Small Quantities For Research And Laboratories (SQRL) Test Program

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Abstract

Establishing reduced quantity-distance (QD) criteria in DoDM 6055.09, *DoD Ammunition and Explosives Safety Standards*, for laboratory-scale explosives operations has been identified as a high priority by the Service Members of the Department of Defense Explosives Safety Board (DDESB). Current QD values in DoDM 6055.09 may be overly conservative and are not well anchored to actual test data at very low charge weights. Current Service criteria in this area are either silent or unsubstantiated by analysis or test data. This led to the development of the Small Quantities for Research and Laboratories (SQRL) test program.

The SQRL Phase I testing was designed to determine the maximum net explosive weight (NEW) which would not cause breaching of the laboratory walls of a specific facility. Wall construction was 5/8" sheetrock on 6" metal studs with batt insulation filling the wall cavities. Tests were performed in a 3666 cu. ft. room with the explosives at 12" and 36" standoffs from the wall. As a result of these tests, a 50 g charge was sited with a 0 ft QD exterior to the laboratory.

The SQRL Phase II tests were designed to determine if the debris distance for small quantities (i.e., $\leq$ 250g (0.5 lb)) can be reduced from the required 200 foot minimum. As a "worst case", the walls tested were ½" sheetrock on standard 2" x 4" wood framing. A standard concrete masonry unit (CMU) wall was also tested to determine debris hazard.

Four goals were identified and each related to a facet of QD criteria and the expected form of the resultant QD criteria.

Goal 1: Determine the maximum Net Explosive Weight (NEW) which does not result in breaching a sheetrock wall at a 12" standoff.

Expected QD Criteria: For a 12" standoff distance, the maximum NEW for which the QD outside the laboratory is 0 ft.

Goal 2: Determine the debris and overpressure hazards from a sheetrock wall due to an explosion of 250 g at a 12" standoff for a room of at least 1000 cu. ft**.**

Expected QD Criteria: For a lightweight (e.g., sheetrock, lightweight metal, etc) wall with a 12" standoff in a laboratory that is at least 1000 cu. ft., Inhabited Building Distance (IBD) is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, Public Traffic Routed Distance (PTRD) is 60% of IBD, and Intraline Distance (ILD) is the 3.5 psi overpressure distance.

Goal 2b: Determine the hazardous debris distance from a sheetrock wall due to an explosion of 250 g at a 48" standoff for a room of at least 1000 cu. ft.

Expected QD Criteria: For a lightweight wall with a 48" standoff in a laboratory that is at least 1000 cu. ft., IBD is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, PTRD is 60% of IBD, and ILD is the 3.5 psi overpressure distance.

Goal 3: Determine the hazardous debris distance from an unreinforced CMU wall due to an explosion of 250 g at a 12" standoff.

Expected QD Criteria: For a wall producing substantial debris (e.g., CMU, brick, concrete, etc) with a 12" standoff in a laboratory that is at least 1000 cu. ft., IBD is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, PTRD is 60% of IBD, and ILD is the 3.5 psi overpressure distance.

A total of 15 tests were performed. Test series 1 (4 tests) and 5 (3 tests) corresponded to Goals 1 and 3, respectively. Test series 2 (3 tests) was performed to give some indication of expected effects of 250 g at 12" from a freestanding sheetrock wall prior to beginning tests in the blast house. The first test performed to test Goal 2b (Shot 4-1) caused severe damage to the blast house and caused revision to the test plan. Test Series 3 (2 tests) and 4 (3 tests) were revised to determine and confirm the maximum quantity within the small interior room (960 ft3) which would not result in a breach.

The following Quantity-Distance (QD) criteria is recommended. "IBD, PTRD, and ILD is zero (0) ft for no more than 25 g of bare explosives within a minimum room volume of 960 cu. ft. at a charge standoff of no less than 12" from the nearest wall."

Recommendations for future testing is discussed.

1.0 Introduction

Default Inhabited Building Distance (IBD) for up to 31 lbs is 200 ft in accordance with U.S. DoD Explosives Safety Manual (DoD 6055.09-M, 2017). This seems like an unreasonably large distance for small laboratory quantities (< 0.25 lbs) of explosives and it is frequently unobtainable in laboratory buildings.

The Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) National Center for Explosives Training and Research (NCETR) is located at Redstone Arsenal, AL. Their main facility includes three explosive laboratories, classrooms and offices. The ATF requested assistance from the US Army Engineering and Support Center, Huntsville (CEHNC) in the development of an explosives safety site plan (ESSP) for this facility. The ATF did not require more than 50 g of explosives in each of these 3 labs but the 200 ft default IBD would result in a waiver situation if a reduced QD could not be justified and approved. Analysis using current approved analysis methods did yield results justifying a reduced QD. So in 2014 a test program to determine the maximum quantity of explosives which would result in zero (0) quantity distance (QD) outside the laboratory was begun. This test program, Small Quantities for

Research and Laboratories (SQRL) (CEHNC-EDS-O-15-01, 2015) became Phase I of a larger test program.

The US Services have ranked the issue of explosives safety siting for laboratory quantities as a high priority for investigation. The Department of Defense Explosives Safety Board (DDESB) sent a survey to the Services regarding sizes and construction and explosive quantities of their laboratories. Additionally, the various Service Explosives Safety Standards were reviewed to determine what, if any, criteria these standards had for small lab quantities. This information and the results of Phase I tests were used to develop plans for SQRL Phase II.

The SQRL Phase II tests were completed in April 2017. The results have been analyzed and have resulted in recommended QD criteria for 25 g or less (CEHNC-EDS-O-17-05, 2017). Future testing, SQRL Phase III, has been recommended and is currently in the planning process.

