PROJECT ESKIMORE – AN UPDATE WITH EMPHASIS ON A PROPOSED EARTH-COVERED MAGAZINE TESTING PROGRAM

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ABSTRACT

Project ESKIMORE, the Department of Defense Explosives Safety Board (DDESB) long-term testing initiative, was started in 2002 and its organization has been described at several previous DDESB Seminars. This paper will provide an update on the overall structure and status of the project, including its various components. One of the elements of the project is the updating of U.S. explosives safety quantity-distance (QD) criteria, to include earth-covered magazine (ECM) criteria. Currently, the U.S. Department of Defense (DoD) has over 25,000 ECM storage sites with many different designs. These explosives storage facilities are used for the majority of U.S. DoD explosives storage, and hundreds of new ECMs are being built every year. This paper describes the scope of a proposed new component of Project ESKIMORE – the ECM Test Program. Elements of the ECM Test Program addressed here include program goals, proposed approach, schedule, debris collection, funding, and participation by other organizations and nations.

1.0 BACKGROUND

In 2002, the DDESB initiated a testing program to support improvement of consequence algorithms for the DDESB's risk-based explosives siting tool[1] (SAFER), and refinement of U.S. explosives safety QD standards[2]. This testing program initially focused on performance of full-scale tests to characterize debris generation from donor structures and blast response of exposed structures, as well as testing to characterize the debris penetration/perforation characteristics of wall and roof elements of exposed structures.

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14. ABSTRACT
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Over the next several years, this testing program was expanded to address other gaps in explosives safety knowledge, to include addressing analytical and modeling shortfalls. In 2006, the program was formalized as a long-term DDESB project, titled Project ESKIMORE (Explosives Safety Knowledge Improvement Operation Redux).

Project ESKIMORE was initially conceived by Mr. Michael Swisdak, Mr. James Tancreto, and Mr. John Tatom[3]. The project is currently managed by Mr. Robert Conway of Naval Facilities Engineering Service Center, with technical support from the DDESB Science Panel.

2.0 PROJECT ESKIMORE OVERVIEW

2.1 Explosive Safety Knowledge Shortfalls

U.S. explosives safety QD standards prescribe the use of a fixed debris inhabited building distance (IBD) of 1,250 ft [381 m] for net explosive weights (NEWs) of 450 lbs [204.1 kg] or more stored in most types of donor structures. This debris IBD is defined as the distance at which the areal number density of hazardous debris becomes one per 600 ft^2 [55.7 m^2], with hazardous debris defined as debris having an impact energy of 58 ft-lbs [79 J] or greater. The adequacy of this debris IBD has been questioned for many years[4], and recent work has indicated that it is not adequate for most donor structures[5]. Currently, the debris IBD is not a function of donor building type or design, nor does it account for loading density (NEW/volume). In addition to the loading density, the internal blast loads are also determined by the donor building geometry, wall and roof mechanical properties, and the available venting surfaces. Also, cruciform-type debris patterns have been seen in several tests of rectangular structures; this debris pattern (with the debris concentrated along lines perpendicular to the walls) is not accounted for in the current methodology for determining debris IBD, or in the debris model in SAFER.

In general, U.S. explosives safety QD standards do not account for exposed site (ES) structure design, especially for determining allowable separation distances for protection of personnel. ES structure design can have a significant effect on personnel protection in terms of building response to the blast loading (collapse of building components and glass breakage), and the protection provided by walls and roof against debris perforation.

Although the DDESB's risk-based siting tool does account for some of the factors addressed above when determining debris hazards, refinement and validation of the consequence algorithms in SAFER is highly desirable, as well as development of physics-based analytical models to more accurately determine the debris hazard as a result of all of the above factors.

2.2 Project ESKIMORE Goals

Project ESKIMORE has been designed to address the gaps in explosives safety knowledge addressed above. The goals of this project are:

- To address the following areas of concern:
    - ISSUE 1: Donor structure debris characterization
    - ISSUE 2: Target structure response to blast loading
    - ISSUE 3: Target structure protection against debris
- To capitalize on testing and analytical efforts to develop and improve explosives safety models and standards

The project consists of several test programs (both DDESB-sponsored and DDESB participation in tests sponsored by other U.S. agencies or other nations) and development and validation of analytical models. The U.S.-sponsored testing consists of three main test programs: SciPan, SPIDER and ISO. A fourth test program, full-scale ECM testing, is currently being developed and funding being sought. Project ESKIMORE also includes ES modeling and debris physics investigation and modeling. The following sections describe the test programs and analytical efforts in more detail.

3.0 SCIPAN TEST PROGRAM

The SciPan test program is intended to address ISSUE 1 and ISSUE 2 described in Section 2.2. This program involves full-scale testing of a donor structure using non-fragmenting explosives, with various target structures. The donor structure is common to all of the tests, except that the dimensions vary; donor structure construction characteristics are provided in Figure 1. Table 1 provides a summary of the key parameters for the completed and planned tests.

