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SHRAPNEL PROTECTION TESTING IN SUPPORT OF THE PROPOSED SITE 300 CONTAINED FIRING FACILITY

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Abstract

To prepare for the planned Contained Firing Facility at the LLNL Site 300, we investigated various multilayered shrapnel protection schemes to minimize the amount of material used in shielding. As a result of testing, we found that two pieces of 1-in.-thick mild steel plate provide adequate general-purpose protection from shrapnel generated by normal hydrodynamic and cylinder shots at Bunker 801.

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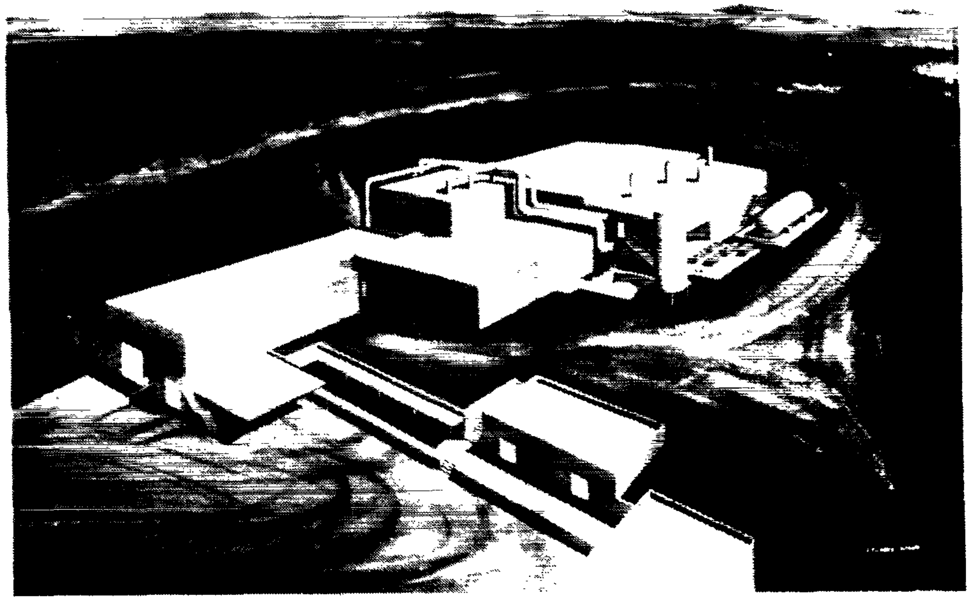

Figure 1. Artist's conception of the planned Contained Firing Facility.

Introduction

The Contained Firing Facility, which is planned to replace open-air testing at Bunker 801, consists of a large rectangular, reinforced-concrete firing chamber lined with steel plates for shrapnel protection. Figure 1 is an artist's conception of the planned Contained Firing Facility at the LLNL Site 300. The Conceptual Design Report[1] requires that a typical wall section consist of 4 feet of reinforced concrete followed by a 1-in. steel pressure liner and two layers of 2-in.-thick steel armor plate.

The purpose of this testing was to experimentally subject various shrapnel protection schemes to normal types of shrapnel generated by hydrotest experiments at Bunker 801. The philosophy was to start with minimum-thickness mild steel plates and work upward, increasing plate thickness as necessary. Multilayer plate technology was selected that uses air spaces to separate steel plates. Moreover, because it was desired to determine damage caused by shrapnel, the steel plates were positioned to minimize the damage from blast effects and maximize the damage from shrapnel.

To obtain shrapnel with realistic fragment velocities and sizes, the tests were performed as "add on" experiments to actual hydrodynamic and cylinder tests. Because of required diagnostics on these shots, the steel test plates could not always be positioned in the path of worst-case shrapnel, but it is believed that most of the worst-case fragments have been sampled. This report describes nine shrapnel tests, including test configurations, comparisons of measured versus calculated penetration and perforation results, and recommendations for general-purpose shrapnel protection for the planned Contained Firing Facility at Site 300.

Objectives

To support the proposed Contained Firing Facility, the shrapnel protection scheme must:

- Allow no damage to the pressure liner.
- Minimize fabrication costs.
- Emphasize versatility for installation and use.
- Afford easy repair and low maintenance.

Test Descriptions

Eight tests were conducted by exposing a large 36 in. × 36 in. block assembly to various shrapnel environments. Appendix A includes a test record for each shot which shows the block geometry, the number and size of plate perforations, test setup, and damage observations from each test. Additional penetration data (Test No. 9) was obtained by observing damage to the shrapnel protection plate for the gamma ray camera (see Figs. 12, 13, and 14), a new radiographic diagnostic being developed.

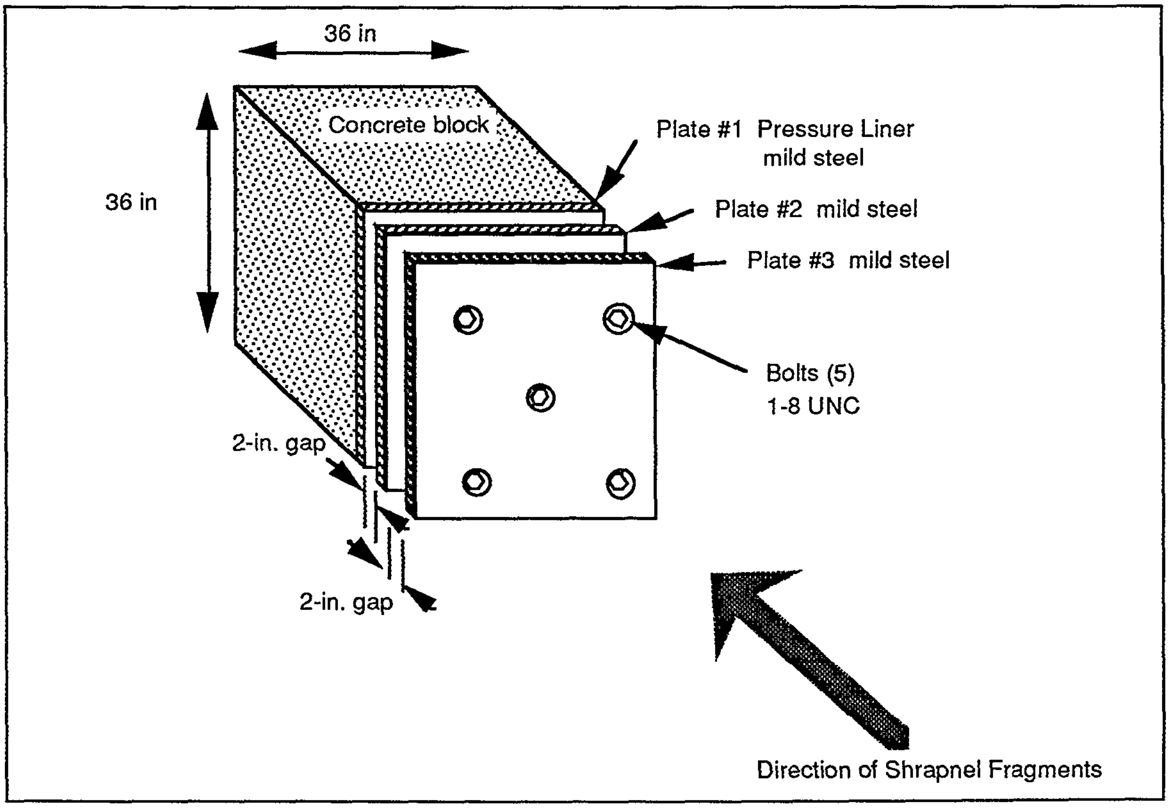

Figure 2. Typical test block.

Figure 2, a typical configuration of the test block, shows the large reinforced-concrete block, the pressure liner, and the multilayered shrapnel protection plates. The large reinforced-concrete block was used to simulate the wall of the Contained Firing Chamber and provide backing and support for the steel pressure liner. The shrapnel mitigation plates Nos. 2 and 3 were spaced 2 in. away from the pressure liner and from each other. The spacing or "air-gap" between plates was maintained by welded-on bosses on the pressure liner and on plate No. 2. The plates were then bolted to each other with 1-in. 8UNC A307-grade bolts and torqued to 250 ft-lb. Mild steel was used instead of armor plate for all the tests because it has roughly 85% of the perforation resistance[2] of armor plate at less than half the cost.

Figure 3 depicts the final shrapnel protection test-block design during the final stages of its construction. This configuration consisted of a 0.5-in.-thick pressure liner and two 1.0-in.-thick shrapnel mitigation plates which were all constructed from mild steel.

