SOAR

STATE-OF-THE-ART REPORT (SOAR)
SEPTEMBER 2017

DSIAC-2018-0847

PROTECTION FOR THE HOMEMADE EXPLOSIVE (HME) RESEARCHER:

Laboratory Shielding and Personal Protective Equipment

By William A. Bagley
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WILLIAM A. BAGLEY

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13. ABSTRACT

This State of the Art Report is an attempt to summarize current and available information to inform and assist energetic researchers in the selection of commercially available personal protective equipment, along with the design and construction thereof. Regulatory requirements relevant to U.S. based laboratories are presented where they serve to aid in selection of equipment or further understanding of the hazards associated with handling of energetic materials. Data has been compiled from reports published by universities, U.S. and U.K. government agencies, and material manufacturers. Additional restricted data exist that may be available directly from the sponsoring agency.

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ABSTRACT

This State of the Art Report is an attempt to summarize current and available information to inform and assist energetic researchers in the selection of commercially available personal protective equipment, along with the design and construction thereof. Regulatory requirements relevant to U.S. based laboratories are presented where they serve to aid in selection of equipment or further understanding of the hazards associated with handling of energetic materials. Data has been compiled from reports published by universities, U.S. and U.K. government agencies, and material manufacturers. Additional restricted data exist that may be available directly from the sponsoring agency.

Keywords:

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SECTION 01

Introduction

1.1 HME HAZARDS

Hazardous chemicals used in the synthesis and formulation of homemade explosives can present both physical hazards and health threats to workers in government, commercial, and academic research laboratories. Hazards encountered may include carcinogens, toxins that affect the liver, kidney, and nervous system, irritants, corrosives, and agents that act on the blood system or damage the lungs, skin, eyes, and mucous membranes. Working with materials having the potential to form explosive mixtures or compounds requires special precautions as some mixtures are sensitive to small amounts of stimuli in the form of friction, impact or shock, electrostatic discharge (ESD), or heat. In addition to the potential for thermal runaway during formulation and compatibility issues impacting storage considerations, some of these compounds may be affected by moisture or acid content, may be volatile with a tendency to sublime or give off toxic fumes, or may be sensitive to light.

The information contained in this document has been prepared to assist energetic materials researchers in selecting protective shields and equipment for conducting activities that involve explosives and explosive ingredients safely. It is the responsibility of the user to ensure the applicability of the information to any specific location, situation, or operation. The information, charts, and figures are provided to guide the handling of IE/HMEs produced in a laboratory setting by individuals authorized to conduct such operations by their organizations. All IE/HME handling should be performed only under the advisement of a qualified Subject Matter Expert (SME). No measure of engineering can guarantee absolute safety; rather it depends upon sound work practices and proper interpretation of guidelines by experts in the fields of explosives and safety engineering to promote a culture of safety.

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SECTION 02

Evaluation and Analysis

2.1 WORKING WITH UNCHARACTERIZED ENERGETIC MATERIALS

The synthesis or blending of uncharacterized energetic materials should be conducted according to the Interagency Protocols on HME Safety and Performance Testing,[1] IE/HME WG Safety Standards Document,[2] and all applicable standards of the facility where work is being executed. The process outlined in the protocols is designed to assist the researcher in the safe scale-up of new or uncharacterized energetic materials. This process extends to new batches of previously characterized explosives, as batch-to-batch variability has been demonstrated.

2.1.1 Primary Hazards Posed by Explosive Materials

The primary hazards posed by initiating an explosive are blast, fragments, and thermal effects. There are also secondary effects, including noise, the ignition of nearby flammable materials, the formation and release of harmful gasses, and chemical contamination. When a laboratory operation involves an explosion hazard and cannot be conducted remotely, a risk analysis should be performed to assess the best hazard-mitigation option. The risk analysis will determine which mitigation techniques are appropriate. Table 2-1, populated with data from NAVSEA OP-5, lists potential effects of blast pressures on personnel.[3]

Table 2-1. Effects of Blasts on Personnel

EFFECT	PSI
1% Eardrum Rupture	3.4
50% Eardrum Rupture	16
Threshold Lung Rupture	10 (50 ms duration)
	20-30 (3 ms duration)
1% Mortality	27 (50 ms duration)
	60-70 (3 ms duration)

"NAVSEA OP-5, Vol. 1, 5th Rev.; Ammunition and Explosives Ashore; Safety Regulations for Handling, Storing, Production, Renovation and Shipping"[3]

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SECTION 03

Protection Measures for Working with Uncharacterized Energetic Materials

3.1 FUME HOODS

The concept of the Hierarchy of Controls described in the Laboratory Standard, 29 C.F.R. § 1910.1450[4], prioritizes intervention strategies based on the premise that the best way to control a hazard is to systematically remove it from the workplace, rather than relying on employees to reduce individual exposure. The types of measures that may be used to protect employees (listed in decreasing order of effectiveness) are: elimination or substitution, engineering controls, administrative controls, and personal protective equipment (PPE). Elimination or substitution of hazards may be accomplished by modification of existing equipment and material acquisition programs. Engineering controls, such as laboratory safety shields, physically separate employees from the hazard. Administrative controls, such as employee scheduling, are established by management to help minimize employees' exposure time to hazards. Protective clothing and PPE are additional protections provided under special circumstances and when exposure is unavoidable.

DoD 6055-9 states personnel protection must limit incident blast overpressure to 2.3 psi [15.9 kPa], fragments to energies of less than 58 ft-lb [79 joules], and thermal fluxes to 0.3 calories per square centimeter per second [12.56 kilowatts per square meter][5]. The amount of energy experienced by the explosive material handlers can be controlled through a combination of distance, shielding, and personal protective clothing. Distance can be used to provide the required level of protection for blast and thermal effects only.

Fume hoods utilized for energetics research should be robust in design; non-frangible materials should be used for the cabinet, safety glass should be employed for window sash construction to mitigate fragmentation, and sacrificial vent panels should be used to mitigate blast effects. Lighting, blowers, and other electrical components should be grounded and non-spark producing. To avoid a confinement hazard in the event of fire or explosion, fume hoods should be located away from the path to the exit, so personnel do not need to pass in front of a hood to exit the lab. Fume hoods should not be situated directly opposite occupied work stations, as materials splattered or forced out of a hood could cause serious injury. Windows in labs containing fume hoods should be fixed in a closed position.

3.2 LABORATORY SAFETY SHIELDS

Laboratory safety shields that comply with Military Standard (MIL-STD)-398, "Shields, Operational for Ammunition Operations, Criteria for Design and Tests for Acceptance,"[6] provide varying degrees of protection for blast, thermal, and fragment effects. Military Standard 398A specifies shields shall be designed to prevent exposure of operating personnel to peak positive incident pressures above 2.3 psi (15.9 kPa), which is below the threshold for a disabling injury, and heat flux should be limited to prevent the onset of second degree burns. Heat fluxes and exposure times experienced by personnel should be less than that given by the equation:

$$t = 200q^{-1.46}$$

where "t" is the time in seconds that a person is exposed.[3]

3.2.1 Shield Protection Levels and Effectiveness

The Naval Surface Warfare Center, Indian Head, conducted testing to measure the blast overpressures and heat flux imparted on both standing and sitting operators resulting from the detonation of ~2.6 g and ~11.5 g of PBXN-5 pellets using Reynolds RP-80 detonators containing 0.2 g of explosive. Results of testing shows that properly designed shields provide adequate protection against blast overpressures and heat flux.[7]