Figure 1. SciPan Donor Structure

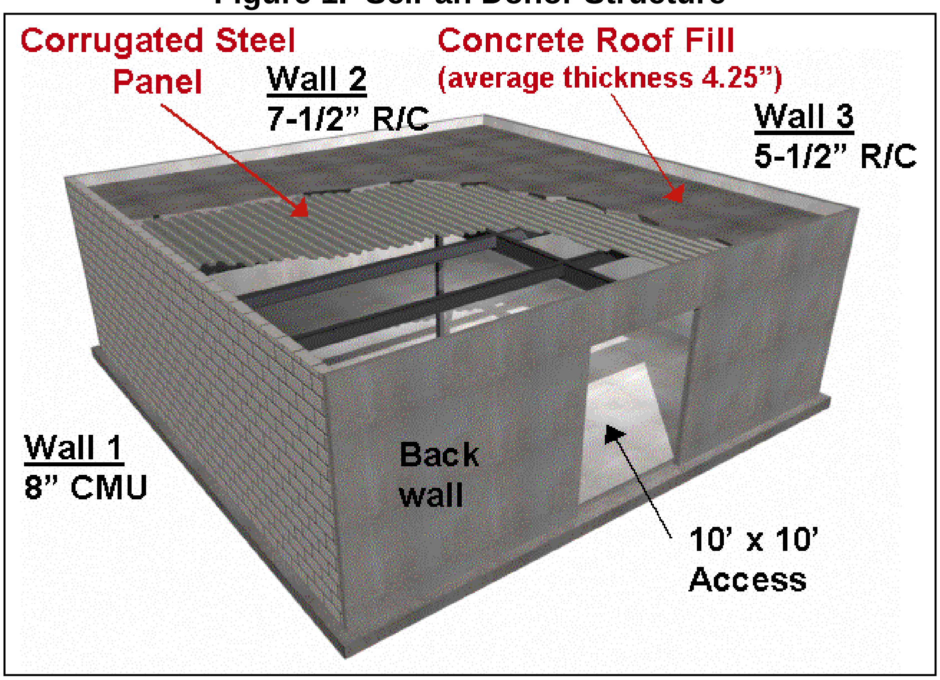


Table 1. SciPan Test Program Summary

Test	Date	Donor Structure[a]	Donor Volume (ft^3) [m^3]	NEW (lbs) [kg]	Loading Density (lbs/ft^3) [kg/m^3]	Target Structure	
						Target 1	Target 2
SciPan 1	19 Feb 03	Type 1	36,864 [1,043.9]	27,005 [12,249]	0.733 [11.74]	5.5” [139.7 mm] Tilt-up RC Wall/Wood Roof	7.5” [190.5 mm] Tilt-up RC Wall/Wood Roof
SciPan 2	9 Jul 03	N/A	N/A	5,005 [2,270]	N/A	5.5” [139.7 mm] Tilt-up RC Wall/Wood Roof	7.5” [190.5 mm] Tilt-up RC Wall/Wood Roof
SciPan 3	6 Apr 05	Type 2	9,000 [254.9]	60,005 [27,218]	6.667 [106.79]	8” [203 mm] Unreinforced CMU/Wood Roof	8” [203 mm] Double Wythe Brick Wall/Wood Roof
SciPan 4	27 Aug 08	Type 2	9,000 [254.9]	2,205 [1,000]	0.244 [3.92]	N/A	N/A
SciPan 5	Spring 11	Type 2	9,000 [254.9]	6,595 [2,991]	0.733 [11.74]	Wood Residential	Steel Frame with Infill Panels
SciPan 6	Spring 14	Type 2	9,000 [254.9]	11,250 [5,103]	1.25 [20.02]	Metal Trailer	Hardened Metal Trailer

a. Type 1: 48’ x 48’ x 16’ [14.6 m x 14.6 m x 4.9 m]
Type 2: 30’ x 30’ x 11’ [9.1 m x 9.1 m x 3.4 m]

3.1 SciPan 1 and SciPan 2

SciPan 1 and SciPan 2 were conducted in 2003 at China Lake, CA, and the final report is available[6]. SciPan 1 was intended to obtain information on donor structure debris and the blast loading response of the tilt-up reinforced concrete target structures. The target structures did not fail during SciPan 1, so a second test (designated SciPan 2) was conducted with an open donor charge to obtain further information on the target structures’ response to blast loading; this test was also used to characterize the TNT equivalency of the flaked TNT explosive used in SciPan 1.

3.2 SciPan 3

SciPan 3 was conducted in 2005 at China Lake, CA, and the final report is available[7]. SciPan 3 was intended to again obtain information on donor structure debris, this time from an extremely high loading density, and the blast loading response of the unreinforced CMU (concrete masonry unit) and brick target structures. This test also included placement of a HESCO-Bastion barricade in front of one-half of the door side of the donor structure.

3.3 SciPan 4

SciPan 4 was conducted in 2008 at China Lake, CA; the final report is not yet available, but results of this test are being reported on at this Seminar[8]. SciPan 4 was intended to obtain information on donor structure debris generated by a low loading density; there were no target structures for this test, but the test did include placement of a HESCO-Bastion barricade in front of one-half of the door side of the donor structure.

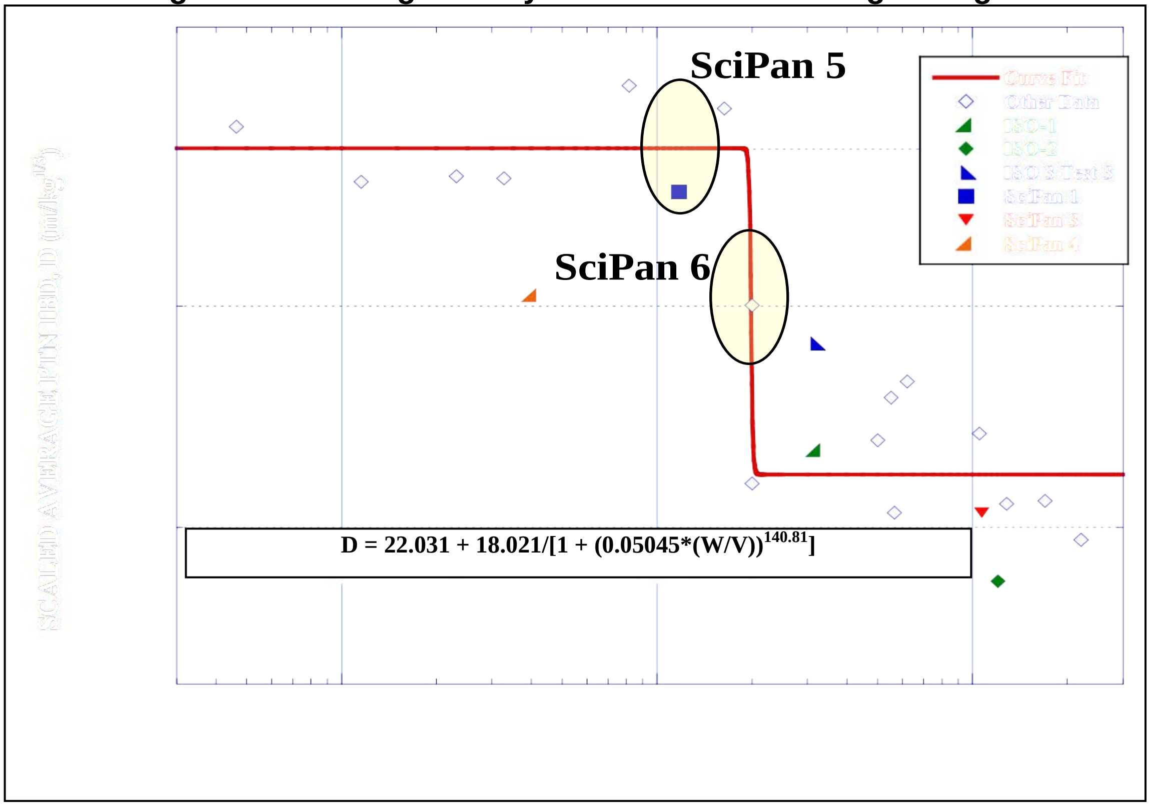
3.4 SciPan 5

SciPan 5 is currently planned for the spring of 2011. SciPan 5 will use the same donor structure as SciPan 3 and SciPan 4, but will have a loading density value in between the two. The loading density for SciPan 5 will be the same as the loading density for SciPan 1, but the structure and NEW will be smaller. This will allow evaluation of the separate effects of structure volume and NEW on debris generation, provide data for improvement and/or validation of the dynamic mass distribution algorithm in SAFER, and provide an additional anchor point for other SAFER curves/equations that are a function of loading density. (The dynamic mass distribution algorithm is used to adjust the mass distribution as a function of the NEW.) Planned target structures are to be representative of a residential wood frame home and a steel frame commercial building with various non-load bearing infill walls.