2.0 Small Quantities for Research and Laboratories (SQRL) Phase I

2.1 National Center for Explosives Training and Research Explosives Laboratories

The main facility for the ATF NCETR contains three labs as well as classrooms and offices. The smallest lab is 40 ft x 53 ft x 15 ft tall for a room volume of 31,800 ft^3. The interior wall construction is 5/8" sheetrock on 3 5/8" x 6" light gage metal studs 16" on center with R-19 batt insulation in the walls. The ceiling is an acoustical tile ceiling below steel roof trusses with an insulated standing seam metal roof. The exterior wall is 5/8" sheetrock interior on 6" metal framing with batt insulation and a clay brick exterior. Windows are dual paned NtGC DuPont PVB laminated glass with the largest unsupported pane of 4'8" x 4'0". The maximum quantity in each of the labs is 50 g. The default QD is 20 ft based on overpressure (K40 distance) and 200 ft minimum for secondary debris. The 200 ft minimum would render several rooms in the facility unusable.

Initial calculations were performed using BLASTX (BLASTX, 2010) with the explosive 3 ft off the floor in the center of the lab to see if these QD could be reduced by analysis. Net explosive weights ranging from 12 g to 60 g were considered with targets placed at various locations at the edges of the room. The results (see Table 2-1) seemed to be unreasonably high for such small weight-to-volume ratios and these weight-to-volume ratios are outside the bounds of the currently accepted analytical methods. Therefore, a test program (SQRL Phase I) was developed and instituted for these small quantities.

2.2 Purpose of SQRL Phase I

The primary reason for these tests was to determine if the debris distance can be reduced from the required 200 foot minimum. With this in mind, the primary objective was to determine if the typical NEWs present in the NCETR labs would breach the interior walls of the labs. Since the exterior walls are more robust, if the charges do not breach an interior wall, they will not breach an exterior wall.

In addition, flush mount pressure gages were mounted in various places on the interior of the test structure to record the pressures. This data was captured to advance the state of knowledge about the effects of small NEW quantities.

Table 2-1 – BLASTX Results for Smallest NCETR Lab

Net Explosive Weight (g)	Weight to Volume Ratio (lbs/ft^3)	Max Peak Pressure (psi)	Max Impulse (psi-ms)
60	0.00122	2.417	14.44
48	0.000980	2.191	12.45
36	0.000735	1.926	11.68
24	0.000490	1.608	10.03
12	0.000245	1.261	7.95

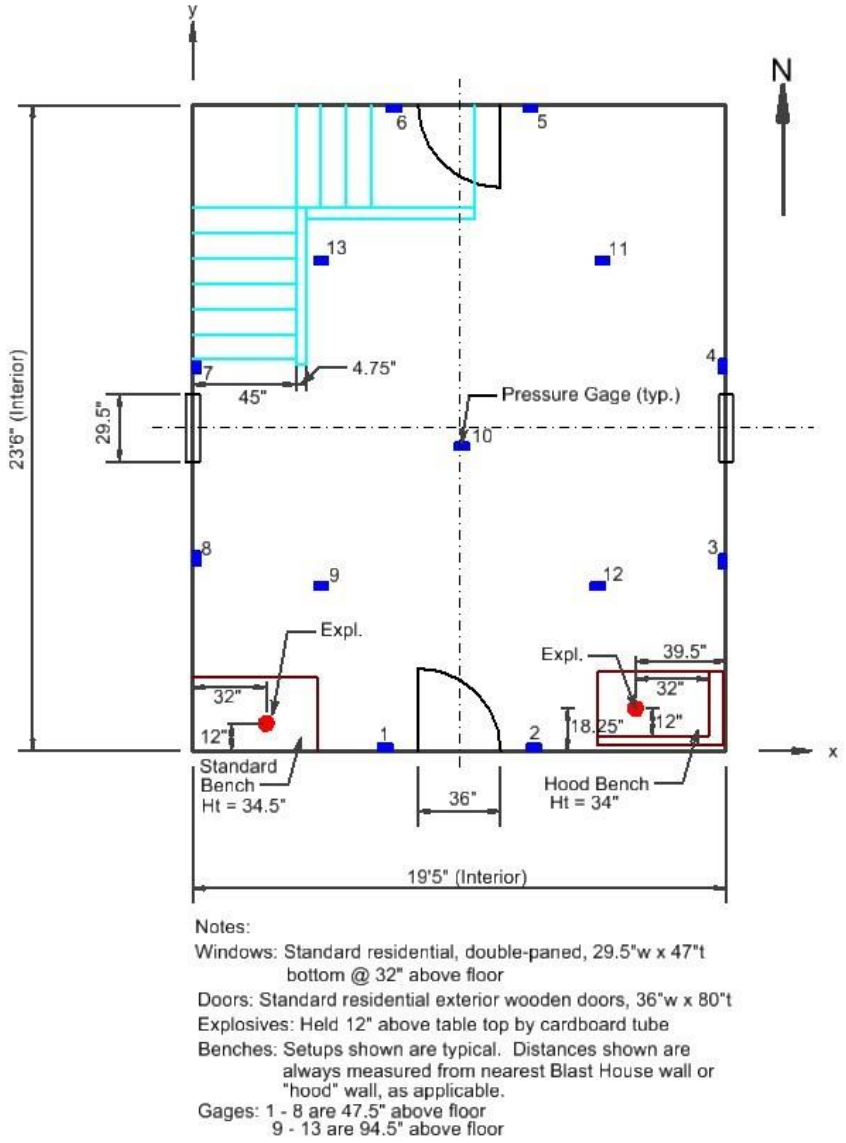
2.2 SQRL Phase I Test Procedure

The ATF has a Blast House (see Figure 2-1) on one of their ranges at Redstone Arsenal. The Blast House is a wood framed structure representing a 2-story residence with dual paned standard residential windows and standard exterior doors. It is important to note that the Blast House was not built to standard residential building codes (e.g., wall framing was not sufficiently anchored to the floor slab) and had been used for internal detonations previous to this test program with repairs made as needed.