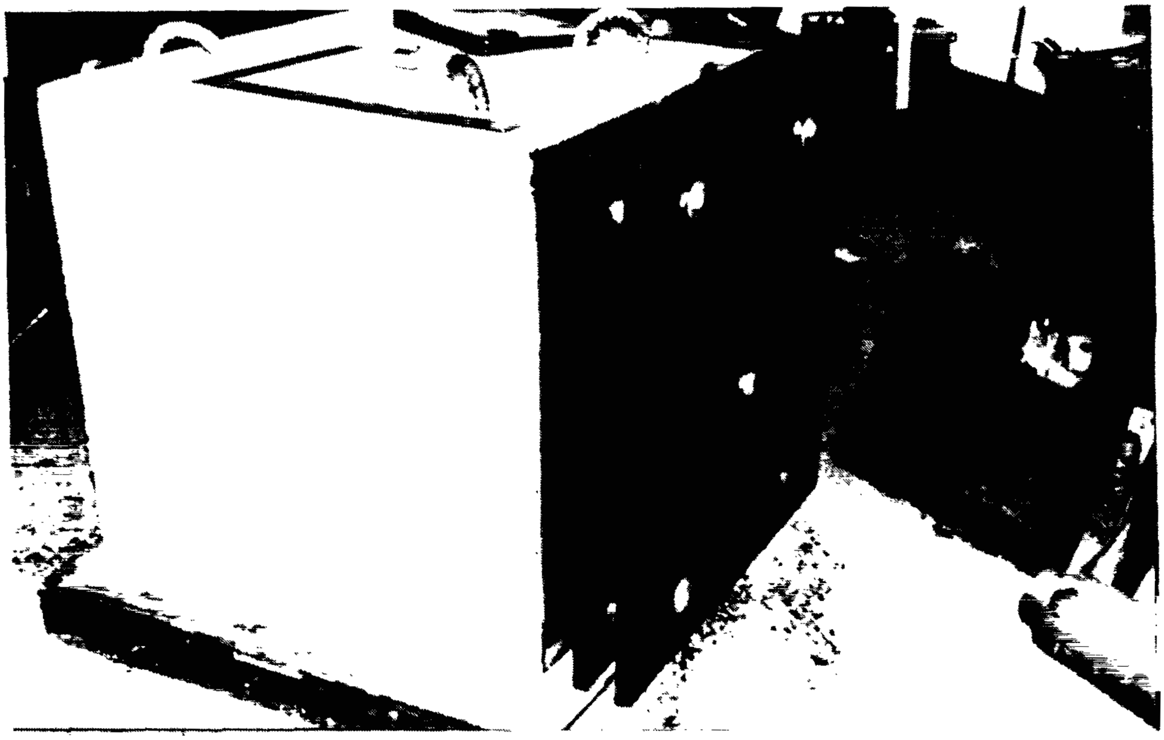

Figure 3. Final shrapnel protection scheme (test block) during final stages of construction.

Most of the shrapnel-producing experiments were from the fragmentation of copper or steel cylinders filled with high explosives. Figure 4 shows a typical cylinder shot (Test No. 4) just before detonating the explosive. The nine tests presented in this report were considered "add on" experiments to the hydrodynamic and cylinder explosive tests. Three of the tests (Nos. 1, 5, and 6) were not simple cylinder shots from a shrapnel generating standpoint, but they produced damage representative of normal hydrodynamic shots that are typically performed at the LLNL Site 300.

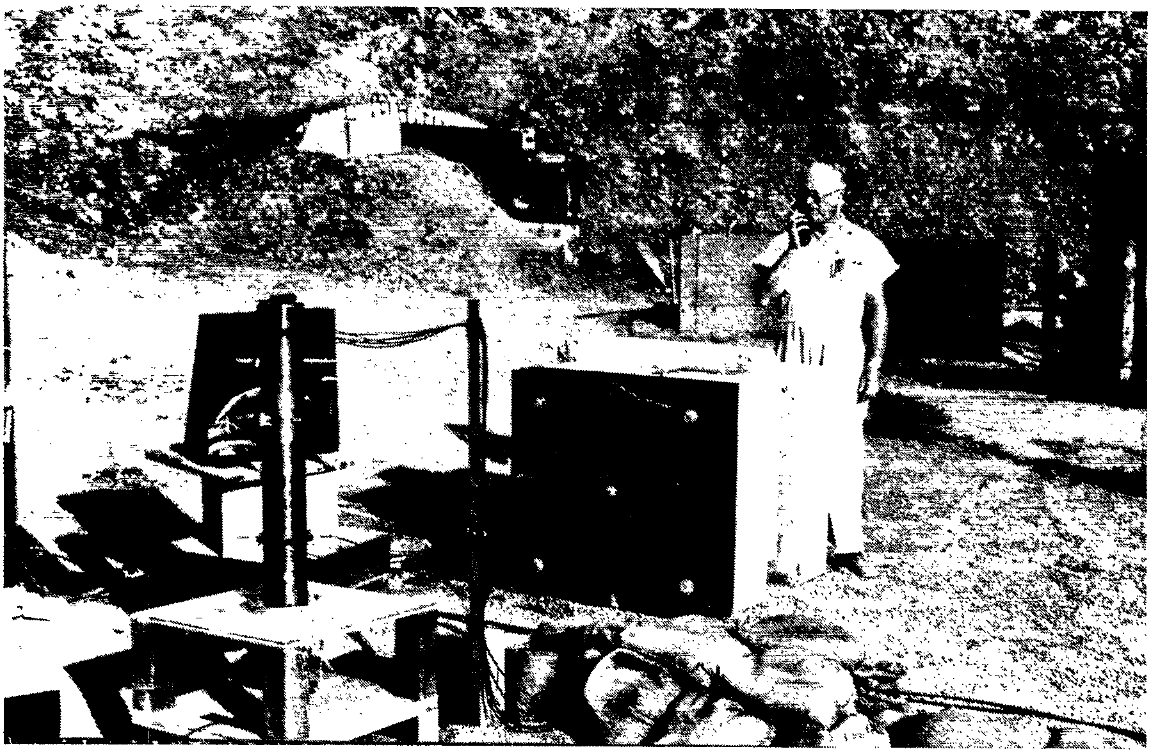

Figure 4. Test setup for a typical 4-in.cylinder shot with shrapnel protection test block in place (Test No. 4).

Figure 5. Workers removing clamping bolts after Test No. 3. Note the plate deformation from blast and pitting from shrapnel for this minimal design.

Figure 6. Example of excessive deformation and pitting resulting from a cased explosive 5 feet from the test block. (Test No. 2).

Test No. 6 produced a shaped-charge metal jet that is usually very difficult to protect against with general-purpose shrapnel protection. It was found that local shielding placed near the point of jet formation significantly reduced full development of the jet and its damage potential. Figure 7 shows a large dent in plate No. 3—approximately 1 inch in diameter and 1.25 inches deep—after the shot was shielded locally with plate glass.

Figure 7. Large dent from the explosively-formed metal jet from Test No. 6. The jet was reduced by passing through a total of 1 inch of glass before the jet hit the target (plate No. 3).

The methodology for shrapnel protection design was to start with a minimal design (1/2-in. mild steel plates) and increase the plate thickness as necessary. The goal was to achieve a balance between deformation caused by blast and perforation caused by shrapnel versus material cost and ease of handling. By increasing plate thickness, it was found that a reasonable, minimal shrapnel shield consisted of two layers of 1-in. mild steel plate separated by a 2-in. air gap. As shown in Table 1, the final design with this configuration (Tests 3 and 5 to 8) provided good protection because there were no perforations of plate No. 2, and bending deformation caused by the blast was acceptable. Figures 8, 9, and 10 show the effects of copper shrapnel on a test block of the final design.