3.5 SciPan 6

SciPan 6 will use the same donor structure as SciPan 3, 4 and 5, but will have a loading density between that of SciPan 5 and SciPan 3. This loading density has been chosen in order to provide a data point in the transition region of the curve shown in Figure 2[9]. Figure 2 has been developed to postulate the relationship between loading density and debris IBD. It is anticipated that once the SciPan test program is completed, the information in Figure 2 will be used to revise current fixed debris IBD criteria in U.S. explosives safety standards for NEWs of 450 lbs [204.1 kg] or greater. Planned target structures are a conventional trailer office building and a hardened trailer office building.

Figure 2. Loading Density Versus Scaled Average Range



4.0 SPIDER TEST PROGRAM

The SPIDER test program is intended to address ISSUE 3 described in Section 2.2. This program involves testing of various wall and roof cross-sections to determine the required kinetic energy for perforation by various impactors. The testing also characterizes the hazards inside target structures from spall due to debris impact, penetration, or perforation. Table 2 provides a summary of the key parameters for the completed and planned tests. The results of the SPIDER test program will be used to update the values used in SAFER for the kinetic energy absorbed by target structure wall and roof components. They may also eventually be used to update QD standards to account for the protection provided to the occupants of ES structures.

Table 2. SPIDER Test Program Summary

Test Variable		SPIDER			
General	**Specific**	**1**	**2**	**3**	**4**
Spherical Impactors	Steel Ball	X	X		
	Concrete Ball	X	X		
Cylindrical Impactors	Steel Rod			X	X
	Concrete Rod			X	X
Roof Targets	Plywood Panel	X		X	
	4" (101.6mm) Reinforced Concrete	X		X	
	22-guage Corrugated Metal Panel	X		X	
Wall Targets	5.5" (139.7mm) Reinforced Concrete		X		X
	22-gauge Corrugated Metal Panel		X		X
	8" (203.2mm) CMU-Reinforced & Grouted		X		X
	8" (203.2mm) CMU-Unreinforced and Ungrouted		X		X
Impact Angle	Perpendicular Impacts	X	X	X	X
	Non-Perpendicular Impacts				
Impact Location	Mid-Panel Impacts	X	X	X	X
	Quarter-point Panel Impacts				
	Panel Edge Impacts				
Impact Velocity	Terminal Velocity	X		X	
	Higher-than-Terminal Velocity		X		X

4.1 SPIDER 1

The SPIDER 1 test program was conducted in 2004 at the Energetics Materials Research and Testing Center, Socorro, NM, and the results have been reported[10, 11]. SPIDER 1 tested the hazard from high-angle debris striking typical roof sections at terminal velocity; the testing was performed with spherical impactors. The SPIDER 1 test results have already been partially incorporated into SAFER.

4.2 SPIDER 2

The SPIDER 2 test program was conducted in 2009 at Redstone Arsenal, AL; the final report is not yet available, but results of this test are being reported on at this Seminar[12]. SPIDER 2 was designed to determine the effect of debris impacting wall cross-sections at velocities consistent with low launch angles; the testing was performed with spherical impactors.

4.3 SPIDER 3 and SPIDER 4

The SPIDER 3 and SPIDER 4 test programs are designed to test the hazard from high-angle cylindrical impactors striking roof sections at terminal velocity and from low-angle cylindrical impactors striking wall sections at higher than terminal velocity, respectively. The schedule for SPIDER 3 and SPIDER 4 has not yet been determined, but it is not expected that SPIDER 3 will take place prior to 2012.

5.0 ISO TEST PROGRAM

The ISO container test program is intended to address ISSUE 1 described in Section 2.2. The use of ISO containers for explosives storage has become more prevalent, especially in field storage and forward operating base situations. This program involves full-scale testing of one or more ISO containers in various configurations, with both fragmenting and non-fragmenting explosives. Table 3 provides a summary of the key parameters for the completed and planned tests.

5.1 ISO-1

ISO-1 was conducted in 2006 at Woomera, South Australia, and the final report is available[13]. ISO-1 was intended to allow characterization of ISO container and truck debris from a 1,055-kg (2,325.9-lb) event, and the airblast attenuation produced by a detonation inside an ISO container located on a flatbed truck (via a separate open-air shot of the same charge configuration at the same charge height as on the truck).

5.2 ISO-2

ISO-2 was conducted in 2007 at Woomera, South Australia, and the final report is available[14]. ISO-2 was similar to ISO-1, except the donor charge was increased to 4,000 kg (8,818.5 lbs); this allowed direct comparison of the effect of loading density on debris generation.

5.3 ISO-3

ISO-3 and ISO-3Cal were conducted in 2009 at Woomera, South Australia; the final report is not yet available, but the initial results of this test have been reported[15, 16], and are being updated at this Seminar[17]. ISO-3 was similar to ISO-1, except the donor charge was fragmenting munitions, and the ISO container was located on the ground (no truck involved). ISO-3Cal was a calibration shot and involved an open-air shot of the fragmenting munitions in the same charge configuration and height as in the ISO container. This test was intended to characterize the effects of fragmenting munitions on the ISO container debris generation (via comparison to ISO-1), and the effects of the ISO container on primary fragment generation (via comparison between ISO-3 and ISO-3Cal).

Table 3. ISO Test Program Summary

Test	Date	NEW (lbs) [kg]	Loading Density (lbs/ft^3) [kg/m^3]	AE Type	Comments
ISO-1	18 May 06	2,325.9 [1,055]	2.12 [33.9]	ANFO	Non-fragmenting AE ISO container on a truck Partial debris recovery (185°)
ISO-2	21 Mar 07	8,818.5 [4,000]	7.52 [120.5]	ANFO	Non-fragmenting AE ISO container on a truck Full debris recovery (360°)
ISO-3	10 Mar 09	2,323.7 [1,054]	2.12 [33.9]	M1 105mm projectiles	Fragmenting AE ISO container on ground Full debris recovery (360°)
ISO-3Cal	24 Mar 09	2,323.7 [1,054]	N/A	M1 105mm projectiles	Fragmenting AE Open air (no ISO container) Full debris recovery (360°)
ISO-4	Fall 2010	2,204.6 [1,000]	1.88 [30.1]	C-4	Non-fragmenting AE ISO container on ground Full debris recovery (360°)
ISO-5	Fall 2011	220.5 to 440.9 [100 to 200]	0.188 to 0.376 [3.01 to 6.02]	ANFO or C-4	Non-fragmenting AE ISO container on ground Full debris recovery (360°)
ISO-6	Spring 2012	2,323.7 per ISO [1,054]	2.12 [33.9]	M1 105mm projectiles	Fragmenting AE Multiple ISO containers Full debris recovery (360°)
ISO-7	Spring 2013	2,323.7 per ISO [1,054]	2.12 [33.9]	M1 105mm projectiles	Fragmenting AE Multiple ISO containers with barricades Full debris recovery (360°)

