SciPan 4: PROGRAM DESCRIPTION AND TEST RESULTS

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ABSTRACT

As part of the U.S. Department of Defense Explosives Safety Board (DDESB) Project ESKIMORE, the U.S. has conducted the fourth test in its SciPan test series, which consists of full-scale donor/acceptor trials examining debris generation and acceptor response. The SciPan 1 and 2 tests and results were reported at the 2004 DDESB Seminar. SciPan 3 was reported on at the 2006 DDESB Seminar. The overall SciPan program is described, with emphasis on the debris generation results from SciPan 4. This event, which was conducted in August 2008 at Naval Air Warfare Center, Weapons Division, China Lake, CA, was a 1,000 kg (2,205 lb) detonation of non-fragmenting munitions inside a typical reinforced concrete operating building. Results from this test including airblast effects, debris densities patterns, and fragmentation characteristics are presented. Comparisons of debris density as a function of azimuth and distance are made with analytical debris prediction models, as well as with traditional Quantity-Distance criteria.

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14. ABSTRACT
As part of the U.S. Department of Defense Explosives Safety Board (DDESB) Project ESKIMORE, the U.S. has conducted the fourth test in its SciPan test series, which consists of full-scale donor/acceptor trials examining debris generation and acceptor response. The SciPan 1 and 2 tests and results were reported at the 2004 DDESB Seminar. SciPan 3 was reported on at the 2006 DDESB Seminar. The overall SciPan program is described, with emphasis on the debris generation results from SciPan 4. This event, which was conducted in August 2008 at Naval Air Warfare Center, Weapons Division, China Lake, CA, was a 1,000 kg (2,205 lb) detonation of non-fragmenting munitions inside a typical reinforced concrete operating building. Results from this test including airblast effects, debris densities patterns, and fragmentation characteristics are presented. Comparisons of debris density as a function of azimuth and distance are made with analytical debris prediction models, as well as with traditional Quantity-Distance criteria.

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BACKGROUND

Introduction

The U.S. Department of Defense Explosives Safety Board (DDESB) is sponsoring the development of a risk-based explosives safety siting program ("SAFER")[1]. One of the benefits of a risk analysis is the quantification of relative risk from different hazards. Because limited funds are available for improving explosives safety criteria, SAFER has been used to identify tests with the most potential for both improving risk prediction and Explosives Safety Quantity-Distance (ESQD) criteria.

In order to create a testing program that would fill in the gaps that most severely limited the development of algorithms, yet were feasible to address with testing, the Science Panel of the DDESB identified the following issues and has made them priorities in the DDESB sponsored Project ESKIMORE[2]:

- ***ISSUE 1:*** Secondary or donor (Potential Explosion Site, PES) debris generation and density versus distance and azimuth
- ***ISSUE 2:*** Target building (Exposed Site, ES) response to blast loading
- ***ISSUE 3:*** Target building (ES) protection against debris afforded to occupants

The SciPan Program under Project ESKIMORE is designed to address the first two of these issues. It derives its name from an abbreviation for the DDESB Science Panel and is in no way affiliated with the city/island of Saipan in the Northern Marianas Islands. Table 1 presents the SciPan program as it is currently envisioned using nominal parameters.

Table 1. SciPan Program Description and Schedule

Test	Date	NEW (lbs) *(kg)*	Loading Density (lbs/ft^3) *(kg/m^3)*	PES Volume (ft^3) *(m^3)*	PES	ES Description: ES 1	ES Description: ES 2
SciPan 1*	2/19/2003	27,005 *(12,249)*	0.733 *(11.74)*	36,864 *(1,043.9)*	Type 1	5.5" Tilt-up RC Wall/Wood Roof *(139.7 mm Tilt-up RC Wall/Wood Roof)*	7.5" Tilt-up RC Wall/Wood Roof *(190.5 mm Tilt-up RC Wall/Wood Roof)*
SciPan 2*	7/9/2003	5,005 *(2,270)*	NA	NA	N/A	5.5" Tilt-up RC Wall/Wood Roof *(139.7 mm Tilt-up RC Wall/Wood Roof)*	7.5" Tilt-up RC Wall/Wood Roof *(190.5 mm Tilt-up RC Wall/Wood Roof)*
SciPan 3**	4/6/2005	60,005 *(27,218)*	6.667 *(106.79)*	9,000 *(254.9)*	Type 2	8" Unreinforced CMU/Wood Roof *(203 mm Unreinforced CMU/Wood Roof)*	8" Dbl Wythe Brick Wall/Wood Roof *(203 mm Dbl Wythe Brick Wall/Wood Roof)*
SciPan 4	8/27/2008	2,205 *(1,000)*	0.244 *(3.92)*	9,000 *(254.9)*	Type 2	NONE	NONE
SciPan 5		6,595 *(2,991)*	0.733 *(11.74)*	9,000 *(254.9)*	Type 2	Wood Residential	Steel Frame with Infill Panels
SciPan 6		11,250 *(5,103)*	1.25 *(20.02)*	9,000 *(254.9)*	Type 2	Metal Trailer	Hardened Metal Trailer

Completed but not reported

Completed and reported

PES Type 1: 48' x 48' x 16' *(14.6 m x 14.6 m x 4.9 m)*

PES Type 2: 30' x 30' x 10' *(9.1 m x 9.1 m x 3.0 m)*

*NAVFAC TM-2371-SHR

**NAVFAC TM-2388-SHR

Organization and Funding

Funding for SciPan 4 and follow-on data collection efforts was provided by the following organizations:

- DDESB
- U.S. Army Technical Center for Explosives Safety (USATCES)

The design and construction of the PES were under the direction and management of APT Research, Inc., Huntsville, AL. Wiss, Janney, Elstner Associates, Inc (WJE) both designed and constructed the PES. Construction began in March 2008 and was completed in May 2008. Test planning and technical support have been provided by the following organizations:

- Naval Facilities Engineering Service Center (NAVFAC ESC)
- Indian Head Division/Naval Surface Warfare Center
- APT Research, Inc.

Personnel either from or provided by the following organizations participated in the post-test debris collection:

- DDESB
- Indian Head Division/Naval Surface Warfare Center
- NAVFAC ESC
- USATCES
- U.S. Army Engineering Support Center, Huntsville
- U.S. Department of Labor, Mine Safety and Health Administration (MSHA)
- APT Research, Inc.
- Institute of Makers of Explosives (IME)

The Naval Air Warfare Center, Weapons Division, China Lake, CA, provided test support.

Objectives

The primary objective for this test was to determine the debris characteristics from an operating-type building PES at a low loading density. Three different wall cross-sections were included in the test:

- 14 cm (5.5”) Reinforced Concrete (R/C),
- 19 cm (7.5”) R/C, and
- Fully-grouted, reinforced 20 cm (8”) Concrete Masonry Units (CMU)

Debris data from the composite reinforced concrete/steel panel roof and the reinforced concrete floor have also been quantified. (NB: The walls shall be referred to by their Imperial Units designations, 5.5” R/C, 7.5” R/C, and 8” CMU for the sake of consistency with previous nomenclature.)

In addition to the primary objective of determining the debris distribution, the test had several potential secondary objectives:

- Quantify the attenuation to the blast wave caused by the interaction with the PES.
- Determine the effects of a HESCO Bastion barricade on the debris distribution
- Observe the interaction of the blast wave/debris field with a vertical face barricade

DESCRIPTION

General

The event consisted of a Net Explosive Quantity (NEQ) of 1,000 kg of flaked TNT detonated in the center of the PES. The test site was the Upper Cactus Range of the Naval Air Warfare Center, Weapons Division, China Lake, CA. This site is at an elevation of approximately 1,525 m. A complete 360-degree debris recovery was planned outside a nominal radius of 100 m from Ground Zero (GZ).

Incident pressure gauges were placed along two radial lines from the PES to determine the external airblast loading and quantify the blast attenuation provided by the structure. Both high-speed and regular speed video cameras were used to document the test and to determine the velocity of selected PES debris.

PES Structure

The donor building included a floor slab and foundation as well as reinforced concrete and masonry walls and a composite reinforced concrete/steel panel roof. The PES was designed for normal dead plus live loads (NB: The PES was not a hardened structure). The PES dimensions and building materials were chosen to represent those of a typical operating building. The building was 9.1m by 9.1m (30' by 30') in floor plan with a ceiling height of 3.05m (10'). A 3.05m by 3.05m (10' x 10') opening was provided in one of the 19 cm RC walls for access during construction and test setup. Figure 1 shows the nominal PES configuration.

The walls were significantly different in cross-section, but typical of normal construction practices. Two walls were 7.5" R/C with No. 15 rebar @ 40 cm (#5 @ 16") centers each way. The third wall was 5.5" R/C with No. 15 rebar @ 40 cm (#5 @ 16") centers each way. The fourth wall was constructed from fully-grouted, 8" CMU with No. 15 rebar vertical @ 40 cm (#5 rebar @ 16") centers and No. 15 rebar horizontal @ 80 cm (#5 @ 32") centers. Each wall was constructed such that it would remain independent, i.e., the walls were not tied together at the corners. This was done in an attempt to isolate the response of the different wall types. Figures 2A and 2B show cross-sections through each of the walls.

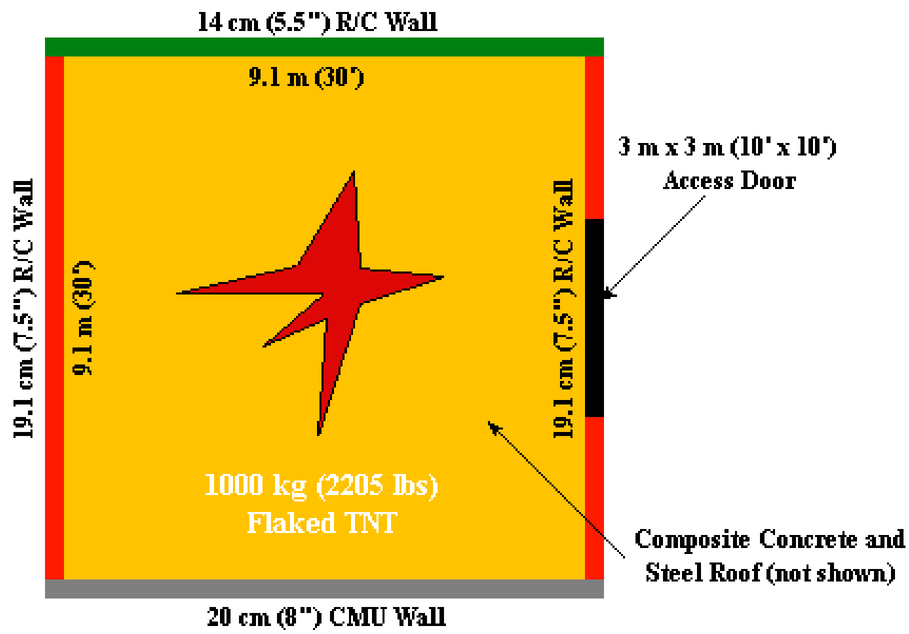

Figure 1. SciPan 4 PES Nominal Configuration

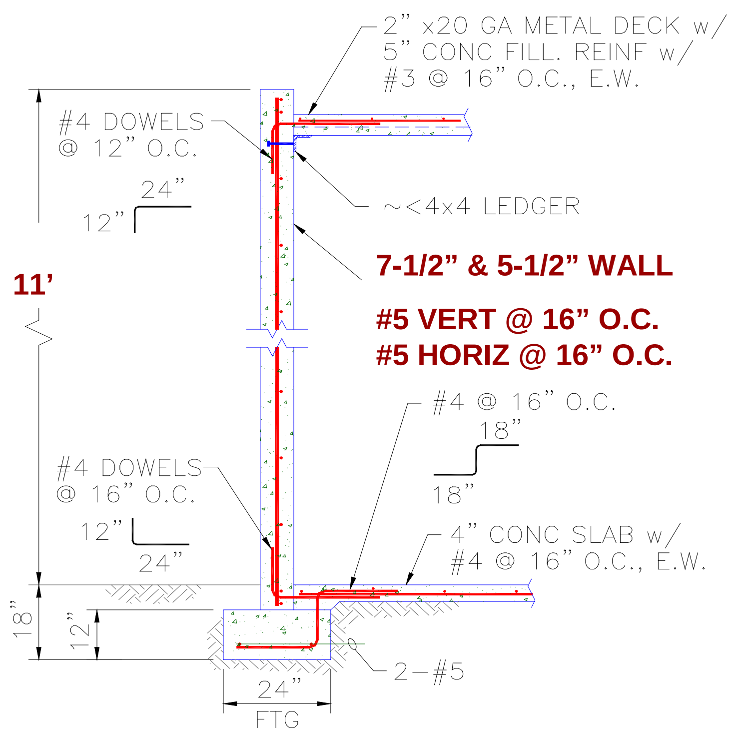

Figure 2A. PES R/C Wall Cross-Sections

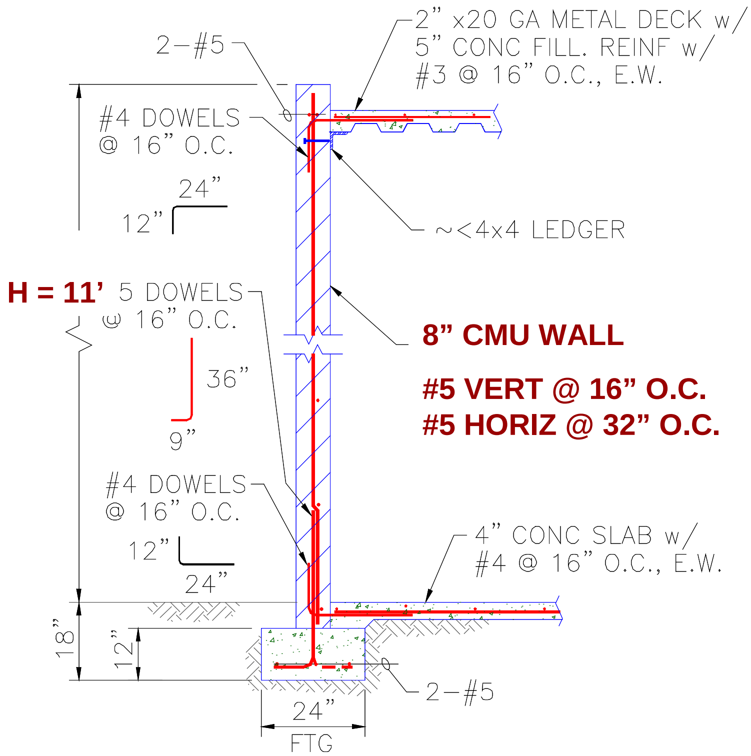

Figure 2B. PES CMU Wall Cross-Section

The roof was a composite section, with a corrugated metal deck, R/C fill, and No. 10 rebar @ 40 cm (#3 @ 16") centers each way. The maximum thickness of the roof concrete was 14 cm (5.5") and the minimum thickness was 7.5 cm (3"); the average thickness was about 11 cm (4.25"). The roof was supported with steel beams spanning the length of the structure.

The floor slab was 10 cm (4") R/C with No. 10 rebar @ 40 cm (#3 @ 16") centers each way. There was a 61 cm wide by 53 cm deep (24" x 21") perimeter footing around the structure.

To ease identification of the sources of the debris, colored pigments were included with the various concretes. Figure 3 shows computer-generated images of the PES structure and the pigment color scheme in the concrete. Figure 4 shows the actual PES structure.