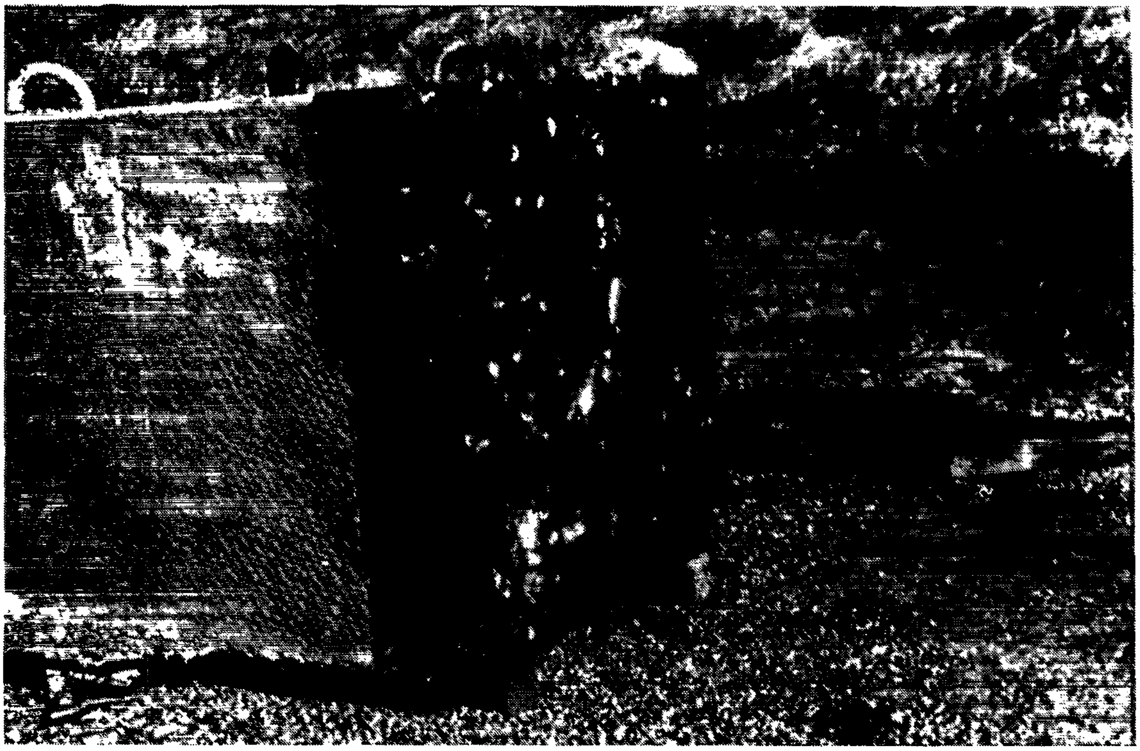

Figure 8. Penetrations and plate bending from copper shrapnel in Test No. 7.

Testing Results

Table 1 summarizes the perforation results for the tests.

Table 1. Shield thicknesses and shrapnel perforations.

	Plate thicknesses (in)			Number of perforations		
Test No.	#1 plate pressure liner	#2 plate	#3 plate	#1 plate pressure liner	#2 plate	#3 plate
1	0.5	0.5	none	1	5	
2	0.5	2.0	0.5	0	0	42
3	0.5	1.0	1.0	0	0	1
4	0.5	0.5	0.5	0	2	18
5	0.5	1.0	1.0	0	0	11
6	0.5	1.0	1.0	0	0	0
7	0.5	1.0	1.0	0	0	5
8	0.5	1.0	1.0	0	0	2
9	none	none	4.0			0

Figure 9. Effects of shrapnel from Test No. 7. Note the destroyed bolt head in the upper-right corner of the plate.

Figure 10. Workers removing remnants of a mangled bolt head after being hit by copper shrapnel from Test No. 7.

Figure 11. Example of plate No. 3 perforation under worst-case conditions (Test No. 8).

The worst-case shrapnel came from Test No. 8 which consisted of an 8-in. steel cylinder with a wall thickness of 0.8 in. The maximum fragment weight was calculated to be approximately 1 pound with a velocity of 4200 ft/s. Figure 11 shows perforation damage for the worst-case condition from this fragment type. Note that even though there was a large perforation in plate No. 3, there was almost no damage to the second plate behind it (plate No. 2).

The last shrapnel protection test (No. 9) in this series was an experiment to access the integrity of a protection housing for a new radiographic diagnostic called the gamma ray camera. Figure 12 shows an overall view of the protection housing with a 4-in.-thick mild-steel shrapnel protection plate in front of the assembly. This plate was used as a witness plate, instead of the multilayered test block, to observe the damage to a much thicker shrapnel protection shield.

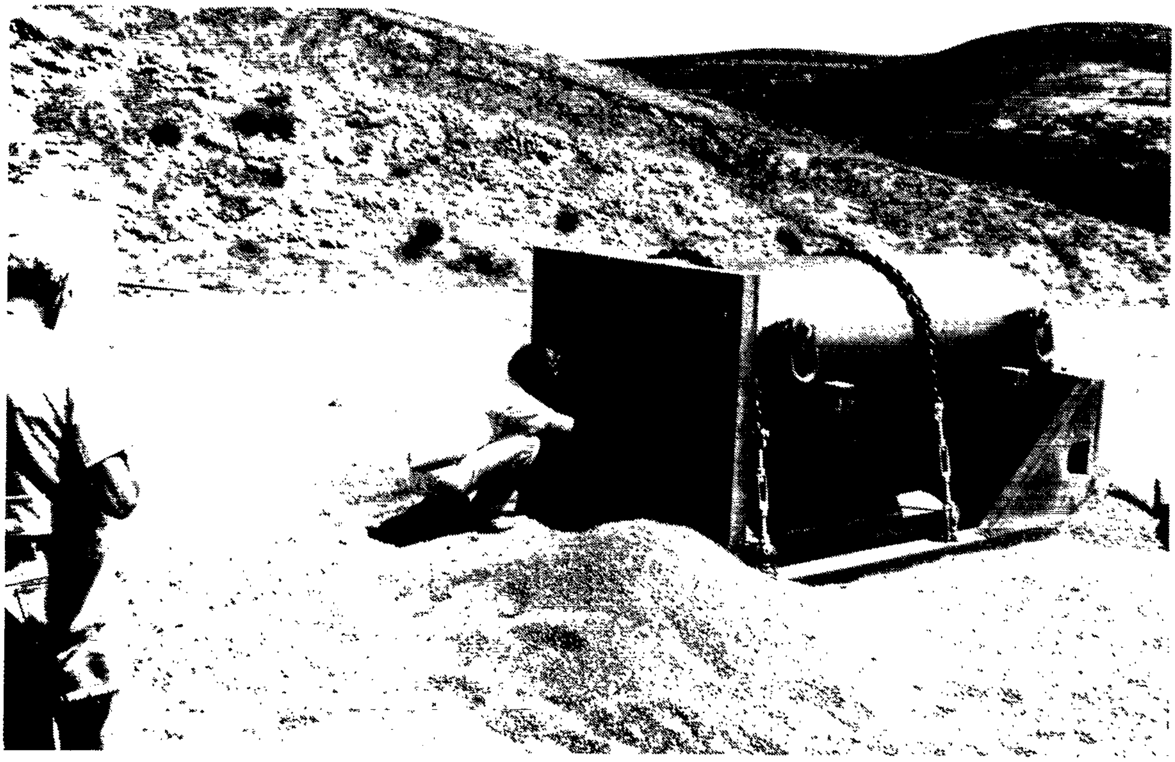

Figure 12. Physicist inspecting damage to the shrapnel protection plate for the gamma ray camera (Test No. 9).

The shrapnel-producing charge for Test No. 9 was a C4 explosive, 10-in. in diameter by 13.25 in. long, cased with a 3/8-in.-thick mild steel cylinder. This particular charge was designed to simulate the worst-case blast and shrapnel of close-up hydrodynamic experiments called core punch shots. Figures 13 and 14 show close-ups of the shrapnel patterns and the depth of penetration from Test No. 9.