5.4 ISO-4

ISO-4 is currently planned for the fall of 2010. ISO-4 will be similar to ISO-3, except the donor charge will be non-fragmenting explosives. This test is intended to characterize the separate components (skin and bracing) of the ISO container debris generation, and to distinguish between ISO roof debris and ISO wall debris; this information was not characterized in previous tests, but U.S. support of development of an ISO container source function[18] for the Klotz Group Engineering Tool[19] software has highlighted the need to treat these debris sources separately in prediction models. Also, this test will involve the use of velocity screens and enhanced high-speed camera coverage in an attempt to allow better characterization of initial debris velocities and launch angles.

5.5 ISO-5, ISO-6 and ISO-7

Planning for future ISO testing is tentative at this time. Per Table 3, some initial test parameters have been identified, but they are subject to change as this program matures. Current planning centers on the need to characterize debris generation for small NEWs in ISO containers, and the effects of multiple ISO containers and barricades on debris generation. This information would be used to update SAFER and the ISO container source function for the Klotz Group Engineering Tool, as well as U.S. explosives safety standards for contingency operations.

6.0 ECM TEST PROGRAM

There are more than 25,000 existing ECMs on U.S. DoD installations world-wide, and approximately 100 new ECMs are constructed each year. As discussed in Section 2.1, U.S. explosives safety QD standards prescribe the use of a fixed debris IBD of 1,250 ft [381 m] for NEWs of 450 lbs [204.1 kg] or more in ECMs. This debris IBD governs up to an NEW of 45,000 lbs [20,411.6 kg], after which the IBD is based on airblast (with an azimuthal variation for the airblast IBD). There have only been two ECM tests that are useful resources for debris data: ESKIMO 1[20] and the UK/Australian SPANTECH Trial[21]. The limited data sets from both of these tests indicate that the debris IBD from an ECM may extend well beyond 1,250 ft [381 m] for larger NEWs, possibly to a scaled distance of 65 ft/lb$^{1/3}$ [25.8 m/kg$^{1/3}$][4].

For an NEW of less than 450 lbs [204.1 kg], U.S. explosives safety QD standards prescribe the use of reduced IBDs (less than 1,250 ft [381 m]), based on debris hazards determined mainly from the Hastings[22] and Navajo[23] tests. The Hastings testing was conducted on “standard” concrete arch ECMs with front barricades (earth-backed vertical concrete walls). Applicability of these reduced IBDs to all ECM designs/configurations (steel arch, box-type, undefined, unbarricaded) is questionable.

Recently, questions have arisen concerning the flat-roof ECM design blast load in U.S. explosives safety QD standards. U.S. explosives safety QD standards require the same minimum scaled separation distance (2 ft/lb$^{1/3}$ [0.079 m/kg$^{1/3}$]) from an ECM front as a potential explosion site (PES) to an ECM rear as an ES, regardless of the acceptor ECM’s blast resistance designation (7-bar, 3-bar or undefined). This results in the application of the same design blast load (a triangular pulse with a peak pressure of 108 psi [7.5 bars, 745 kPa] and an impulse of 19W$^{1/3}$ psi-ms [170Q$^{1/3}$ Pa-s]) to all flat-roof (box-type) ECMs.

6.1 Goals

The ECM test program is intended to address ISSUE 1 and ISSUE 2 described in Section 2.2. This program involves full-scale testing of ECMs. Specific goals of the ECM test program are:

- Debris characterization (to include any azimuthal variation) of arch and box-type ECMs, at both small and large NEWs

- Validation or determination of design blast loading for flat-roof ECMs (consistent with current U.S. explosives safety QD standards for ECM intermagazine separation distances)

It is anticipated that the data developed from the ECM test program would be used to update U.S. explosives safety QD standards. It should be noted that if these data indicate the need for significantly increased debris IBDs, it is likely that reevaluation of the bases for the debris IBD criteria – both the hazardous debris areal number density value and the minimum impact energy value for hazardous debris – will probably be pursued prior to adoption of any increased debris IBDs.

6.2 Proposed Approach

Planning for the ECM test program is in the early stages, but the initial approach for the large NEW testing is currently envisioned to involve testing of two ECMs, with one of the ECMs acting as an exposed structure to an ECM donor for the first test, and then this exposed ECM becoming the donor for the second test. The choice of ECM design(s) to use for the two tests is driven by the following factors:

- If new (more conservative) debris IBD criteria are to be applied to existing ECMs, then the design(s) chosen for testing should be as representative of the majority of existing ECMs as possible
- If new (more conservative) debris IBD criteria are only to be applied to new ECMs constructed after promulgation of the new criteria, then the design(s) chosen for testing should as representative as possible of the majority of designs chosen for new ECM construction

A compromise between these two possibly conflicting factors would be to choose two different designs to satisfy each of the two factors. Currently, the U.S. has no database that would provide information on the number of existing ECMs constructed per each known definitive design. However, determination of the designs most frequently chosen for new construction can easily be made by review of recent explosives safety site plans submitted to the DDESB for approval; anecdotally, these are the:

- COE 421-80-06 (modified with a 7-bar front door) in either the 11-ft or 14-ft interior height configuration; this is a reinforced concrete box-type ECM design that was approved by testing
- COE 33-15-74; this is a reinforced concrete arch ECM design
- NAVFAC Type C; this is a reinforced concrete box-type ECM design

An alternative to new construction of ECM test structures is to use the existing SPANTECH ECMs that already exist at Woomera, South Australia. Unofficial discussions have been held with the Australian and United Kingdom owners of these structures regarding their availability for destructive testing. One of the SPANTECH ECMs is quite a bit larger than ECM designs used in the U.S., and extensive modeling would be required to determine applicability of the test results for use in determining debris IBDs for U.S. ECM designs.

It is currently envisioned that a box-type design would be used as the exposed structure for the first test. It would be located with its rear facing the front of the donor ECM for the first test, and heavily instrumented with a large number of strain gauges embedded in the rebar and concrete in order to measure its response to the detonation loads of the first test. In both tests, extensive pressure and impulse measurements would be taken to validate the ECM design blast loads in U.S. explosives safety standards and assess the overpressures and impulses beyond the minimum intermagazine separation distances in these same standards. It has not yet been determined whether other target structures would be included in either test; the use of any additional target structures would have to be considered in light of the impact to debris recovery efforts. Table 4 provides a summary of the proposed large NEW ECM test program.