Figure 2-1 – ATF Blast House

In order to represent the interior lab walls, the structure was modified on the first floor from the window on the east wall around the southern end of the structure to the window on the west wall. The exterior plywood on this southern portion of the first floor was replaced by 5/8” gypsum board, R-19 batt insulation was installed and interior walls sheathed with 5/8” gypsum board. The original framing of the structure is a wood framed, 2”x4” studs, 16” on center; to match the depth of the interior walls in in the NCETR building a 2”x6” stud was attached to each of the 2”x4” studs. A ceiling was installed on the first floor from the south wall extending 8 ft into the room. For tests 1 – 4 the ceiling was 5/8” gypsum board and for tests 5 – 10 it was oriented strand board (OSB). Figure 2-1 shows the locations used for detonations and the 13 pressure gages. Table 2-2 shows a summary of the tests performed.

Figure 2-2 – Blast House Floor Plan with Explosives and Gage Locations



Notes:
Windows: Standard residential, double-paned, 29.5"w x 47"t bottom @ 32" above floor
Doors: Standard residential exterior wooden doors, 36"w x 80"t
Explosives: Held 12" above table top by cardboard tube
Benches: Setups shown are typical. Distances shown are always measured from nearest Blast House wall or "hood" wall, as applicable.
Gages: 1 - 8 are 47.5" above floor
9 - 13 are 94.5" above floor

Tests 1 – 6 were performed with the explosives on the Standard Bench (i.e., a wooden table) in the southwest corner and tests 8 and 9 in the southeast corner. These eight tests were performed using non-containerized bare charges (see Figure 2-3). In the lab, the only place that glass laboratory containers are used is in the hood. Therefore, hood wall material from the hood manufacturer was mounted on two sides of the Hood Bench placed in the southeast corner and explosives placed in a standard 250 ml glass beaker (see Figure 2-4). In addition to testing breaching of the hood wall, these tests (7 and 10) were designed to test possible penetration of the glass beaker into the hood.

Thirteen flush mount pressure transducers were placed as shown in Figure 2-2 to record pressure-time histories for each test. Two high-speed video cameras were used to capture video of any external debris for each shot and a GoPro video camera was placed inside to capture real time video of each detonation.

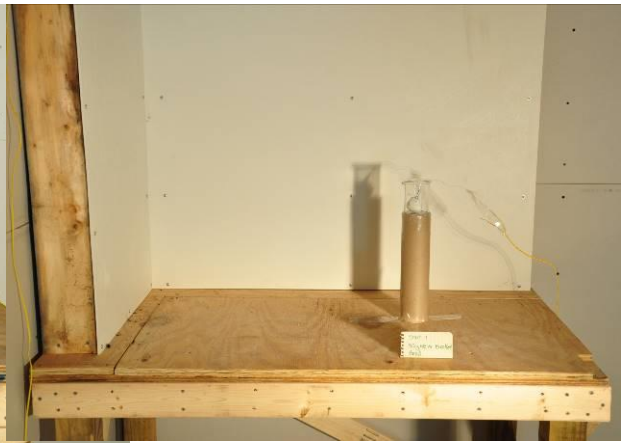
Table 2-2 – SQRL Phase I Test Summary

Test No.	Explosive Weight (g)					Explosive Location				Hood Walls (Y/N)?	Glass Container (Y/N)?
	RISI RP-83 (1.031g RDX + 0.080g PETN)	C-4	Total NEW	TNT Equivalent for Pressure	TNT Equivalent for Impulse	SW or SE corner	Bench Type	Height above table (in)	Height above floor (in)		
1	1.111	6.57	7.68	10.608	9.260	SW	Standard	12	46.5	N	N
2	1.111	14.27	15.4	21.157	18.423	SW	Standard	12	46.5	N	N
3	1.111	21.96	23.1	31.692	27.574	SW	Standard	12	46.5	N	N
4	1.111	29.64	30.8	42.214	36.714	SW	Standard	12	46.5	N	N
5	1.111	37.34	38.5	52.763	45.877	SW	Standard	12	46.5	N	N
6	1.111	48.89	50	68.586	59.621	SW	Standard	12	46.5	N	N
7[A]	1.111	48.89	50	68.586	59.621	SE	Hood	12	46	Y	Y
8	1.111	48.89	50	68.586	59.621	SE	Standard	12	46.5	N	N
9	1.111	48.89	50	68.586	59.621	SE	Standard	12	46.5	N	N
10[A]	1.111	8.89	10	13.786	12.021	SE	Hood	12	46.5	Y	Y

[A]Shots 7 and 10 were performed on the Hood Bench.

Figure 2-3 – Test 8, 50 g Total Net Explosive Weight (NEW) Non-Containerized Bare Explosives

Figure 2-4 – Test 7, 50 g Total NEW in Glass Beaker on Hood Table



2.3 SQRL Phase I Results

The primary purpose of the SQRL Phase I test program was to determine if NEWs between 10 g and 50 g would cause a breach in the interior gypsum board walls of the labs at NCETR. Total NEWs between 7.681 g and 50 g (see Table 2-2) bare, non-containerized explosives were detonated at 12" stand-offs from one wall and 32" stand-offs from another wall. None of these detonations resulted in a wall breach (i.e., damage to the exterior layer of sheetrock). Figure 2-5

shows the damage to the interior wall (12” stand-off) from test 9 (50 g total NEW). This was the most significant damage to the interior wall.