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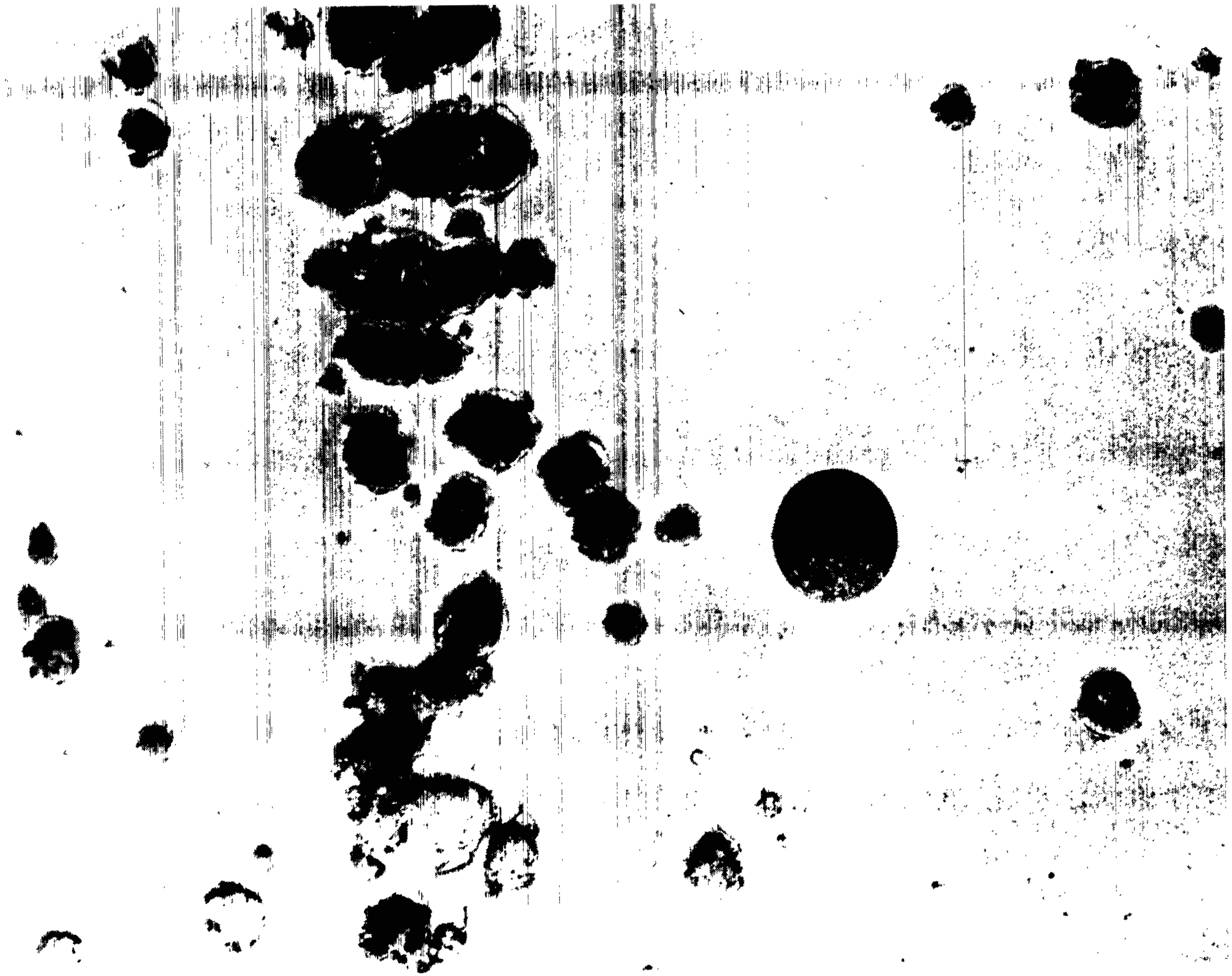


Figure 13. Skewed shrapnel pattern on the shield from Test No. 9. Cased explosive was purposely rotated 10 degrees to prevent most of the shrapnel from hitting the center hole in the protection plate.

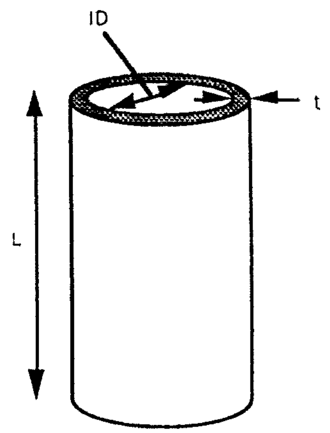
Figure 14. Cratering of 4-in.-thick steel plate surface caused by shrapnel fragments from Test No. 9.

Calculated Shielding Requirements

In addition to observing the shrapnel perforations, basic shrapnel penetration calculations were performed to compare and to make recommendations for general purpose shrapnel shielding for the Contained Firing Facility. The calculation methodology that was used is demonstrated below using the parameters from a single test (Test #7). The penetration calculations for all of the tests are given in Appendix B and a summary of these results is presented in Table 2.

The penetration caculations were performed as a two step process.'First a calculation of the shrapnel mass and velocity was performed. The penetrations were then calculated by using three accepted but different formulas. Due to the fact that penetration formulas are generally empirically based and were derived for differing regimes, three different formulas were used to assure a greater confidence in predicted penetration.

<u>Sample Calculation</u> (Test No. 7 parameters)



W = charge weight = 30# Lovex explosive
ID = case inside diameter = 4.0 in
t = case thickness = 0.4 in
l = case length = 48 in
$\gamma = \rho_f g$ = case weight density for copper= 0.323 $\frac{\text{lb}}{\text{in}^3}$

The case weight, W_c, is given by $W_c = \gamma \frac{\pi}{4}\left[(ID + 2t)^2 - ID^2\right] L$.

$$W_c = \left(0.323 \frac{\text{lb}}{\text{in}^3}\right)\frac{\pi}{4}\left[(4\text{ in} + 2(0.4)\text{in})^2 - (4\text{ in})^2\right] 48\text{ in} = 85.7\text{ lb} \ .$$

The initial velocity, V_o, of a case fragment is given by the Gurney[3] equation

$$V_o = \sqrt{2E}\sqrt{\frac{\frac{W_c}{W}}{1 + \frac{W_c}{2W}}}$$

where $\sqrt{2E}$ = Gurney energy constant = 8068 fps for Lovex.[4]

$$V_o = 8068\frac{\text{ft}}{\text{s}}\sqrt{\frac{\frac{85.7\text{ lb}}{30\text{ lb}}}{1 + \frac{85.7\text{ lb}}{2(30\text{ lb})}}} = 4403\text{ fps} \ .$$

The largest case fragment, W_f, is given by the Mott equation[5] with a fragment distribution factor, M_a, as:

$$M_a = B(t)^{\frac{5}{6}}(ID)^{\frac{1}{3}}\left(1+\frac{t}{ID}\right)$$

where

B = explosive constant $= 0.22\,(oz)^{\frac{1}{2}}\,(in)^{\frac{-7}{6}}$.

$$M_a = \left(0.22(oz)^{\frac{1}{2}}\,(in)^{\frac{-7}{6}}\right)(0.4\text{ in})^{\frac{5}{6}}(4\text{ in})^{\frac{1}{3}}\left(1+\frac{0.4\text{ in}}{4\text{ in}}\right) = 0.179\,(oz)^{\frac{1}{2}} .$$

$$W_f = \left[M_a\left(\ln 8\,\frac{W_c}{M_a^2}\right)\right]^2 = \left[0.179\text{ oz}^{\frac{1}{2}}\left(\ln 8\,\frac{85.7\text{ lb}}{\left(0.179\text{ oz}^{\frac{1}{2}}\right)^2}\right)\right]^2 = 3.18\text{ oz} .$$

The penetration depth (p) of the case fragment into the shrapnel protection plate is calculated by three different methodologies for comparison. The penetration formulas used are:

1. Demarre.
2. THOR equations modified for density.
3. Christman and Gehring.

Method No. 1: Demarre's equation[3]

$$p = c\,(W_f)^{\frac{1}{3}}\left(\frac{V_s}{1000}\right)^{\frac{4}{3}}$$

where

p = penetration depth (in.) ,

$c = 0.112\text{ (in)}(\text{ oz})^{\frac{-1}{3}}\left(\frac{ft}{s}\right)^{\frac{-4}{3}}$ for mild steel.

$$p = (0.112)\,(3.18\text{ oz})^{\frac{1}{3}}\left(\frac{4403\text{ fps}}{1000}\right)^{\frac{4}{3}} = 1.19\text{ in}.$$

penetration = 1.19 in

Method No. 2: Modified THOR equation

The original THOR[6] equation is given by

$$V_r = V_s - 10^{c1}(hA)^{\alpha}(7000W_f)^{\beta 1}(\sec\theta)^{\gamma 1}V_s^{\lambda 1}$$

where

V_r	=	residual velocity after perforating (fps),
V_o	=	striking velocity at the target (fps),
h	=	target thickness (in),
A	=	fragment cross sectional area (in^2),
W_f	=	fragment weight (lb),
θ	=	angle between fragment trajectory and the normal to the target material (deg),
$\alpha 1, \beta 1, \gamma 1, \lambda 1$	=	target specific material constants.