For the small NEW testing, it is anticipated that suitable abandoned ECMs (possibly at one or more DoD installations to be closed as part of the Base Realignment and Closure Act) could be identified where sufficient space is available to protect unrelated personnel from the test hazards. As with the Hastings testing, this testing would involve a series of tests across a range of NEWs (possibly 100 to 450 lbs [45.4 to 204.1 kg]). It would be desirable to perform the testing on a range of existing ECM designs that encompasses the most predominant minimum and maximum interior volumes.

Table 4. Proposed Large NEW ECM Test Program Summary

Test	Tentative Donor Design	NEW (lbs) [kg]	AE Type	Blast IBD (ft) [m]	Scaled Debris IBD of 65 ft/lb$^{1/3}$ [25.8 m/kg$^{1/3}$]	Comments
ECM-1	33-15-74	44,900 [20,366]	234 MK 82 bombs (39 pallets)	1,250 [381]	2,310 [704]	ECM-2 would be a target structure, with ECM-2 rear facing ECM-1 front
ECM-2	421-80-06	100,000 [45,400]	522 MK 82 bombs (87 pallets)	2,320 [708]	3,000 [914]	

6.3 Schedule

The large NEW ECM test program is projected to take approximately six years, as described in Table 5.

Table 5. Proposed Large NEW ECM Test Program Schedule

Year	Activities
Year 1	• Solicit participation by other organizations/nations • Develop test requirements • Prepare cost benefit analysis for existing versus new construction • Prepare cost benefit analysis for debris collection approaches • Select ECM type(s)/design(s) and site arrangement • Prepare construction drawings
Year 2	• Prepare detailed test and instrumentation plans • Select test site • Prepare detailed construction and test cost estimates
Year 3	• Lay-out test site • Construct ECM-1 and ECM-2 • Install instrumentation • Update test and instrumentation plans
Year 4	• Conduct test of ECM-1 • Collect debris • Analyze ECM-2 response, and identify costs to refurbish ECM-2 • Analyze data
Year 5	• Prepare final report for ECM-1 test • Refurbish ECM-2 • Update test and instrumentation plans • Conduct test of ECM-2 • Collect debris
Year 6	• Restore test site • Analyze data • Prepare final report for ECM-2 test • Prepare report for recommended changes to U.S. QD standards

6.4 Debris Collection

In the ISO tests and SciPan 4, debris collection was performed by marking the location of each piece of debris with a theodolite or differential GPS unit, and then identifying (by type) and weighing each piece of debris (type and mass information was entered into the GPS unit). For earlier SciPan tests, debris was collected in radial sectors, sorted by predetermined mass bins, and the number of pieces in each mass bin recorded. Ideally, the debris collection for the large NEW ECM tests would use the GPS method, and would include a 360° debris collection. However, the effort involved for such a debris collection may not be feasible or even necessary. Table 6 provides a very preliminary estimate of the debris and fragment numbers for each large NEW ECM test, with values provided for three different ranges of mass bins[24].

Table 6. Estimate of Debris and Fragment Numbers for Large NEW ECM Tests

Test	Mass Bins	ECM Debris			Primary Fragments	Total Number of Pieces
		Concrete	Steel	Total ECM		
ECM-1	1 to 10	9,614,436	1,201,620	10,816,056	934,362	11,750,418
	1 to 9	1,235,831	154,364	1,390,194	527,670	1,917,864
	1 to 8	450,336	56,270	506,606	240,552	747,158
ECM-2	1 to 10	9,614,436	1,201,620	10,816,056	2,084,346	12,900,402
	1 to 9	1,235,831	154,364	1,390,194	1,177,110	2,567,304
	1 to 8	450,336	56,270	506,606	536,616	1,043,222

Notes:

a. Based on a 100-m [328-ft] radius non-collection zone.
b. Primary fragment and ECM debris estimates derived from SAFER.
c. Does not include earth cover debris or crater ejecta.

For both the ISO and SciPan tests, debris was not collected inside a predetermined radius due to fragment/debris saturation. In order to reduce the scope of the debris collection effort, the size of this non-collection zone could be extended. Other alternatives are to limit the collection to only mass bins 1 through 8, to perform less than a 360° collection, to perform sector collection, or to perform a mix of GPS and sector collection. Table 7 provides a rough order estimate for a 360° GPS collection of mass bins 1 through 8. As can be seen from Table 7, such a debris collection could range from 3 to 8 months for both tests combined.

Table 7. Estimate of Debris Collection Manpower for Large NEW ECM Tests

Test	Number of Pieces	Crew Size	8-hr Work Day		9-hr Work Day	
			Number of Days	Number of 6-day Work Weeks	Number of Days	Number of 6-day Work Weeks
ECM-1	750,000	50	78	13.0	70	11.7
		75	52	8.7	47	7.8
		100	39	6.5	35	5.8
ECM-2	1,000,000	50	104	17.3	93	15.5
		75	70	11.7	62	10.3
		100	52	8.7	46	7.7

Note: Based on a collection efficiency of 25 pieces per man-hour.

6.5 Funding

Funding has not yet been secured for the ECM test program. Total program cost estimates range between $6M and $9M, depending upon several factors. Year 1 effort will probably commence in 2012, as overall Project ESKIMORE funding allows.

6.6 Participation by Other Organizations and Nations

It is recognized that the proposed ECM test program represents a large financial investment that would be difficult for most individual nations, including the U.S., to accomplish. Contributions, financial or otherwise, by other organizations and nations are welcome. It is also recognized that this proposed test program represents a once-in-a-lifetime opportunity, and the DDESB welcomes any and all input to ensure the most information possible is obtained from this test. It is envisioned that initial test planning will involve a formal planning meeting with participants invited from various U.S. and international organizations.

7.0 OTHER TESTING

As opportunities arise, the ESKIMORE project has and will involve participation in testing sponsored by other nations or U.S. organizations. As part of the UK/Australian Defence Trial ADF 859 in 2006/2007 at Woomera, South Australia, the U.S. provided a target structure similar to the one used in SciPan 3; the results of the U.S. target structure portion of this test have been reported[25]. Also, other tests are under consideration for addition to the ESKIMORE project, such as further flaked TNT characterization testing.