Figure 2-5 – Test 9 (50 g total NEW) Interior Wall Damage at 12” Stand-off

Total NEWs of 10 g and 50 g bare explosives in standard 250 ml glass beakers were detonated at 12” stand-offs from one hood wall and 32” stand-offs from another hood wall. Neither of these detonations resulted in a breach of the hood wall or the sheetrock wall behind it. Additionally, there were no glass fragment penetrations into or perforations through the hood wall.

A further observation was that there was no debris inside the Blast House after test 7 (50 g) that could be identified as part of the glass beaker. This led to test 10 (10 g) to determine if a smaller NEW would result in glass beaker debris. After test 10, six small glass beaker pieces were found in the Blast House. They all appeared to have come from the curved rim of the beaker and the largest was approximately 0.25” square (see Figure 2-6).

Figure 2-6 – Largest Glass Beaker Debris, Test 10 (10 g total NEW)

2.4 SQRL Phase I Conclusions

The SQRL Tests showed that the standard construction interior walls of the NCETR explosives labs are sufficient to prevent any debris hazard in adjacent rooms or hallways from the detonation of:

- 50 g total NEW bare charge at 12” minimum stand-off from interior wall

- 50 g total NEW bare charge in a standard glass beaker at 12" minimum stand-off in the hood
- 50 g total NEW bare charge at 12" minimum stand-off from hood wall

The SQRL Tests showed that there is no appreciable effect outside the Blast House (no debris or structural failure). Therefore, the explosives safety Q-D for a maximum of 50 g total NEW bare charge at a 12" minimum stand-off from an interior wall or 50 g total NEW bare charge in a standard glass beaker inside a hood at a 12" minimum stand-off from the hood wall should be zero (0') feet outside a laboratory that is at least as large as the Blast House for the standard construction walls tested (i.e., 5'8" gypsum board wall panels on 6" studs, 16" on center with R-19 batt insulation between wall panels).

3.0 Small Quantities for Research and Laboratories (SQRL) Phase II

3.1 Existing Criteria for Small Lab Quantities

Establishing reduced QD criteria in DoD 6055.09-M, *DoD Ammunition and Explosives Safety Standards*, for laboratory-scale explosives operations has been identified as a high priority by the Service Members of the DDESB. Current QD values in DoD 6055.09-M may be overly conservative and are not well anchored to actual test data at very low charge weights. Current Service criteria in this area are either silent or unsubstantiated by analysis or test data.

The Navy's OP 5 (OP 5 Volume 1, 2017) has the following criteria, the basis for which is unknown, for small quantities:

> *G-12.13.2. Minimum Q-D Requirements for Small Amounts of Energetic Material having 1.1 Hazard Classification. This manual requires that inhabited building distance of 236 feet be observed as a minimum distance requirement for NEW 0.5 pounds or less. This distance is the larger of two distances, one based upon air blast and the other based upon debris thrown. For many laboratory situations, however, it can be demonstrated that adequate personnel protection is provided at distances significantly less than 236 feet. Using the methodology described in paragraph 7-6.2 the distances shown in table G-5 have been determined for NEW common to laboratory situations.*

> *Table G-5. Guidelines for Minimum Q-D Requirements for Small Amounts of Energetic Material Having 1.1 Hazard Classification*

Net Explosive Weight (NEW)	*Inhabited Building Distance*	*Public Traffic Route Distance*	*Intraline Distance*
Less than 0.003kg/0.00066lb	*0*	*0*	*0*
0.003 kg – 0.01 kg/ 0.0066 lb – 0.022 lb	*5m / 16.5 ft*	*3m / 9.9ft*	*2m / 6.6 ft*
0.01 kg – 0.25 kg/ 0.022 lb – 0.50 lb	*15m / 49.5 ft*	*9m / 29.7ft*	*5m / 16.5ft*

The Air Force (AFMAN 91-201, 2017) allows storage of small amounts of AE in facilities or locations that are not explosives sited. Small quantities in laboratories are addressed in paragraph 11.23.

11.23. Research and Development Laboratories for Specific Experiments. *When necessary, units may license a limited quantity, not to exceed 200 grams in each licensed location, of HD 1.1 material for research use in laboratories. Licensing explosives used solely for a research project is allowed only for the length of the project. Commander-approved, locally-written procedures are required for the explosives operation.*

The DDESB sent questionnaires to the Services to gather data on Service laboratories. The U.S. Army Engineering and Support Center, Huntsville (CEHNC) has reviewed the responses to this questionnaire and collated some of the most critical information. Table 3-1 shows the range of net explosive weights (NEWs) for the labs responding to the questionnaire. Comparing this information to the NEW's in OP 5 Table G-5, the limits in Table G-5 would cover 80% of the typical laboratory siting.