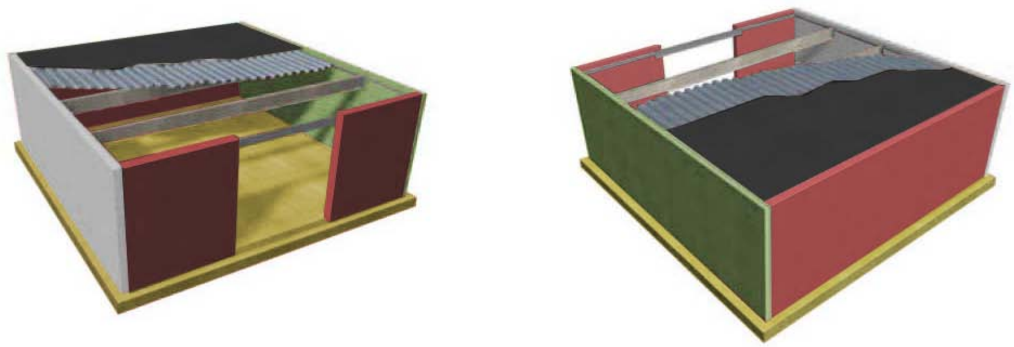

Figure 3. SciPan 4 PES (Computer Generated)

Figure 4. SciPan 4 PES

Charge Description

The donor charge was composed of flaked TNT contained in fiberboard boxes, with each box weighing approximately 25 kg. 40 boxes were used to achieve the nominal NEQ of 1000 kg. The charge was stacked as a rectangular parallelepiped located in the center of the PES, carefully placed such that it was equidistant from the walls. Four blocks of C-4 were used as a booster in conjunction with four 50-cm lengths of detonating cord to ensure complete detonation of the TNT. Figure 5 depicts this setup of the donor charge and the initiation system.

Figure 5. Charge Arrangement and Initiation Setup

Barricade

A sand-filled HESCO Bastion barricade was constructed 4.6 meters in front of one half of the door side of the PES. Figure 6 shows the barricade location while Figure 7 shows photographs of the completed barricade.

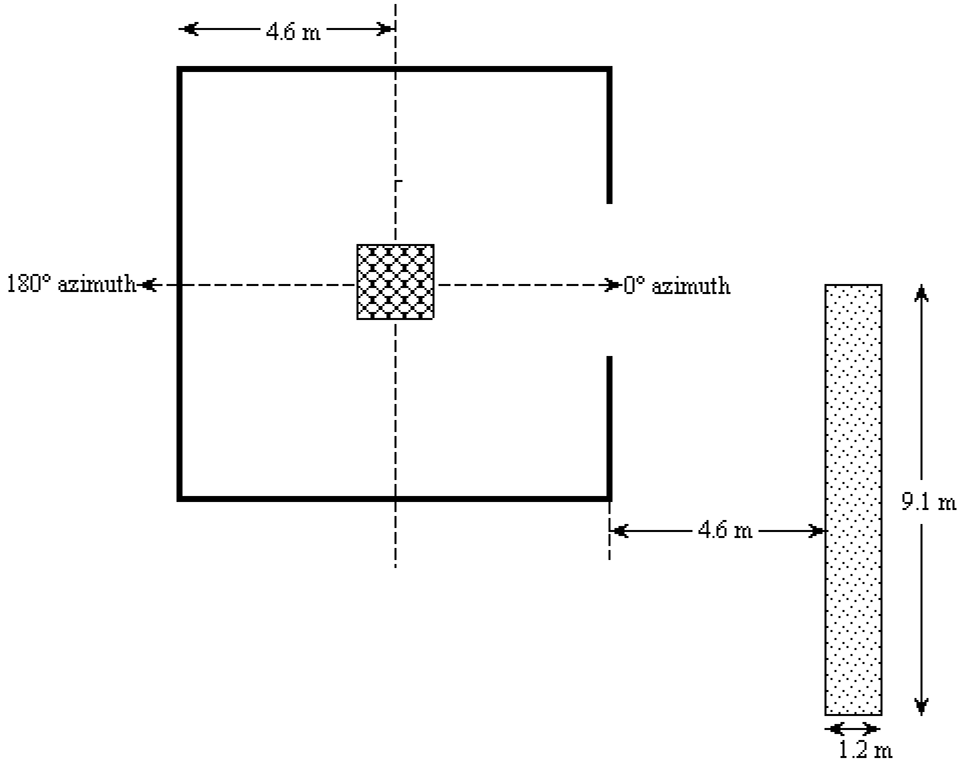

Figure 6. HESCO Bastion Barricade Schematic

Figure 7. HESCO Bastion Barricade

DATA COLLECTION

Airblast

Incident airblast was measured along two radial lines extending from the center of the PES out along the 180º and 270º azimuths, as shown in Figure 8. Pressure transducers were placed at the following nominal distances from the center of the PES:

- 15.2 meters (50 feet)
- 30.5 meters (100 feet)
- 45.7 meters (150 feet)
- 61.0 meters (200 feet)
- 91.4 meters (300 feet)
- 121.9 meters (400 feet)
- 152.4 meters (500 feet)

Photographic Coverage

Multiple high-speed cameras were used to record the event along with two normal speed videos. Some of these high-speed cameras were used primarily for determining secondary debris characteristics from the event, as shown in Figure 8 (NB: The camera locations are not to scale). Fiducial markers were used as reference points to calculate debris velocity in post-test data analysis. The primary function of cameras C3 and C4 was to determine debris velocities originating from the 5.5" R/C wall and the CMU wall, respectively. Cameras C1a, C1b, and C1c were positioned to quantify the effects of bounce, shatter, and roll as the debris field impacts the ground.

Still photography was taken post-test of GZ and the surrounding areas. Photographs were taken at the 100 meter markers every 5° focusing both in towards GZ and out along the radial. Additional photographs were also taken along the normals and at other places of interest.

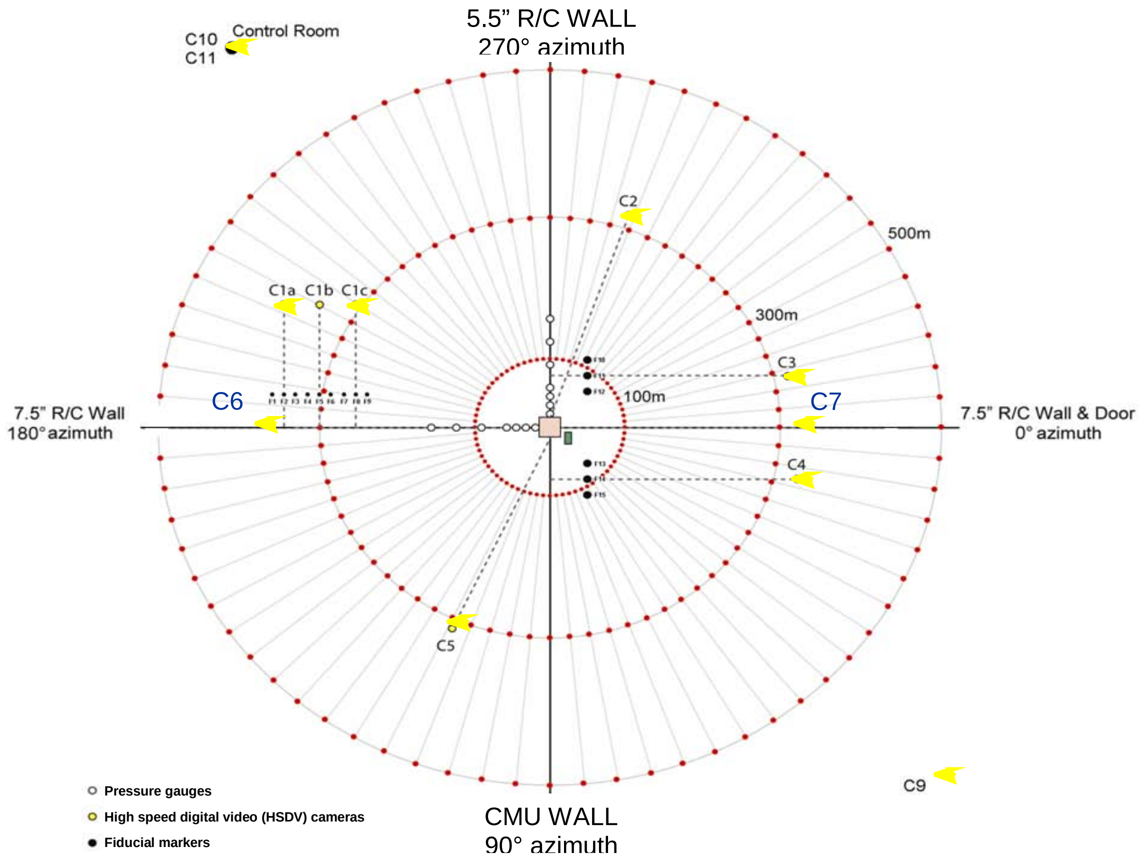

Figure 8. SciPan 4 Instrumentation Layout

Debris Collection

The debris recovery grid was marked out in 5° x 200 m sectors, starting at 100 m and going out to 500 m. The sectors were marked out over the entire 360° domain and the origin of the recovery grid was the center of the PES. As shown in Figure 8, the normal to the 7.5" R/C wall and door side is the 0° reference azimuth, with the normal to the full 7.5" wall in the 180° direction. The normal to the CMU wall is the 90° direction, while the normal to the 5.5" R/C wall is the 270° direction. Markers were placed at each intersection of radial distance with azimuthal angle for reference during the collection and cataloguing process. These markers are represented by the red dots in Figure 8.

In addition to the 360° collection grids out to 500 meters, additional collection grids were surveyed normal to each wall face with the additional markers +/- 5° of each normal (0°, 90°, 180°, and 270°) at 750 meters and 1000 meters.

Debris recovery and cataloguing was done as a two step process. Debris recovery teams performed an organized sweep of each sector, marking each piece of debris with a flag. The debris cataloguing teams followed behind with a mobile scale and a Leica 1200

Series Differential GPS system to record the type of debris, weight, and location. The cataloguing teams had the ultimate decision as to the type of debris.

Pieces of significant interest were identified and photographed. Pieces that were too large to be moved by the cataloguing team were initially surveyed and later weighed by a separate crew before disposal.

In an effort to ultimately quantify the hazards associated with explosion produced debris, mass bins have been defined for the SciPan Program[3], and have been used on previous tests[4,5,6,7]. These mass bins were again used as a basis for the characteristics of the debris collected. Table 2 provides the size and mass ranges for material in each of the mass bins collected.

Table 2. Mass Bin Characteristics

	CONCRETE				STEEL			
Bin	WEIGHT			SIZE	WEIGHT			SIZE
Number	(lbs)	(oz)	(kg)	(in)	(lbs)	(oz)	(kg)	(in)
1	>54	>864	>24.49	>10.8	>26	>416	>11.79	>5.5
2	21 - 54	336 - 864	9.525 - 24.49	7.9 - 10.8	10 - 26	160 - 416	4.536 - 11.79	4.1 - 5.5
3	9.5 - 21.5	152 - 344	4.309 - 9.752	6.0 - 7.9	4.5 - 10	72 - 160	2.041 - 4.536	3.1 - 4.1
4	4 - 9.5	64 - 152	1.814 - 4.309	4.5 - 6.0	1.8 - 4.5	28.8 - 72	0.816 - 2.041	2.3 - 3.1
5	1.7 - 4	27.2 - 64	0.771 - 1.814	3.4 - 4.5	0.8 - 1.8	12.8 - 28.8	0.363 - 0.816	1.8 - 2.3
6	0.6 - 1.7	9.6 - 27.2	0.272 - 0.771	2.5 - 3.4	0.3 - 0.8	4.8 - 12.8	0.136 - 0.363	1.3 - 1.8
7	0.3 - 0.6	4.8 - 9.6	0.136 - 0.272	1.9 - 2.5	0.14 - 0.3	2.24 - 4.8	0.064 - 0.136	1.0 - 1.3
8	0.12 - 0.3	1.92 - 4.8	0.054 - 0.136	1.4 - 1.9	0.06 - 0.14	0.96 - 2.24	0.027 - 0.064	0.7 - 1
9	0.05 - 0.12	0.8 - 1.92	0.023 - 0.054	1.0 - 1.4	0.025 - 0.06	0.4 - 0.96	0.011 - 0.027	0.56 - 0.7
10	<0.05	<0.8	<0.023	<1.0	<0.025	<0.4	<0.011	<0.56

SCIPAN 4 PREDICTIONS

Crater

Based on SAFER algorithms and the results of SciPan 1 and 3, the crater was expected to have the following properties:

- Average radius = 2.0 meters
- Maximum ejecta range = 100 meters
- Ejecta mass = 1050 kilograms

Airblast

The expected airblast was predicted using Version 6.3 of the Blast Effects Computer[8]. The summary table is shown in Table 3.

The following input conditions were selected:

- ***Select PES***: AGS
- ***Select Type of Weapon***: Bulk/Light Cased: STANDARD
- ***Select Type of Explosive***: TNT
- ***Enter Total NEW***: 1000 kg
- ***Enter Altitude***: 1525 m
- ***Enter Temperature***: 35° C

Table 3. Predicted Airblast

RANGE @ Altitude (m)	SCALED DISTANCE (m/kg1/3)	RANGE @ Sea Level (m)	TIME OF ARRIVAL (ms)	INCIDENT PRESSURE (kPa)	INCIDENT IMPULSE (Pa-s)	POSITIVE DURATION (ms)	REFLECTED PRESSURE (kPa)	REFLECTED IMPULSE (Pa-s)	DYNAMIC PRESSURE (kPa)	DYNAMIC IMPULSE (Pa-s)
25.0	2.5	23.5	31.52	72.92	689.00	22.96	194.85	1,701.20	21.46	197.09
30.0	3.0	28.2	41.24	56.63	591.22	26.57	143.38	1,376.52	13.24	119.15
35.0	3.5	32.9	51.66	45.64	512.28	29.06	110.97	1,142.08	8.67	77.74
40.0	4.0	37.6	62.65	37.84	449.30	30.86	89.19	969.24	5.96	54.35
45.0	4.5	42.3	74.10	32.08	398.86	32.25	73.80	838.64	4.26	40.12
50.0	5.0	47.0	85.94	27.67	358.04	33.40	62.48	737.59	3.15	30.87
60.0	6.0	56.3	110.48	21.46	296.90	35.32	47.18	593.33	1.87	19.96
70.0	7.0	65.7	135.86	17.35	253.96	37.00	37.48	496.70	1.21	13.99
80.0	8.0	75.1	161.82	14.46	222.48	38.57	30.85	428.21	0.83	10.35
90.0	9.0	84.5	188.19	12.33	198.56	40.05	26.07	377.42	0.60	7.98
100.0	10.0	93.9	214.87	10.71	179.84	41.47	22.48	338.40	0.46	6.35
112.5	11.3	105.6	248.55	9.15	161.48	43.15	19.08	300.77	0.34	4.95
125.0	12.5	117.4	282.55	7.96	147.05	44.73	16.49	271.62	0.26	3.98
137.5	13.8	129.1	316.81	7.01	135.39	46.23	14.46	248.33	0.20	3.29
150.0	15.0	140.9	351.30	6.25	125.73	47.63	12.82	229.25	0.16	2.78
175.0	17.5	164.3	420.89	5.09	110.59	50.21	10.36	199.69	0.11	2.07
200.0	20.0	187.8	491.11	4.29	99.11	52.50	8.59	177.58	0.08	1.62
225.0	22.5	211.3	561.70	3.59	89.98	54.55	7.27	160.20	0.06	1.30
250.0	25.0	234.8	632.38	3.06	82.43	56.41	6.24	145.99	0.04	1.06
275.0	27.5	258.2	702.81	2.66	76.01	58.10	5.41	134.02	0.03	0.87
300.0	30.0	281.7	772.68	2.33	70.44	59.66	4.74	123.71	0.02	0.71
325.0	32.5	305.2	out of range	0.08	65.23	61.13	out of range	114.65	out of range	0.57
350.0	35.0	328.7	out of range	0.07	60.62	62.65	out of range	106.59	out of range	0.46
400.0	40.0	375.6	out of range	0.06	out of range	out of range	out of range	out of range	out of range	out of range
450.0	45.0	422.6	out of range	0.05	out of range	out of range	out of range	out of range	out of range	out of range
500.0	50.0	469.5	out of range	0.04	out of range	out of range	out of range	out of range	out of range	out of range

Debris Throw

The maximum debris range in any direction was expected to be less than 920 meters. The following debris ranges were expected for the various components:

- Roof concrete < 610 meters
- Roof rebar < 610 meters
- Roof metal (non rebar) < 760 meters
- CMU wall debris < 920 meters
- 7.5” R/C wall debris < 920 meters
- 5.5” R/C wall debris < 920 meters
- Wall rebar < 760 meters

RESULTS

General

The charge was detonated on 27 August 2008 at the Upper Cactus Range of NAWC-WD, China Lake, CA. The initial debris collection began immediately after the test and continued through 6 September 2008. Due to the enormity of the task at hand, follow-on collection efforts were undertaken to collect and catalogue as much data as possible. These efforts, referred to as the Debris Investigation and Recovery Task (DIRT), took place over two different time periods. The first of these efforts, named DIRT 4.1, was conducted the week of 15 December 2008. The second follow on collection effort, DIRT 4.2, was conducted the week of 14 September 2009.