Table 3-1. Safety Shield Manufacturers and Protection Levels

Shield Descriptor	Charge Size & Mass/ Confinement if any	Standing Operator		Sitting Operator		Observer
		ta (ms)	p (psi)	ta (ms)	p (psi)	p (psi)
Bazil	0.5" dia. x 0.5", 2.8 g	1.2, 1.6	1.0, 3.7	*N/A*	*N/A*	1.1
Bazil	0.5" dia. x 0.5", 3.0 g	1.1, 1.7	1.3, 3.2	*N/A*	*N/A*	1.3
Bazil	0.5" dia. x 0.5", 2.8 g	1.2, 1.7	1.5, 3.5	*N/A*	*N/A*	1.7
Bazil	1.25" dia. x 0.35", 11.5 g	0.8	9.2	0.9	5.0	4.2
Bazil	0.5" dia. x 0.5", 2.8 g	1.2, 1.7	1.5, 3.6	1.1	2.5	2.0
Bazil	0.5" dia. x 0.5", 2.8 g	1.1, 1.6	2.1, 1.2	1.1	2.3	1.3
	0.628 O.D. steel sleeve					
Bazil	0.5" dia. x 0.5", 2.8 g	1.0, 1.6	2.3, 1.5	1.1	2.2	1.5
	0.628 O.D. steel sleeve					
None	0.5" dia. x 0.5", 2.8 g	1.0	*N/A***	0.7	8.0	3.7
None	0.5" dia. x 0.5", 2.8 g	1.0	*N/A***	0.7	8.0	3.6
Bazil	0.5" dia. x 0.5", 2.8 g 0.626 O.D. steel sleeve	0.9, 1.5	3.0, 1.1	1.0	1.9	1.9
Bazil	0.5" dia. x 0.5", 2.8 g 0.754 O.D. steel sleeve	0.9, 1.7	1.9, 0.9	1.0	1.6	1.3
Groves	0.5" dia. x 0.5", 2.8 g	1.6	2.7	1.3	2.9	1.6
Double	0.5" dia. x 0.5", 2.8 g	1.7	2.6	1.3	2.9	1.7
26x26	0.5" dia. x 0.5", 2.8 g	1.2, 1.9	1.2, 1.2	1.5	1.9	1.1
25x49	0.5" dia. x 0.5", 2.8 g	1.9, 2.4	1.4, 1.2	1.6	1.5	1.1
Wing 1	0.5" dia. x 0.5", 2.8 g	1.9, 2.1	1.0, 1.4	1.3	1.0	1.1
Bazil	0.5" dia. x 0.25", 1.3 g	1.3, 1.7	1.1, 1.7	1.2	1.5	1.2
Bazil	0.5" dia. x 0.25", 1.3 g	1.3, 1.7	0.9, 1.8	1.2	1.3	1.2
Wing 2	0.5" dia. x 0.5", 2.8 g	1.9, 2.3	0.8, 1.2	1.3	1.2	1.1
Wing 2	1.25" dia. x 0.35", 11.7 g	1.4, 2.0	0.9, 3.1	1.4	2.1	3.0
LabGard	0.5" dia. x 0.25", 1.3 g	1.4	1.7	1.3	1.6	0.8
LabGard	0.5" dia. x 0.5", 2.8 g	1.2	3.1	1.2	3.0	1.9
Bazil	Shotshell, 2.0 g powder	7.9	1.1	7.5	0.8	0.6

Sandusky, H.W. and Moore, V.D., "Effectiveness of Transparent Shields in Protecting Explosive Operations Personnel," Naval Surface Warfare Center, Indian Head, MD (1994)[7]

Table 3-2. Shield Protection Effectiveness

Descriptor in Table 2	Dimensions (in)			Material	Charge Distance	Comments
	W	H	T			
None					20.75	Free-field measurements
Bazil	20	24	½	PC	29.0	18° tilt from operator, 4 ¼" wide x 7 ¾" high cutouts for arms
Groves	20	34	½	PC	28.2	8" high x 2" wide cutouts for arms
Double	20	34	1 ½	PC		Bazil's shield + Groves' shield with ½" air space between them and flush at the top
26x26	26	26	2 ½	PMMA		3° tilt from operator
25x49	25	49	1 ½	PC	37.2	
Wing 1	33	34	½	PC	42.4	Groves' shield with side extensions of ¼" PC angled 35° toward operator
Wing 2	33	34	1 ½	PC	42.4	Wing 1 with 114" PC top
LabGard	15	29	⅛ PC + ¼ PMMA		26.5	Lab-Guard Model D, semi-circular PC shield with weighted base and PMMA liner

Sandusky, H.W. and Moore, V.D., "Effectiveness of Transparent Shields in Protecting Explosive Operations Personnel," Naval Surface Warfare Center, Indian Head, MD (1994)[7]

When explosive operations require personnel to reach around a shield to manipulate equipment, exposure should be minimized. The following table, accompanying notes, and guidelines are from the DOE Explosives Safety Manual DOE-M-440 1-1A[8] and list shields that have been tested and found acceptable for the indicated quantities of explosives. Operators should always follow the operating procedures, explosive limits, and explosive safety protocols of their organization.

NOTE: Shields listed in Table 3-3 were not tested for metal-fragment penetration and thus may not offer effective protection when the explosive is closely confined in a heavy-walled metal container. If an experiment poses a metal-fragment hazard (as opposed to a glass-fragment hazard) and the experiment cannot be conducted remotely, the proposed shield should be tested and approved under conditions simulating an explosion in the experimental setup but with at least 125% of the anticipated explosive content.

1. The shield should be anchored to the hood frame or benchtop when it is being used for protection against more than 0.16 oz (5 grams) of TNT equivalent.
2. Other shields may be used upon approval after successfully passing a test of 125% of the rated explosive charge.
3. For confined areas, a blast vent having less strength than the shield should be provided.

Blast testing has shown that laminated tempered glass is superior to monolithic tempered glass, and polycarbonate is superior to acrylic plastics, such as Lucite. Shields manufactured from these materials are recommended to be of equal or greater thickness than those listed in the table. Proof testing specific to the intended application of the shield is highly recommended. When using a polycarbonate in the design of a new safety shield and/or the replacement of an existing one, the polycarbonate should be UV stabilized, treated for abrasion resistance, and meet Mil Spec P-46144C. When using laminated glass in the design of a new

Table 3-3. Shield Material and Explosives Limit

Shield	Minimum Distance from Explosive	Explosives Limit
Leather gloves, jackets, or coats, and plastic face shields	----	.77 gr (50 mg)
.12 in (3 mm) tempered glass	3.15 in (8 cm)	.77 gr (50 mg)
.2755 in (7 mm) Lucite/equivalent material	5.905 in (15 cm)	.0882 oz (2.5 g)
.8 in (20 mm) Lucite/equivalent material	5.905 in (15 cm)	.3527 oz (10 g)
.6 in (15 mm) laminated resistant glass	7.874 in (20 cm)	.7054 oz (20 g)
.9999 in (25.4 mm) Lexan/Lexguard	11.81 in (30 cm)	1.764 oz (50 g)
2 units each of .9999 in (25.4 mm) plate glass laminated with .4882 in (12.4 mm) polycarbonate with a .374 in (9.5 mm) air gap between units (glass sides facing the explosive)	11.81 in (30 cm)	1.764 oz (50 g) (steel confined)

DOE Explosives Safety Manual, DOE M 441.1-1A, U.S. Department of Energy, Office of Environment, Safety and Health, 1 September 2006[8]

safety shield and/or the replacement of an existing one, the laminated glass should be coated with a 0.1 mm fragment-resistant film on the viewer’s side to minimize spalling. The shield, shield frame, and anchoring system should be designed to resist maximum credible overpressure and fragments.[8]

Minimizing the number and size of glass panels in a laboratory safety shield and, if possible, orienting the shield to minimize blast loads on glass panels is recommended when a risk assessment indicates that a fragment hazard is present.