Table 3-1 – Typical Laboratory NEW limits

Net Explosive Weight Limits (grams)	No. of Rooms Reported Within Limits	Max NEW (grams)	Percentage of Rooms Reported With NEW < Max NEW
NEW $\leq$ 50	57	$\leq$ 50 g	35.85
50 < NEW $\leq$ 225	69	$\leq$ 225 g	79.25
225 < NEW $\leq$ 500	14	$\leq$ 500 g	88.05
500 < NEW $\leq$ 1000	5	$\leq$ 1000 g	91.19
1000 < NEW $\leq$ 2300	6	$\leq$ 2300 g	94.97
2300 < NEW $\leq$ 3500	0		
3500 < NEW $\leq$ 4500	1	$\leq$ 4500 g	95.60
NEW > 4500	7	> 4500 g	4.40

Only 34 of the 162 labs in the surveys specified room sizes. The rooms varied in size from 720 ft^3 to 182,160 ft^3 with an average room size of 9,925 ft^3 and a median room size of 3,046 ft^3. It was decided to use a 10 ft x 12 ft x 8 ft (960 ft^3) room for the testing.

3.2 Purpose of SQRL Phase II

The primary reason for these tests was to determine if the debris distance for small quantities (i.e., $\leq$ 250g (0.5 lb)) can be reduced from the required 200 foot minimum. As a "worst case" wall, the walls tested were ½" sheetrock on either side of a standard 2" x 4" wood frame wall with studs 16" on center. A standard concrete masonry unit (CMU) wall was also tested to determine debris hazard.

Four goals were identified to develop QD criteria for laboratory quantities. Each of these goals were related to a facet of QD criteria and the expected form of the resultant QD criteria.

- Goal 1: Determine the maximum NEW (*xx*) which does not result in breaching a sheetrock wall at a 12" standoff.

- Expected QD Criteria: For a 12” standoff distance, the maximum NEW for which the QD outside the laboratory is zero (0) ft.

Net Explosive Weight (NEW)	Inhabited Building Distance	Public Traffic Route Distance	Intraline Distance
Less than (*xx/1.25)*	0	0	0

- Goal 2: Determine the debris and overpressure hazards from a sheetrock wall due to an explosion of 250 g (1.25 x 200 g) at a 12” standoff for a room of at least 1000 ft^3.

  - Expected QD Criteria: For a lightweight (e.g., sheetrock, lightweight metal, etc) wall with a 12” standoff in a laboratory that is at least 1000 ft^3, IBD is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, PTRD is 60% of IBD, and ILD is the 3.5 psi overpressure distance.

Net Explosive Weight (NEW)	Inhabited Building Distance	Public Traffic Route Distance	Intraline Distance
(xx/1.25) – 200 g	Greater of 1.2 psi overpressure distance or the debris distance determined by testing	60% of IBD	3.5 psi overpressure distance

- Goal 2b: Determine the hazardous debris distance from a sheetrock wall due to an explosion of 250 g (1.25 x 200 g) at a 48” standoff (i.e., lab bench away from wall) for a room of at least 1000 ft^3.

  - Expected QD Criteria: For a lightweight (e.g., sheetrock, lightweight metal, etc) wall with a 48” standoff in a laboratory that is at least 1000 ft^3, IBD is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, PTRD is 60% of IBD, and ILD is the 3.5 psi overpressure distance.

Net Explosive Weight (NEW)	Inhabited Building Distance	Public Traffic Route Distance	Intraline Distance
(xx/1.25) – 200 g	Greater of 1.2 psi overpressure distance or the debris distance determined by testing	60% of IBD	3.5 psi overpressure distance

- Goal 3: Determine the hazardous debris distance from an unreinforced CMU wall due to an explosion of 250 g (1.25 x 200 g) at a 12” standoff.

  - Expected QD Criteria: For a wall producing substantial debris (e.g., CMU, brick, concrete, etc) with a 12” standoff in a laboratory that is at least 1000 ft^3, IBD is the greater of the 1.2 psi overpressure distance and the debris distance determined by testing, PTRD is 60% of IBD, and ILD is the 3.5 psi overpressure distance.

Net Explosive Weight (NEW)	Inhabited Building Distance	Public Traffic Route Distance	Intraline Distance
(xx/1.25) – 200 g	Greater of 1.2 psi overpressure distance or the debris distance determined by testing	60% of IBD	3.5 psi overpressure distance

