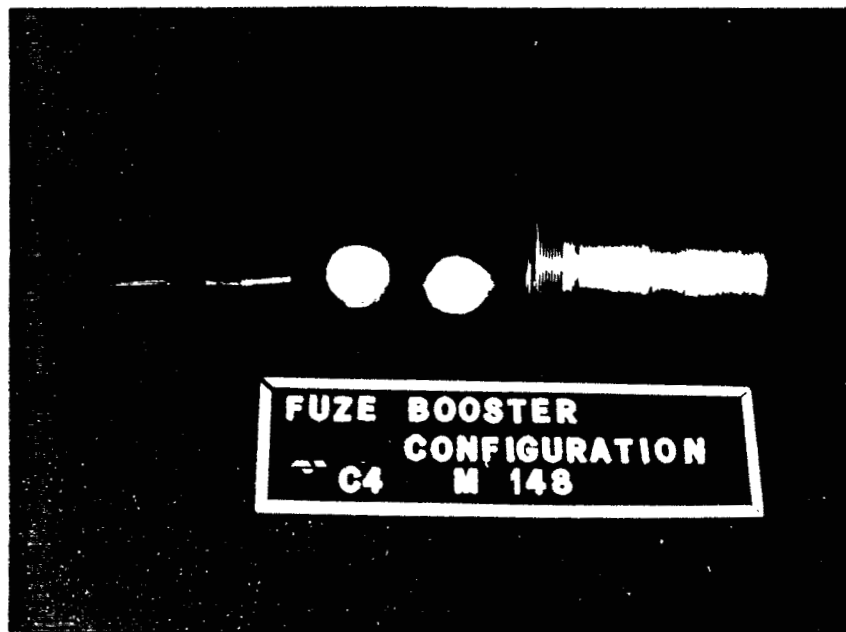
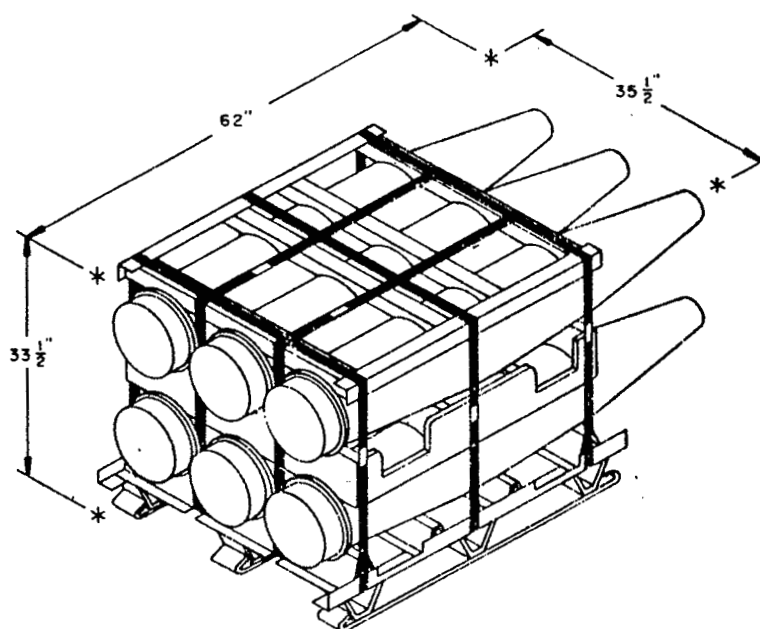


Figure 7c. Initiation Test Configuration 3: M-148 Auxiliary Booster

TNTO Sympathetic Detonation Testing

Reliable suppression of sympathetic detonation in 500-pound bombs is difficult to achieve. MK-82 bombs are stored in pallets containing 6 bombs as shown in Figure 8.



PALLET UNIT

AIR FORCE UNIT,
6 BOMBS PER METAL PALLET.

UNIT WEIGHT ----- 3,150 LBS (APPROX)
CUBE ----- 42.67 CUBIC FEET

Figure 8. MK-82 Storage Configuration

The separation distance (skin-to-skin) between adjacent bombs in this configuration is approximately 0.5 inches. The bombs are approximately 10.75 inches in diameter, resulting in a separation distance of about 5-5.25 inches for the diagonally spaced bombs. The only barriers between bombs in this configuration are very thin steel cross support members.

Full-scale sympathetic detonation testing begins with the single package test in the configuration shown in Figure 9.



Figure 9. Single Package Test Configuration

The donor bomb is located in the bottom row center position of a standard metal pallet, positioned between a live acceptor bomb and a BDU-50 (inert-filled bomb). The top row of the pallet consists of a BDU-50 positioned between a live acceptor bomb and another BDU-50. The live acceptors are on opposite sides of the pallet to allow individual assessment of the conditions at the adjacent and diagonal acceptor positions. The package is placed on a 1-inch thick rolled homogeneous armor (RHA) witness plate. RHA witness plates are also positioned on each side and above the package to obtain fragment signatures from any detonating items. Piezoelectric pins are spaced precisely along the donor bomb to track the time of arrival of the detonation wave to obtain its detonation. Post test recovery of case remnants and unreacted explosive and the evaluation of the witness plate signatures are used to determine the results of the experiment.

Full-scale (MK-82) testing of TNTO II and TNTO IV formulations in this configuration has been conducted. The results are shown in Figure 10 and summarized in Table VII.

Table VII. TNTO Full-Scale Sympathetic Detonation Testing

	<u>Adjacent Acceptor</u>	<u>Diagonal Acceptor</u>
TNTO II (TNT/NTD/D2/Al) (32/ 42/ 7/ 19)	Violent Explosion	Detonation
TNTO IV (TNT/NTD/D2/Al) (30/ 40/ 10/20)	No Detonation	No Detonation

For TNTO IV, the less energetic and less sensitive of the two formulation tested, no propagation of the donor detonation occurred. The recovered pieces of both live acceptor bomb cases were large and platelike. The charging tube and fuzewell were recovered from the diagonal bomb. The diagonal bomb was broken up more severely than the side acceptor but showed no evidence of detonation. A portion of the adjacent live acceptor bomb casing from the nose region contained heavy impact markings from the impact of the donor bomb. Unreacted explosive was recovered after the test.

The recovered pieces from the inert diagonal acceptor bomb also included a large portion of its nose, heavily scarred by donor fragment impact. Another piece was recovered from the inert diagonal item which appeared markedly different from the adjacent item remnants. It was severely riddled, possibly from the jet impact region where the two adjacent items focused the products and fragments from the donor bomb. The two remnants of the remaining inert items looked quite similar to each other. The signature from the initial "slapper" impact of the donor bomb was observed as was severe deformation of the bomb bodies.