Crater

The crater formed by the event was far smaller than those seen in previous SciPan tests. The approximate diameter of the crater varied between 2.5 and 3.0 meters. The maximum depth of the crater was approximately 0.65 meters. Figure 9 shows two views of the crater.

Figure 9. SciPan 4 Crater

Airblast

The recorded airblast data is presented in Table 4. Upon examination of the data for the 270° array (to the side of the PES) and the 180° array (to the rear of the PES), it can be seen that at smaller distances ($\leq$ 60 meters), the peak overpressure was higher to the side of the PES and the wave arrived sooner, which is to be expected. When the data is compared to the predictions by BEC for an AGBS and an open hemispherical surface burst, BEC under-predicts the magnitude of the overpressure at smaller distances for an AGBS with this NEQ. Additionally, it can be determined that the blast attenuation provided by the presence of the donor structure has little effect at larger distances, as the values become consistent with what would be expected from a open detonation.

Table 4. Airblast Results and Prediction Comparison

Distance from Ground Zero	SciPan 4 Test Data				BEC v6.3 Predictions			
	270° array		180° array		AGBS		Open	
	P_{SO}	t_A (ms)	P_{SO}	t_A (ms)	P_{SO}	t_A (ms)	P_{SO}	t_A (ms)
15.24 m (50 ft)	200.91 kPa (29.14 psi)	21.41	210.08 kPa (30.47 psi)	22.21	141.20 kPa (20.48 psi)	15.34	507.80 kPa (73.65 psi)	9.46
30.48 m (100 ft)	91.29 kPa (13.24 psi)	52.14	62.26 kPa (9.03 psi)	54.12	55.36 kPa (8.03 psi)	42.81	105.83 kPa (15.35 psi)	34.15
45.72 m (150 ft)	42.89 kPa (6.22 psi)	86.5	35.85 kPa (5.20 psi)	90.66	31.37 kPa (4.55 psi)	76.86	47.02 kPa (6.82 psi)	67.77
60.96 m (200 ft)	33.65 kPa (4.88 psi)	124.22	30.06 kPa (4.36 psi)	129.42	20.96 kPa (3.04 psi)	114.47	28.41 kPa (4.12 psi)	105.41
91.44 m (300 ft)	15.72 kPa (2.28 psi)	203.04	15.65 kPa (2.27 psi)	211.13	12.07 kPa (1.75 psi)	194.7	15.24 kPa (2.21 psi)	185.34

Debris Counts

Figure 10 shows the debris data collected and the areas that were searched in the debris recovery effort. Due to time constraints and logistical concerns, not all sectors were searched in the same manner. The shading of the sectors in Figure 10 denotes the level of detail given in the collection of debris in each sector.

Beyond 500 meters, a much less rigorous debris search was conducted, with the exception of the locations off of the normals. Those areas were searched in a similar manner to the sectors inside 500 meters.

The normals were completely saturated with debris from 100 to 300 meters, and it proved inefficient to focus debris collection efforts there. Though the sectors within +/- 10° of each normal were not rigorously searched out to 300 meters, complete recovery efforts were conducted in strategic areas inside these normals to aid debris characterization of these areas.

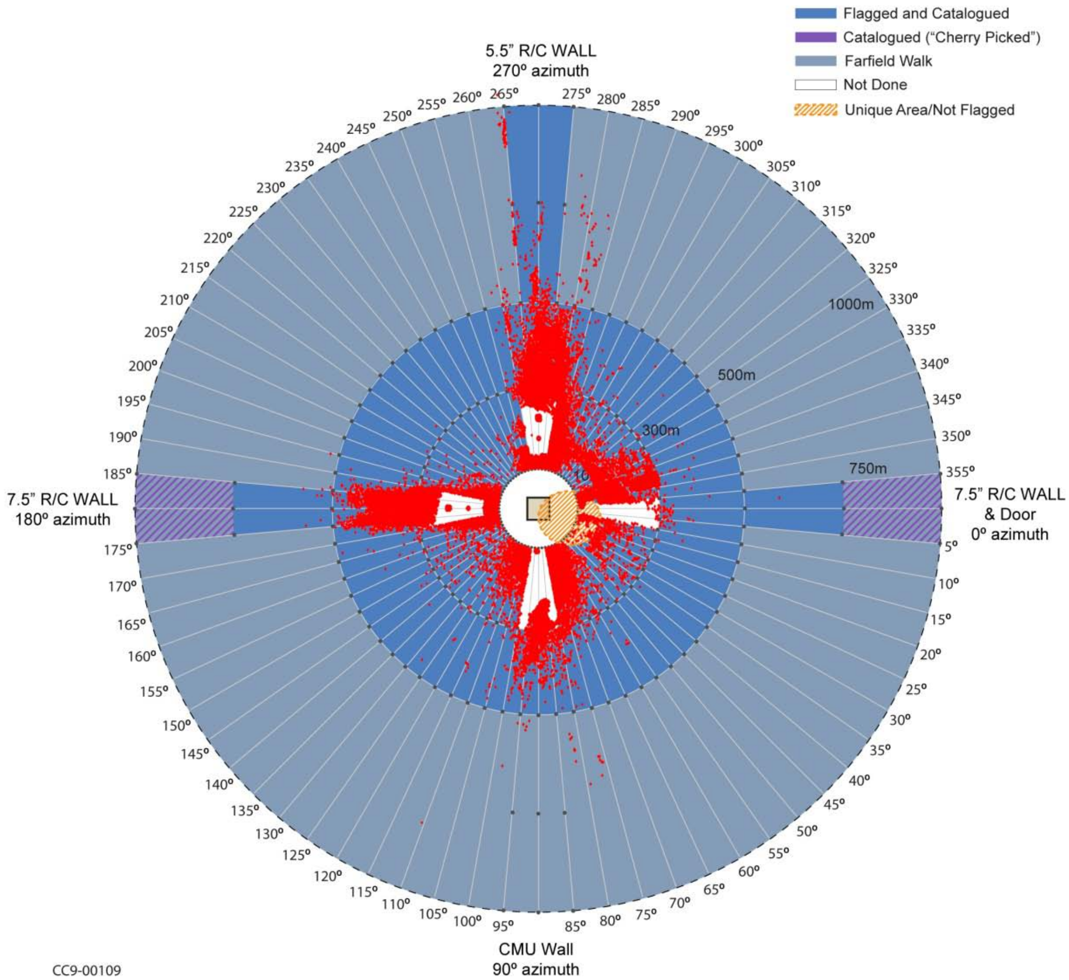

Figure 10. SciPan 4 Debris Scatter Plot

Figures 11A through 11C show the debris pattern for a given wall type. All dimensions for these plots are in meters. Note that only concrete debris is included in all of the following data analyses, figures, and tables presented in this paper. Steel and other miscellaneous debris will not be discussed herein. (NB: The discussions of CMU wall debris hereafter shall consider both the CMU block and CMU grout in discussion of generated wall debris.)

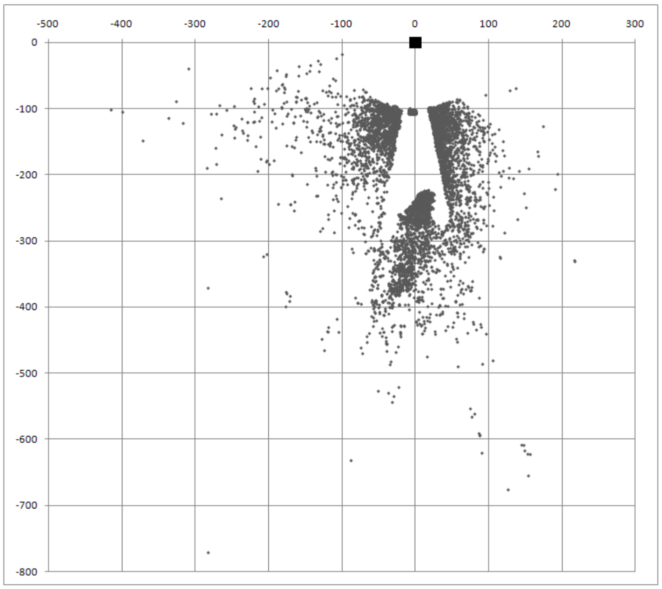

Figure 11A. CMU Wall Debris

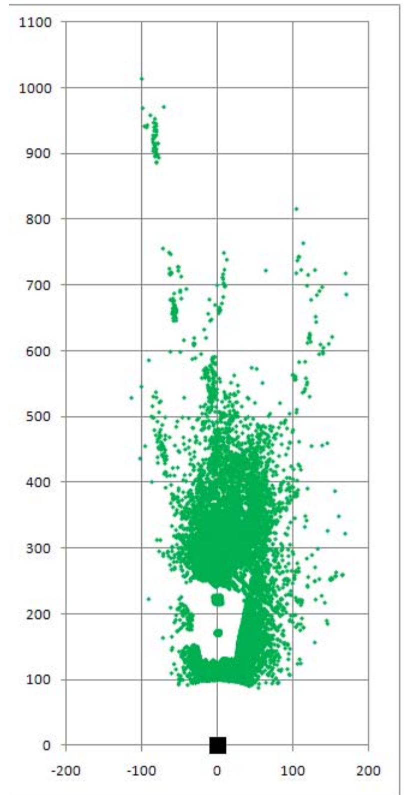

Figure 11B. 5.5” Wall Debris

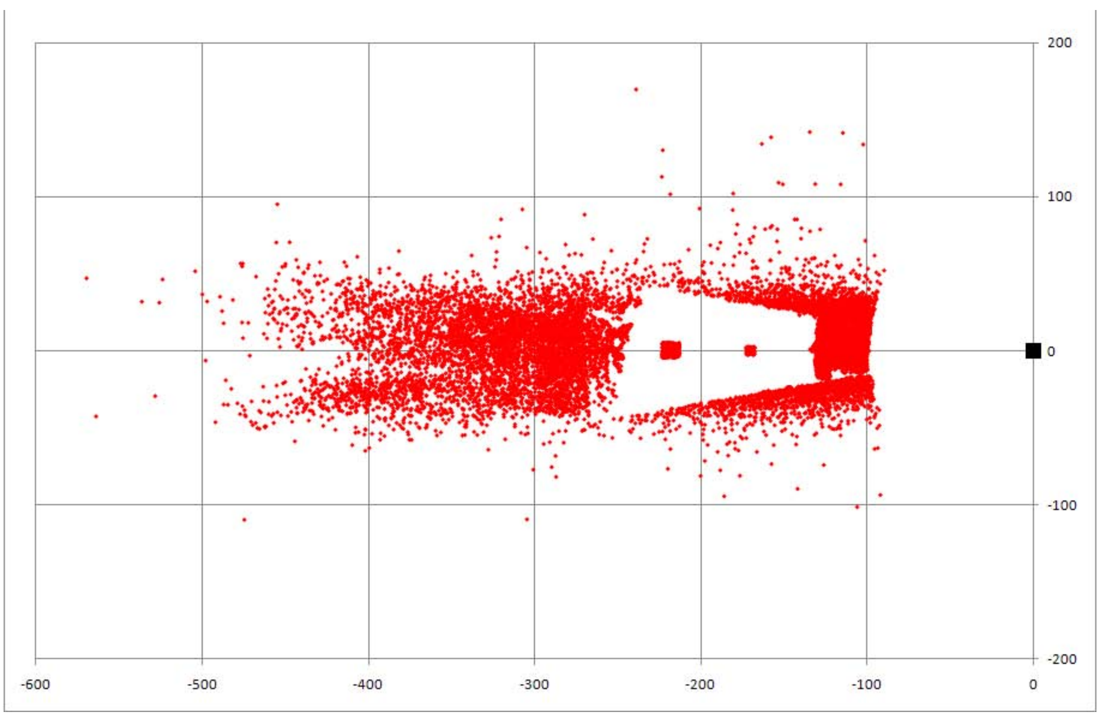

Figure 11C. 7.5” Wall Debris (180° direction)

Table 5 displays the debris counts for the three different wall components and the roof. Note that these values only consider the concrete, and omit all wall steel and reinforcement within the respective walls. The column for “All Debris” consists of all debris generated by the PES, both concrete and steel, from the four walls, the roof, and the floor. The debris is counted according to Mass Bin. Many pieces of debris were collected that are smaller than the minimum mass for Mass Bin 10. These pieces are counted as “giblets,” and notated in Table 5 by “G.”

Table 5. Debris Counts

Mass Bin	Number of Pieces				
	7.5" Wall	5.5" Wall	CMU Wall	Roof	All Debris
1	13	0	0	0	25
2	39	15	16	12	93
3	115	80	53	50	342
4	274	276	123	94	808
5	392	461	235	196	1,318
6	731	734	485	452	2,445
7	1,314	929	696	723	3,700
8	2,784	1,677	1,234	1,470	7,197
9	4,940	3,568	1,484	2,368	12,399
10	7,713	7,475	1,618	3,276	20,138
G	3,453	4,961	360	1,415	10,203
Total	21,768	20,176	6,304	10,056	58,668
1 to 10 Total	18,315	15,215	5,944	8,641	48,465

Expanding from the Mass Bin format, Figure 12 shows the cumulative mass distributions for the individual structure components tabulated in Table 5. The plots are shown to plateau for values less than 10 grams, but it should be kept in mind that debris less than 9 grams was not targeted in the collection effort. Debris was collected that weighed less than the threshold, but in all likelihood the actual cumulative mass distribution for this test continues to rise as the horizontal axis approaches 1 gram.

The amplitude of the curves in Figure 12 is directly proportional to the total number of pieces collected for a given component. There was approximately twice as much 5.5” R/C debris collected as there was CMU debris, so a direct comparison of their respective mass distributions becomes difficult. Perhaps a better way to compare the break-up of the various components of the SciPan 4 donor structure is to normalize the cumulative mass distributions by dividing each curve by its corresponding total number of pieces collected. Figure 13 shows this comparison, and allows for qualitative comparisons between the components. It can be asserted that the 5.5” R/C wall was broken into a higher fraction of small pieces than the other components. Conversely, it appears that the CMU wall had a tendency to break into larger pieces than that of any other component.