3.2.2 Shield Protection Testing

In addition to the testing conducted by the DOE, the Atomic Weapons Establishment (AWE) tested a number of standard safety shields to assess the level of protection provided. The shields were tested against detonating charge masses of 0.3 g, 1.0 g, 5.0 g and 7.5 g for PETN-based explosives, and 1.3 g for a HMX-based explosive[9]. The fragment sources used in the trials were Glass Round Bottom Flask (RBF), Porcelain Buchner Funnel (BF) or Glass Test Tube (TT). Complete details on charge selection, composition and test configurations can be found in the reference. The shields tested are listed below with a test summary including results shown in Table 3-4. The shield tests used the more powerful HMX based explosive.

- Fisher safety screen, 3-section, SAT-575-010N, 3 mm polycarbonate
- Nalgene laboratory shield 6350, 4.8 mm (3⁄16”) polycarbonate
- SciCron Technologies PC350 sheet, 6 mm PC350 static dissipative polycarbonate
- SciCron Technologies PC350 sheet, 12 mm PC350 static dissipative polycarbonate.

3.2.3 Securing Screens

In addition to screen selection, a suitable method for securing the screen must be utilized. Screens were tested in both loosely- and firmly-clamped configurations. The results from loosely-clamped shields may not be representative of outcomes from screens with heavy bases (for small charges) or fixed screens (for larger charges).

3.2.4 Thermal Protection and Shielding

Using sufficient distance or barricades to protect from blast or fragments will also provide some degree of thermal protection against small charges with little thermal output.

Table 3-4. Safety Shield Protection Levels

Description of test	Nalgene Lab Shield, 4.8 mm	Fisher Safety Screen, 3.0 mm	PC 350 sheet 6 mm	PC 350 sheet 12 mm
0.3 g, BF	No penetration	-	-	-
1.0 g, RBF	-	No penetration	-	-
1.0 g, BF	No penetration		-	-
1.3 g, RBFP	-	-	No penetration	No penetration
1.3 g, BFP	-	-	No penetration	-
5.0 g, TT	-	Screen shattered	No penetration	-
7.5 g, RBF	-	Screen shattered	-	-

Murray, C., et al., Protective Equipment for Small-scale Laboratory Explosive Hazards. Part 2. Shielding Materials, Eye and Face Protection, J. Chem. Health Safety (2015)[9]

Thermal shielding between the thermal source and personnel can provide protection to researchers from injuries sustained by exposure to fireballs and heat flux that occur during unanticipated reaction events. Any shielding used must comply with all applicable standards. When shielding is either not possible or inadequate, to include protection for personnel's respiratory and circulatory systems, augmentation with personnel protective clothing and equipment may be necessary. Thermal protective clothing that is capable of limiting bodily injury to first degree burns (0.3 calories per square centimeter per second [12.56 kilowatts/m^2]) and protective equipment capable of providing respiratory protection from the inhalation of hot vapors or any toxicological effects should be worn by energetic researchers to achieve the minimally required level of thermal and respiratory protection.[5] "Review of Standards for Thermal Protection PPE in the Explosives Industry," published by the UK's Health and Safety Executive, compared the test standards currently used to assess PPE against thermal flux that may occur during explosivevents[10]. The review determined that because the tests are designed to replicate thermal conditions more likely to occur during firefighting operations or automotive racing crashes, they do not accurately assess performance against burning explosive materials. Such events have been found to exhibit significantly higher thermal energy, causing levels of heating and burning which would produce significant injury to individuals wearing currently approved PPE. The report also recommends that risk assessments consider the damage to the respiratory system cause by events with high thermal flux.

Fire detection and extinguishing systems in areas where energetic materials with a high probability of ignition and potential for a large thermal output are handled can greatly reduce the risk of thermal injuries to personnel. Caution should be exercised in the design and placement of pressurized systems, with consideration given to the physical effects upon discharge. Extinguishing agent must be compatible with chemicals present in the area of discharge.[5]

3.3 SHIELD DESIGN AND COMPLIANCE

When purchasing or building laboratory safety shields, or as part of a routine hazard analysis, shields should be assessed to ensure compliance with all applicable regulatory requirements as well as suitability for the specific application. Design considerations that impact performance include material selection, how the shield material is captured in the frame, the size of the unsupported span, how the shield is supported in the system, and the threat from overpressure and fragments, amongst others. Below are images that show the shape and dimensions of two shield designs (figures 3-1 and 3-2) evaluated by the White Oak Detachment, Indian Head Division NSWC.

CPNI has constructed shields of their own design that incorporates a large transparent window in a robust metal frame with arm cut-outs. The size of the shield and material selection results in a shield that balances portability with stability due to weight. Specific information regarding the design and testing of these shields may be acquired directly from CPNI.

3.3.1 Effective Implementation of Shielding

The implementation of laboratory safety shields that have not been designed effectively may not only fail to protect personnel but may also contribute to injuries. Most shielding never sees a failure event, as they are usually implemented as a redundant safety measure. However, if a shield has not been designed effectively, and there is an event, failures can be catastrophic. Table 3-5 describes three shields tested by the White Oak Detachment, Indian Head Division NSWC and the approved working net explosive weight (NEW).

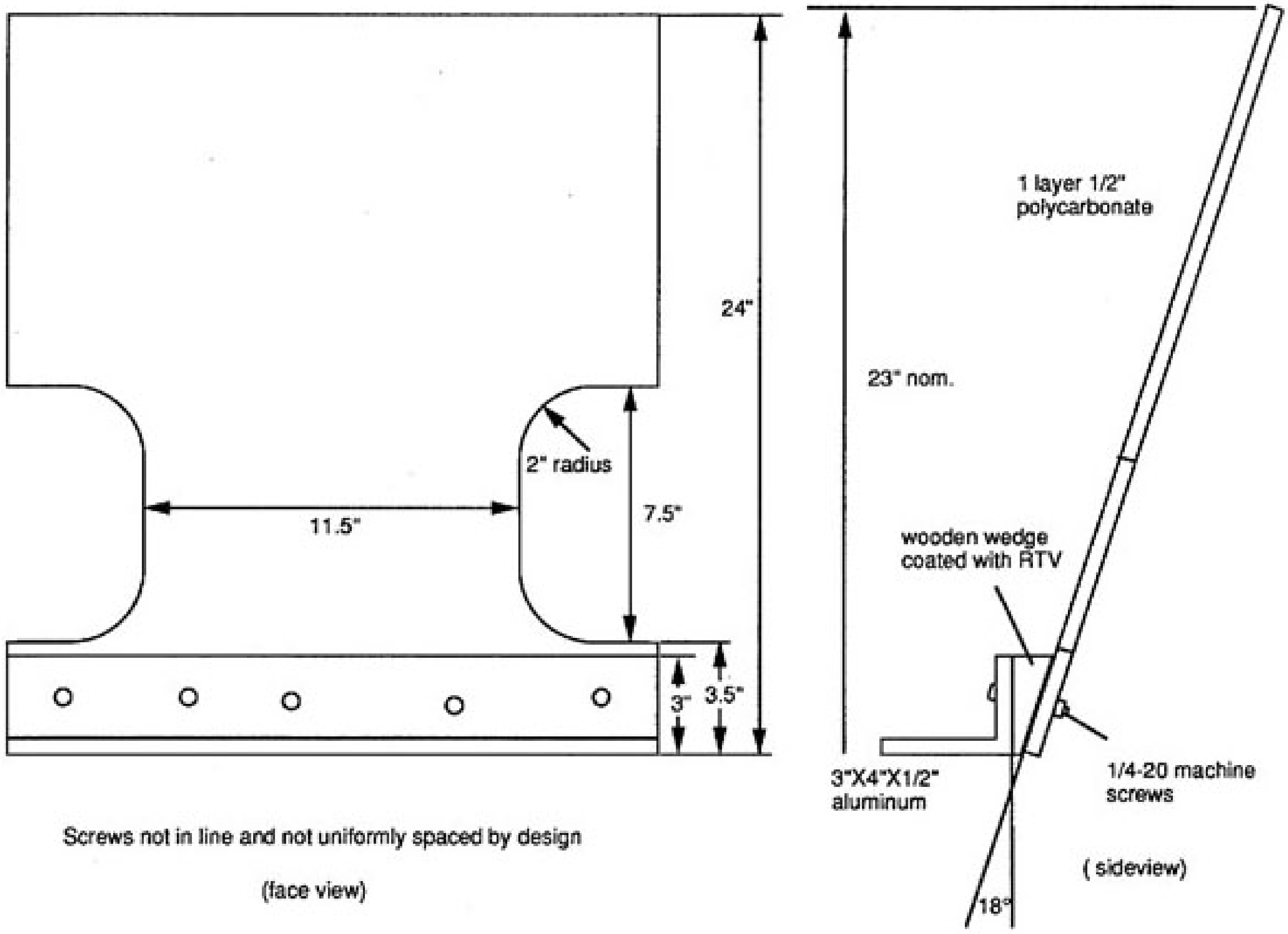

Figure 3-1. Shape and Dimension of Shield Design (Front and Side View)