Witness plates from the TNTO IV test were essentially clean except for the severe scarring and cracking of the bottom plate from the donor bomb fragments. The top witness plate was cracked into two pieces from the impact of the inert bomb directly above the donor bomb. No fragment markings from the live acceptor bombs were observed.

For TNTO II, the more energetic and more sensitive of the two formulations tested, propagation of the donor detonation occurred in the diagonal acceptor bomb. Only a small portion of the diagonal live acceptor bomb casing was recovered. It showed evidence of multiple impacts from high velocity fragments and detonation products. Large, platelike pieces of the adjacent live acceptor bomb were recovered. No unreacted explosive was recovered after the test. The adjacent inert item was damaged severely, having been directly exposed to two detonations. Likewise, only a small portion of the inert acceptor bomb from the top center position was recovered. The diagonal inert bomb was not recovered. The bottom witness panel was scarred heavily by fragments and cracked into two pieces. The portion of the plate beneath the live adjacent item was clean. The top and side plates contained multiple perforations from the high velocity fragments of the detonating acceptor bomb. By comparison the other side panel (on the

side of the adjacent live acceptor bomb) was relatively clean except for a few significant penetrations from large, high velocity fragments. The live adjacent acceptor bomb reacted violently but did not propagate the donor detonation like the diagonally position live acceptor.

The latter test was conducted to determine if the energy to sensitivity ratio for this formulation was small enough to prevent propagation in this configuration and to aid in establishing a margin of safety for the TNT IV formulation.



Figure 10a. Remnants of Live Diagonal Acceptor from TNT IV Single Package Test



Figure 10b. Remnants of Live Adjacent Acceptor from TNTO IV Single Package Test



Figure 10c. Live Adjacent Acceptor Panel for TNTO IV



Figure 10d. Live Diagonal Acceptor Panel for TNTO IV



Figure 10e. Case Remnants of Live Adjacent Acceptor from TNT II Single Package Test.



Figure f. Case Remnants of Live Diagonal Acceptor from TNT II Single Package Test

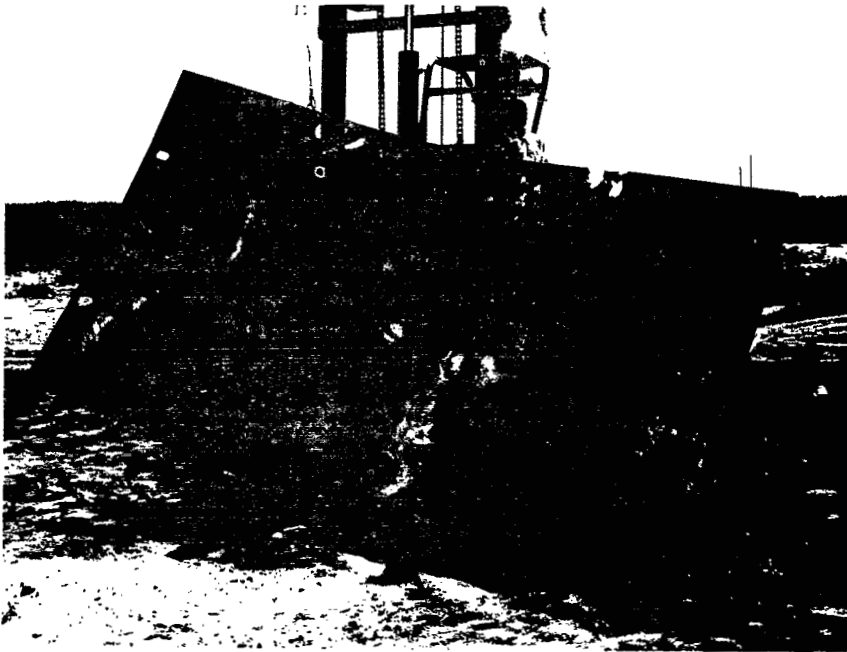


Figure 10g. Vertical Witness Plate from Live Adjacent Acceptor Side for TNT II

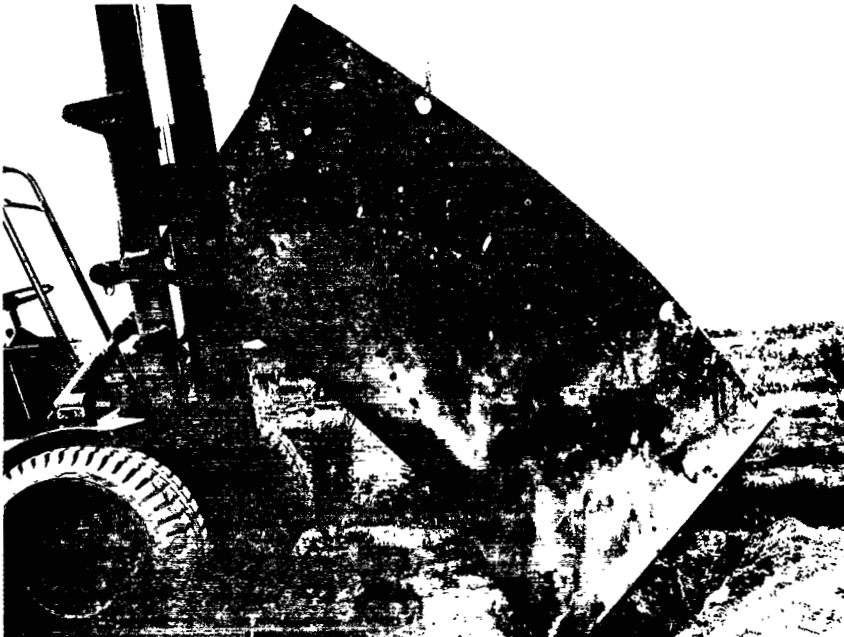


Figure 10h. Vertical Witness Plate from Live Diagonal Acceptor Side for TNT II

TNTO IV Full-Scale Slow Cookoff

A full-scale (MK-82) slow cookoff was conducted for TNTO IV in the configuration shown in Figure 11.