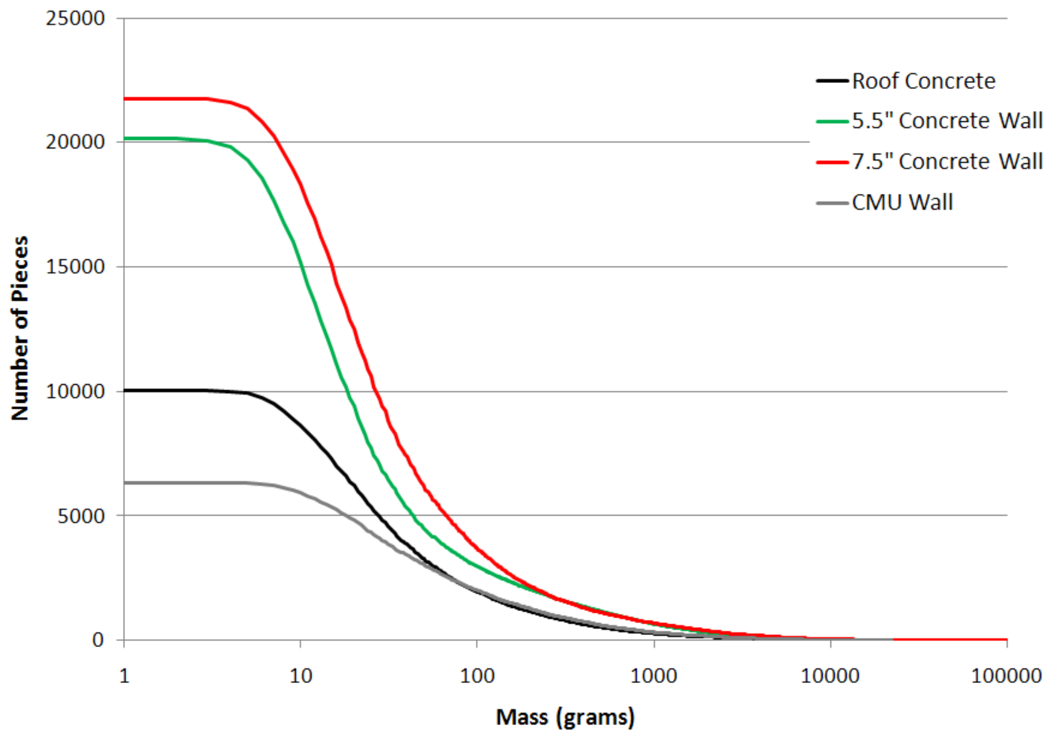

Figure 12. Cumulative Mass Distribution for Components of SciPan 4

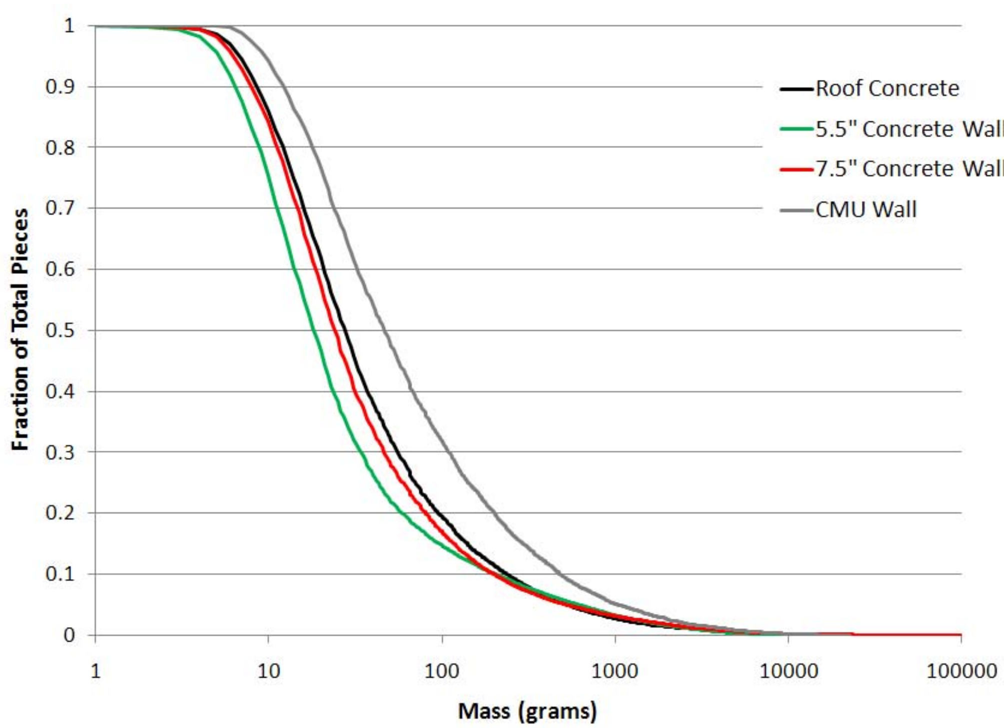

Figure 13. Normalized Cumulative Mass Distribution for Components of SciPan 4

It should be noted that the debris counts and mass distribution data presented herein reflect pick-up data collected after the test, and do not necessarily represent the mass distribution of the debris field as it is being launched from the donor structure. It is known that concrete debris is prone to shatter upon impact with the ground, and anecdotal evidence suggests that the mass distribution of the debris field traveling in flight is quite different than the debris field that is found lying on the ground. Additionally, flight physics equations demonstrate that relatively small debris generally do not make it to relatively great distances.

Efforts were taken during the debris collection process to collect all shattered debris and count it as a single larger piece where evidence on the ground clearly stated this was the case. This process could be performed with a high degree of certainty in far-field sectors where the debris density was fairly sparse, but proved much more problematic or practically impossible in the near field or in areas where the debris density was quite high.

The problem of how to address debris shatter is a known issue, and steps to solve this problem are currently being undertaken by the international explosion produced debris community.

Mass Bin Distribution

The debris counts for each component presented in Table 5 can be expressed in two different formats to graphically display the debris distributions: by fraction of the total mass and by fraction of the total debris count. The individual masses for all debris in a given Mass Bin have been summed for a total debris mass in that particular Mass Bin. Once the totals for all Mass Bins 1 through 10 have been determined (ignoring the "G"-bin contribution), the fractions of the total mass can be calculated. Table 6 shows how much mass of the total debris for a given component resides in each Mass Bin. Also shown in Table 6 is the Mass Bin distribution used in the Quantitative Risk Assessment (QRA) method of Technical Paper No. 14 (TP 14)[1] and the associated QRA software SAFER for calculations of reinforced concrete wall and roof components.

While the contribution of all pieces smaller than Mass Bin 10 has been removed from the test data for this comparison, it should be noted that the Mass Bin distribution presented within TP 14 accounts for the entire mass of the donor structure, and thus all pieces of debris smaller than Mass Bin 10 are included in that Mass Bin. Due to this philosophical decision, the mass fraction and the total debris count fraction values of Mass Bin 10 for TP 14 presented in Tables 6 and 7 are artificially high. This should be taken into consideration prior to making any direct comparisons between the TP 14 values and the test data for this Mass Bin.

Table 6. Comparison of Fractions of Total Mass per Mass Bin

Mass Bin	Fraction of Total Mass				
	7.5" Wall	5.5" Wall	CMU Wall	Roof	SAFER
1	0.125	0.000	0.000	0.000	0.075
2	0.141	0.065	0.128	0.094	0.125
3	0.170	0.170	0.190	0.210	0.2
4	0.175	0.256	0.189	0.163	0.125
5	0.109	0.183	0.157	0.139	0.075
6	0.085	0.126	0.137	0.135	0.075
7	0.064	0.067	0.085	0.093	0.075
8	0.058	0.050	0.064	0.079	0.075
9	0.043	0.044	0.033	0.054	0.075
10	0.030	0.040	0.016	0.033	0.1

A secondary method of expressing the debris distribution is to display the fraction of the total number of debris residing within a given Mass Bin. The debris counts in Table 5 have been expressed in terms of fraction of the total debris count in Table 7. Again a comparison is made with those values utilized in the QRA method of TP 14.

Table 7. Comparison of Fractions of Total Debris Count per Mass Bin

Mass Bin	Fraction of Total Debris Count				
	7.5" Wall	5.5" Wall	CMU Wall	Roof	SAFER
1	0.0007	0	0	0	0.0002
2	0.0021	0.0010	0.0027	0.0014	0.0008
3	0.006	0.005	0.009	0.006	0.003
4	0.015	0.018	0.021	0.011	0.004
5	0.021	0.030	0.040	0.023	0.006
6	0.040	0.048	0.082	0.052	0.015
7	0.072	0.061	0.117	0.084	0.036
8	0.152	0.110	0.208	0.170	0.083
9	0.270	0.235	0.250	0.274	0.187
10	0.421	0.491	0.272	0.379	0.665

The values presented in Tables 6 and 7 are plotted graphically in Figures 14 and 15. As can be seen in the figures, the mass distributions of the roof and three wall components all trend in a similar manner.

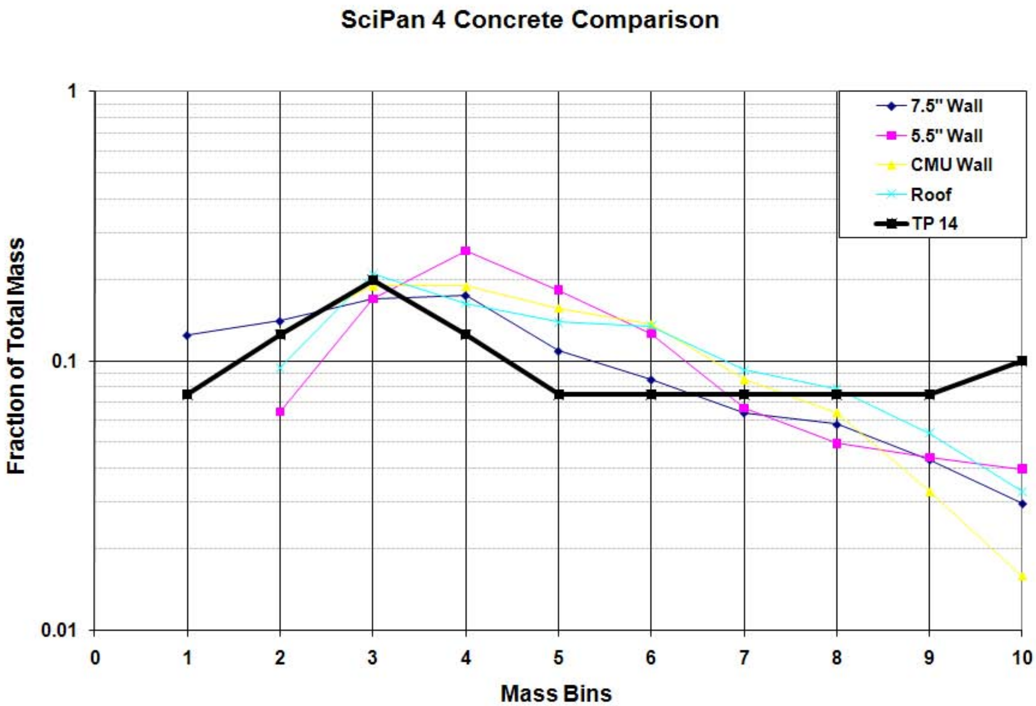

Figure 14. Fraction of Total Mass Comparison per Mass Bin for SciPan 4

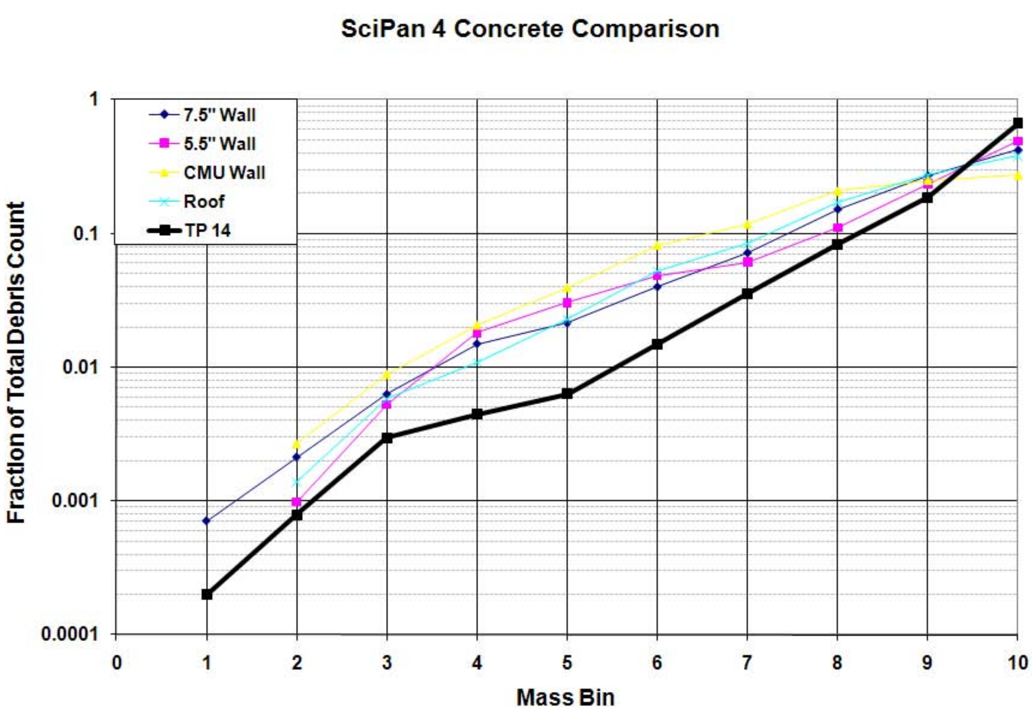

Figure 15. Fraction of Total Debris Count Comparison per Mass Bin for SciPan 4

Average Mass Comparison

SAFER, using the algorithms of TP 14, predicts the total number of concrete debris pieces in a given Mass Bin as a function of the component weight, the percent of concrete in that component, the percent of mass in a given Mass Bin, and the average mass for that Mass Bin. Ideally a comparison would be made between the total number of pieces collected in the test for a given Mass Bin and that of the SAFER prediction. Realistically a complete debris recovery becomes impractical, as the cost to collect all pieces in areas of high saturation becomes economically impractical.

Alternatively, the arithmetic mean of the mass of the collected debris can be compared with the TP 14 average mass per Mass Bin to assess if the debris count predicted to be thrown in the analytical model is accurate (assuming the mass in the bin is correct). Table 8 compares the predicted average mass per Mass Bin of TP 14 with those of the various components in the SciPan 4 test.

Table 8. Comparison of TP 14 Average Mass with SciPan 4 Test Data

Mass Bin	Avg. Mass (g)	Arithmetic Mean Mass (g)				Percent Difference			
		7.5"	5.5"	CMU	Roof	7.5"	5.5"	CMU	Roof
1	34,201	39,810	N/A	N/A	N/A	-14.1%	N/A	N/A	N/A
2	14,288	14,981	12,588	13,494	12,622	-4.6%	13.5%	5.9%	13.2%
3	6,078	6,147	6,171	6,057	6,730	-1.1%	-1.5%	0.3%	-9.7%
4	2,545	2,654	2,701	2,597	2,785	-4.1%	-5.8%	-2.0%	-8.6%
5	1,080	1,153	1,156	1,129	1,139	-6.4%	-6.6%	-4.4%	-5.2%
6	454	484	502	478	478	-6.3%	-9.6%	-5.0%	-5.1%
7	191	203	209	207	205	-6.1%	-9.0%	-7.9%	-7.1%
8	81.6	86.7	85.9	88.1	86.2	-5.8%	-5.0%	-7.3%	-5.3%
9	36.3	36.1	35.8	37.2	36.6	0.5%	1.4%	-2.6%	-0.8%
10	13.6	15.9	15.5	16.6	16.1	-14.5%	-12.0%	-18.1%	-15.2%

It should be sated that the comparisons between the average masses of Mass Bins 1 and 10 are not completely valid comparisons for two separate reasons. For Mass Bin 1, TP 14 does not define an upper mass limit, so an artificial average mass is chosen. For the Mass Bin 10 comparison, it is known that not all of the debris greater than the minimum collection value is catalogued in the areas that have been searched. Previous testing efforts[7] conducted post-collection, extremely thorough sampling efforts to quantify miss rates in catalogued sectors. The vast majority of missed debris data was not much larger than the minimum mass value of Mass Bin 10. With this in mind, it would follow that the TP 14 average mass would tend to under-predict the average mass for Mass Bin 10 when compared to the collected data.

Maximum Debris Range

The maximum fragment distance varied greatly depending on the wall type. The farthest recovered fragments in each direction were as follows:

- 0° direction, 7.5" R/C Wall and Door – 376.8 meters @ 345.2°
- 90° direction, CMU Wall – 821.1 meters @ 110.1°
- 180° direction, 7.5" R/C Wall – 571.6 meters @ 184.7°
- 270° direction, 5.5" R/C Wall – 1018.3 meters @ 264.4°

The venting out the door of the structure drastically reduced the impulsive build up on the door side of the PES, and greatly reduced the initial velocities and corresponding distances of the fragments in that direction. Additionally, with one third less debris and the presence of the barricade on one half of the wall, the limited maximum debris range is quite understandable out the front of the PES.

As for the other three walls, it is intuitive that the maximum fragment distance is inversely proportional to the areal density of the walls. If a general assumption is made that all three walls had equivalent impulsive loads and comparable material densities, then it would follow that the debris generated from the 5.5" R/C wall would have higher initial velocities than debris from the other two walls, and as such, would result in a greater maximum fragment distance.

Azimuthal Debris Density Variation

Debris Inhabited Building Distance (IBD) is defined as the range at which the density of hazardous fragments falls below a value of 1 per 55.7 m^2. A hazardous fragment is defined as a fragment with an impact kinetic energy of at least 79 Joules.

The debris data have been analyzed to estimate the Pseudo-Trajectory Normal (PTN) debris density[9] as a function of range for each 5° azimuthal sector. In order to develop a debris density plot based on a debris data catalogue, it is necessary to develop a relationship between mass and kinetic energy. Moreover, it is necessary to define how a fragment arrived at its final resting location to determine whether or not it had a kinetic energy of at least 79 Joules at impact. Obviously, this information is not known, so a series of assumptions must be made. A mass of 90 grams was chosen as the minimum value for a fragment to have an impact energy of 79 Joules. This value corresponds to the approximate mass of a piece of concrete debris in the shape of a rough sphere falling at terminal velocity. (NB: The hazardous fragment definition in previous SciPan test reports was based on different assumptions.)