By setting residual velocity equal to zero ($V_r = 0$; no perforation) and rearranging terms yields the THOR equation for minimum shield thickness to prevent perforation:

$$h_{min} = \frac{1}{A}\left[\frac{V_o}{10^{c1}(7000W_f)^{\beta 1}(\sec\theta)^{\gamma 1}}\right]^{\frac{1}{\alpha 1}}.$$

Because the original THOR equations were for steel projectiles (fragments), the calculated fragment weight, W_f, was modified by the ratio of the densities of actual fragment material, ρ_f, to that of steel, ρ_s:

$$h_{min} = \frac{1}{A}\left[\frac{V_o}{10^{c1}\left(7000W_f\frac{\rho_f}{\rho_s}\right)^{\beta 1}(\sec\theta)^{\gamma 1}}\right]^{\frac{1}{\alpha 1}}.$$

The target specific material constants for mild steel from Table 6.17[7] are:

$$\alpha 1 = 0.906$$
$$\beta 1 = -0.963$$
$$\gamma 1 = 1.286$$
$$c1 = 6.523.$$

Using Test No. 7 parameters with $\theta = 0°$,

$$A = \frac{W_f}{(\rho_f g)t} = \frac{3.18\text{ oz}}{\left(0.323\frac{\#}{\text{in}^3}\right)(0.4\text{ in})}\left(\frac{\#}{16\text{ oz}}\right) = 1.54\text{ in}^2,$$

$$h_{min} = \frac{1}{1.54\text{ in}^2}\left[\frac{4403\text{ fps}}{10^{6.523}\left(7000(3.18\text{ oz})\left(\frac{\#}{16\text{ oz}}\right)\frac{0.323}{0.283}\right)^{-0.963}(\sec 0)^{1.286}}\right]^{\frac{1}{0.906}} = 1.09\text{ in}.$$

$$\boxed{\text{penetration} = 1.09 \text{ in}}$$

Method No. 3: Christman and Gehring[8]

$$p_c = (L - D)\left(\frac{\rho_f}{\rho_t}\right)^{\frac{1}{2}} + 0.13\left(\frac{\rho_f}{\rho_t}\right)^{\frac{1}{3}}\left(\frac{E_1}{\beta_{max}}\right)^{\frac{1}{3}}$$

where

p_c = total penetration depth (in),
L = length of projectile (in),
D = diameter of projectile (in),
E_1 = projectile kinetic energy (J),
β_{max} = maximum target hardness after impact Brinell hardness ($kg/(mm)^2$).

For Test No. 7:

$L = t = 0.4$ in ,

$$D = \left(\frac{4A}{\pi}\right)^{\frac{1}{2}} = \left(\frac{4(1.54 \text{ in}^2)}{\pi}\right)^{\frac{1}{2}} = 1.4 \text{ in}^2.$$

Because $L/D < 1$, the first term in the penetration equation, associated with long rod penetrators, is insignificant and can be neglected to yield:

$$p_c \cong 0.13\left(\frac{\rho_f}{\rho_t}\right)^{\frac{1}{3}}\left(\frac{E_1}{\beta_{max}}\right)^{\frac{1}{3}}.$$

The kinetic energy of the fragment E_1 is given by

$$E = \frac{1}{2}\frac{W_f}{g}(V_o)^2 .$$

$$E_1 = \frac{1}{2}(3.18 \text{ oz})\left(\frac{\#}{16 \text{ oz}}\ \frac{0.454 \text{ kg}}{\#}\right)\left(\frac{4403 \text{ ft}}{\text{s}}\ \frac{\text{m}}{3.28 \text{ ft}}\right)^2 = 8.1 \times 10^4 \text{ J} ,$$

which gives a penetration depth of

$$P_t \cong 0.13\left(\frac{\rho_f}{\rho_t}\right)^{\frac{1}{3}}\left(\frac{E_1}{\beta_{max}}\right)^{\frac{1}{3}} = 0.13\left(\frac{0.323}{0.283}\right)^{\frac{1}{3}}\left(\frac{8.1 \times 10^4\ \mathrm{J}}{165\ \frac{\mathrm{kg}}{\mathrm{mm}^2}}\right)^{\frac{1}{3}} = 1.07\ \mathrm{in}.$$

$$\boxed{\text{penetration} = 1.07\ \text{in}}$$

These calculated depths of penetration compare quite favorably with the values measured and listed in Table 1 for Test No. 7 . Test No. 7 had five perforations through the inner plate and small dents less than 1/8 in. in the second plate. These data correspond to a total penetration of approximately 1 in. + ≈1/8 in. ≈ 1.125 in. compared to 1.19 in., 1.09 in., and 1.07 in. calculated above.

Table 2 provides a summary of results using all three calculation methodologies compared to the measured penetration depths. Tests 1, 5, and 6 were jet producing tests and did not produce shrapnel.

Table 2. Calculated versus measured penetration depths for tests producing shrapnel.

	Calculated Depth (in)				
Test No.	Demarre	Modified THOR	Gehring and Christman	perforation + penetration	Measured Depth (in)
1	na	na	na	0.5 + 0.5 + ?	1.00 +
2	1.97	1.40	1.45	0.5 + 1.5	2.00
3	0.75	0.55	0.62	0.5 + .125	0.63
4	1.52	1.34	1.21	0.5 + 0.5 + 0.1875	1.19
5	na	na	na	0.5	0.50
6	na	na	na		*
7	1.19	1.09	1.07	1 + 0.125	1.13
8	1.92	2.30	1.78	? + 1	1.50†
9	2.71	1.48	1.60	1.5	1.50

* Metal jet formed without significant shrapnel..

† Total measured depth cound not be determined because the largest fragment struck and shattered a 0.5-in.-thick granite sheet before perforating plate No. 3.

na Not applicable for a calculational method.

Conclusions and Recommendations

1. These recommendations are good for *general purpose* shrapnel protection and are based on the assumption that local primary shielding is provided on a shot-by-shot basis. This assumption allows for conservatism and redundancy.

2. An analysis of the optimal air gap between plates is not provided. The 2-in. air gap between plates was based on earlier LLNL work.[2]

3. Provide a 1-in. mild-steel intermediate plate (plate No. 2 in Fig. 1) for redundancy and safety. A 2-in. air gap is recommended between all plates (plates 1, 2, and 3).

4. A minimum of 1/2 in. of mild steel should be provided for the pressure liner (plate No. 1) or other weldable, easily installed liner.

5. A 1-in. minimum of mild steel should be used for the innermost chamber plate (plate No 3 of Fig. 1) to prevent bending and minimize penetration and plate replacement.

6. Seal or exclude high-explosive (HE) particles or other contaminated material that might become lodged between the plates, under bolt heads, and in bolt threads. If this precaution is not taken, safety problems could be encountered during disassembly and re-assembly.

7. Measured shrapnel penetration depths compare quite favorably with calculational techniques in common use and provide a reference for shrapnel protection design in a contained chamber. Specifically, the calculational method of Gerhing and Christman provided the best overall match to the measured data for fragment sizes and velocities encountered in the testing.

Acknowledgments

The authors would like to thank Wayne Conner for coordinating construction of the test blocks as well as measuring and photographing the effects of these experiments. We would also like to acknowledge Michele Doyle for her help in documenting the test results. Our appreciation also to Fred Sator and his Bunker 850 crew for their assistance in the gamma ray camera blast and shrapnel testing.

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Appendix A. Test records, Nos. 1 to 8.

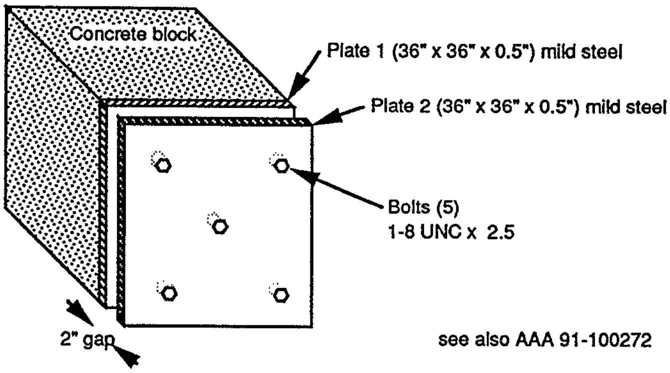
TEST RECORD

Test # 1 B Division Shot # 3113-A Test Date 12/5/90

HE type Comp. B / LX-17 HE wt. 16# / 40#

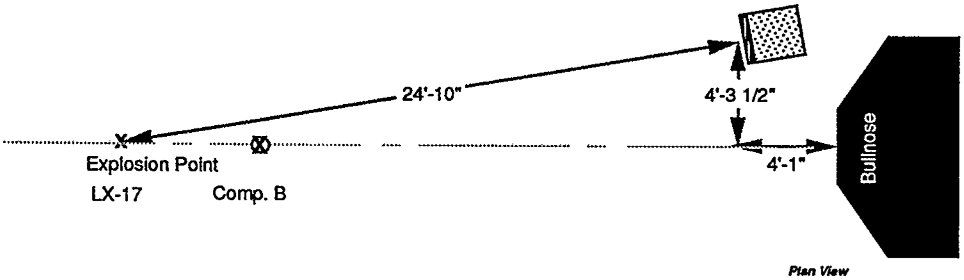
Fragment Velocity______ Fragment wt. (max)______ Fragment Matl'______

Test Assembly



see also AAA 91-100272

Test Setup



Results/ Conclusions

	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	Max. hole
Perforations in plate # 1	1	0	0	0	0.1875"
Perforations in plate # 2	0	2	1	2	.75" x 1"

Numerous pits in plate #2, five perforations of plate #2 . Because of a single perforation of plate #1, the geometry is unacceptable.