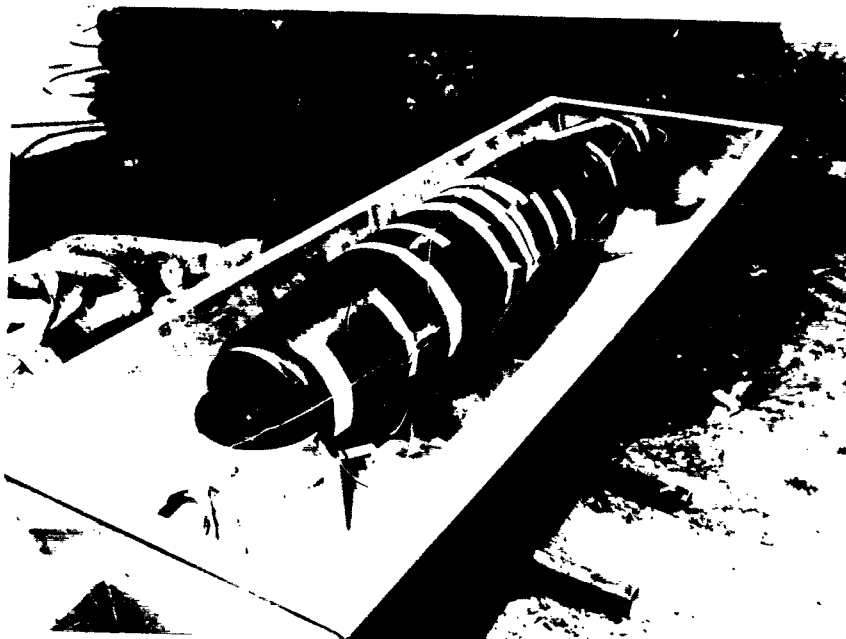


Figure 11a. Internal View of Oven Showing Exudation Troughs and Thermocouples



Figure 11b. Slow Cookoff Oven with Resistive Element Heat Tapes



Figure 11c. Insulated Slow Cookoff Oven Prior to Testing Note:
No Video Monitoring Ports Shown in This Set Up.

In this set-up, the item is enclosed in an aluminum oven with windows in each end to allow video monitoring. The bomb is supported by a steel, angle-iron stand. Exudation troughs are provided for the removal of any molten explosive prior to reaction. The oven is equipped with ducts which circulate air driven by a blower to maintain a uniform temperature throughout the oven. Heating is provided by electrical resistive element tapes wrapped around the exterior of the oven. Insulation covers both the oven and the air ducts and thermocouple wires are placed on and around the test item. The thermocouple positions and temperature profiles for the TNT0 IV slow cookoff are shown in the drawing in Figure 12. The average of the temperatures recorded for thermocouples 3, 4, 5, and 6 was used as the control for the heat tapes in this experiment.

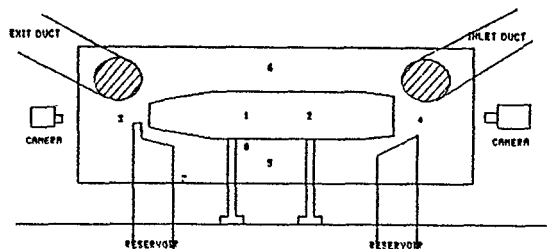
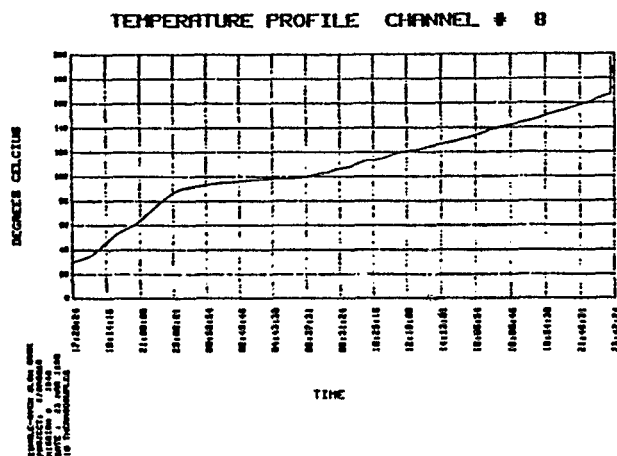
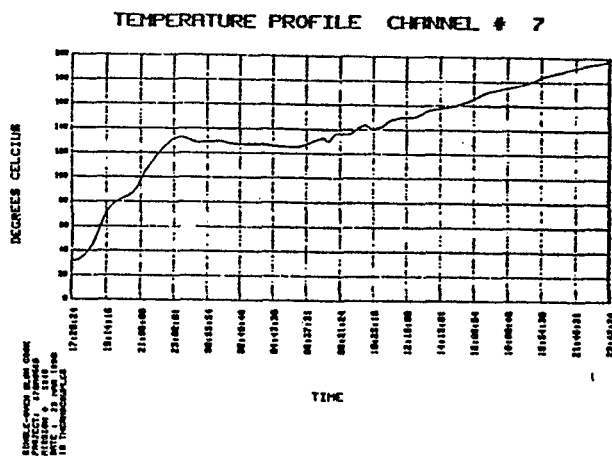


Figure 12a. Slow Cookoff Test Set Up



Figures 12h-i. TNTO IV Slow Cookoff Temperature Profiles (cont.)

The oven temperature was initially raised to 100°C at the approximate heating rate of 12.4°C/hr. The item was soaked at this condition for 6.5 hours. The oven temperature was then raised at a rate of 3.5°C/hr until reaction occurred. Equilibrium between the internal portion of the test item and the oven space was not achieved during the soak prior to final ramping; however, the internal heating rate had slowed considerably. Self heating of the item began near 134°C. Reaction occurred at an oven temperature of 160°C when the internal item temperature was 190°C. Nearly 3.5 hours passed between the time at which self-heating was observed and final reaction occurred (See Figure 13).

The item vented mildly from the nose and burned non-propulsively in place. The nose fuze well liner was partially inverted and slightly crushed, tearing it from the bomb skin and forming a one-inch diameter vent hole. The tail fuze well liner was also slightly inverted, allowing molten explosive to flow through the charging tube hole into the collection reservoir below the item. Prior to reaction, smoke was observed from the



Figure 13. Remnants of TNT IV Slow Cookoff

reservoir beneath the nose of the item indicating some venting and exudation had occurred. After reaction, the test fixture and surrounding insulation were engulfed in flames. Large quantities of charred explosive residue were observed around the test stand after the test. The bomb case did not fragment or rupture but remained intact and in position throughout the test. The results of this test meet the requirements for Division 1.6 articles as specified by the United Nations Test Series 7.