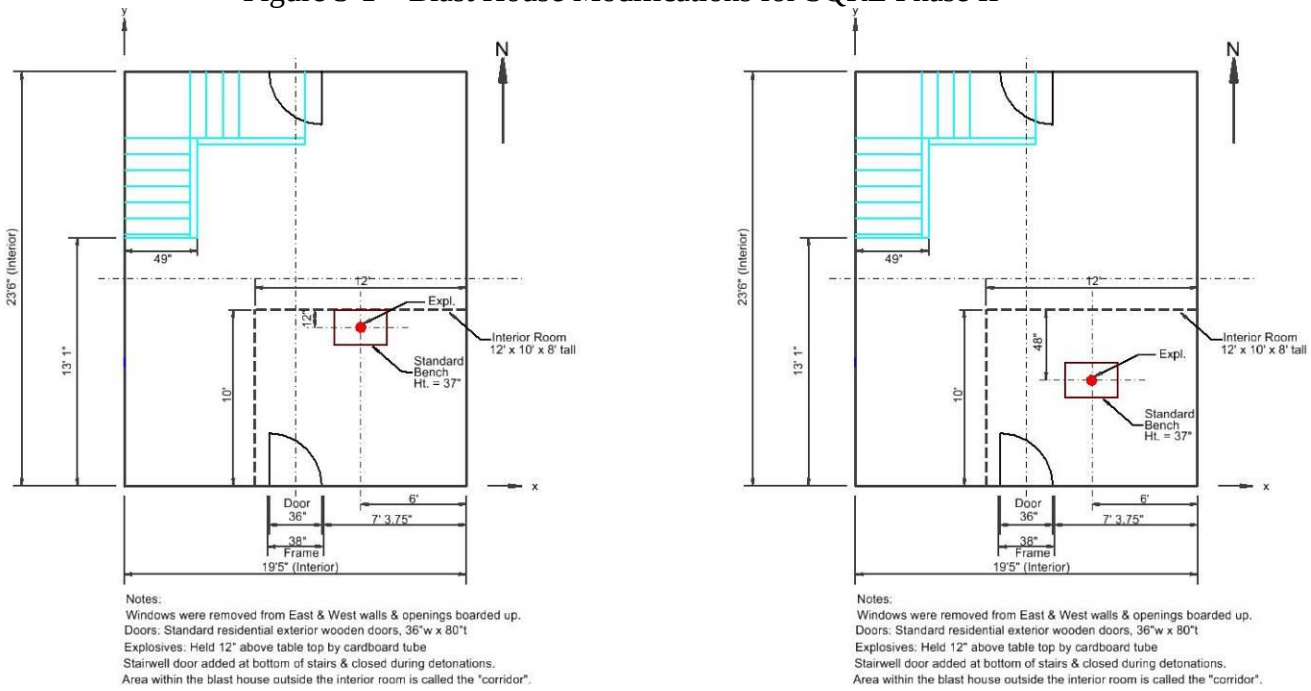
3.3 SQRL Phase II Test Procedure

Two types of walls were used throughout these tests: sheetrock walls and CMU walls. The sheetrock walls were constructed of ½" sheetrock on both faces of 2x4 wood frame walls with the studs 16" on center. The framing was attached to the concrete slab with anchor bolts. The freestanding sheetrock walls were back-braced to prevent sliding or tipping of the wall. The sheetrock wall framing in the blast house was attached to both the floor slab and the second floor joists.

The CMU wall was 8"x8"x16" standard lightweight CMU in a running bond with #4 – 60 ksi vertical rebar on 24" centers (every third cell). The cells containing the vertical rebar was fully grouted and the other cells were ungrouted. The wall was constructed on a concrete slab and back-braced to prevent sliding or tipping of the wall. This wall was tested only in the freestanding configuration.

The Blast House used in SQRL Phase I was repaired and a small (10' x 12' x 8') room built in the southeast corner of the Blast House (see Figure 3-1). This small room was used for the tests for Goals 1, 2 and 2b.

Figure 3-1 – Blast House Modifications for SQRL Phase II



A spherical charge of Composition C-4 (C-4) was used with an exploding bridge wire (EBW) detonator for all detonations. The spherical charge was placed on top of a cardboard tube on a plywood table such that the center of the charge was at a height of 48" for each detonations.

Each detonation was recorded using high speed video cameras, GoPro video cameras for real time records, and still photography for pre- and post-detonation evidence. Pressure data was collected at various locations for each shot. Weather data (temperature, barometric pressure, and relative humidity) was recorded at the time of each shot.

The tests performed are summarized in Table 3-2. Note that all explosive weights are given in actual weights not TNT equivalent weights and the total NEW includes the detonator explosive weight (1.11 g).

Table 3-2 – Detailed Testing Summary for SQRL Phase II

Test Series - Shot Number	Date	Time	Temp (^{o}F)	Humidity (%)	Atmospheric Pressure		Wall Construction		Explosive Weight		Location of Explosive		
					(inHg)	(psi)	Material	Free-standing / Blast House?	C-4 (g)	Total NEW[A] (g)	Height (in)	Distance from Left End of Wall (in)	Standoff (in)
1-1	3/28/2017	12:06	71	72	29.94	14.71	Sheetrock	Free-Standing	70	71.11	48	24	12
1-2	3/28/2017	13:40	75	62	29.95	14.71	Sheetrock	Free-Standing	40	41.11	48	24	12
1-3	3/28/2017	14:40	77	58	29.99	14.73	Sheetrock	Free-Standing	40	41.11	48	24	12
1-4	3/28/2017	15:58	82	49	29.92	14.70	Sheetrock	Free-Standing	40	41.11	48	24	12
2-1	3/29/2017	11:13	76	52	29.95	14.71	Sheetrock	Free-Standing	250	251.11	48	24	12
2-2	3/29/2017	12:58	86	47	29.95	14.71	Sheetrock	Free-Standing	250	251.11	48	24	12
2-3	3/29/2017	14:10	87	46	29.92	14.70	Sheetrock	Free-Standing	250	251.11	48	24	12
3-1	4/13/2017	15:00	91	25	30.14	14.80	Sheetrock	Blast House	40	41.11	48	72	12
3-2	4/19/2017	14:10	82	49	30.1	14.78	Sheetrock	Blast House	30	31.11	48	72	12
4-1	4/12/2017	10:45	79	43	30.22	14.84	Sheetrock	Blast House	250	251.11	48	72	48
4-2	4/13/2017	10:35	83	33	30.21	14.84	Sheetrock	Blast House	40	41.11	48	72	48
4-3	4/19/2017	9:50	74	65	30.15	14.81	Sheetrock	Blast House	30	31.11	48	72	48
5-1	3/30/2017	10:34	74	64	29.75	14.61	CMU	Free-Standing	250	251.11	48	60	12
5-2	3/30/2017	11:15	76	58	29.75	14.61	CMU	Free-Standing	250	251.11	48	20	12
5-3	3/30/2017	12:01	77	58	29.74	14.61	CMU	Free-Standing	250	251.11	48	108.5	12

3.4 SQRL Phase II Results

3.4.1 Test Series 1 (Freestanding Sheetrock Walls, 12" Stand-off)

Test Series 1 was designed to determine the maximum NEW at 12" stand-off from the sheetrock wall that would not cause breach of the wall. The first test at 70 g C-4 resulted in a full breach of the wall and the sheetrock on both sides of the wall was blown off the frame. The second test at 40 g C-4 caused a hole in the blast side of the wall with some cracking but no breach on the back side of the wall (see Figure 3-2). The cracking on the back side of the wall was determined to be sufficient to indicate incipient breach. This test was repeated two more times for confirmation with similar results.