Test Record No. 1

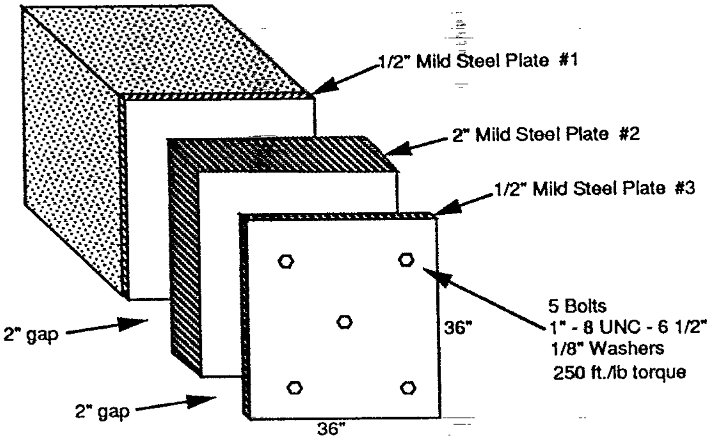
TEST RECORD

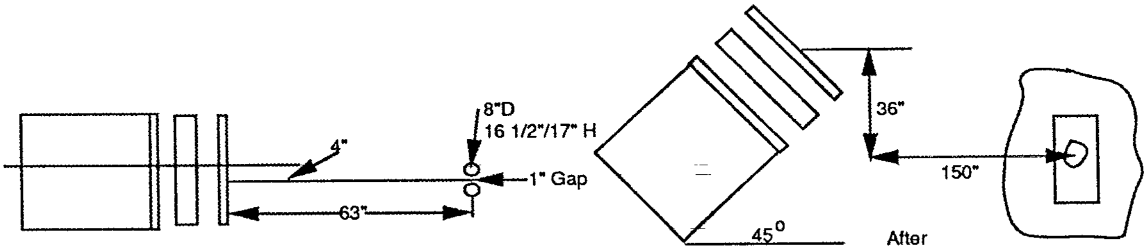
Test # 2 B Division Shot #CPLOV-109 Test Date 2/4/91

HE type RX-35-BT HE wt. 41lb. each - 82 lb. total

Fragment Velocity______ Fragment wt. (max) 128 lb. Fragment Matl' 1/2 " Mild Steel

Test Assembly





	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	1.0" - 1.5"	1.5" - 2.0"	2" - 3"
Perforations in plate # 1	0	0	0	0	0	0	0
Perforations in plate # 2	0	0	0	0	0	0	0
Perforations in plate # 3	0	0	5	7	14	9	7

Plate #1 - Impacts at edges. Bent plate at corners where concrete broke.

Plate #2 - No perforations. One stand-off loose. Major impacts up to 1 1/2" deep. Thirty impacts. Two-in. bend on edge of plate caused by blast.

Test Engineer - Frank Helm

Test Record No. 2

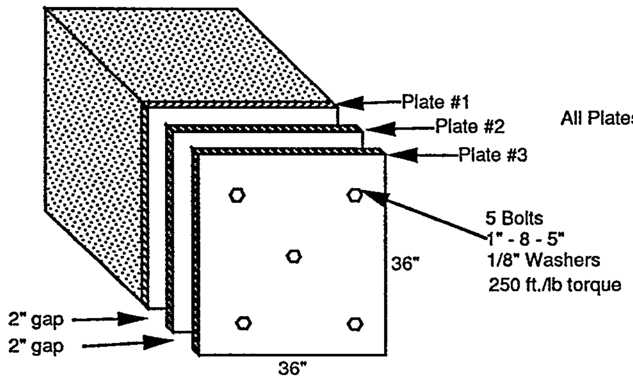
TEST RECORD

Test # 3   B Division Shot # K260-566   Test Date 2/5/91

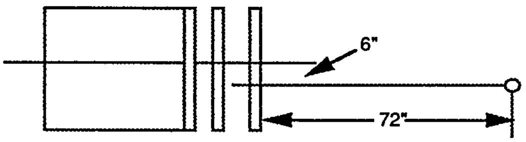
HE type RX-35-BT   HE wt. 2 1/2 lb.

Fragment Velocity______   Fragment wt. (max) 5.27 lb.   Fragment Matl' Cu. 0.2 Wall Thickness 12" H Cylinder Shot - 2" I.D.

Test Assembly



Test Setup



Results/ Conclusions

Perforations in plate # 3	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	Max. hole
	0	1	0	0	1/4" x 3/8"

Numerous pits in plate #3, one perforation of plate #3 .

Test Engineer - Don Breithaupt

Test Record No. 3

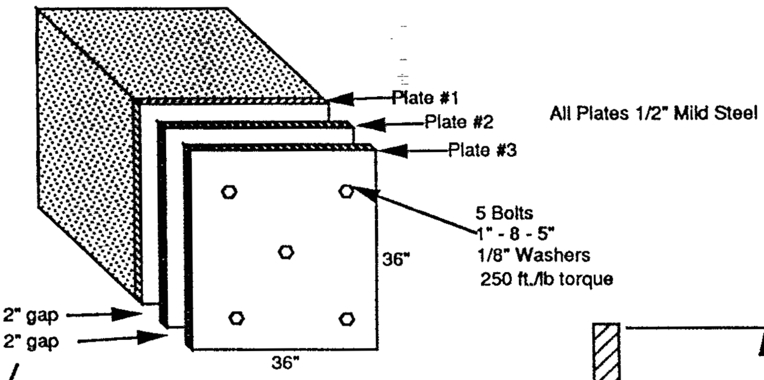
TEST RECORD

Test # 4 B Division Shot # K260-567 Test Date 2/6/91

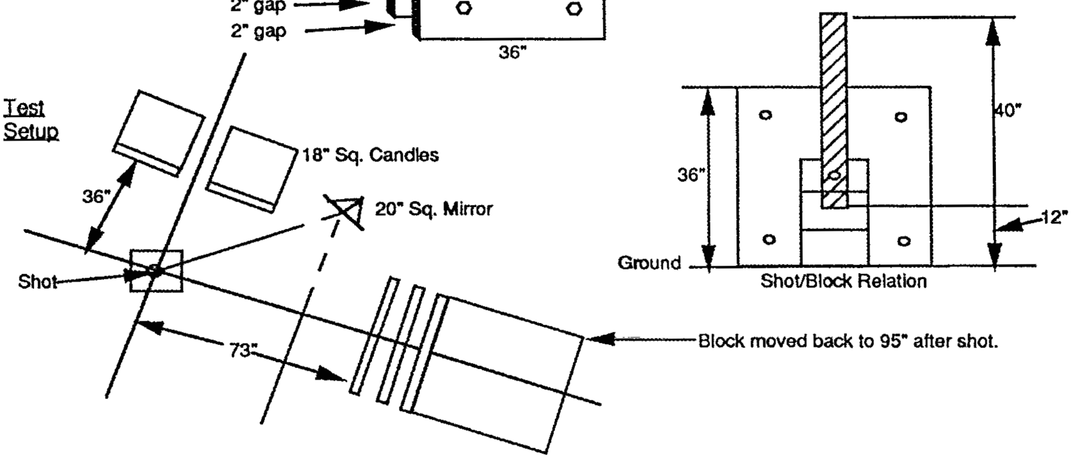
HE type RX-35-BT HE wt. 40 lb.
Comp. B - 8lb.

Fragment Velocity______ Fragment wt. (max) 70.28 lb. Fragment Mat'l Cu. Cylinder Shot 4.8" O.D. 0.4" Thickness. 40" High

Test Assembly



Test Setup



	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	1.0" - 1.5"	1.5" - 2.0"	2" - 3"
Perforations in plate # 2	0	0	1	1	0	0	0
Perforations in plate # 3	1	2	2	2	7	2	2

Two impacts on plate #1: one is a surface discolor, the other a 1/2" x 3/4" circular depression 3/16" deep.

Sixteen impacts on plate #2. Cracked weld at standoff.

One damaged area, 5/8" x 3/4" by 1/4" deep.