Sandusky, H.W. and Moore, V.D., "Effectiveness of Transparent Shields in Protecting Explosive Operations Personnel," Naval Surface Warfare Center, Indian Head, MD (1994).

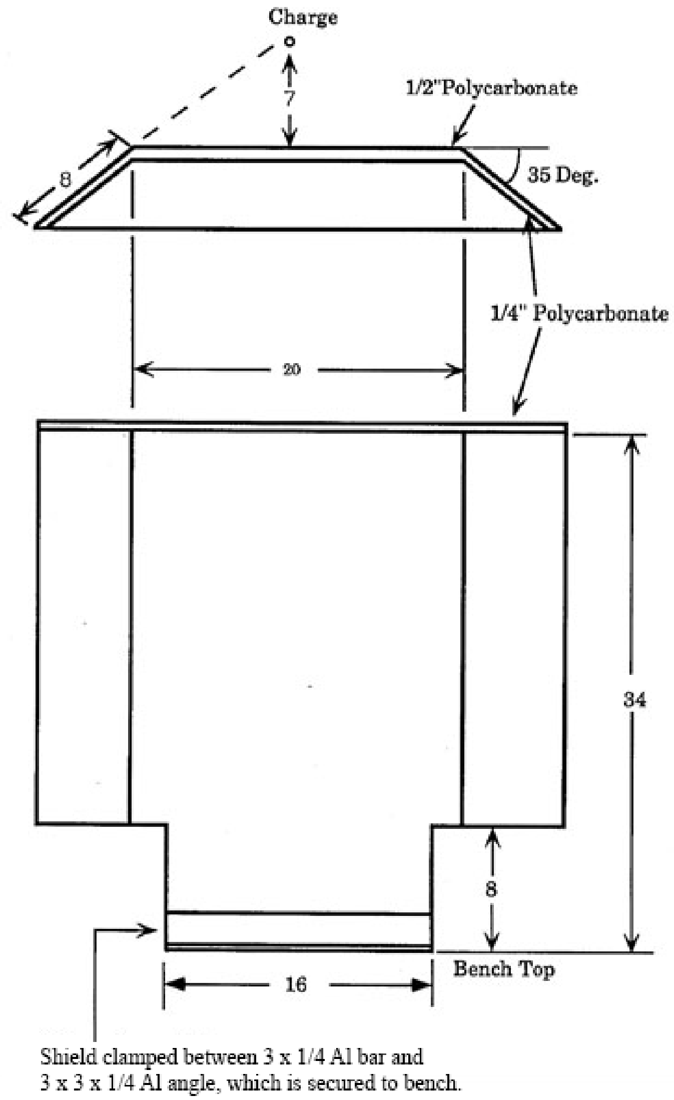

Figure 3-2. Shape and Dimension of Shield Design (Front and Top View)

Sandusky, H.W. and Moore, V.D., "Effectiveness of Transparent Shields in Protecting Explosive Operations Personnel," Naval Surface Warfare Center, Indian Head, MD (1994).

Net Explosive Weight is the explosive limit for blast overpressure (including the 25% safety factor) The Lab Guard model# D-15-29PC is a commercially available semi-circular PC shield with a PMMA liner and weighted base.

The following chart summarizes performance characteristics for materials that were tested in different thicknesses and in various configurations against numerous size explosive charges. The data presented can help guide researchers in laboratory shield material selection only, and is not intended to be used as part of a risk assessment or as sole justification for material selection. All shield designs should be tested against the hazard for which they are intended to protect against.

Table 3-7 below summarizes performance characteristics as reported by manufacturers of candidate materials for local manufacture of laboratory safety shields. This data is presented to guide researchers in material selection and is not meant as an endorsement of any particular product or manufacturer.

Table 3-5. Explosives Safety Shield Standards

Shield	Dimensions (in.)			Material	Distance to Head of Operator	Comments	NEW
	W	H	T				
Bazil	20	24	0.5	PC	29	base secured to table	1.5 g
Sandusky	33	34	0.5	PC	42	base and top secured	9.0 g
Lab Guard Model # D-15-29PC	15	29	0.125 PC & 0.25 PMMA		26	top secured to lattice	1.3 g

Ammunition and Explosives Safety Ashore, NAVSEA OP 5, Volume 1, Revision 7, January 2013.[5]

Table 3-6. Performance Characteristics of Various Safely Shield Materials

Material	Thickness of Shield (in.)		Air Space (in.)	Weight of Explosives (g.)	Distance from Shield (in.)	
	Individual	Total			Protection	Failure
Single Thickness Plexiglass	¼			5	6	
				25	30	
	⅜			7 ½	8	5
				25	13 ½	
				50	26	
	½			20		4
				25	12 (a)	10 (a)
				50	15	12 (b)
	1			20	2	
				50	10	
				100		
Double Thickness Plexiglass	¼ + ¼	½	4	25		6[a]
		½	unknown	50	20	
	¼ + ½	¾	¼	20	4	2
	⅜ + ⅜	¾	unknown	50	12	
	½ + ½	1	¼	50	7	
	¼ + 1	1 ¼	¼	20	2	½
		1 ¼	¼	50	8	
		1 ¼	¼	100	12	
	⅜ + 1	1 ⅜	1	50	6	
	½+ 1	1 ½	0	50		6
	¼ + 1 ½	1 ¾	¼	100		8
	4 + 4[b]	8	6	1,068	24	
Laminated Safety Glass	¼	½	0	5	10 ¼	
		½	0	7 ½	12	8
		½	0	25	17 ½	
	¾	1 ½	0	18	6	5
		2 ¼	0	18	2	1
		3	0	18	1	0
Butecite-Cored Lucite	½			1.8	3	2
	⅝			2.7	3	2
				0.7-0.9	6	
				0.08-1.2		12
Single-Thickness Lucite	¼			18		12
	½			18	5	4
	¾			18	3	2
	1			18	2	1
				36		12

Paul A. Donaldson, "Personal Shielding" Technical Progress Report 326, U.S. Naval Ordnance Test Station China Lake (1963).[11]