Figure 16 shows the SciPan 4 PTN debris IBD for each 5° azimuthal sector. The maximum distances in each direction are as follows:

- 0° direction, 7.5" R/C Wall and Door – 325 meters @ 5°
- 90° direction, CMU Wall – 500 meters @ 80°
- 180° direction, 7.5" R/C Wall – 486 meters @ 185°
- 270° direction, 5.5" R/C Wall – 686 meters @ 265°

The direct correlation in azimuthal sector between maximum debris range and maximum debris IBD for a given direction can be noticed.

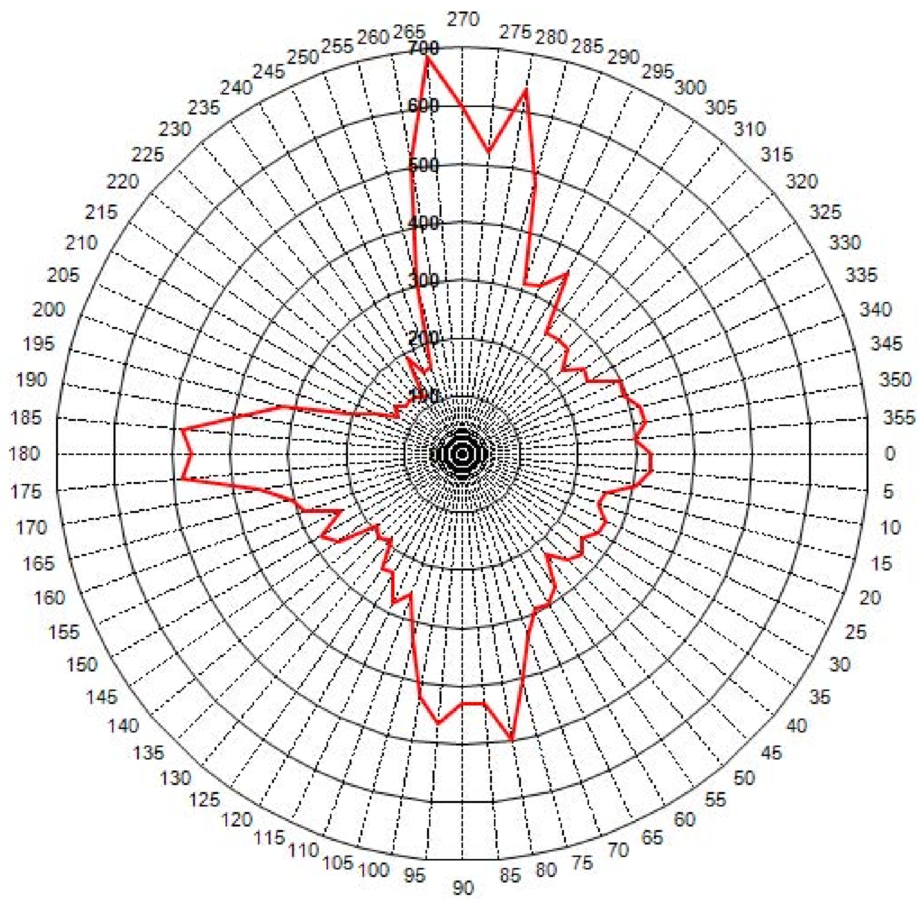

Figure 16. SciPan 4 PTN Debris IBD

When the SciPan 4 debris data are averaged over the full 360° of azimuth, a PTN debris IBD of 307 meters is obtained. It has been shown that the cube root of the PTN debris IBD has a high correlation to the loading density of the structure[10]. This relationship is presented in Figure 17 with the data point for SciPan 4.

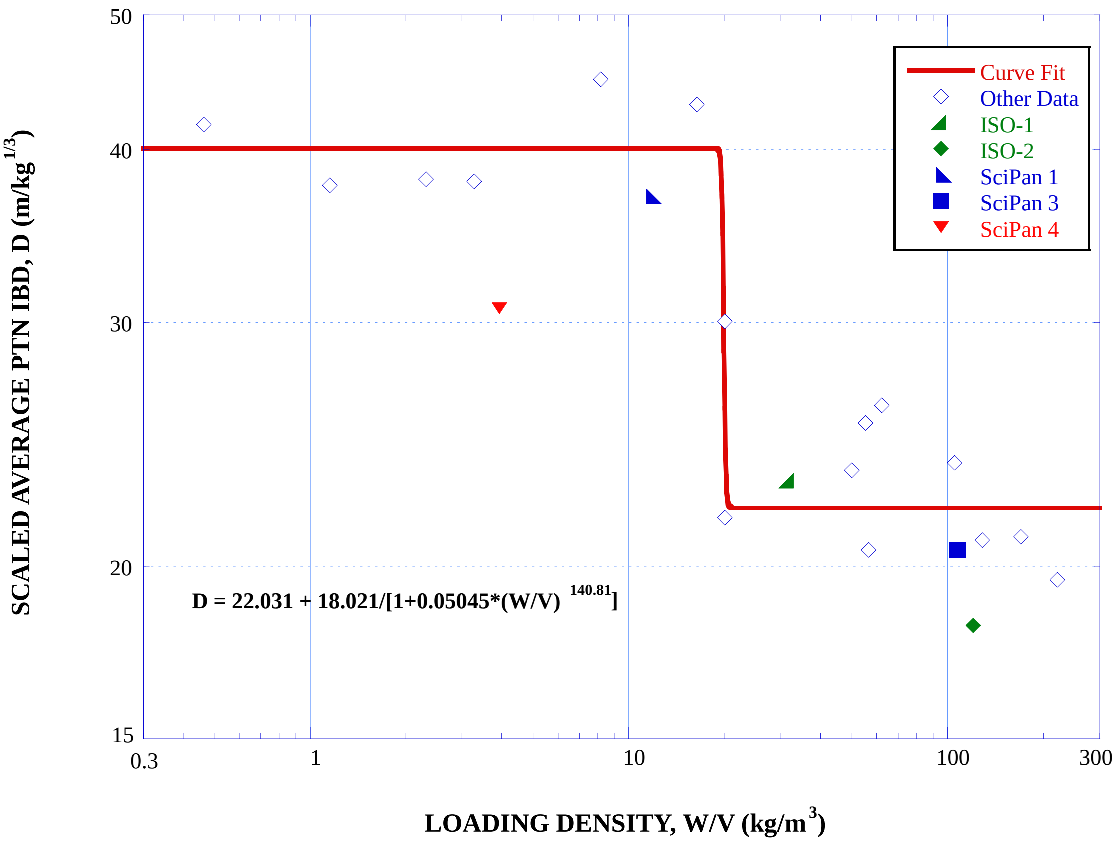

Figure 17. Scaled PTN Debris IBD Chart

<u>Barricade Effects</u>

Figure 18 shows the barricade after the detonation. The portion of the barricade that was directly normal to the 7.5" wall was completely obliterated, while the rest of the barricade remained standing, albeit after sustaining massive damage.

The debris was not fully catalogued in the vicinity due to the 100 meter threshold for collection, as well as the aforementioned saturation of the normals with debris. However a quantitative comparison can be made of the 7.5" R/C debris collected beyond 100 meters in that direction. In the region from the normal to 20° clockwise of the door, the portion of the wall obstructed by the barricade, beyond 100 meters there were only 214 pieces of 7.5" R/C debris collected. Conversely, in the region from the normal to 20° counter-clockwise of the door, the portion of the wall not obstructed by the barricade, beyond 100 meters there were 2,785 pieces of 7.5" R/C debris collected.

A general observation made of the debris field was that there were multiple very large pieces of concrete debris from the 7.5” R/C wall within 100 meters on the barricaded side of the wall. Conversely, neither the un-barricaded side of the 7.5” R/C wall on the 0° azimuth nor the 7.5” R/C wall on the 180° azimuth were characterized in this manner. Furthermore, upon examination of the high-speed video data, several large pieces of concrete debris from the 7.5” R/C wall on the 180° azimuth were seen traversing the field of view, but those large pieces of concrete debris were not found during the debris recovery process.

These observations provide additional anecdotal evidence to the concept previously mentioned that concrete debris is prone to shatter upon impact with the ground, and that the mass distribution of the debris field traveling in flight is quite different than the debris field that is found lying on the ground. It is theorized that the sand-filled barricade provided a much less rigid impact surface than the ground, and upon striking the barricade the debris did not violently shatter as is the case when the hard ground is impacted.

Figure 18. Barricade Results Post-Test

SUMMARY

The SciPan 4 test resulted in the collection of nearly 60,000 points of debris data. This data advances the state-of-the-art in the understanding of secondary debris generated by accidental explosions, and better quantifies the overall debris throw phenomenon from PES structures.

For each debris type and category, analyses have been performed to quantify the debris mass distributions and horizontal launch angle distributions. Detailed analyses of the mass distribution have been performed for the reinforced concrete and CMU components and comparisons have been made with the values in the prediction algorithms of TP 14.

Further investigation into relationships between the various parameters will be performed and relationships between mass distribution, range, and bearing will be developed. Determining these debris characteristics will provide information to better quantify the debris hazard from PES structures.

The information generated by this test and the rest of the SciPan Program will be incorporated into DOD Quantitative Risk Assessment software such as SAFER, as well as be used to update existing Quantity-Distance regulations and enhance the state-of-the-art in debris prediction models.

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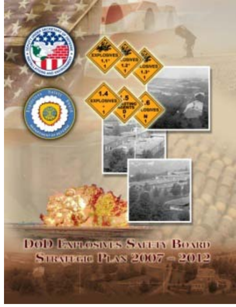

SciPan 4: Program Description and Test Results

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Project ESKIMORE Background

- Sponsored by the U.S. Department of Defense Explosives Safety Board (DDESB) under Project ESKIMORE
- The DDESB Science Panel acts as the steering group
- Goal is to provide data in explosion effects areas where data are lacking or absent entirely
- Project ESKIMORE investigates the following issues:
  - Issue 1: Secondary or donor (Potential Explosion Site, PES) debris generation and density versus distance
  - Issue 2: Target building/vehicle (Exposed Site, ES) response to blast loading
  - Issue 3: Target building (ES) protection against debris afforded to occupants
- SciPan Test Program intended to address Issues 1 and 2

SciPan Program Guide

Test	Date	NEW (lbs) *(kg)*	Loading Density (lbs/ft^3) *(kg/m^3)*	PES Volume (ft^3) *(m^3)*	PES	ES Description: ES 1	ES Description: ES 2
SciPan 1*	2/19/2003	27,005 *(12,249)*	0.733 *(11.74)*	36,864 *(1,043.9)*	Type 1	5.5" Tilt-up RC Wall/Wood Roof *(139.7 mm Tilt-up RC Wall/Wood Roof)*	7.5" Tilt-up RC Wall/Wood Roof *(190.5 mm Tilt-up RC Wall/Wood Roof)*
SciPan 2*	7/9/2003	5,005 *(2,270)*	NA	NA	N/A	5.5" Tilt-up RC Wall/Wood Roof *(139.7 mm Tilt-up RC Wall/Wood Roof)*	7.5" Tilt-up RC Wall/Wood Roof *(190.5 mm Tilt-up RC Wall/Wood Roof)*
SciPan 3**	4/6/2005	60,005 *(27,218)*	6.667 *(106.79)*	9,000 *(254.9)*	Type 2	8" Unreinforced CMU/Wood Roof *(203 mm Unreinforced CMU/Wood Roof)*	8" Dbl Wythe Brick Wall/Wood Roof *(203 mm Dbl Wythe Brick Wall/Wood Roof)*
SciPan 4	8/27/2008	2,205 *(1,000)*	0.244 *(3.92)*	9,000 *(254.9)*	Type 2	NONE	NONE
SciPan 5		6,595 *(2,991)*	0.733 *(11.74)*	9,000 *(254.9)*	Type 2	Wood Residential	Steel Frame with Infill Panels
SciPan 6		11,250 *(5,103)*	1.25 *(20.02)*	9,000 *(254.9)*	Type 2	Metal Trailer	Hardened Metal Trailer

Completed but not reported

Completed and reported

PES Type 1: 48' x 48' x 16' *(14.6 m x 14.6 m x 4.9 m)*

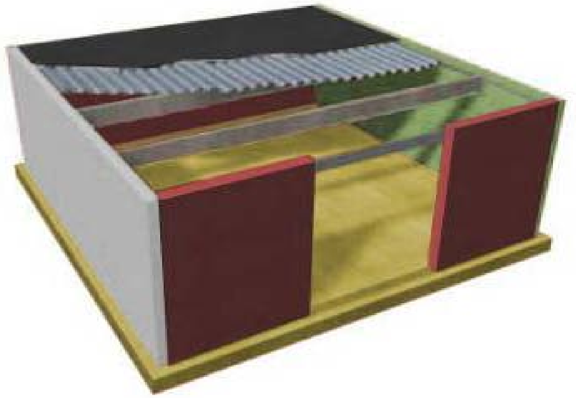
PES Type 2: 30' x 30' x 10' *(9.1 m x 9.1 m x 3.0 m)*

*NAVFAC TM-2371-SHR

**NAVFAC TM-2388-SHR

SciPan 4 General Information

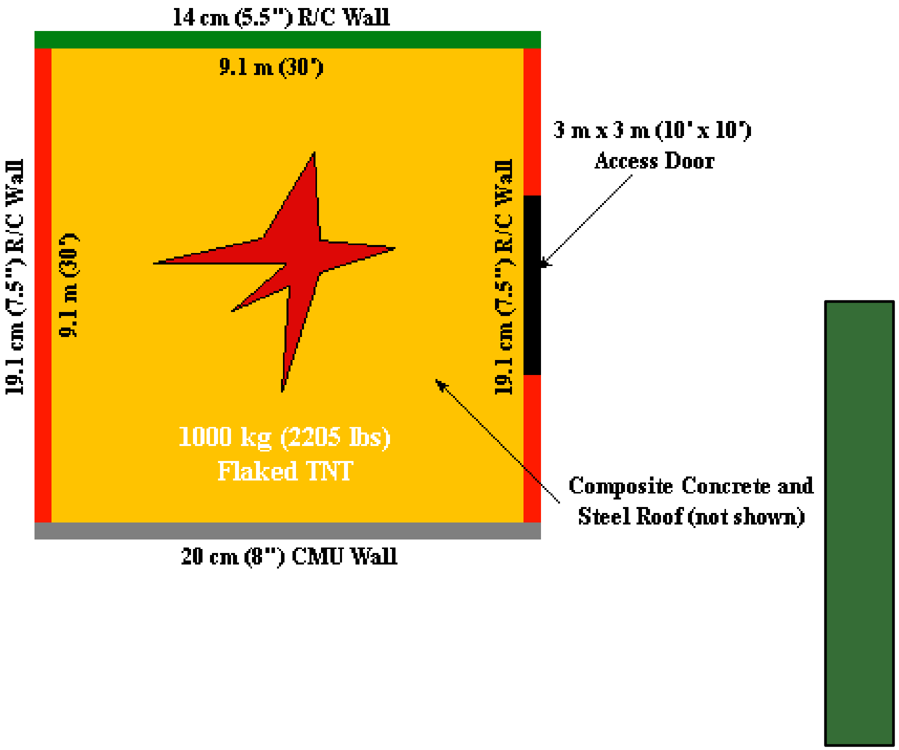
- Potential Explosion Site (PES) was designed as a typical reinforced concrete (R/C) and reinforced masonry operating building
- NEW = 1,000 kg (2,205 lbs) of flaked TNT in the center of the structure
- Loading density = 3.92 kg/m^3 (0.244 lbs/ft^3)
- Composite roof (concrete on steel deck) and three different wall types:
  - 19 cm (7.5") R/C
  - 14 cm (5.5") R/C
  - 20 cm (8") reinforced Concrete Masonry Unit (CMU)
  - R/C roof over corrugated metal panel