Figure 3-2 – Damage from SQRL Phase II Test 1-2 (40 g C-4, 12” Stand-off)

3.4.2 Test Series 2 (Freestanding Sheetrock Wall, 12” Stand-off)

Test Series 2 was designed to determine the debris distance from a sheetrock wall when 250 g C-4 was detonated at a 12” stand-off. Additionally, a second sheetrock wall was placed 10 ft behind the target wall to determine if the debris from the target wall had sufficient energy to perforate this second wall. The 250 g C-4 at 12” stand-off resulted in almost complete destruction of the sheetrock of the target wall. The acceptor wall was damaged on its front face but no debris perforated the back face of the acceptor wall. Typical damage is shown in Figure 3-3.

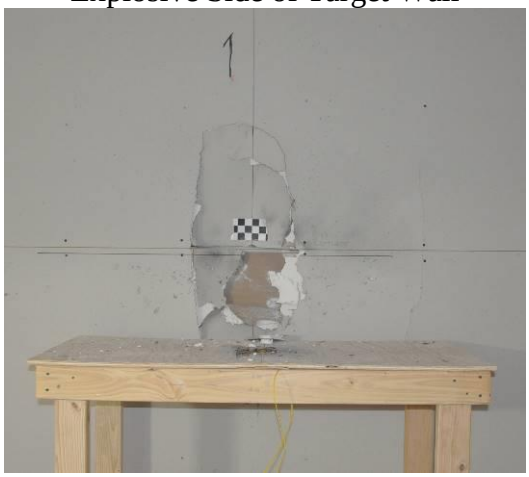
Figure 3-3 – Typical Damage from SQRL Phase II Test Series 2 (250 g C-4, 12” Stand-off)

3.4.3 SQRL Phase II Test Series 3 (12" Stand-off in Blast House)

The first shot in Test Series 4 (see Section 3.4.4) was performed prior to Test Series 3 which resulted in Test Series 3 being revised to confirm/determine the maximum NEW at a 12" stand-off in the small room of the Blast House that would not result in a breach of the sheetrock wall.

Based on the results of Test Series 1, Test Series 3 started with 40 g C-4 resulting in a breach of the target wall. The explosive weight was reduced to 30 g C-4 which did not cause a breach of the target wall. This caused a hole in the explosive side of the target wall but no hole in the back side of this wall (see Figure 3-4).

Figure 3-4 – SQRL Phase II, Test 3-2 (30 g C-4, 12" Stand-off, Blast House) Damage to Explosive Side of Target Wall



3.4.4 SQRL Phase II Test Series 4 (48" Stand-off in Blast House)

The initial purpose of this test series was to determine the effects of 250 g of C-4 at a 48" standoff from the North wall of the interior room of the Blast House.

The first shot (Test 4-1) caused severe damage to the Blast House (see Figure 3-5): complete destruction of the interior room, west wall Blast House displaced approximated 3" at ceiling height, north wall of the Blast House displaced approximately 6.5" at floor, nails popped out of flooring on 2nd floor, gap opened at apex of roof (nails popped loose).

After this shot, the test plan was revised and this series was changed to confirm the explosive weight which would not cause a breach. The next shot in the series (Shot 4-2) was 40 g of C-4 at a 48" standoff from the North wall of the interior room. This shot resulted in no breach of either the explosive side or the back side of any of the walls of the interior room. There was some loose sheetrock but none came off the framing.

After Shot 3-1 was performed (40 g C-4 at 12" standoff), the explosive weight for Shot 4-3 was reduced to 30 g C-4 at a 48" standoff. This shot resulted in no breach of either the explosive side or the back side of any of the walls of the interior room. There was no loose sheetrock in the interior room. There was some loose sheetrock in the hallway on the back side of the interior room walls but none came off the framing.

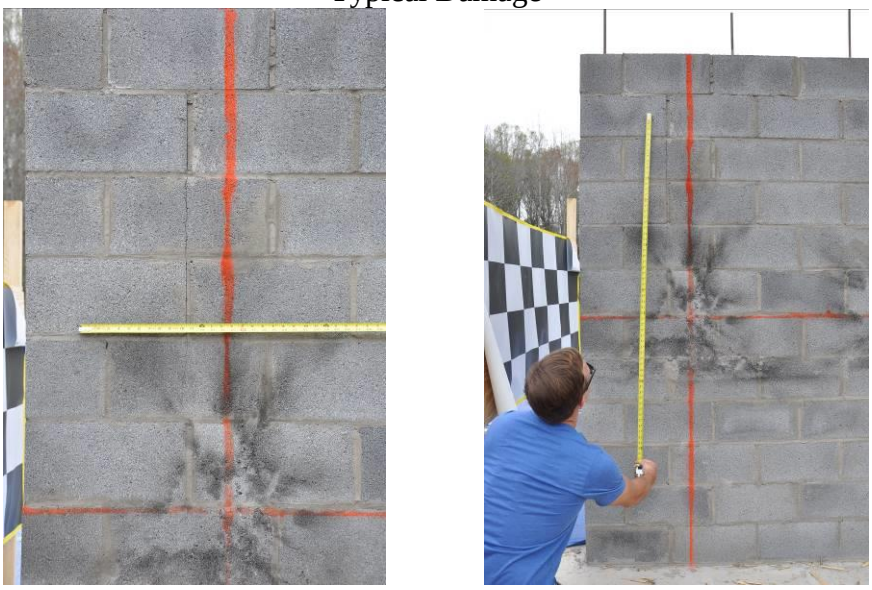
Figure 3-5 – SQRL Phase II, Test 4-1 (250 g, 48” Stand-off, Blast House), Damage to

3.4.5 SQRL Phase II Test Series 5 (Freestanding CMU Wall, 12” Stand-off)

The purpose of Series 5 was to determine if 250 g C-4 would breach a standard CMU wall at a 12” standoff from the ungrouted cells. In the event of a breach, the debris distances would be recorded.