Table 3-7. Performance Characteristics of Laboratory Safety Shield Materials

Material	Product	Tensile Strength (psi)	Rockwell Hardness	Impact Strength (ft.-lbs./in.)	Dielectric Strength (volts/0.001 in.)
ABS	ABS	5,100-6,100	R102-R109	5.2-7.7	450-1,220
ABS/PVC	Electrically Conductive ABS/PVC	4,500	R87	2	Not Rated
Acetal	Acetal	6,400-9,500	M51-M88	1-1.8	420-500
	Delrin® Acetal Resin	9,000-11,000	M89-M94	1-2.4	435-500
	Glass-Filled Delrin® Acetal Resin	8,700	M81	0.8	450
	PTFE-Filled Delrin® Acetal Resin	6,800-12,490	M77-M78	0.7-1.2	400-500
	Turcite Acetal	5,900-7,600	M63-M81	0.54-0.57	Not Rated
Acrylic	Cast Acrylic	8,000-11,250	M94-M103	0.04-0.5	400-430
	Extruded Acrylic	8,100-11,030	M68-M95	0.3-0.7	430-760
Acrylic/ PVC	Kydex Acrylic/PVC	6,100	R94	15	Not Rated
Cellulose	Acetate	4,500-8,000	R78-R120	2.0-8.5	250-600
	Butyrate	4,800	R78	4.5	300-475
CPVC	CPVC	7,100-7,300	R116-119	8-9	1,250
CTFE	CTFE	4,860-5,710	Shore D85- D95	2.5-3.5	500
FEP	FEP	3,000	R25	No Break	1,800
HDPE	HDPE Polyethylene	4,000-4,100	Shore D60- D68	1.1	450-1,800
LDPE	LDPE Polyethylene	3,100-6,100	Shore D42- D56	Not Rated	Not Rated
Lexan®	903XXX Series	9,500	M70-R118	12-16	Not Rated
Nylon	Glass-Filled Nylon	13,000	M88	1.8	530
	Kevlar-Filled Nylon	17,200	R121	2.7	350
	MDS-Filled Cast Nylon	10,000-13,500	R115-R125	0.7-0.9	500-600
	MDS-Filled Nylon 6/6	11,000-12,400	R108-R120	0.08-1.2	300-350
	Nylon 6/6	11,200-12,400	R108-R121	0.6-1.4	300-400
	Nylon 6/12	8,000	R114	0.9	Not Rated
	Oil-Filled Cast Nylon	9,500-11,000	R100-R120	1.2-1.8	500-600
PAI	Torlon PAI	15,000-20,000	E70-E87	0.08-2.0	Not Rated
PEEK	PEEK	14,000-17,400	R126	0.8-1.57	190-500
	Carbon-Filled PEEK	11,000	M85	0.7	Not Rated
PEI	Ultem PEI	14,200-17,000	M109-M112	0.05-1.0	830
PETG	PETG	7,100-10,250	R106-R115	1.8	410
PFA	PFA	3,600-4,000	Shore D60	No Break	2,000

Material	Product	Tensile Strength (psi)	Rockwell Hardness	Impact Strength (ft.-lbs./in.)	Dielectric Strength (volts/0.001 in.)
Polycarbonate	Polycarbonate	8,000-16,000	R118-R126	1.5-18	380-490
	Glass-Filled Polycarbonate	16,000	Not Rated	2.06	490
	Thermally Conductive Polycarbonate	6,235	Not Rated	5	Not Rated
Polyester	Polyester	6,100-28,000	Not Rated	0.7	400
Polyimide	Kapton® Polyimide	16,000-33,000	Not Rated	0.58	2,000
	Vespel® Polyimide	12,500	E45-E60	0.8	560
Polypropylene	Polypropylene	2,500-5,400	R55-R102	0.9-10.1	500-660
Polystyrene	Polystyrene	2,560-3,700	R97	2.2-3.3	550
	Rexolite Polystyrene	8,000-10,500	R130	1.2	2,000
Polysulfone	Polysulfone	10,200	R120	1.3	425
PPO	Noryl PPO	9,200	R119	3.5	500
PPS	PPS	13,500	R125	0.6	540
PPSU	Radel PPSU	10,100	R122	13.0	380
PTFE Material PTFE	PTFE	1,500-4,500	Shore D50- D65	2.3-3.5	600-2,000
	Shapes Made with Teflon® PTFE	4,500	R58	2.0-3.49	600-2,000
	Antistatic PTFE	4,500	R58	2.0	Not Rated
	Glass-Filled PTFE	2,100-4,500	R58	2.0-2.3	330-600
	Product	Tensile Strength (psi)	Rockwell Hardness	Impact Strength (ft.-lbs./in.)	Dielectric Strength (volts/0.001 in.)
	Reprocessed PTFE	1,500-1,885	R58	Not Rated	Not Rated
	Rulon PTFE	1,500-4,500	Shore D60-D65	2.0-6.0	100-1,100
	Weldable PTFE	4,000	Shore D52	2.9	Not Rated
PVC	PVC	6,000-10,300	Shore D80	0.65-1.0	985-1,410
	Foam PVC	1,600-2,300	Shore D79-D85	0.32-0.54	280
	Strengthened PVC	5,600-6,200	R111	10-17	335-690
PVDF	PVDF	7,550-7,800	R100	2.5-3.0	280
UHMW	UHMW Polyethylene	2,470-7,740	Shore D61-D77	16.8	450-2,300
	Abrasion-Resistant UHMW	5,600	Shore D69	No Break	2,300
	Electrically Conductive UHMW	2,600-3,200	Shore D63- D68	No Break	Not Rated
	High-Temperature UHMW	5,800	Shore D68	No Break	2,300
VHMW	VHMW Polyethylene	>3,800	Shore D65	No Break	Not Rated

McMaster-Carr Supply Co, Sabic Innovative Plastics [12]

SECTION 04

Personal Protective Equipment

4.1 HAND PROTECTION

Regulation 29 C.F.R. § 1910.132[13] requires employers to ensure that personal protective equipment be provided, used, and maintained in a sanitary and reliable condition to prevent injuries. This includes protection of any part of the body from hazards through absorption, inhalation, or physical contact. PPE should not be used as a substitute for engineering controls, safe work practices, or administrative controls.

OSHA requires that many categories of PPE meet–or be equivalent to–standards developed by the American National Standards Institute (ANSI)[14]. OSHA's PPE protection levels definition and standards can be found in 29 C.F.R. § 1910.120[1]5. There are four levels of protection, based on the amount needed to best guard against inhalation, ingestion, skin absorption, and eye contact, when working with chemical hazards. OSHA guidelines on PPE do not address physical hazards associated with initiation of explosive materials. The primary hazards associated with an initiation are noise, fragments, blast, and heat. An unintended initiation can also result in many secondary hazards, i.e. ignition of flammable materials, release of hazardous fumes, etc.

The Hand Protection standard, 29 C.F.R. § 1910.138[16,] requires employers to select and ensure that workers use appropriate hand protection when their hands are exposed to hazards such as those from skin absorption of harmful substances; severe cuts or lacerations, severe abrasions, punctures, chemical burns, thermal burns, and harmful temperature extremes.

A risk analysis should be conducted prior to the start of any new task and this should be the basis for the proper selection of hand and arm protective wear. The following are examples of some factors that may influence the selection of protective wear in the workplace.

- Type of chemicals handled
- Nature of contact (total immersion, splash, etc.)
- Duration of contact
- Area requiring protection (hand only, forearm, arm)
- Grip requirements (dry, wet, oily)
- Thermal protection
- Size and comfort
- Abrasion, cut, and puncture-resistance requirements
- ESD hazards.

In addition to the manufacturers' guidelines, OSHA has a "Chemical Resistance Selection Chart for Protective Gloves" in its PPE information booklet, OSHA 3151-12R 2003.[17]

4.1.1 PPE and ESD

The donning and doffing of protective gloves can cause charge buildup resulting in an ESD hazard and should be done outside the processing/handling area, after which grounding procedures should be performed. Where ESD is a concern, conductive shoes in conjunction with conductive flooring should be used. All protective footwear should be in compliance with ASTM F2413-05 standards (supersedes ANSI Z41-1999).[14]

Garments that resist the buildup of static electricity are required when working with ESD sensitive materials. This typically restricts the use of synthetic materials, as they are non-conductive and will generate and store a static charge during use. Clothing made of 100% cotton or NOMEX® IIIA is recommended. NOMEX® IIIA is a blend of 93% NOMEX®, 5% KEVLAR®, and 2% P140 carbon fiber (proprietary static dissipative fiber). The P-140 fiber dissipates static generated from fabric-to-fabric and fabric-to-surface rubbing, minimizes the contribution of clothing to static hazards, and reduces apparent electric field strength and nuisance static. In addition, NOMEX® IIIA is flame resistant.