8.0 ES MODELING

The SAFER software tool currently contains 16 ES structures, which are modeled in the worst-case orientation to the PES (long side facing the PES). Also, the pressure-impulse (PI) method currently used to model the ES response to blast loading, and subsequent injury/fatality for building occupants, is based on the overall response of the ES structure (versus by component response). The ES modeling project is intended to use test data (primarily from the SciPan test program) to improve and validate existing physics-based building response models. These physics-based models can then be used to develop response predictions as a function of key ES structure design characteristics (e.g., aspect ratio, plan geometry, number of floors, orientation to the donor, building frame type, and wall, roof and window characteristics). These response predictions will then be used to develop fast-running models that can be used in a stand-alone mode or incorporated into quantitative risk-based programs such as SAFER.

9.0 DEBRIS PHYSICS

The debris physics project will involve investigation of key characteristics of the hazards from debris, testing as necessary to generate missing data, and development and validation of analytical models to predict debris hazards. Debris hazard characteristics to be addressed include:

- Launch Parameters – Effects on initial debris mass distribution, initial horizontal and vertical debris angles, and initial debris velocity, as a function of:
    - NEW and donor structure volume
    - Donor structure construction type

    - Donor structure venting (via frangible and structural walls/roof/doors)
- Trajectory – Variation with debris shape, density and velocity
- Impact Parameters – Effects from breakup on impact, bounce, ricochet, and roll, as a function of:
    - Impact angle
    - Impact velocity
    - Debris characteristics (mass, shape, material)
    - Impact surface characteristics
- Non-propagation Wall (NPW) Elements
    - Refinement of criteria for design and siting
    - Expansion of list of materials suitable for use in construction
- Injury/Fatality Models – Degree of injury/fatality versus debris characteristics at impact

10.0 SUMMARY

Project ESKIMORE is a comprehensive program intended to address specific gaps in explosives safety knowledge via testing and analytical efforts, and then incorporate the results into U.S. explosives safety models and QD standards. The DDESB is open to sponsorship from other agencies and nations, and willing to adapt specific test programs to meet additional needs; interested parties should contact the authors of this paper.

11.0 ACKNOWLEDGEMENTS

The authors wish to thank Mr. Michael Swisdak for his dedication to the development and management of Project ESKIMORE up until his retirement in late 2009. Mr. Swisdak's contributions to this project have ensured it will result in more realistic and appropriate explosives safety standards and models that will contribute significantly to the U.S. explosives safety management program.

12.0 REFERENCES

1. DDESB Technical Paper 14, "Approved Methods and Algorithms for DoD Risk-Based Explosives Siting," 21 July 2009
2. DoD 6055.09-STD, "DoD Ammunition and Explosives Safety Standards," 21 August 2009
3. Tatom, John, Swisdak, Michael, and Tancreto, James, "Status of Testing Program to Benefit Explosives Safety Standards Development in the United States Department of Defense," Minutes of the 31st DDESB Seminar, August 2004
4. Swisdak, Michael, "A Re-examination of the Airblast and Debris Produced by Explosions Inside Earth-Covered Igloos," 28 January 1991
5. Swisdak, Michael, "Debris Based Inhabited Building Distances for Aboveground Structures," Minutes of the 31st DDESB Seminar, August 2004

6. Swisdak, Michael, Tancreto, James, and Tatom, John, "SciPan 1 and SciPan 2 Response of Reinforced Concrete Tiltup Construction to Blast Loading," NAVFAC TM-2371-SHR, July 2004
7. Swisdak, Michael, Tancreto, James, and Tatom, John, "SciPan 3: Debris Hazards From a Concrete and Masonry PES and Response of Unreinforced Masonry to Blast Loading," NAVFAC TM-2388-SHR, March 2006
8. Conway, Robert, Tatom, John, and Swisdak, Michael, "SciPan 4: Program Description and Test Results," Minutes of the 34th DDESB Seminar, July 2010
9. Swisdak, Michael, Conway, Robert and Tatom, John, "Status of Testing Program to Benefit Explosives Safety Standards Development in the U.S. Department of Defense," Proceedings from the 13th International Symposium on the Interactions of the Effects of Munitions with Structures, May 2009
10. Tancreto, James, Tatom, John, and Swisdak, Michael, "SPIDER – A Test Program to Determine the Response of Typical Wall and Roof Panels to Debris Impact," Minutes of the 31st DDESB Seminar, August 2004
11. Tatom, John, Tancreto, James, and Swisdak, Michael, "SPIDER – A Test Program to Determine the Response of Typical Wall and Roof Panels to Debris Impact," Minutes of the 7th Australian Ordnance Symposium, PARARI 2005, November 2005
12. Crull, Michelle, Tatom, John, and Conway, Robert, "SPIDER 2 Tests – Response of Typical Wall Panels to Debris and Fragment Impact," Minutes of the 34th DDESB Seminar, July 2010
13. Swisdak, Michael, and Tatom, John, "Characterization of an Explosion Inside an ISO Container Located on a Truck," IHTR 2837, 22 February 2007
14. Swisdak, Michael, and Tatom, John, "ISO-2 Program Description and Data Summary," IHTR 3000, 10 April 2009
15. Swisdak, Michael, Conway, Robert and Tatom, John, "ISO-3: Program Description and Progress," Minutes of the 9th Australian Ordnance Symposium, PARARI 2009, November 2009
16. Davis, Jesse, Tatom, John, Swisdak, Michael, and Conway, Robert, "ISO-3 Debris Data Visualization and Comparison to ISO-1 Results," Minutes of the 9th Australian Ordnance Symposium, PARARI 2009, November 2009
17. Conway, Robert and Tatom, John, "ISO-3 Program Description and Test Results," Minutes of the 34th DDESB Seminar, July 2010
18. Tatom, John and Conway, Robert, "ISO Container Source Function Development for the Klotz Group Engineering Tool," Minutes of the 34th DDESB Seminar, July 2010
19. Dorr, Andreas, van der Voort, Martijn, Kummer, Peter, Pfanner, Tobias, Weerheijm, Jaap, and van Amelsfort, Ruud, "The Development and Application of the Klotz Group Software," Minutes of the 33rd DDESB Seminar, August 2008
20. Weals, F. H., "ESKIMO 1 Magazine Separation Test," NWC TP 5430, April 1973
21. Hoing, Craig, "DOSG Building Trials Summary," DOSG/ST/REP/097/2008 Issue 1, April 2008
22. Reeves, Harry and Robinson, Walton, "Hastings Igloo Hazards Tests for Small Explosive Charges," ARBRL-MR-03356, May 1984

23. Howe, P., Reeves, H. and Lyman, O., "An Approach to Munitions Storage Applicable to the McNair Compound of the Berlin Brigade," ARBRL-SP-00013, U.S. Army Ballistic Research Laboratory, September 1979
24. Tatom, John, Davis, Jesse, and Swisdak, Michael, "Continued Study of the SAFER/SciPan Mass Bin Concept," Minutes of the 34th DDESB Seminar, July 2010
25. Conway, Robert, Tancreto, James, and Malvar, Javier, "Testing and Analysis of Tilt-Up Reinforced Concrete and Unreinforced Masonry Structures under Blast Loads," Minutes of the 8th Australian Ordnance Symposium, PARARI 2007, November 2007