Test Engineer - Don Breithaupt

Test Record No. 4

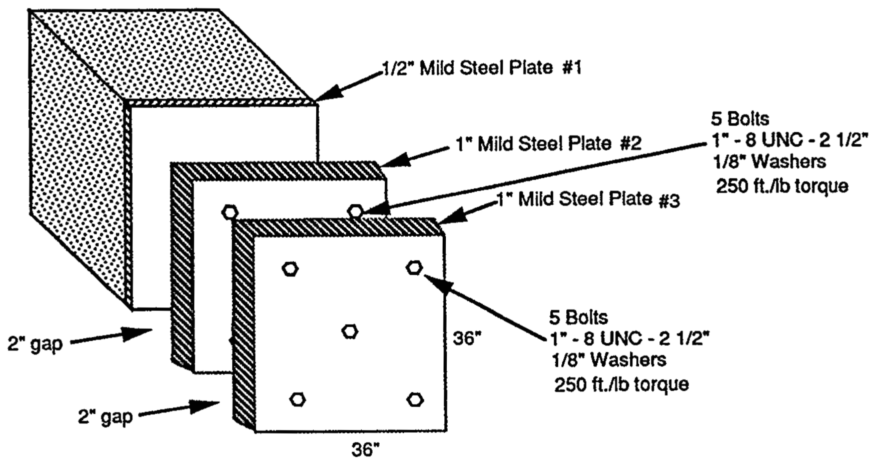
TEST RECORD

Test # 5 B Division Shot # 495-A Test Date 4/4/91

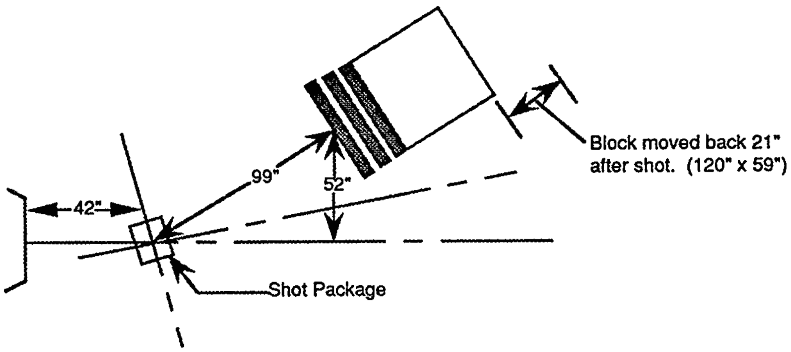
HE type LX-17 HE wt. 50 lb.

Fragment Velocity______ Fragment wt. (max) 25Kg Fragment Matl' D-38

Test Assembly



Test Setup



	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	1.0" - 1.25"	Max. Hole
Perforations in plate # 1	0	0	0	0	0	0
Perforations in plate # 2	0	0	0	0	0	0
Perforations in plate # 3	0	1	3	6	1	1 5/8" x 5/8"

- Numerous minor impacts.
- No perforations.
- Two edge hits on plate #3 - 3/4" and 1".
- Very slight bend in plate #3 caused by blast.
- Assembly would be reusable without changing plates.
- We probably received impacts from the most damaging fragments.
- The assembly may have been partially shielded.
- We may have received fragments from the waste.

Test Record No. 5

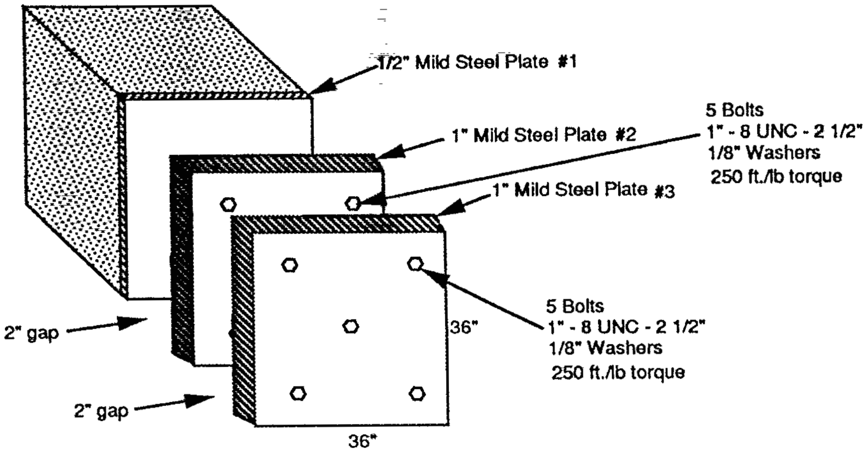
TEST RECORD

Test # 6 B Division Shot # 417A Test Date 4/11/91

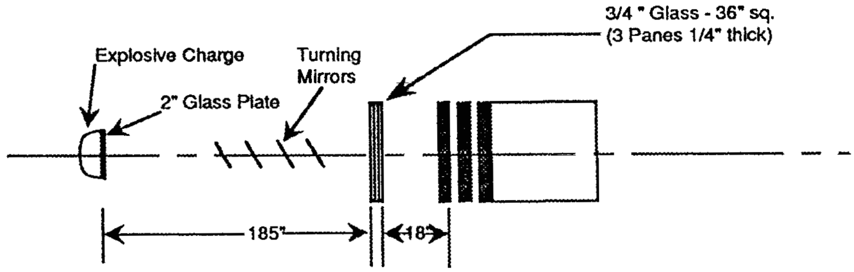
HE type LX-17 HE wt. 10 lb.
Comp B 18 lb.

Fragment Velocity______ Fragment wt. (max) 25Kg Fragment Mat'l D-38

Test Assembly



Test Setup



- Large dent in plate #3 as if hit by a projectile approximately 1" in diameter. Dent is approximately 1 1/4 " deep.
- Did not penetrate 1"-thick plate #3. Plate is deformed on back surface and does have a slight bend.
- No damage to plates #1 or #2.
- Explosive charge was covered with 2" glass plate on surface face of hemisphere. Other turning mirrors may have also attenuated the impact.
- Since the test, we have learned that placing glass close to the explosive charge has a much greater effect on reducing the jet than placing the glass near the block assembly. Therefore, the effect of glass plates near the block assembly alone cannot be determined.
- The explosive charge generated a jet effect and did not produce shrapnel.
- In our experiment, the total effect of the glass (explosive charge face, turning mirrors, and plate glass) successfully protected our block assembly.

Test Record No. 6

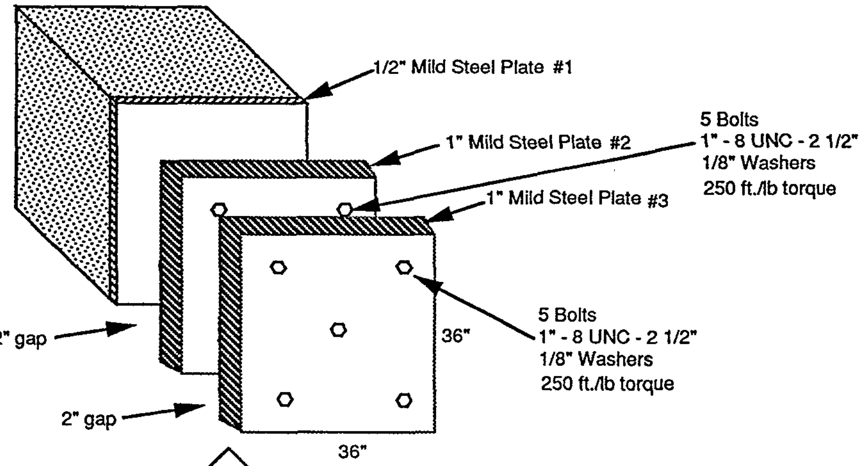
TEST RECORD

Test # 7 B Division Shot # K260-570 Test Date 5/30/91

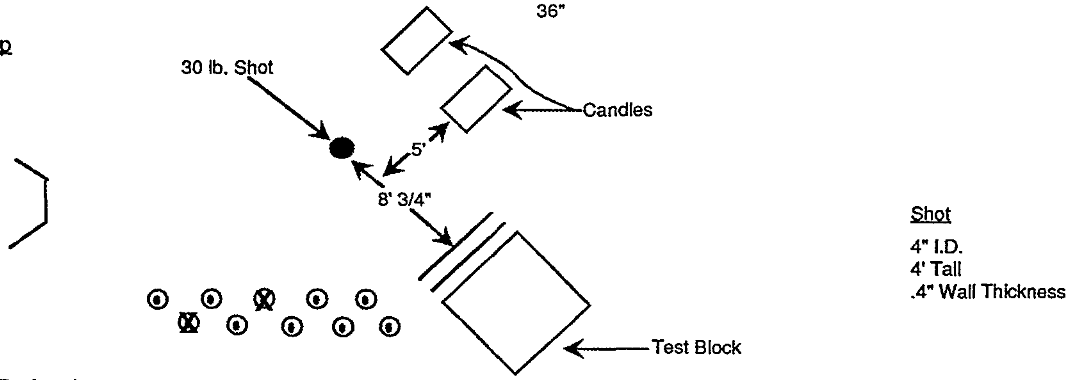
HE type Lovex, Comp B HE wt. 30lb., 16lb.