To avoid the risk of static charge accumulation, it is recommended that street clothing, including undergarments, be made of cotton or other conductive materials. Lab coats are appropriate for minor chemical splashes and solids contaminations, while plastic or rubber aprons are best for protection from corrosive or irritating liquids. Disposable outer garments may be useful when cleaning, particularly when it is difficult to decontaminate reusable clothing. Fire-resistant clothing should be used when the risk of spontaneous ignition exists. Synthetic materials should be avoided, as these materials increase the risk of electric charge build-up and subsequent discharge.

4.1.2 Damage to Hands from Explosive Detonation in Lab Equipment

Tests conducted at the Atomic Weapons Establishment (AWE) have shown as little as 0.3 g of PETN-Sylgard 182 explosive paste is capable of causing significant injury at small standoff distances when surrounded by a suitable fragment source (Murray, et al, 2014)[18]. Fragment velocities taken from a 0.3 gram initiation of PETN-Sylgard 182 explosive paste inside a round-bottom flask (RBF) and Büchner funnel (BF) were recorded at 503 and 85 ms^{-1} respectively at the radial position.

During testing at AWE, a hand surrogate was subjected to 0.3 g of PETN-Sylgard 182 explosive paste inside a 50 ml round bottom flask. The hand surrogate sustained a number of lacerations and penetrations from glass fragments generated by the expolsion (figure 4-1). Tests conducted by Klapötke, et al, (2010, figure 4-2) demonstrates the damage caused by 1.0 g lead azide in a 10 ml round-necked flask being held firmly by a plasticine surrogate hand.[19]

Hand and arm protective wear is evaluated on its ability to provide protection from mechanical damage including punctures, cuts, abrasions, fractures, and amputations, as well as protection against heat and chemical contamination. The current standards for testing against mechanical damage, EN 388 and ANSI/ISEA 105, are not representative of the hazards posed by a small-scale explosive event and therefore do not accurately represent the threat.

Figure 4-1. (top) 0.3g RBF trial, damage to dummy hand (Murray, et al, 2014)

Figure 4-2. (bottom) Unprotected hand surrogate holding 10ml round necked flask containing 1g lead azide (Klapötke, et al, 2010)

4.1.3 Manual Dexterity While Wearing PPE

Physical hazards encountered while working with energetic materials pose a significant challenge in the implementation of PPE. Protective gear must provide adequate protection while also not too severely inhibiting dexterity and loss of grip, as this can introduce additional hazards. Klapötke, et al, 2010 and Murray, et al, 2014 tested a variety of gloves, wrist, and arm protectors to assess the level of protection offered by various materials. In addition, limits on motoric function were evaluated. Gloves tested are summarized in Table 4-1 and wrist protectors are summarized in Table 4-2.

4.1.4 Summary of Glove Protection Tests

Conclusions from testing at AWE and the Ludwig-Maximillian University of Munich:

- At the 0.3 g level, all the gloves tested were able to demonstrate near-complete protection with the Ansel Powerflex offering the highest level of dexterity (Replicate testing did result in a limited degree of penetration).
- At the 1.0 g scale with the RBF fragment source, damage to an unprotected hand would be severe. All of the gloves were penetrated, as were the wrist protectors and apron samples. The

Table 4-1. Glove Types and Materials

Glove	Material
Ansel Neptune Kevlar 70-205P[b]	Kevlar
Ansel Powerflex 80-658P[a]	Steel/glass fiber/Kevlar, latex dipped
Hexarmor Hercules Gauntlet 400R6EP[a]	2 Layers of Superfabric armored fabric
Hexarmor Steel Leather III-5033P[a]	Leather with one layer of
HyFlex 11-627P[b]	DSM Dyneema® and Lycra®, Polyurethane coated
Keep Safe Gauntlet 304357P[a]	Cotton lined leather
UNIGLOVE Exam GloveP[b]	Latex
Matex-RP[b]	Latex, Thick
MultiLUX® 940P[b]	Double steel core Kevlar
MultiMEX 941P[b]	Steel core Kevlar
T-TEXP[b]	Rubber-coated Kevlar glove
Wegusta GmBH Welding Glove (EN 388, 2)P[b]	Leather

Table 4-2. Wrist Protector Types and Materials

Wrist Protector	Material
Ansel Neptune Kevlar 70-205Pb	Kevlar
Ansel Powerflex 80-658Pa	Steel/glass fiber/Kevlar, latex dipped
Hexarmor Hercules Gauntlet 400R6EPa	2 Layers of Superfabric armored fabric
Hexarmor Steel Leather III-5033Pa	Leather with one layer of
HyFlex 11-627Pb	DSM Dyneema® and Lycra®, Polyurethane coated

a. Murray, C., et al., Protective Equipment for Small-scale Laboratory Explosive Hazards. Part 1. Clothing for hand and body protection, J. Chem. Health Safety (2014).

b. Klapötke, et al., Hands on Explosives: Safety Testing of Protective Measures, J. Safety Science (2010) grey Hexarmor® Hercules R6E gauntlet provided the most effective fragment mitigation of all the gloves tested at this scale, although the extent of potential injury suffered could still be significant.

- At the 7.5 g scale with the RBF fragment source, fragment injuries to the unprotected hands would be catastrophic. The Hexarmor® Hercules R6E gauntlet provided the highest level of mitigation of all the gloves tested, however injuries due to fragment penetration would still be significant.
- Avoid going with synthetic materials when possible, such as Hexarmor products, due to potential ESD risk. Hexarmor Protective Sleeve AS019S was easily charged to 20 kV.
- A double glove combination of HyFlex gloves worn under double steel core Kevlar gloves provided the highest level of protection 1 g of lead azide inside 10 ml round neck flask. The combination recommended reduced dexterity.[9,19]

These results should not be taken as a recommendation or endorsement for a specific product but as a reference to assist in selecting protective gear.

4.1.5 Handling Small Explosive Samples in Flasks

During testing, gloves and material samples placed underneath the flask, and subject to both the directional detonator output and fragments driven by explosives in direct contact with the glass, were more severely damaged. A similar observation was made in the Klapötke paper, and this has implications when training people in handling small explosive samples. Sample containers should ideally be safely held or clamped as far away from the energetic material as possible, as seen in figure 4-3.

4.2 EYE AND FACE PROTECTION

Eye and face protection should be one of the paramount concerns when working with explosives.

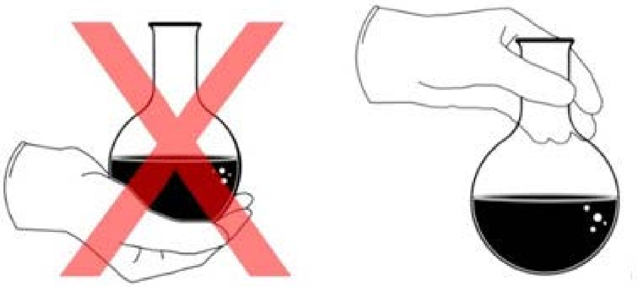

Figure 4-3. Objects should be safely held as far from the energetic material as possible

Regulation 29 C.F.R. § 1910.133[20] requires that employees wear appropriate eye protection with side shields that protect from flying objects. Other potential hazards due to molten metal, liquid chemicals, acids or caustic liquids, chemical gases or vapors, or potentially injurious light radiation should also be accounted for. If prescription lenses are normally worn by an employee, that employee should wear approved eye protection per 29 C.F.R. § 1910.133 that incorporates the prescription into the protection or can safely fit over and does not alter the placement of the prescription lenses.