Project ESKIMORE – An Update With Emphasis on a Proposed ECM Testing Program

Ms. Lea Ann Cotton, DoD Explosives Safety Board
Mr. Robert Conway, Naval Facilities Engineering Service Center

34th DDESB Seminar, July 2010

Background

- In 2002, DDESB initiated a testing program
  - ➢ Support improvement of consequence algorithms in SAFER
  - ➢ Refine quantity-distance (QD) standards
- Program was subsequently expanded, and formalized in 2006 as Project ESKIMORE
- Currently managed by Mr. Robert Conway (NAVFAC ESC), with technical support from DDESB Science Panel

ESKIMORE Goals

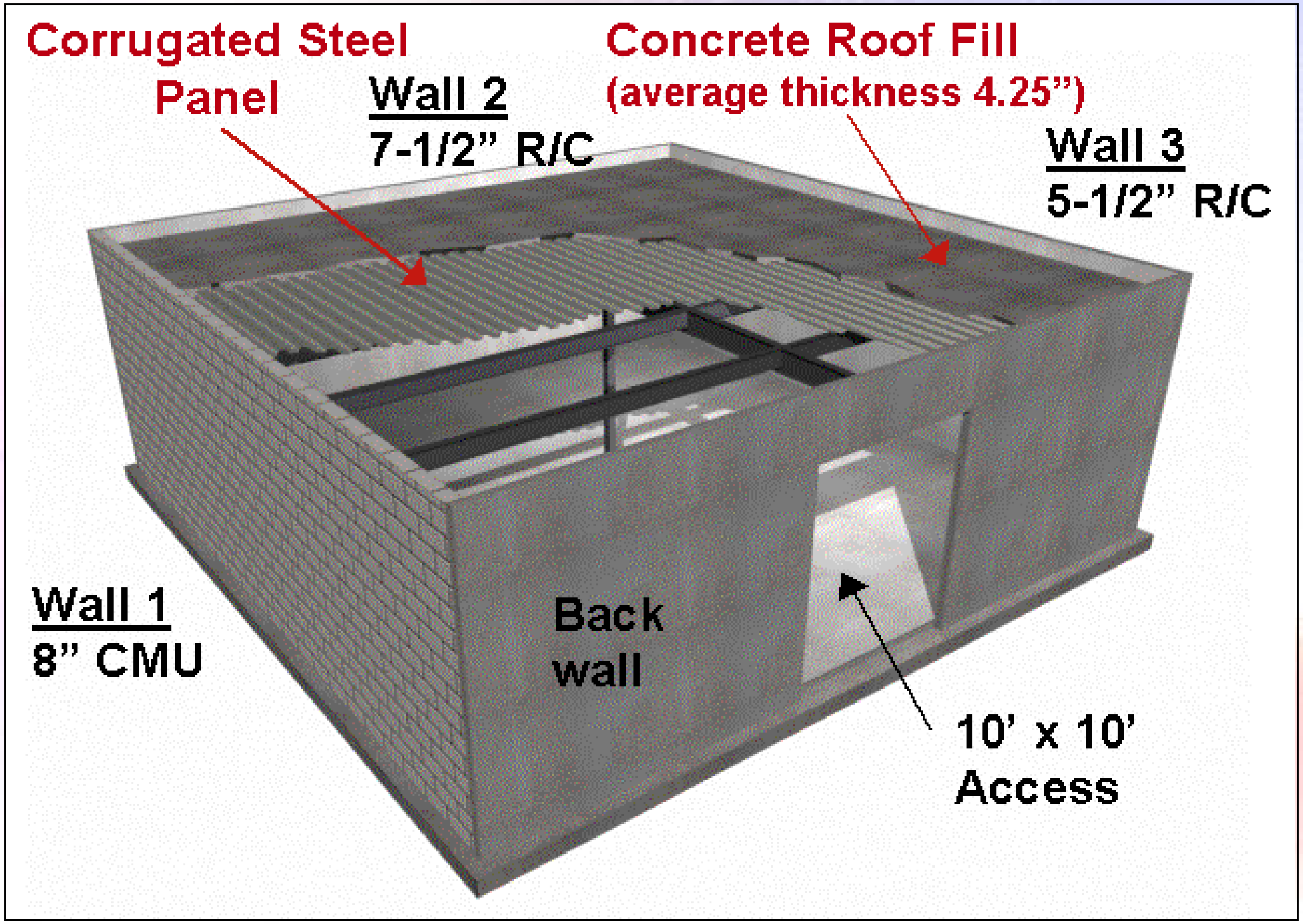
- To address the following areas of concern:
  - ISSUE 1: Donor structure debris characterization
  - ISSUE 2: Target structure response to blast loading
  - ISSUE 3: Target structure protection against debris
- To capitalize on testing and analytical efforts to develop and improve explosives safety models and standards