Effects of Item Positioning On Sympathetic Detonation

Experimental Results

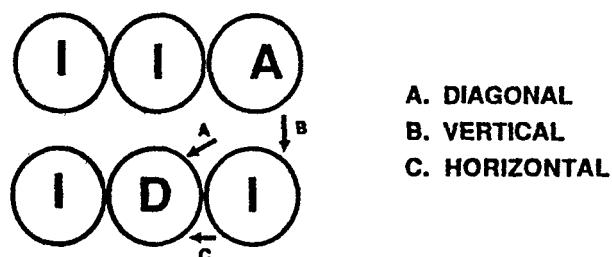
The current Air Force general purpose bomb fill, tritonal (a mixture of TNT and aluminum powder) propagates the detonation of the donor bomb in both the adjacent and diagonal positions of the standard metal pallet. Tritonal shows a sensitivity to long duration (tens of microseconds) shock impulses with a peak pressure of about 10 kbars in the 8-inch diameter gap test. Items filled with a wax desensitized tritonal formulation developed by the

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Air Force, AFX-1100 (References 9 and 16), do not sympathetically detonate in the adjacent position, but do propagate in the diagonal position of the standard metal pallet. AFX-1100 shows an insensitivity to long duration impulses with a peak pressure of about 43 kbars. A study was conducted by S. A. Aubert and J. G. Glenn of the Air Force Armament Laboratory (Reference 10) to determine experimentally the factors influencing propagation of the bomb in the diagonal position of the standard pallet. The results are summarized in Figure 14. As is shown, when the separation distance between the top and bottom rows of bombs is increased to 3.00 inches, propagation was eliminated.

SYMPATHETIC DETONATION TEST RESULTS

EXPLOSIVE: AFX-1100 (500-POUND BOMB)



TEST #	VERTICAL	DIAGONAL	HORIZONTAL	REACTION
1	5.25"	9"	.5"	NO PROPAGATION
2	3.25"	7.8"	.5"	NO PROPAGATION
3	.5"	5.25"	5."	PROPAGATION
4	3.00"	7"	.5"	NO PROPAGATION
5	1.63"	6.25"	.5"	PROPAGATION

Figure 14. Sympathetic Detonation Test Results

Hydrocode Predictions

E. A. Lundstrom of the Naval Weapons Center used the AFX-1100 equation of state parameters determined by J. C. Dallman of Los Alamos National Laboratories to study this problem using the MESA two-dimensional Eulerian hydrocode (References 11, 12, 20). Graphical representation of his calculations using inert acceptors are shown in Figure 15.

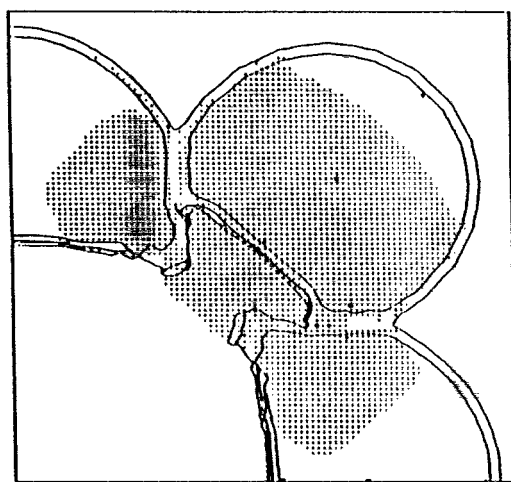
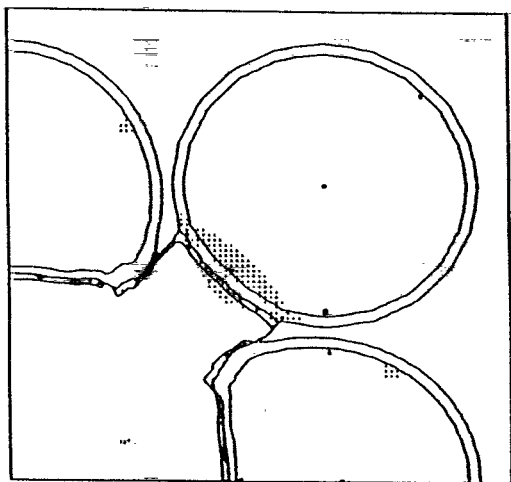
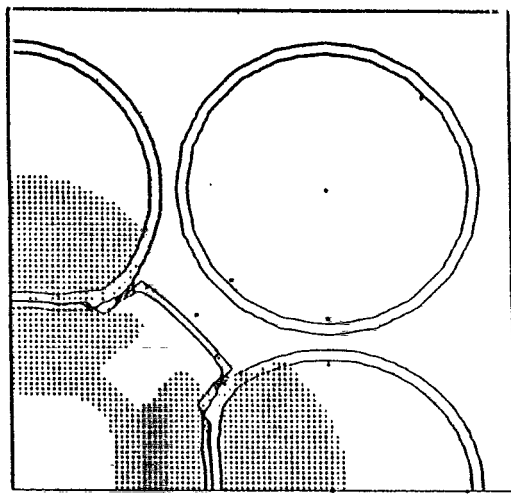
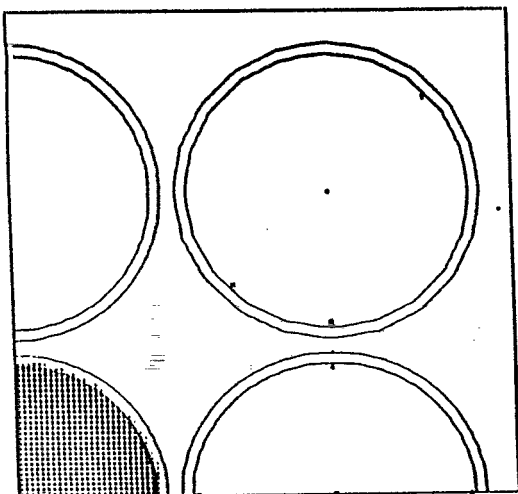


Figure 15a-d. Hydrocode Calculation of Symmetrical Pallet Configuration with Inert Acceptors