4.2.1 Eye and Face Protection Standards and Best Practices

Face and eye protection should at a minimum meet the requirements of ANSI Z87.1-2010[14], but this standard has very low limits for protection against impact and does not offer much in the way of protection against explosion hazards. For energetic materials work it is recommended that protective eyewear meet the requirements of MIL-PRF-31013[21], which requires ballistic resistance of the spectacles to be such that they will pass a VO test using a 0.15 caliber, 5.8 grain, T37 shaped projectile at a velocity of 640 to 660 feet per second when tested in accordance with MIL-STD-66242V50 Ballistic Test for Armor.[22] The VO Point is the maximum velocity at which no complete penetration will occur.

Some organizations choose to adopt a policy that requires contact lenses to be removed before working in eye-hazardous areas to avoid any permanent damage that may be caused by exposure to gases or vapors. In these cases, it is important to obtain eye protection that incorporates prescription lenses so that vision is not impaired.

The AWE tested a number of face shields, safety glasses, and combinations of both to assess the level of protection provided. The equipment was tested against detonating charge masses of 0.3 g, 1.0 g, 5.0 g and 7.5 g for PETN-based explosives, and 1.3 g for a HMX based explosive. The fragment sources used in the trials were glass round-bottom flasks, porcelain Buchner funnels, and glass test tubes.[18] Selected data from these tests is presented below in Table 4-3.

4.3 RESPIRATORY PROTECTION

The Respiratory Protection Standard, 29 C.F.R. §1910.134[23], establishes the required program for

Table 4-3. Damage to Test Article from Explosions in Laboratory Equipment

RESULTS FROM 1.0 G ROUND BOTTOM FLASK TRIALS.		
Test article (Approximate Stand-off, cm)	**Damage to Surface of Test Article**	**Penetration of Test Article**
Keep Safe Hunter Safety glasses (7.0)	Significant surface abrasion, 206 impacts > 1 mm No back surface damage	None
Bolle Tracker II Safety glasses (7.0)	Significant surface abrasion, 69 impacts > 1 mm No back surface damage	None
1 mm PC face shield and Keep Safe Hunter safety spectacles (11.0) (face shield section measured 111 mm x 205 mm)	Face shield section: Significant surface abrasion with large number of impacts < 1 mm, 140 further impacts: 138 x 1–2 mm; 2 x 3–4 mm 19 visible deformation points on back surface Safety spectacles: light scratching of surface from contact with face shield	None
6 mm Demining visor (13.0) (visor measured 220 x 295 mm)	Multiple abrasions, 425 impacts > 1 mm	None
3 mm polycarbonate safety screen (8.0) (section measured 600 x 220 mm, clamped at side of charge)	Significant abrasion of screen section nearest to flask. 409 impacts > 2 mm	None
Results from 7.5 g Round Bottom Flask Trials.		
RESULTS FROM 7.5 G ROUND BOTTOM FLASK TRIALS.		
Test article (Approximate Stand-off, cm)	**Damage to Surface of Test Article**	**Penetration of Test Article**
1 mm PC face shield and Keep Safe Hunter safety spectacles (10.5) (size of face shield section 115 61TD mm x 205 mm approx, clamped at side of charge)	Face shield section: severe abrasion, multiple heavy impact points with back surface damage Safety spectacles: 180 areas of abrasion from contact with areas of back-surface damage or penetration of face shield section	Face shield section: Partially shattered, remaining areas have multiple penetrations. Safety spectacles: Surface damage only
Test article (Approximate Stand-off, cm)	**Damage to Surface of Test Article**	**Penetration of Test Article**
5.5 mm [63TD$DIF] demining visor (8.0) (visor measured 215 mm x 295 mm)	Severe abrasion and pitting. 637 impacts > 1 mm	None
3 mm polycarbonate safety screen (8.0) (600 mm x 220 mm, freely supported above charge)	Severe abrasion and pitting; some impacts produced back-surface cracking	Screen shattered

properly selecting and using respirators. OSHA OSHA 3384-09 2011 Small Entity Compliance Guide for Respiratory Protection Standard provides a general overview and is intended to assist program administrators, employers who need to develop a program, employees who may be required to wear respirators, and licensed medical professionals who must evaluate an employee's ability to wear respirators, among others. Generally, employers or lab managers are required to establish a respiratory protection program whenever they or OSHA require employees to wear respirators.

For further guidance on respiratory protection, OSHA offers a comprehensive eTool, which can be found here: *https://www.osha.gov/SLTC/etools/respiratory/index.html.*[24]

4.4 NOISE PROTECTION

A concern for laboratory personnel working with explosives is the overpressures caused by an accidental initiation. Studies have shown that fast rising overpressures with a peak positive incident overpressure of 3.4 psi have resulted in eardrum ruptures 1 % of the time, and for overpressures of 16 psi the percentage of ruptures goes up to 50%.[26] The Naval Surface Warfare Center, Indian Head, conducted testing looking at the blast overpressures resulting from the detonation of ~2.6 g and ~11.5 g of PBXN-5 pellets using Reynolds RP-80 detonators containing 0.2 g of explosive. Overpressures were measured at the head position of a standing and sitting operator. The peak incident overpressure measured at the head location of a sitting operator without shielding was 8 psi which is well above the threshold for a disabling injury.[7]

Damaging noise, like other laboratory hazards, can be addressed using the Hierarchy of Controls presented in Prudent Practices. Choosing low-noise machinery, properly maintaining and lubricating equipment, and installing sound barriers are means through which elimination, substitution, and engineering controls can be used to reduce laboratory exposure to damaging noise. Administrative controls can be implemented to limit the number of personnel exposed, the duration of exposure, and the distance of personnel from the source of noise. Complete requirements can be found in 29 C.F.R. § 1910.95.[25]

While hearing protection devices, such as earmuffs and plugs, are considered an acceptable, but less desirable option to control exposures to noise in a laboratory setting, they can limit awareness and hinder communication. Where accidental initiation may occur, and the maximum credible incident could result in injury, protective shielding should be used. Military Standard 398A specifies shields shall be designed to prevent exposure of operating personnel to peak positive incident pressures above 2.3 psi (15.9 kPa), which is below the threshold for a disabling injury.[6]

SECTION 05

Proper Storage of Explosives and Highly-Sensitive Materials Used in Explosive Research

5.1 CLASSES OF EXPLOSIVE

Proper storage of explosives and highly-sensitive materials used in explosives research is essential not only for the safety of laboratory personnel, but also to ensure compliance with federal, state, and local laws and regulations. The federal explosives regulations in 27 C.F.R.§ 555, promulgated by the ATF, provides specific requirements for explosives storage. All explosive materials must be kept in locked magazines unless they are:

- In the process of manufacture;
- Being physically handled in the operating process of a licensee or user;
- Being used; or
- Being transported to a place of storage, or use by a qualified explosive materials handler.[27]

When none of the above conditions apply, explosive materials must be kept in magazines that meet the construction, security, table of distance and other requirements of 27 C.F.R. § 555.201 – 555.224.[28] Any person who stores explosive materials shall notify the authority having jurisdiction for fire safety in the locality in which the explosive materials are being stored. This authority must be provided with the type, magazine capacity, and location of each site where such explosive materials are stored. Such notification shall be made orally before the end of the day on which storage of the explosive materials commenced, and in writing within 48 hours from the time such storage commenced. ATF must also be notified of newly-acquired storage magazines, or changes in construction to magazines, in accordance with 27 C.F.R. § 555.63.[29]

For storage purposes, the ATF separates explosives into three classes, which are: high explosives, low explosives, and blasting agents.[30] Separate categories exist for fireworks and ammonium nitrate. Familiarity with these classes of explosive materials is essential to an understanding of the type of magazine in which they may be legally stored. Below are the three classes of explosives:

- High Explosives: Explosive materials that can be caused to detonate by means of a blasting cap when unconfined. Typical examples: dynamite, flash powders, and bulk salutes.
- Low Explosives: Explosive materials that can be caused to deflagrate when confined. Typical examples: black powder, safety fuse, igniters and fuse lighters.
- Blasting Agents: Any material or mixture, consisting of fuel and oxidizer, that is intended for blasting and not otherwise defined as an explosive, only if the finished product, as mixed for use or shipment, cannot be detonated by means of a No. 8 test blasting cap when unconfined. Typical examples include: ANFO, certain emulsions, slurries, and water gels.