- ES structures
  - None
- Planned Debris Collection
  - 360º recovery outside 100 m from Ground Zero
- Test conducted at NAWC-WPNS, China Lake
  - Test detonated on 27 August 2008
  - Debris cataloging began immediately after shot and ended 6 September
  - A follow-on recovery effort (DIRT 4.1) took place 15 – 20 December 2008
  - Another follow-on recover effort (DIRT 4.2) took place 14 – 19 September 2009

Pre-Test PES Views

Barricade


14 cm (5.5") R/C Wall
9.1 m (30')
3 m x 3 m (10' x 10')
Access Door
19.1 cm (7.5") R/C Wall
9.1 m (30')
19.1 cm (7.5") R/C Wall
1000 kg (2205 lbs)
Flaked TNT
Composite Concrete and
Steel Roof (not shown)
20 cm (8") CMU Wall


SCIPAN 4 8014
PRE TEST
NAWCWD 27 AUG 08

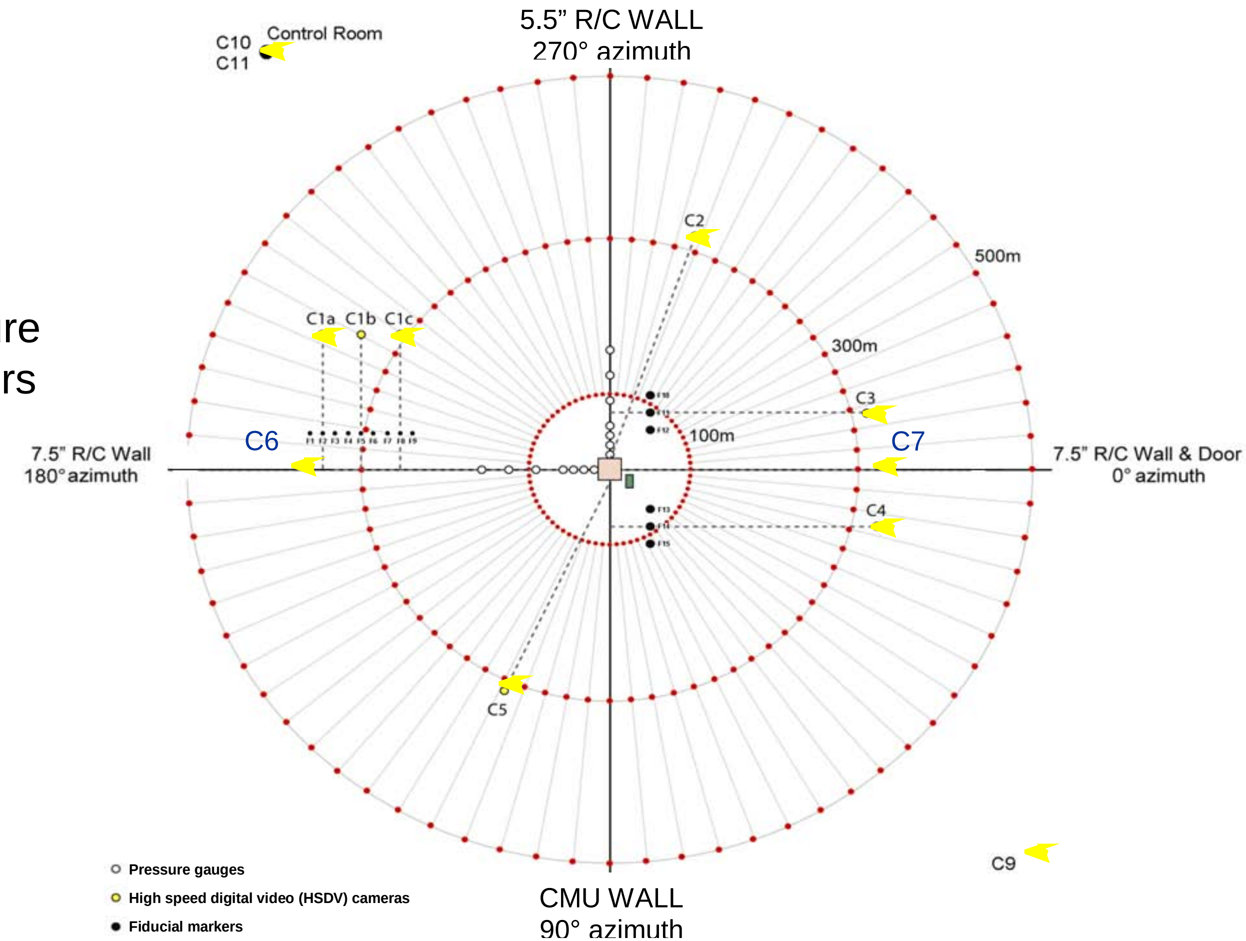

SCIPAN 4 8014
PRE TEST
NAWCWD 27 AUG 08

Donor Charge

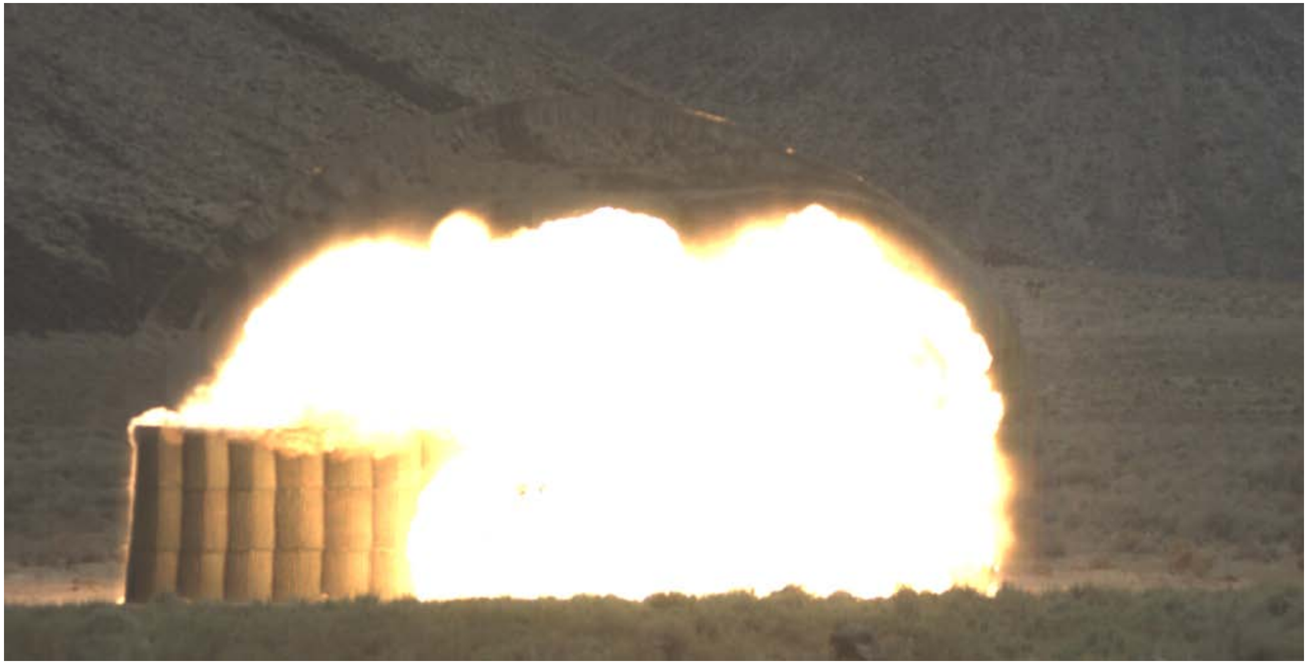
1,000 kg Flaked TNT

Instrumentation Schematic

- Multiple high-speed and normal speed cameras for video coverage
- Two radials of pressure gauges from 15 meters to 150 meters
- Debris recovery grid marked out in 5° sectors at 100, 300, and 500 meters



SciPan 4 Detonation

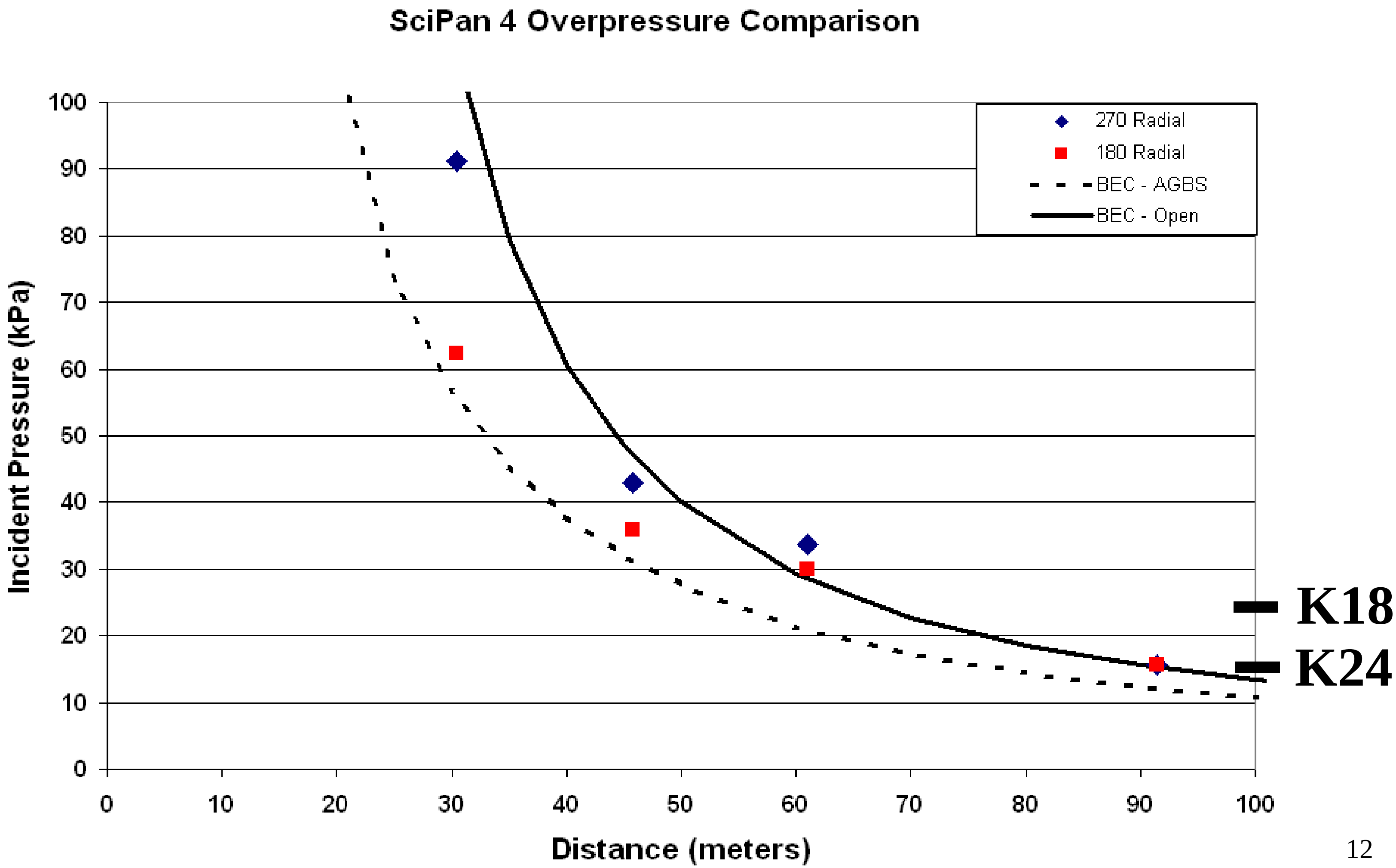


Crater

- Crater diameter varied between 2.5 and 3 meters
- Maximum depth of crater approximately 0.65 meters

Barricade

Pressure Data Comparison



Debris Collection Process

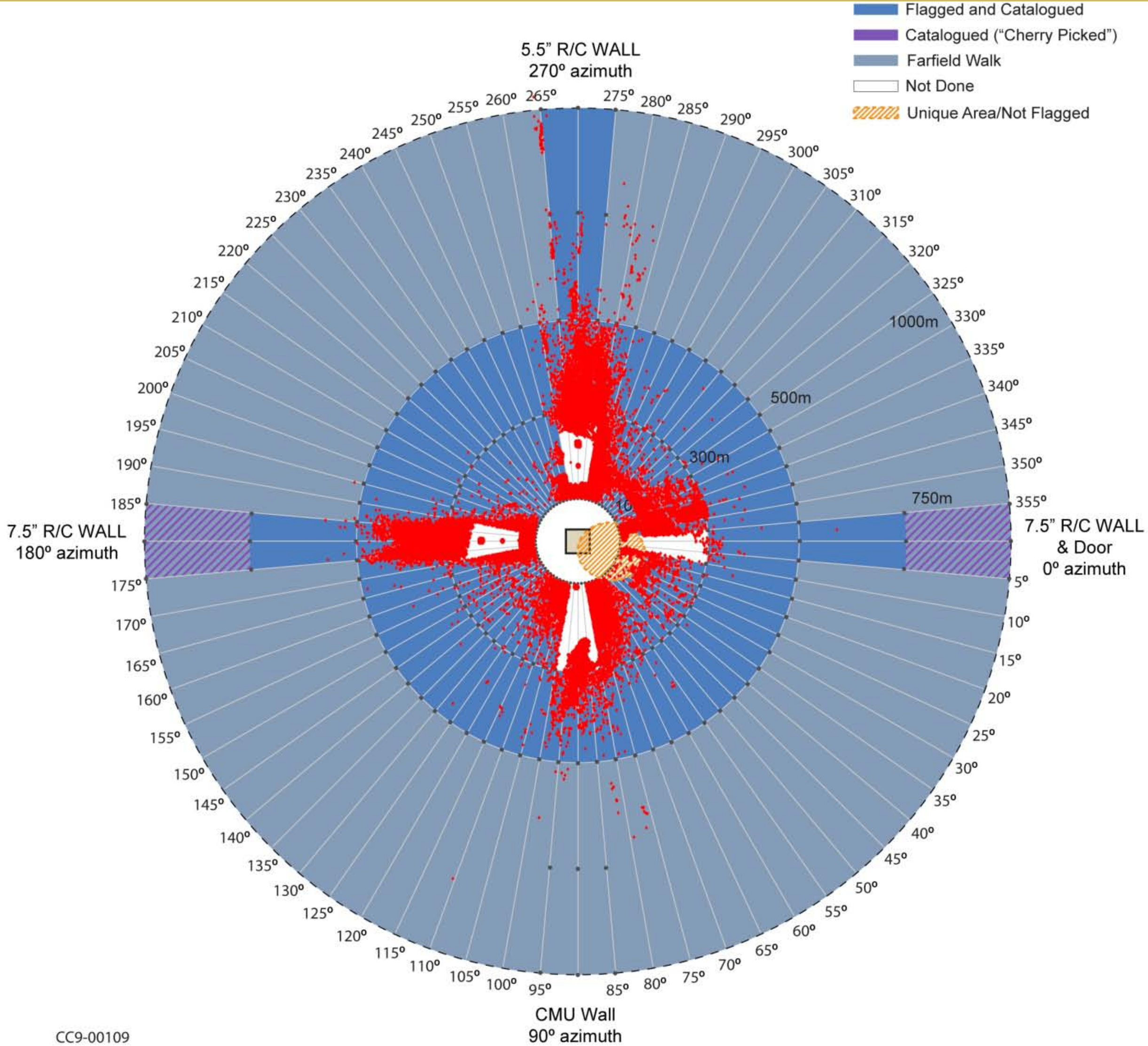
- Two step process
  - Location (flagging team)
    - Find each debris piece and place flag at its location
  - Cataloging (surveying team)
    - For each debris piece determine range, bearing, weight, and description using a differential GPS
- Flagging Teams
  - Two (or more) teams, each with at least 8 members
- Surveying Teams
  - Three teams, each with at least 3 members

Debris Collection – Observations

The areas within +/- 10 degrees of the normals out to ~400 meters were **very** heavily saturated with debris

The decision was made to concentrate cataloging effort outside 300 meters (complete 360°clean-up) and off-normals inside 300 meters (everything but the normals)