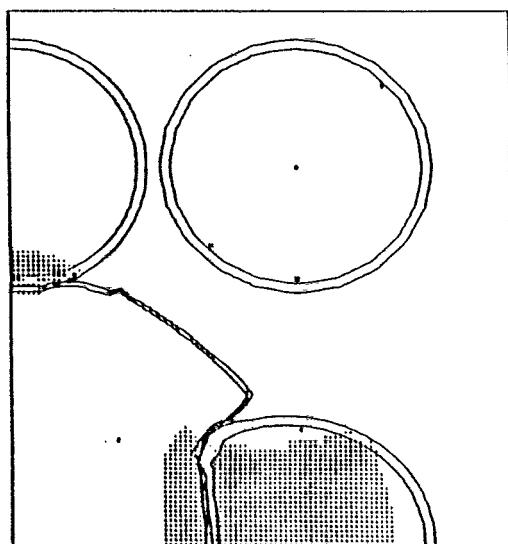
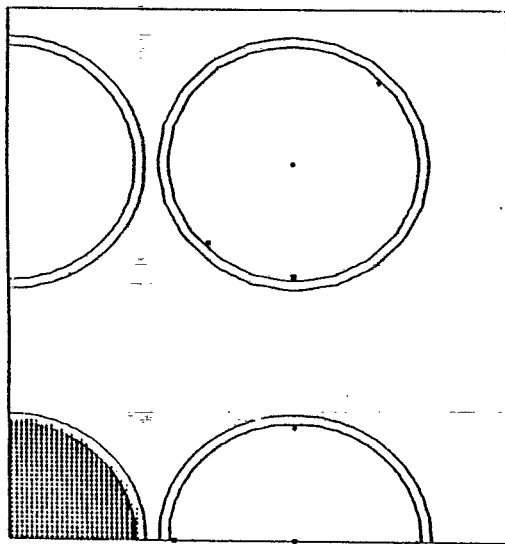


Figure 15e-f. Hydrocode Calculation of Non-Symmetrical Pallet Configuration with Inert Acceptors

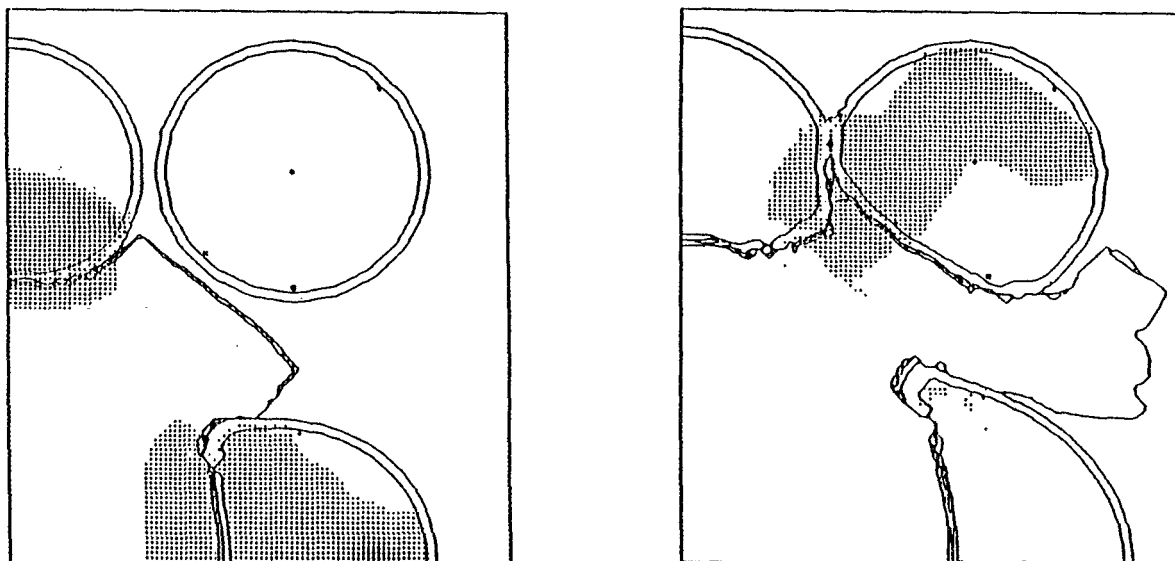


Figure 15g-h. Hydrocode Calculation of Non-Symmetrical Pallet Configuration with Inert Acceptors (cont.)

These were fairly coarse resolution calculations (2 elements per centimeter) with a 9-member three-by-three array of bombs implied by symmetry and the rigid boundaries along the left and bottom edges. However, they show the contrast between the environments of the diagonal bomb in two different geometrical configurations. At 0.5 inches of separation, the donor case has little space for expansion and the diagonal acceptor bomb is impacted with a relatively thick "flyer" plate over a fairly small portion of its circumference. The acceptor bomb is severely deformed and the confinement from the adjacent items allows no relief for the reaction products. At a vertical separation distance of 3.0 inches, the "flyer" plate from the donor becomes quite thin and, in reality, probably fragments before impacting the acceptor bomb. Its energy is less concentrated as it is released along a much larger portion of the circumference. Additionally, there is less confinement from the adjacent acceptors allowing some of the donor energy to release to the atmosphere.

The calculations to determine the response of live acceptor bombs have been completed and are shown graphically in Figure 16 provided by Lundstrom. The reactive calculations were performed using a Forest Fire Burn Model, calibrated with wedge test data sensitivity parameters approximating those for AFX-1100. With an initial symmetrical separation (Figure 16 a-d) distance of 0.5 inches, the acceptor bomb in the diagonal position transitions promptly to detonation upon impact. When spaced unsymmetrically with a vertical separation of 3.25 inches, an unreactive shockwave tranverses the item (Figure 16 e-l). Upon impacting the rear interior casewall, the wave is reflected and converges upon itself. Pressure increases at these interfaces; however, for this formulation the pressure change is not large enough to initiate a reactive detonation wave. This is consistent with the experimental results for AFX-1100. The response for a more sensitive formulation is shown in Figure 16 m-t. In this example, the diagonal item does transition to detonation after convergence of the reflected shockwave.

The calculations do not account for the desensitization of the acceptor explosive by the initial shockwave. Initiation via a reflected shockwave is questionable in reality since the resulting pressure is incapable of initiating the desensitized material (Reference 21). However, the calculation is still useful to complement experimental testing by determining margins of safety for the limited experimental data base. This is the fundamental value of all hydrocode calculations.

As is shown, a very slight modification of pallet designs including moderate alterations of spacing between items has a dramatic impact on the vulnerability of stored munitions.