5.2 AMMONIUM NITRATE STORAGE

Separation distances specific to ammonium nitrate are regulated by 27 C.F.R. § 555.220, which specifically addresses the storage of ammonium nitrate in the vicinity of high explosives or blasting agents.[31]

Additional requirements may apply based on the location of the storage facility and the authority under which the explosives are being stored. In addition to the requirements of the C.F.R., the DoD also requires adherence to DOD 6055,9-STD[32] and the DOE requires storage to be in accordance with DOE M-440-1.1A.[33]

5.3 STORAGE MAGAZINES

A magazine is defined in 27 C.F.R. § 555.11as any building or structure, other than an explosives manufacturing building, used for storage of explosive materials.[34] There are five types of magazines approved for the storage of explosive materials:

- Type 1 magazines are permanent magazines for the storage of high explosives. Other classes of explosive materials may also be stored in Type 1 magazines.
- Type 2 magazines are mobile or portable indoor and outdoor magazines for the storage of high explosives. The Institute of Makers of Explosives recommends that magazines of this class shall be painted red and shall bear lettering in white, on all sides and top, at least 3 inches high, stating "Explosives—Keep Fire Away." Type 2 magazines, when located in warehouses, and in wholesale and retail establishments, shall be provided with substantial wheels or casters to facilitate easy removal in the case of fire and located no more than 10 feet from an exterior, grade level door.[35]
- Type 3 magazines are portable outdoor magazines for the temporary storage of high explosives while attended (a day box, for example).
- Type 4 magazines are for the storage of low explosives. Blasting agents, or non-mass-detonating detonators, safety fuses, electric squibs, noiseless trunk line (explosive shock tube), igniters, and igniter cords. At no time can Blasting Agents be stored within the same magazine as initiating explosives.
- Type 5 magazines are for the storage of blasting agents only.

Except as provided under 27 C.F.R. § 555.213, detonators may not be stored in the same magazine with other explosive materials.[36]

5.4 MAGAZINE LOCATIONS

Explosives and explosives containers should not be placed directly against an interior wall of a magazine to facilitate proper ventilation and should be organized in such a way that identifying marks are visible and easy to read. Smoking, matches, open flames, and spark-producing devices should not be permitted in any magazine, in any room containing an indoor magazine, or within 50 feet of any outdoor magazine. Lab procedures conducted in IE/HME research facilities that involve open flame or testing procedures that result in sparks or small detonations such as impact or friction test should not be conducted in an explosives storage magazine, in a room that contains an indoor magazine, or within 50 feet of any outdoor magazine.

5.5 MAGAZINE SAFETY INSPECTIONS

All magazines containing explosive materials should be inspected at regular intervals of no more than seven days to determine if there has been any unauthorized entry into the magazines or unauthorized removal of the magazines or their contents. Magazine doors should include locks that meet the forcing surreptitious entry ratings of at least Grade 5 of the American Society for Testing and Materials F-883-13 Standard Performance Specification for Padlocks and ATF standards and should be locked when the magazine is unattended[37]. Interiors should be clean, dry, and free of grit, paper, empty packages and containers or excess combustible material of any kind. Floors should be swept regularly.

Tools used to open packages and to clean the magazine should not produce sparks. Exteriors of indoor and outdoor magazines should be clear of rubbish, brush, dry grass, or small trees (except live trees more than 10 feet tall) within 25 feet of the magazine. No volatile materials should be located within 50 feet of outdoor magazines. Indoor magazines are limited to a maximum of 50 lbs of net explosive weight per building regardless of the number of magazines.[38] The NFPA recommends a minimum distance of 10 feet between indoor magazines and that indoor magazines be located within 10 feet of a ground-level entry point.[39]

5.6 PRECURSOR CHEMICAL STORAGE

Precursor chemical storage is not regulated by the ATF. Carefully read the label before storing a hazardous chemical. The SDS will provide any special storage information as well as information on incompatibilities. Do not store unsegregated chemicals in alphabetical order. Do not store incompatible chemicals in close proximity to each other.

Chemicals should be segregated into the following hazard classes for safe storage:

- Flammables
- Oxidizers
- Corrosives-acids, bases
- Highly Reactive (IE/HME)
- Extreme Toxic/Regulated Material
- Low Hazard

Flammability should be the primary consideration for classification of hazardous materials. Some materials may be classified into multiple categories. Careful consideration of the hazards associated with the material and consultation with manufacturers and Environmental Health and Safety personnel can assist in the appropriate storage determination.

Use approved storage containers for flammable liquids. Flammable chemicals should be stored in a NFPA-approved flammable liquid storage cabinet. Flammable chemicals requiring refrigeration must be stored only in refrigerators and freezers designed for flammable storage. Properly vented storage cabinets are a preferred storage location for volatile materials. Chemicals of different chemical storage classification can be segregated by placing them in trays or on different shelves. Do not store volatile chemicals on benchtops or in hoods. Store liquids—especially corrosives or solvents—below eye level. Use secondary containers made of non-reactive materials with reduced friction lids for hazardous chemicals. Refer to ATF P 5400.7 for specific information pertaining to rulings that address indoor storage of explosives.

Limiting public disclosure of information on quantities and locations of explosives storage to a need-to-know basis may help to reduce the likelihood of a facility being targeted by criminals. Persons storing explosive materials are required by 27 C.F.R. 555.63[29] to notify the ATF and the local authority having jurisdiction for fire safety in the locality where the explosive materials are stored. This notification should include the type, magazine capacity, and location of each site where the explosive materials are being stored. Notification must be made orally before the end of the day on which storage commences, and in writing within 48 hours from the time such storage commenced. The authority having jurisdiction for fire safety is typically the local fire department. Storage within an ATF approved magazine does not provide relief from any applicable state and/or local regulations regarding explosives storage.

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APPENDIX A

ADDITIONAL RESOURCES

Additional resources for the regulatory and industry standards for explosive safety are listed below:

- **National Safety Council;**
  http://www.nsc.org/products_training/Training/workplacesafety/Pages/WorkplaceSafety.aspx
- **U.S. Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF);**
  https://www.atf.gov/content/Explosives/explosives-industry?qt-explosive_tab=0#qt-explosive_tab
- **National Institute for Occupational Safety and Health (NIOSH);**
  http://www.cdc.gov/niosh/contact/
- **U.S. Department of Transportation (DOT);**
  http://phmsa.dot.gov/
- **U.S. Mine Safety and Health Administration (MSHA);**
  http://www.msha.gov/
- **U.S. Occupational Safety and Health Administration (OSHA);**
  https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10117
- **American National Standards Institute (ANSI);**
  http://www.ansi.org/library/overview.aspx?menuid=11
- **International Society of Explosives Engineers (ISEE);**
  https://www.isee.org/
- **Department of Defense Explosives Safety Board (DDESB);**
  https://www.ddesb.pentagon.mil/
- **Army Publishing Directorate;**
  http://www.apd.army.mil/

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21. MIL-PRF-31013, Performance Specification: Spectacles, Special Protective Eyewear Cylindrical Systems (SPECS), 1996.
22. MIL-STD-662F, VR50R Ballistic Test for Armor, 1997.
23. 29 C.F.R. § 1910.134, Respiratory Protection, 2014.
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PROTECTION FOR THE HOMEMADE EXPLOSIVE (HME) RESEARCHER:

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