Shots 5-1 through 5-3 were detonated at a 12” standoff from the ungrouted cells of a free-standing CMU wall. There was no breach from any of these shots. There was some small pitting (approximately 1/8” deep) on the blast side of the wall from Shots 5-2 and 5-3. Cracks were formed on both sides (blast and back) of the wall. Figure 3-6 shows typical wall damage.

Figure 3-6 – SQRL Phase II, Test Series 5 (250 g, 12” Stand-off, Freestanding CMU Wall) Typical Damage



3.5 SQRL Phase II Debris Data

3.5.1 SQRL Phase II Test Series 2 (Freestanding Sheetrock Wall, 12" Stand-off)

Debris from the target wall was mapped using a global positioning system (GPS) unit for each of the three shots in this series. The furthest debris for each shot is shown in Table 3-1.

Table 3-1 – Test Series 2 – Maximum Debris Distance

Test Series - Shot Number	Explosive Weight		Standoff (in)	Maximum Debris Distance (ft)
	C-4 (g)	Total NEW[A] (g)		
2-1	250	251.11	12	93.500
2-1	250	251.11	12	95.779
2-3	250	251.11	12	71.183

3.5.2 SQRL Phase II Test 4-2 (250 g, Blast House, 48" Stand-off)

Shot 4-1 (250 g C-4 at 48" standoff) was the only shot in the blast house that produced debris outside the blast house. The maximum debris distance from the East wall was 22 ft and from the South wall was 19 ft. On the south side, the maximum debris distance was limited by the timber structure. The door appeared to have hit the timber structure.

3.6 Recommended Explosives Safety QD Criteria Based on SQRL Phase II

The SQRL II Test Series tested the non-breach capacity of fairly weak walls (1/2" sheetrock on 2x4 wood studs at 16" on center) in a 960 ft^3 room. The room had a 1' x 1' open vent in one wall next to a standard residential exterior door. It was found that 30 g of C-4 plus the detonator did not cause breach at either a 12" or 48" standoff. Using the standard safety factor of 1.25, the resultant recommended QD is for a NEW of 25 g.

It is recommended the following Quantity-Distance (QD) criteria be adopted.

Minimum Room Volume (ft^3)	Minimum Standoff Distance (in)	Net Explosive Weight (NEW)	Inhabited Building Distance (ft)	Public Traffic Route Distance (ft)	Intraline Distance (ft)
960	12	$\leq$ 25 g	0	0	0

4.0 Future Work

Phase I testing showed that 50 g would not breach a standard current construction interior sheetrock wall (5/8" sheetrock, 6" studs at 16" on center, batt insulation inside wall) at a 12" stand-off in a room with an interior volume of at least 3600 ft^3. However, because of the purpose of Phase I testing, the testing was not continued to determine the NEW required to cause breach of this structure. Phase II testing showed that 30 g would not breach a weaker sheet rock wall (1/2" sheetrock, 4" studs at 16" on center, no insulation) at a 12" stand-off in a room with an interior volume of at least 960 ft^3.

Based on the data returned from the Services in the survey on laboratories, the lab room volumes reported are:

- Minimum room size = 720 ft^3 (only 1 room was smaller than 960 ft^3)
- Maximum room size = 182,160 ft^3
- Average room size = 9,925 ft^3
- Median room size = 3,046 ft^3

Several future testing options are suggested:

- Testing similar to Phase II Goal 1 (maximum NEW which does not result in a breach) using a larger volume rooms.
  - The first floor of the blast house is approximately 3,345 ft^3 with the stairway blocked. This would be slightly larger than the median room size from the survey.
  - If the plywood floor for the 2nd floor was removed, the volume of the blast house would be approximately 7500 ft^3. This is smaller than the average room size from the survey but would give another data point for room volume.
  - A 10,000 ft^3 room which would require construction of a new structure.
- Testing similar to Phase II Goal 1 (maximum NEW which does not result in a breach) using a stronger structure and a larger volume room.
  - Standard current construction used in Phase I.
  - CMU or reinforced concrete construction which would require construction of a new structure.
- Testing of the Phase II structure to determine if retrofits such as an additional layer of ½" sheetrock can increase the NEW that does not result in a breach.

The personnel involved in the Phase I and Phase II testing have defined the following priorities for SQRL Phase III testing goals.

- Define an NEW that has a zero (0) QD in a room with a realistic volume but has weak/worst case scenario walls (room volume > 3000 ft^3, sheetrock walls from Phase II).
- Define an NEW that has a zero (0) QD in a room with a realistic volume but has realistic construction or weak walls that have been retrofit (room volume > 3000 ft^3, sheetrock walls from Phase I or retrofit walls from Phase II).
- Define a non-zero QD (IBD < 200 ft current default distance) for a larger NEW in a room with a realistic volume and/or the Phase II room and sheetrock wall structure.

References:

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