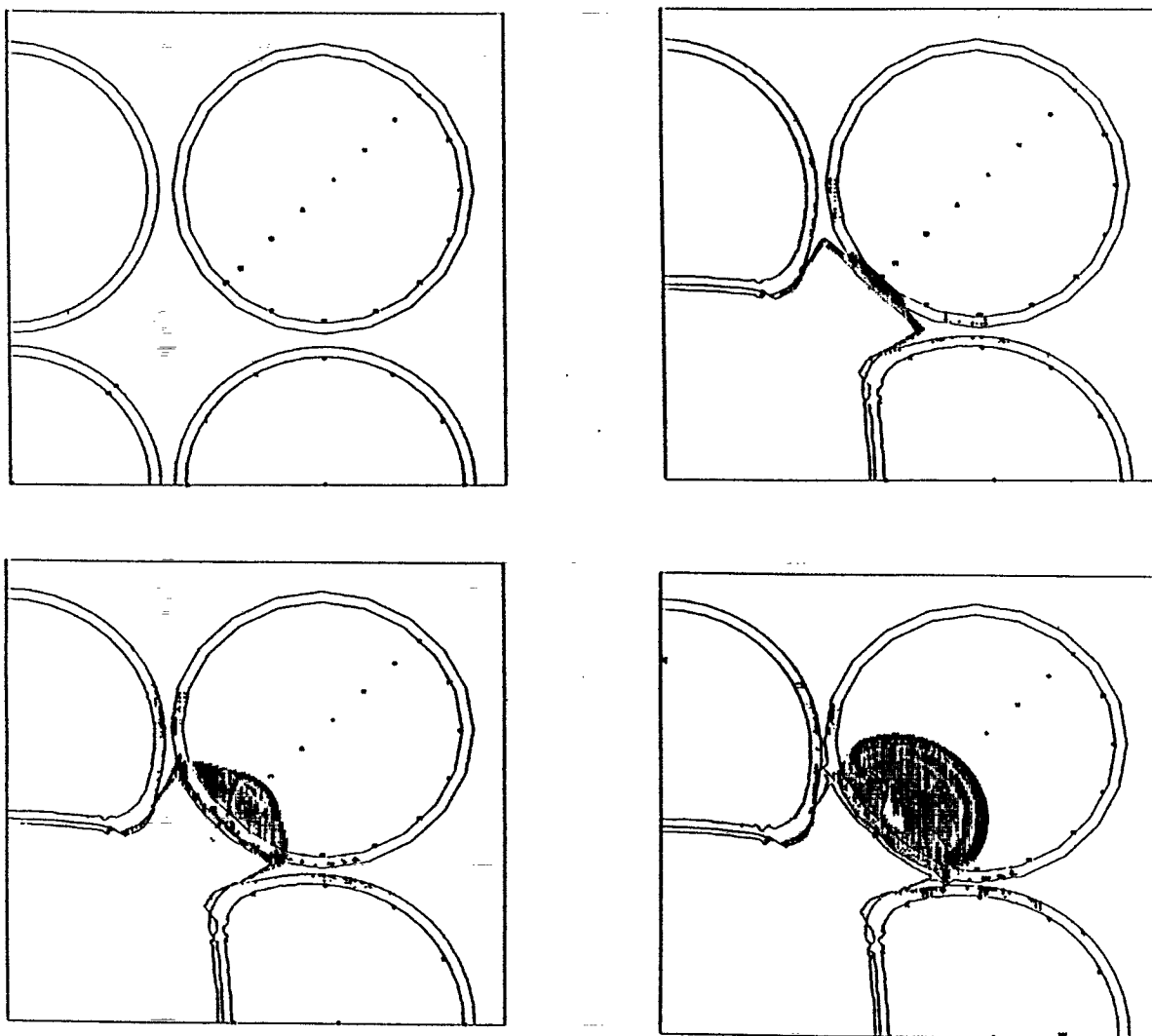
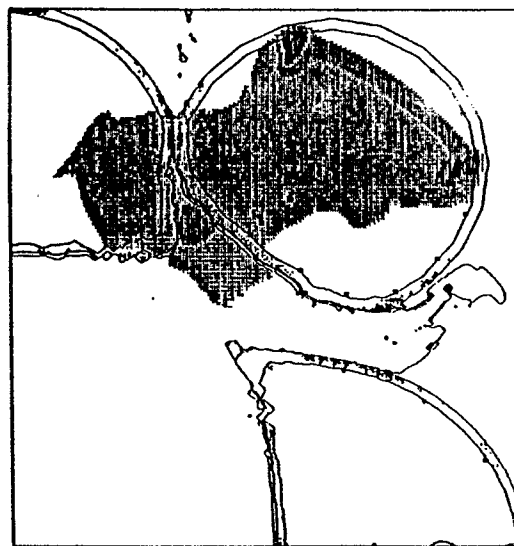
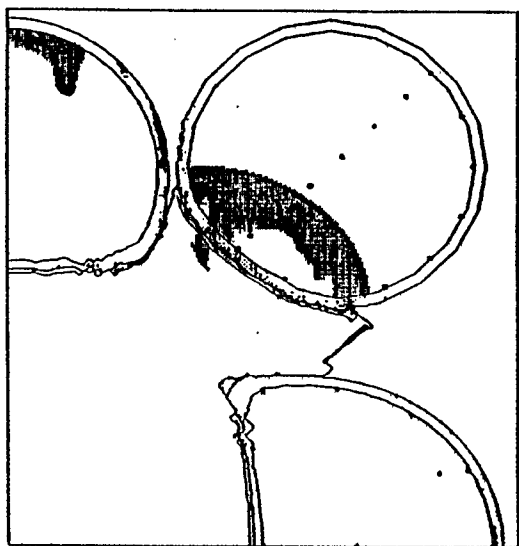
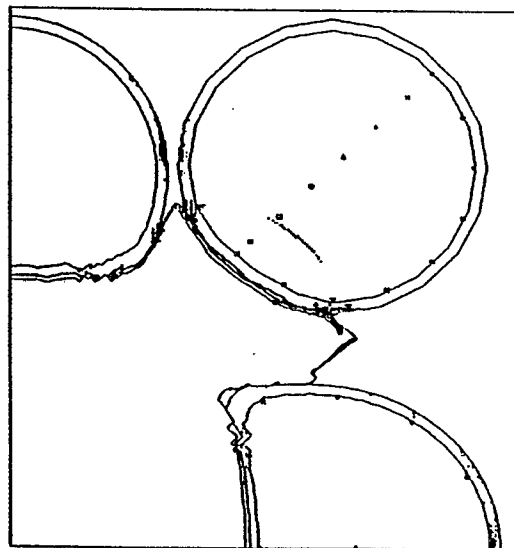
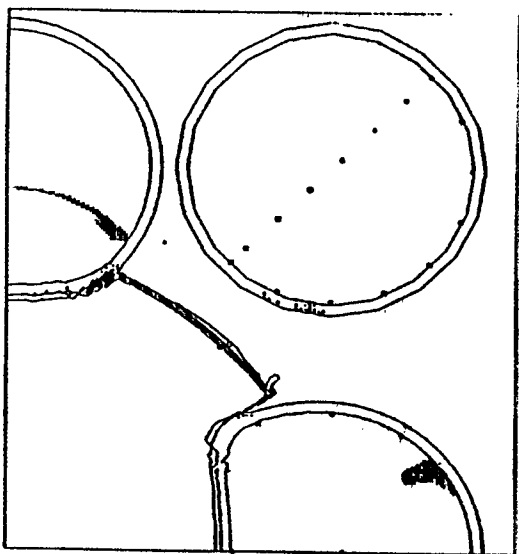
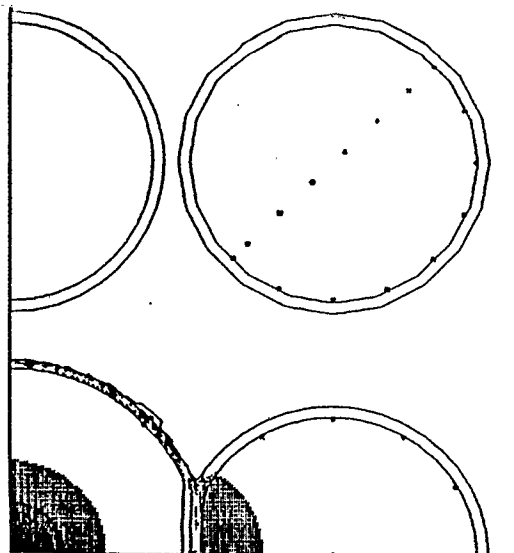
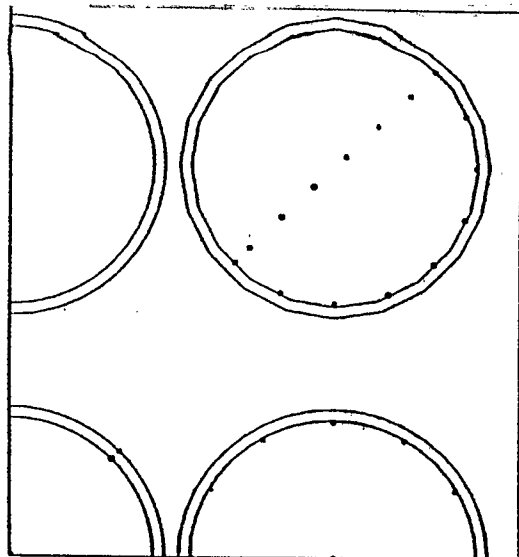
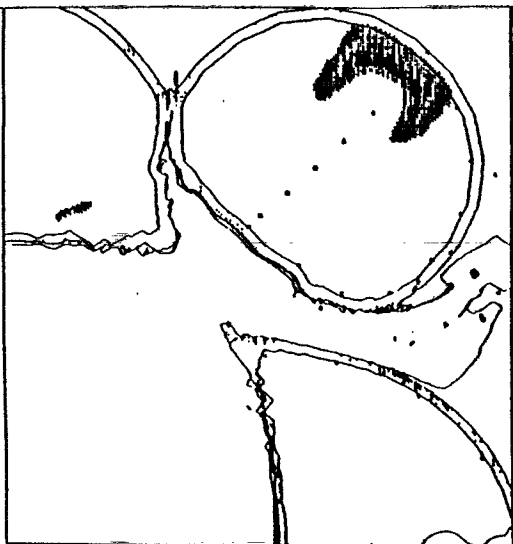