SciPan 4 Debris Scatter Plot



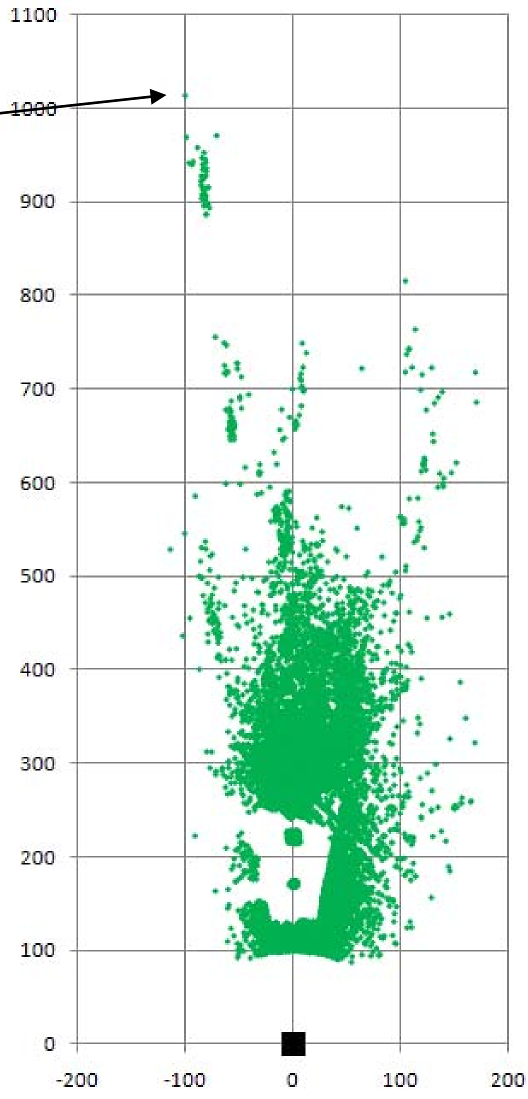
Maximum Debris Ranges

- The maximum fragment distance varied greatly depending on the wall type. The farthest recovered fragments in each direction were as follows:
  - 0° direction, 7.5” R/C Wall and Door – 376.8 meters @ 345.2°
  - 90° direction, CMU Wall – 821.1 meters @ 110.1°
  - 180° direction, 7.5” R/C Wall – 571.6 meters @ 184.7°
  - 270° direction, 5.5” R/C Wall – 1,018.3 meters @ 264.4°

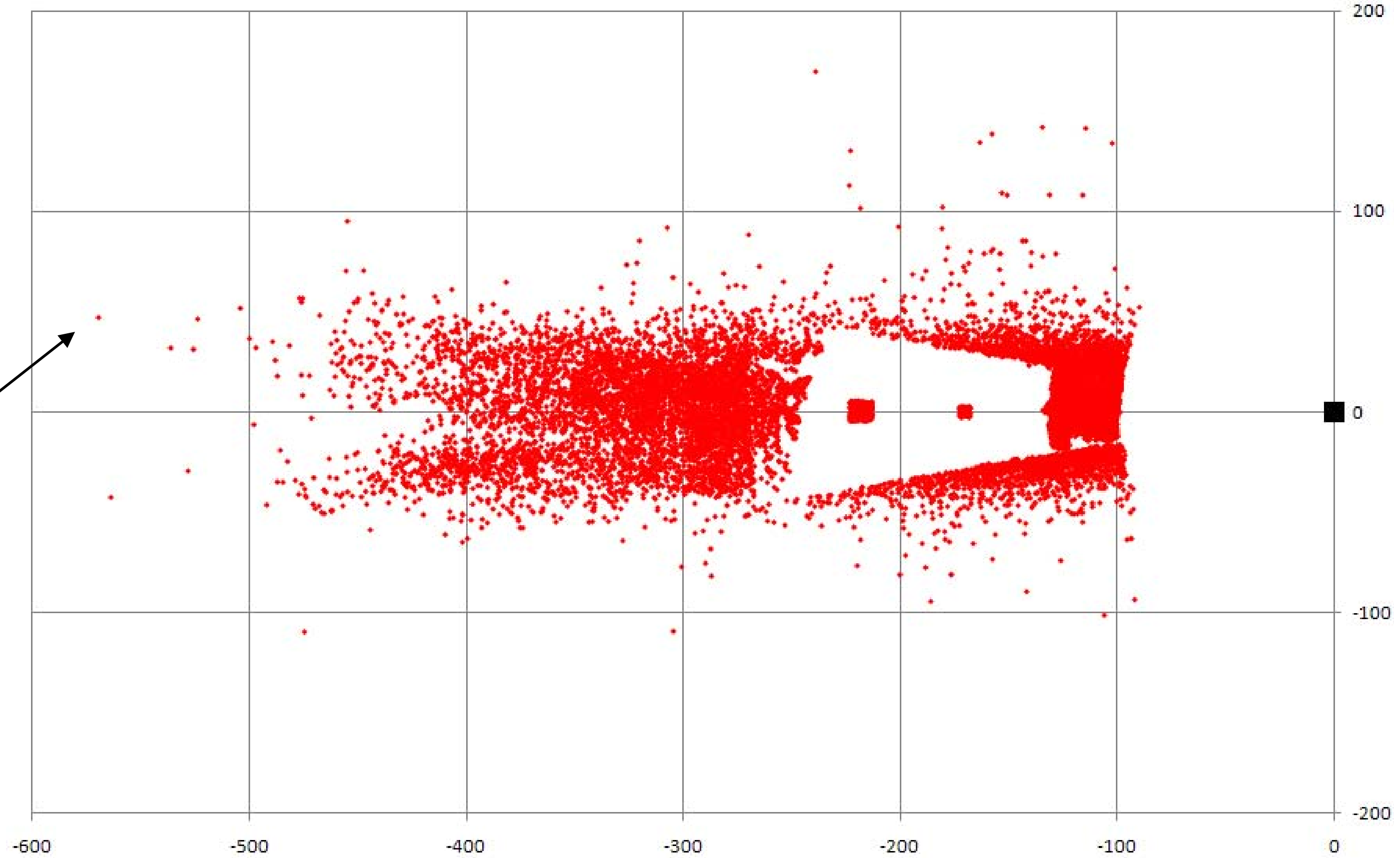
Debris Pattern: 5.5" Concrete Wall

Farthest piece found at 1,018 meters

- The directionality of the wall debris pattern is quite apparent
- The high density area of +/- 10° out to 300 meters was not collected in the initial effort
- During DIRT 4.2, the area from 100 to 120 meters, +/- 10° of the normal was collected, as well as two square sections centered on the normals
- This was done on both the 5.5" R/C wall and the 7.5" R/C wall
- Having this information allows for interpolation of the areas not collected