Fragment Velocity ______ Fragment wt. (max) 73 lb. Fragment Matl' Copper

Test Assembly



Test Setup



	0"-0.25"	0.25"-0.5"	0.5"-0.75"	0.75"-1.0"	Max. hole
Perforations in plate # 1	0	0	0	0	0
Perforations in plate # 2	0	0	0	0	0
Perforations in plate # 3	0	1	1	1	1 1/2" x 3/4", 1 1/4" x 5/8"

- No impacts on plate #1.
- Five impacts on plate #2. No perforations. Small dents to 1/8" deep, approximately 1/2" diameter.
- Major damage to plate #3. Slight bend in plate. Five perforations.
- Upper-right bolt head destroyed. Had to be removed with hammer, chisel, and channel lock pliers.
- Bolts holding plate #3 were at reduced torque. Damaged bolt was loose.
- Bolts holding plate #2 were still tight but at approximately 200 ft./lb torque. They were retorqued to 250 ft./lb.
- This was a very successful test. Plate #1 received no impacts.
- Plate #3 received impacts from Tests # 5, 6, and 7. It has now been replaced with a new plate.

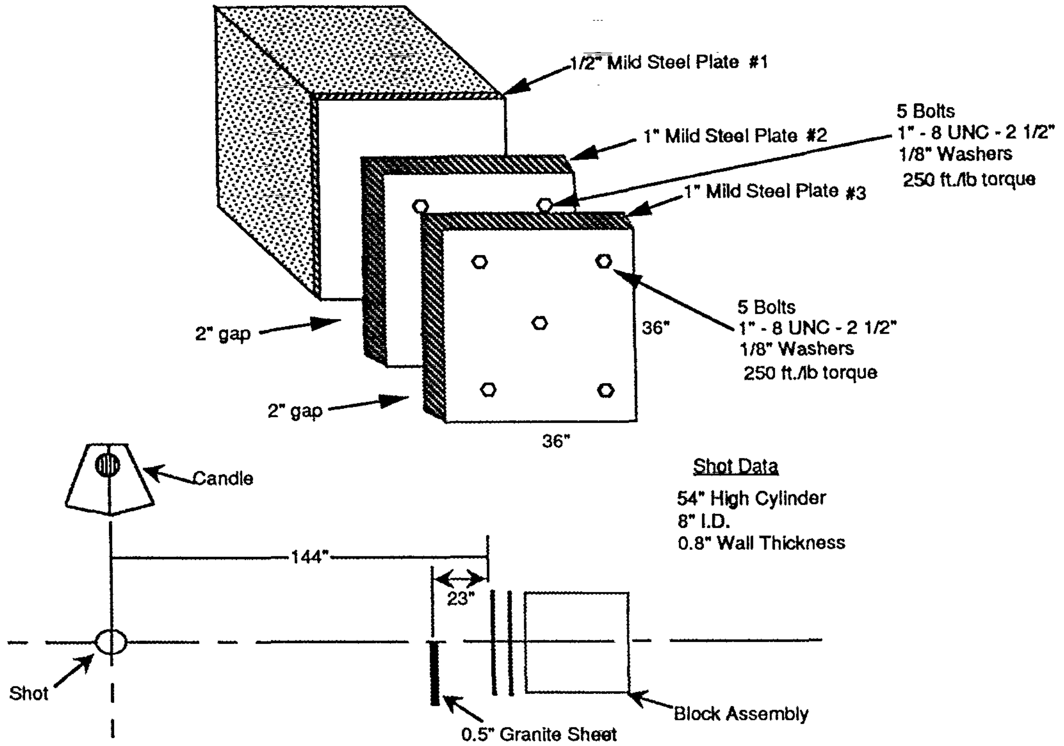
Test Record No. 7

TEST RECORD

Test # 8 B Division Shot # K260-572 Test Date 6/28/91

HE type PBXN-103 - Main Charge HE wt. 173 lb.
Comp B - Candle 16 lb.

Fragment Velocity______ Fragment wt. (max) 360 lb. Fragment Matl' Cu



	0-1"	1"-2"	2"-3"	Perforations
Impacts in plate # 1	0	0	0	0
Impacts in plate # 2	0	0	0	0
Impacts in plate # 3	1	6	2	2 (8" x 2.25"), (2.4" x 1.8")

- Plate #1 received no impacts.
- Plate #2 was not perforated. It did receive a large dent when impacted by shrapnel from plate #3. The plate was distorted by 1.1" at the edge and tapered toward center bolt.
- Plate #3 received 20 major impacts; however, only two were perforations. One perforation was quite large and impacted plate #2 severely.
- A 0.5-in.- thick granite sheet was placed 23 in. in front of one-half of the impact block. This action was taken to test the shrapnel mitigation potential of various materials. We are currently considering glass, ceramics, and granite. By chance, that half of the block received the major impacts. The performance of the granite sheet is inconclusive.
- Although the witness block assembly was impacted by large shrapnel pieces, the two 1-in. steel plates successfully protected the one-half-in. pressure liner plate #1 on the block face.

Test Record No. 8

Appendix B. Spreadsheet of Penetration Calculations

Test No.		Plate Thicknesses (in)			Number of Perforations	
	#1 plate pressure liner	#2 plate	#3 plate	#1 plate pressure liner	#2 plate	#3 plate
1	0.5	0.5	none	1	5	
2	0.5	2	0.5	0	0	42
3	0.5	1	1	0	0	1
4	0.5	0.5	0.5	0	2	18
5	0.5	1	1	0	0	11
6	0.5	1	1	0	0	0
7	0.5	1	1	0	0	5
8	0.5	1	1	0	0	2
9	-	-	4	-	-	0

Test No.	Charge Wt. (lb)	Case ID (in)	Case Thickness (in)	Case Length (in)	Case Wt. (lb)	Case density lb/in^3	Mott Explosive constant "B"
1	40		c				
2	41	8	0.5	17	64.23536	0.283	0.22
3	2.5	2	0.2	12	5.357798	0.323	0.22
4	40	4	0.4	40	71.4373	0.323	0.22
5	50		c				
6	10		c				
7	30	4	0.4	48	85.72476	0.323	0.22
8	173	8	0.8	54	385.7614	0.323	0.22
9	60	10	0.375	13.25	45.83229	0.283	0.22

Test No.	Gurney Energy Const. (fps)	Mott Constant Ma	Calculated Frag. Wt. (lb)	Calculated Frag. Wt. (oz)	Gurney Frag. velocity (fps)
1					
2	8068	0.262375504	0.342182	5.474909	5612.10101
3	8068	0.07974137	0.030888	0.494201	4962.58001
4	8068	0.179013324	0.191917	3.070678	5336.22557
5					
6					
7	8068	0.179013324	0.199133	3.186128	4403.09836
8	6986	0.401871324	0.980897	15.69436	4228.24739
9	8800	0.217155171	0.236544	3.784704	7827.64662

Appendix B. Spreadsheet of Penetration Calculations (continued)

Test No.		Calculated Depth (in)			Measured Depth (in)
		Modified	Gehring &	Perforation &	
	Demarre	THOR	Christman	penetration	Total
1					
2	1.96869	1.402139574	1.446696	.5 + 1.5	2
3	0.74954	0.552870682	0.624808	.5 + .125	0.625
4	1.51801	1.343886927	1.205612	0.5+0.5+0.1875	1.1875
5					0.5
6					
7	1.18937	1.08951833	1.073742	1 + 0.125	1.125
8	1.91725	2.303601418	1.778258	1+	
9	2.71271	1.48341677	1.596858	1.5	1.5

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6. *The Resistance of Various Metallic Materials to Perforation By Steel Fragments; Empirical Relationships, for Fragment Residual Velocity and Residual Weight (U)*, Ballistics AnalysisLaboratory/ BRL, Project THOR Technical Report No. 47 (April 1961).

7. *A Manual for the Prediction of Blast and Fragment Loadings on Structures*, United States Department of Energy, DOE/TIC 11268 (November 1980).

8. D. R. Christman and J. W. Gehring, "Analysis of High Velocity Projectile Penetration Mechanics," *J. Appl. Phys.*, **37** (4) (March 15, 1960).