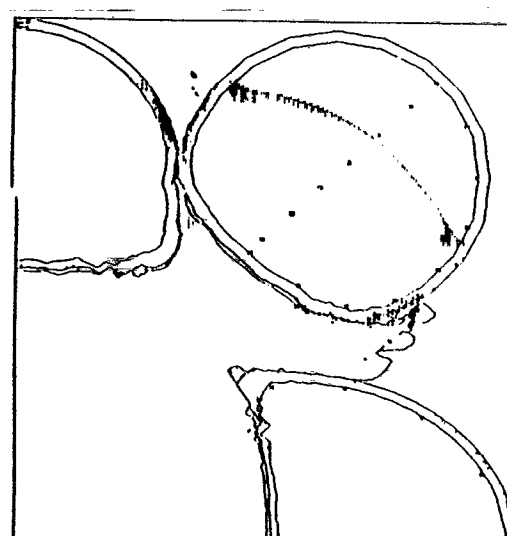
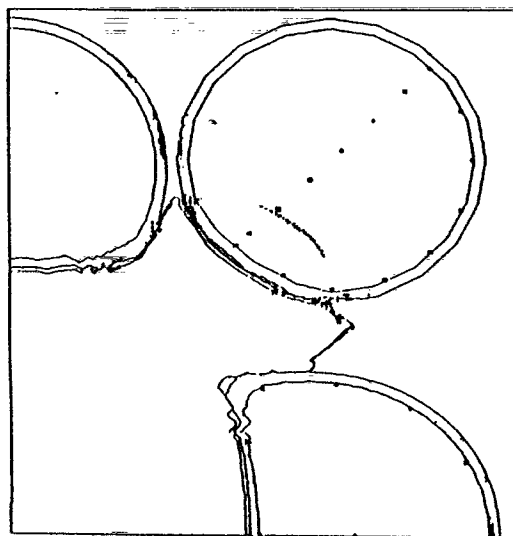
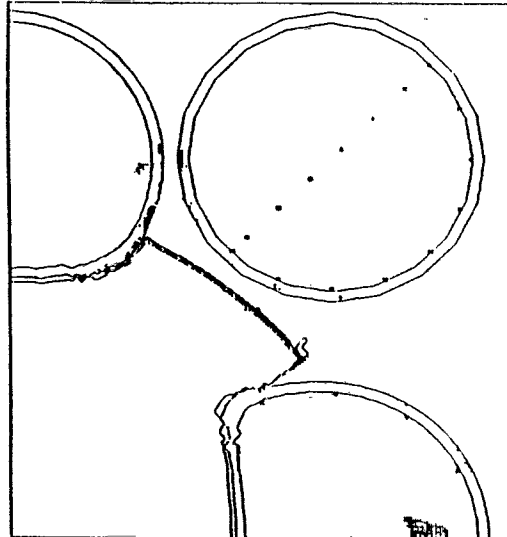
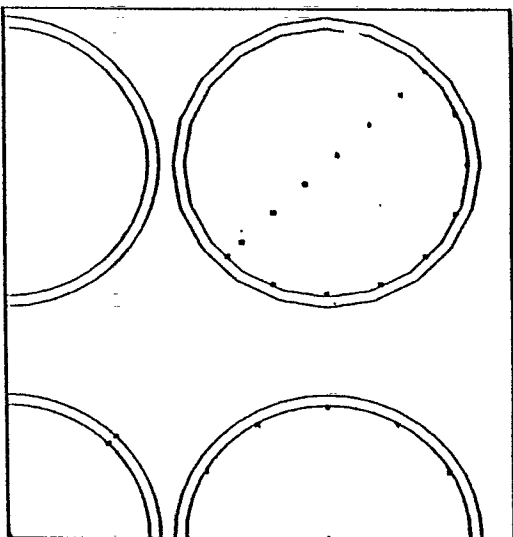
Figure 16a-d. Prompt Initiation of an AFX-1100-Type Explosive in the Symmetrical Configuration