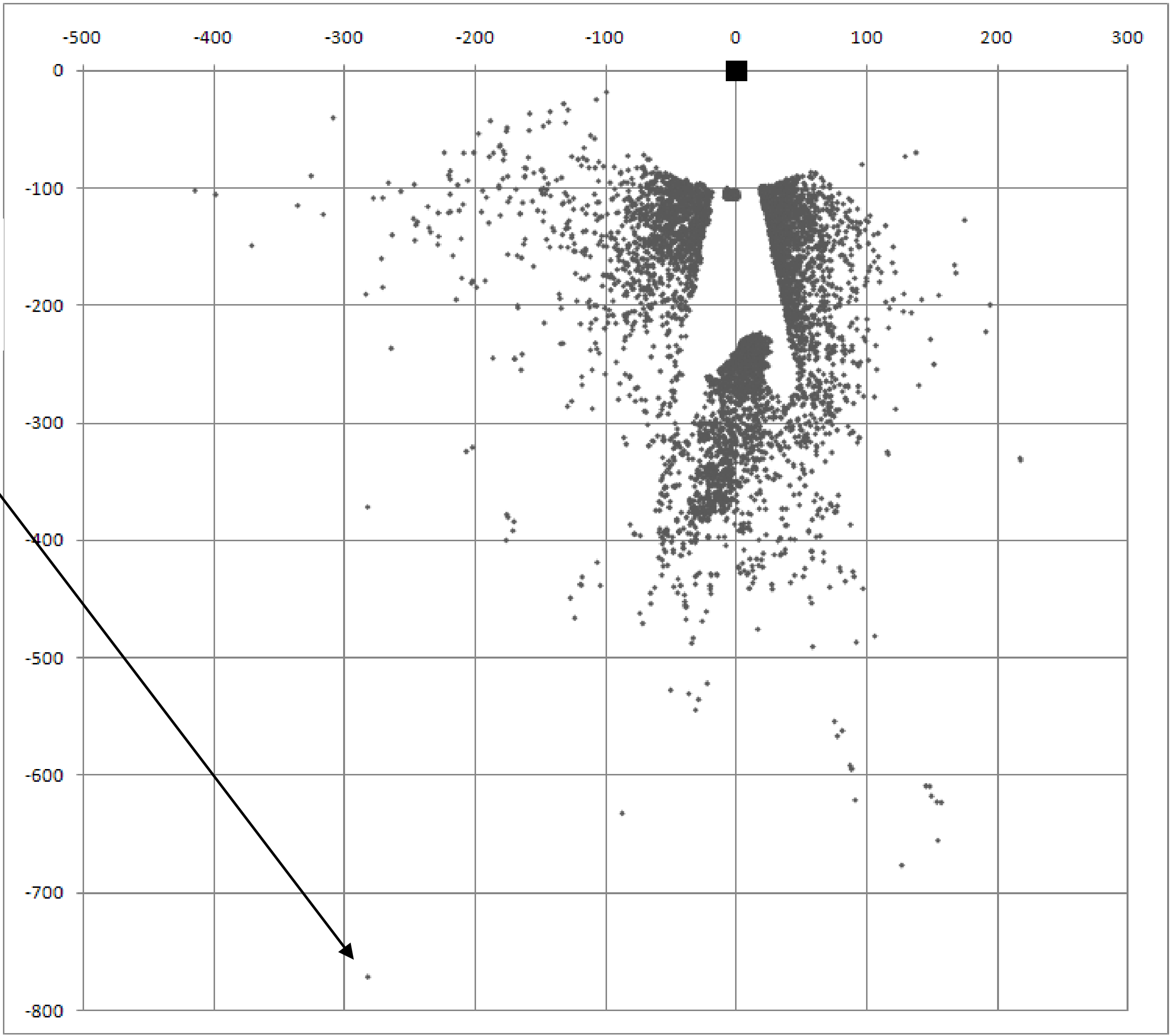
Debris Pattern: 7.5” Concrete Wall

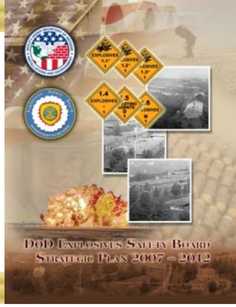


Farthest piece found at 572 meters

Debris Pattern: CMU Wall

Farthest piece found at 821 meters

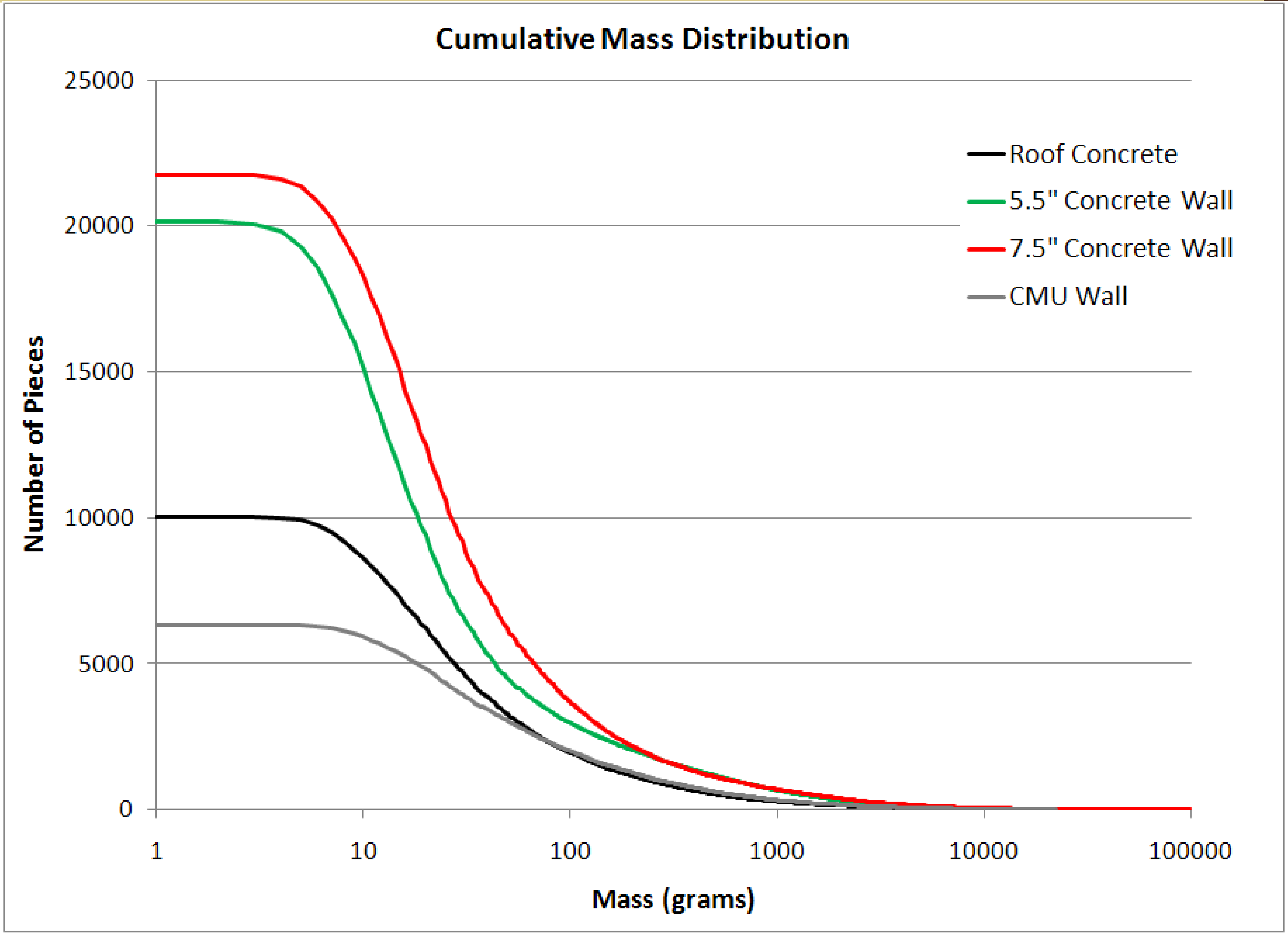




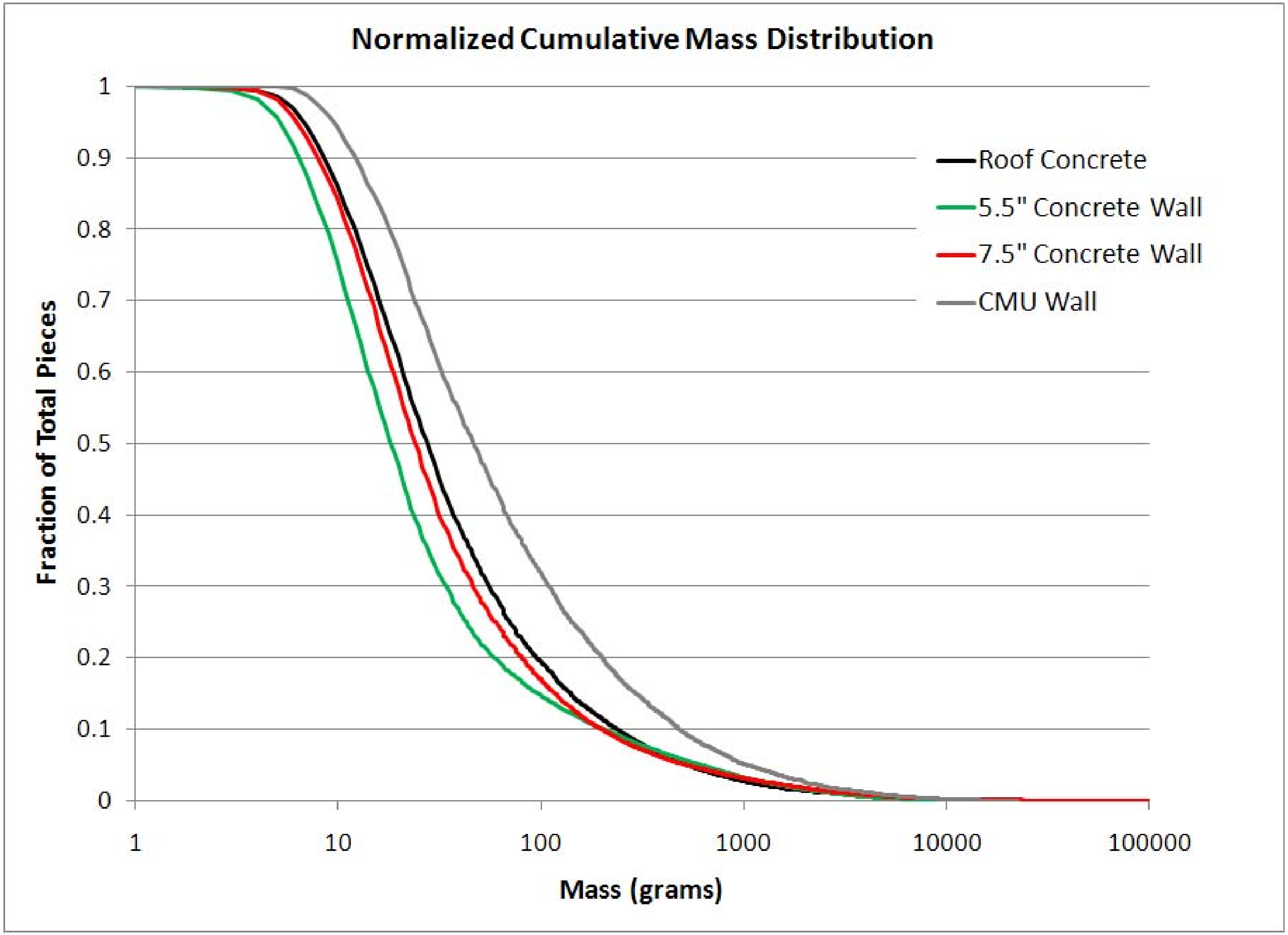
Debris Counts

Mass Bin	Number of Pieces				
	7.5" Wall	5.5" Wall	CMU Wall	Roof	All Debris
1	13	0	0	0	25
2	39	15	16	12	93
3	115	80	53	50	342
4	274	276	123	94	808
5	392	461	235	196	1,318
6	731	734	485	452	2,445
7	1,314	929	696	723	3,700
8	2,784	1,677	1,234	1,470	7,197
9	4,940	3,568	1,484	2,368	12,399
10	7,713	7,475	1,618	3,276	20,138
G	3,453	4,961	360	1,415	10,203
Total	21,768	20,176	6,304	10,056	58,668
1 to 10 Total	18,315	15,215	5,944	8,641	48,465

Mass Distribution of Concrete Debris



Normalized Mass Distribution

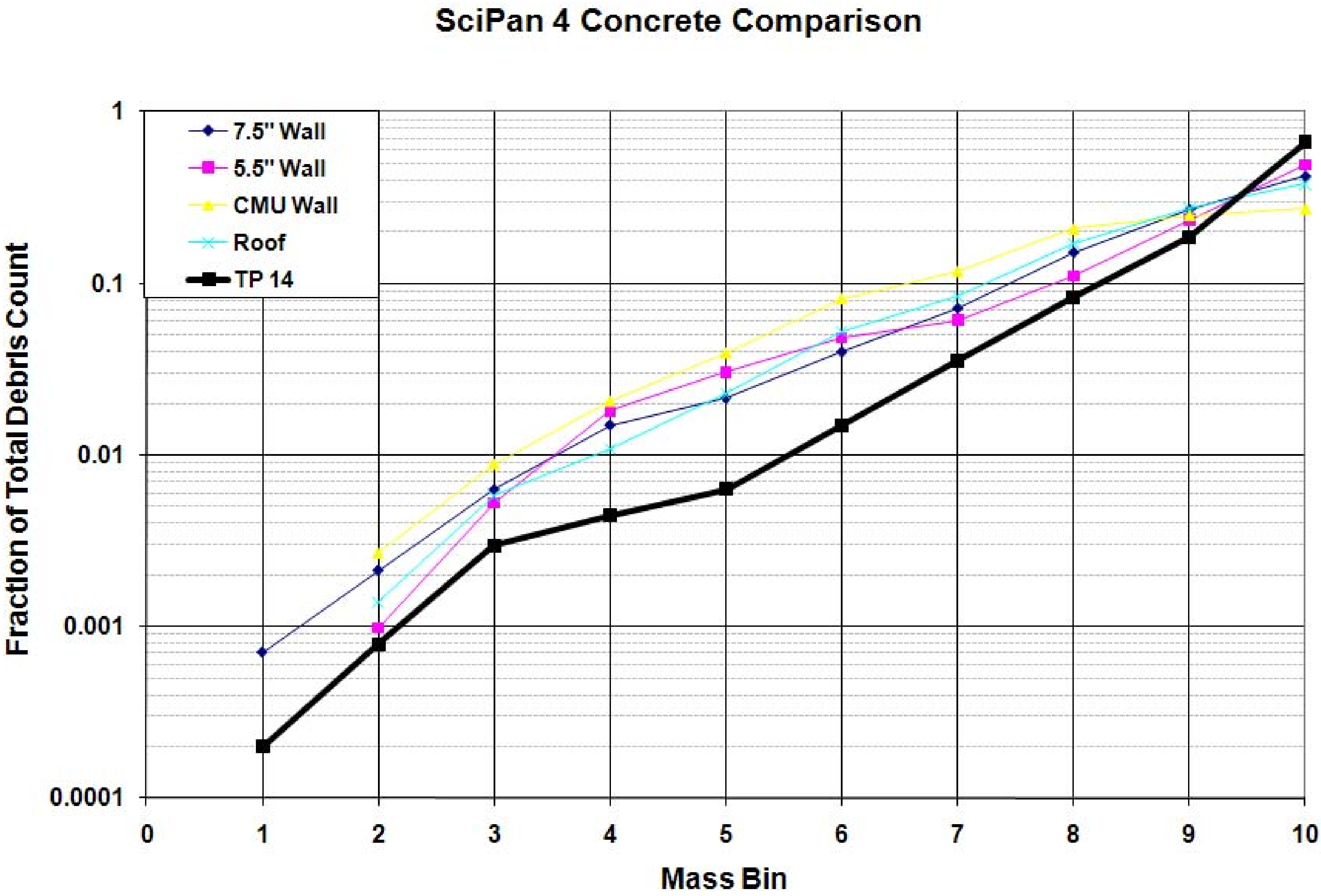


Mass Bin Comparison

- The Quantitative Risk Assessment (QRA) method of Technical Paper No. 14 (TP 14) and the associated QRA software SAFER use Mass Bin distributions of the PES components in consequence calculations.
- The debris counts for each component can be expressed in two different fractional Mass Bin formats:
  - Fraction of the Total Mass
  - Fraction of the Total Debris Count
- These distribution calculations were performed for the following components:
  - 7.5” R/C wall
  - 5.5” R/C wall
  - CMU wall
  - R/C roof.
- Comparisons to those values used in TP 14 are presented.

Mass Bins: Fraction of Total Mass

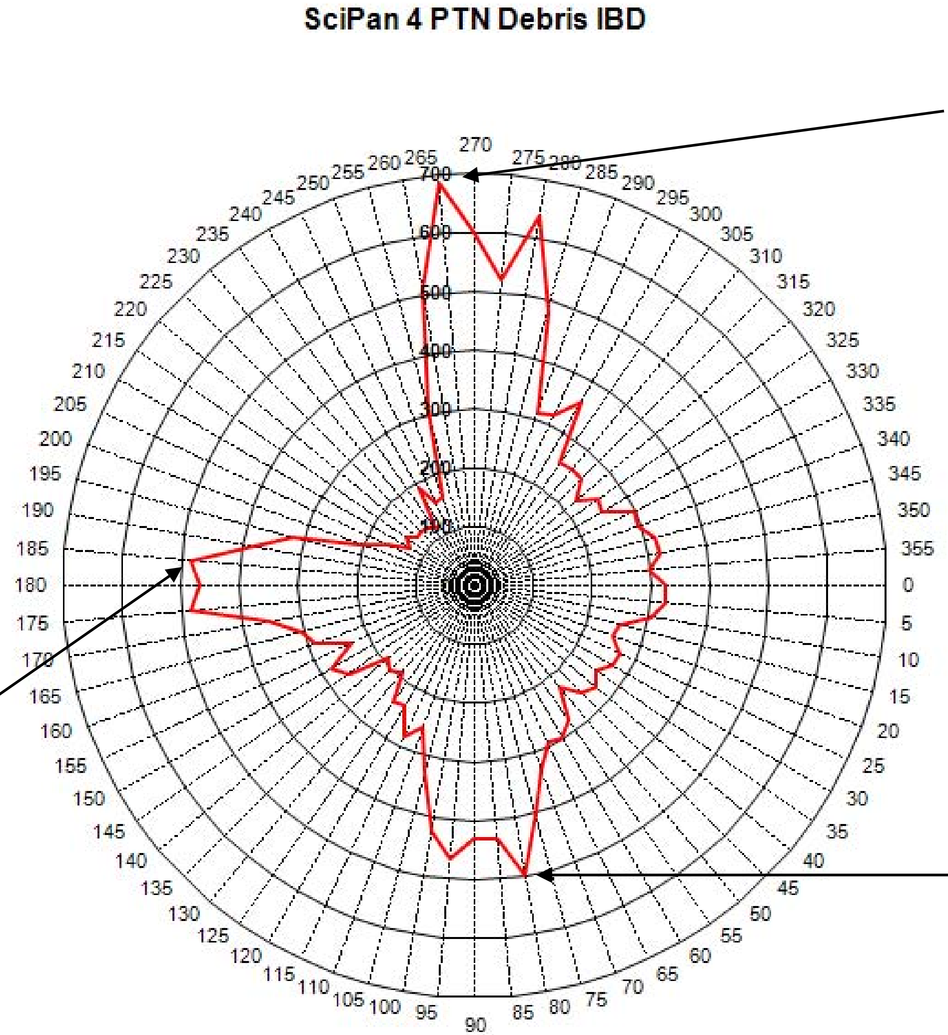
Mass Bins: Fraction of Total Debris Count



Azimuthal Debris Density Variation

- Debris Inhabited Building Distance (IBD) is defined as the range at which the density of hazardous fragments falls below a value of 1 per 55.7 m^2 (1/600 ft^2). A hazardous fragment is defined as a fragment with an impact kinetic energy of at least 79 Joules (58 ft-lbs).
- The Pseudo-Trajectory Normal (PTN) debris IBD was calculated for each 5-degree sector.
- The maximum PTN debris IBD in each direction is as follows:
  - 0° direction, 7.5" R/C Wall and Door – 325 meters @ 5°
  - 90° direction, CMU Wall – 500 meters @ 80°
  - 180° direction, 7.5" R/C Wall – 486 meters @ 185°
  - 270° direction, 5.5" R/C Wall – 686 meters @ 265°

SciPan 4 PTN Debris IBD



5.5” R/C Wall
Debris IBD:
686 meters
(2,251 feet)

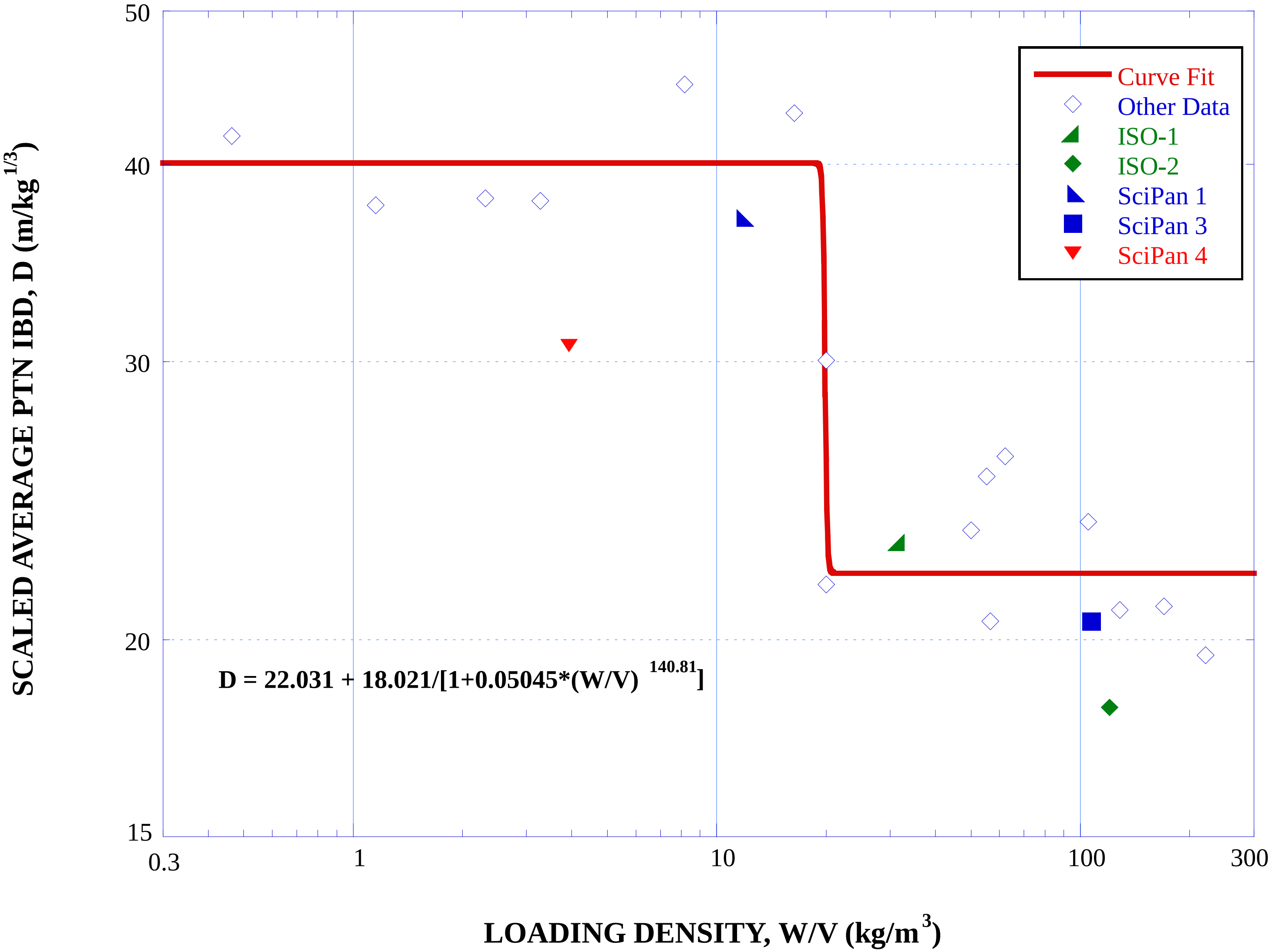
7.5” R/C Wall
Debris IBD:
486 meters
(1,594 feet)

CMU Wall
Debris IBD:
500 meters
(1,640 feet)

Scaled PTN Debris IBD Relationship

- When the SciPan 4 debris data are averaged over the full 360° of azimuth, a PTN debris IBD of 307 meters is obtained.
- It has been shown that the cube root of the PTN debris IBD has a high correlation with the loading density of the structure.
- Previous test data under Project ESKIMORE has reinforced this correlation
- The results of SciPan 4 are <u>not</u> consistent with this proposed relationship.
- Hazardous fragment definition used here differs from those assumptions used to generate the plot
- This discrepancy warrants examining past test data with low loading densities to explain the difference

Scaled PTN Debris IBD Function



SciPan 4 Summary

- Nearly 60,000 data points were collected during the initial SciPan 4 debris collection and follow-on recovery efforts.
- Analysis of the mass distribution has been performed and comparisons made with the values of the prediction algorithms of TP 14.
- The results of SciPan 4 are not consistent with the proposed relationship between scaled PTN debris IBD and loading density, and will be investigated further
- Further data analysis is ongoing. For each debris type and category, these analyses will determine:
  - Horizontal launch angle distribution
  - Vertical launch angle distribution
  - Mass distribution
  - Initial velocity distribution
- Additionally, mass distribution will be quantified as a function of range and azimuth for each component type
- Results will be incorporated into TP 14, as well as enhance the state-of-the-art of debris prediction models