Figures 16e-j. Response of AFX-1100-type Explosive in Unsymmetrical Configuration (No Propagation)



Figures 16k-l. Response of AFX-1100-type Explosive in Unsymmetrical Configuration (No Propagation) (cont.)



Figures 16m-p. Response of Relatively Sensitive Explosive In Unsymmetrical Configuration

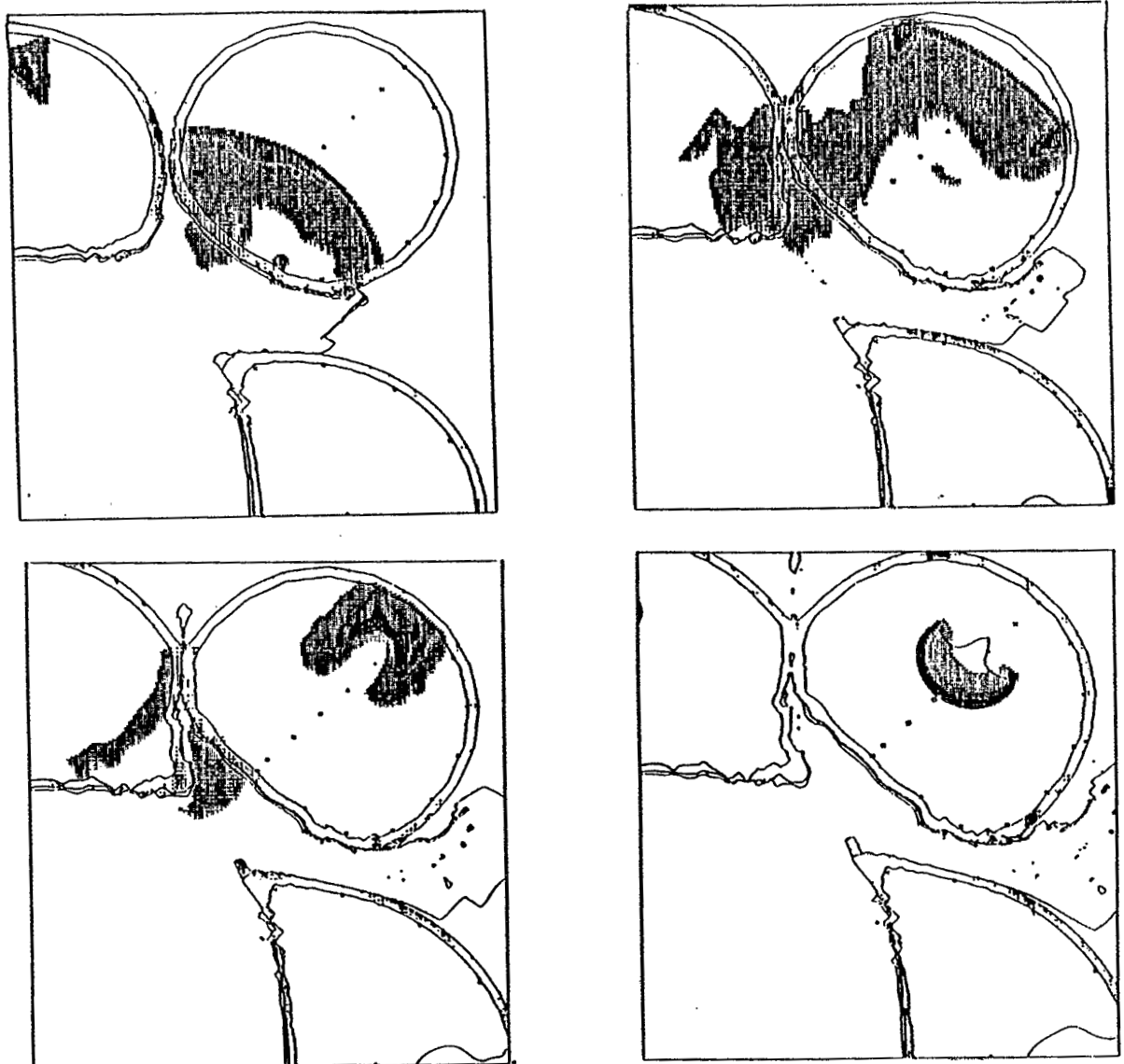


Figure 16q-t. Response of Relatively Sensitive Explosive In Unsymmetrical Pallet

Summary

The Air Force is responding to the challenge of developing safe explosives which continue to meet performance requirements. The approach of having concurrent in-house and contractual development processes increases the probability of success and the rate at which this success will be achieved.

The TNT0 IV formulation has survived full-scale sympathetic detonation testing without propagating. This formulation has also achieved the 1.6 Hazard Classification criteria for slow cookoff in a single test. Next steps for this formulation include optimization of performance and sensitivity parameters as well as specification of the individual ingredients. Equation of state parameters of the final formulation will be determined and incorporated into modeling systems to predict full-scale behavior and provide margins of safety for the experimental results. The

EIDS substance tests for 1.6 Hazard Classification of the optimized formulation are scheduled for 1QFY91.

Sympathetic detonation is becoming better understood as full-scale testing results are being used to calibrate hydrocode models. The proper design of storage configurations and item separation distances is important for controlling sympathetic detonation.

The U S Air Force is committed to protecting its assets as well as those belonging to the communities and host nations in which its forces reside by providing safer munitions.

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