ESKIMORE Overview

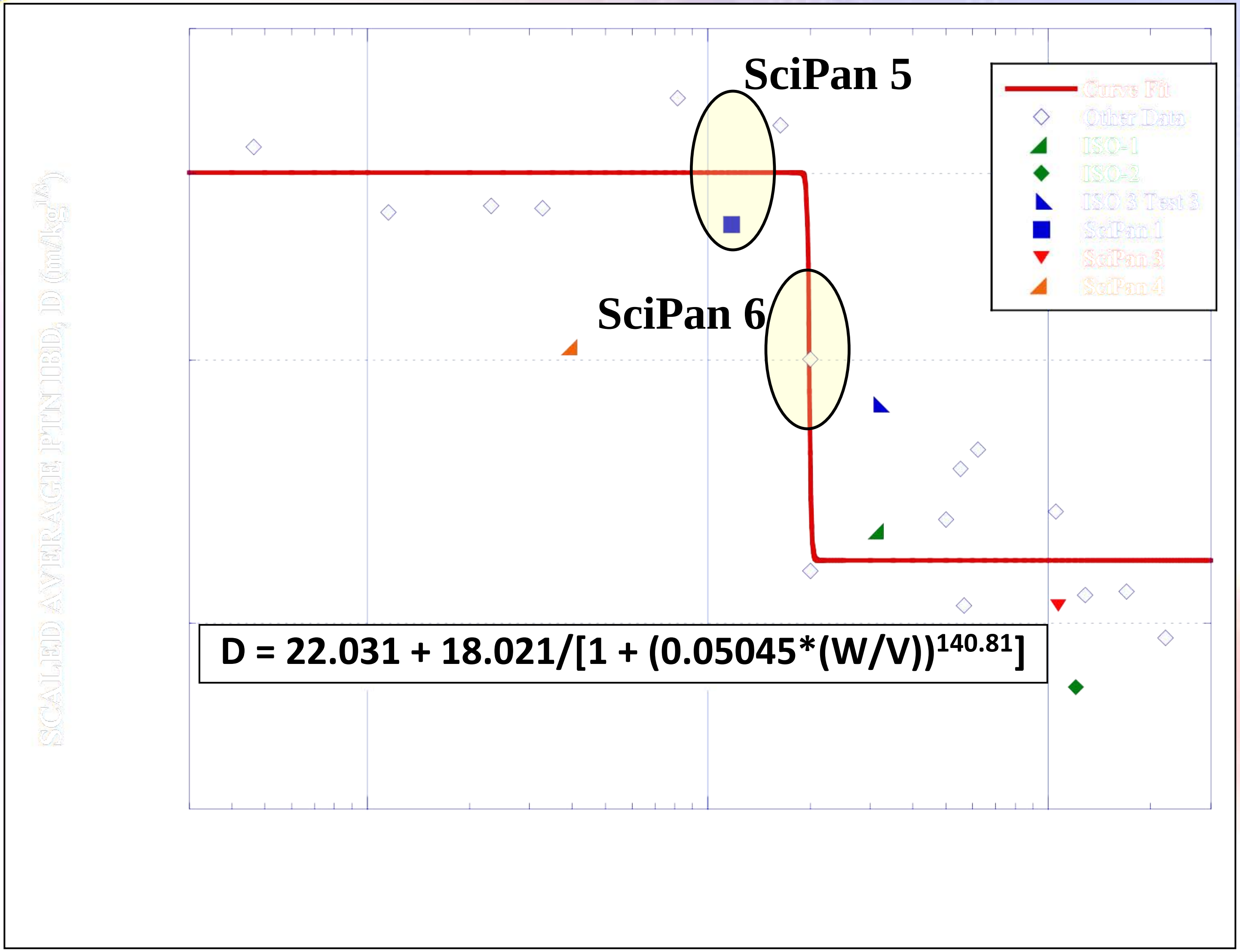
- **Project ESKIMORE includes test programs and analytical/modeling efforts**

- **Project ESKIMORE components:**
  - **SciPan Test Program**
  - **SPIDER Test Program**
  - **ISO Test Program**
  - **ECM Test Program**
  - **Other Testing**
  - **ES Modeling**
  - **Debris Physics**

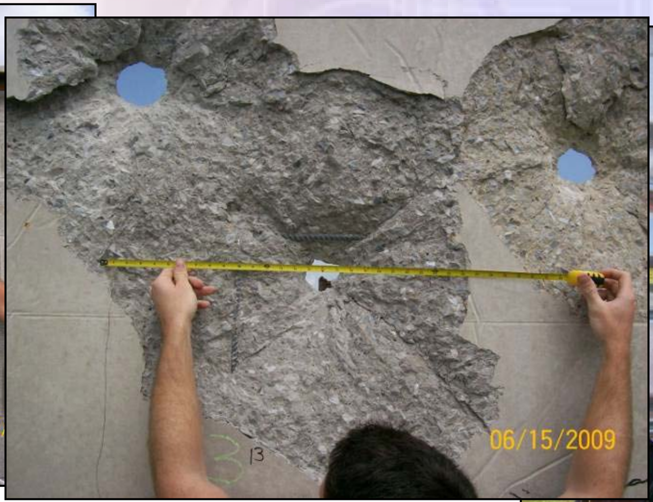
SciPan Test Program



SciPan Test Program



SPIDER Test Program



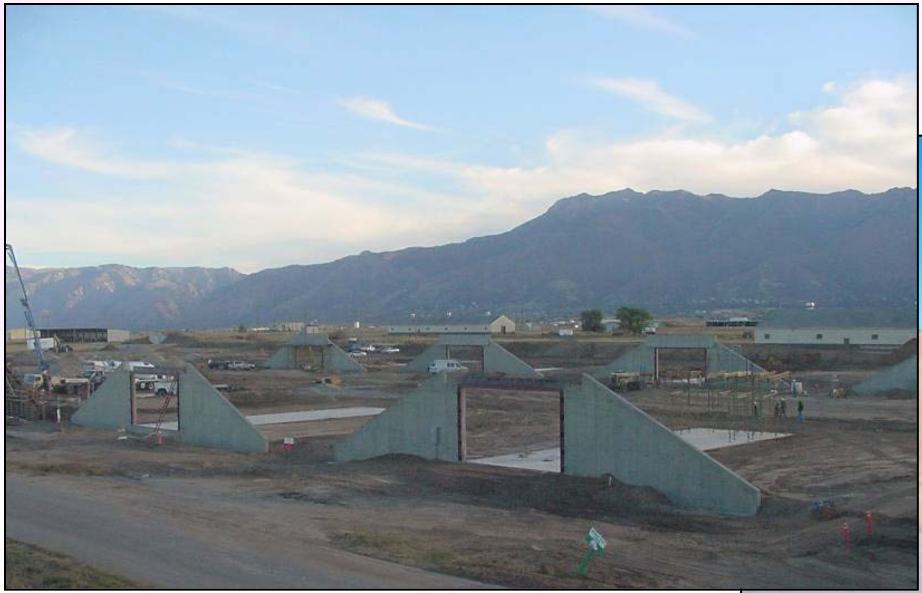
ISO Test Program

ECM Test Program

- **Over 25,000 ECMs at U.S. DoD installations**
- **Only two good sources of test data for ECM debris for large NEWs**
  - ➢ **ESKIMO 1**
  - ➢ **SPANTECH Trial**

ECM Test Program

- U.S. QD for ECMs are questionable
- U.S. blast design load for flat-roof ECMs is possibly too conservative



U.S. QDs for ECMs

NEW	Front	Side	Rear
≤ 150 lbs	500 ft	250 ft	250 ft
≤ 68 kg	*152.4 m*	*76.2 m*	*76.2 m*
150 to 450 lbs	700 ft	250 ft	250 ft
68 to 204.1 kg	*213.6 m*	*76.2 m*	*76.2 m*
450 to 45,000 lbs	1,250 ft	1,250 ft	1,250 ft
204.1 to 20,412 kg	*381 m*	*381 m*	*381 m*
> 45,000 lbs	K35/50	K35/50	K25/50
> 20,412 kg	$K_m13.9/19.8$	$K_m13.9/19.8$	$K_m9.9/19.8$

U.S. QDs for ECMs

NEW	Front	Side	Rear
< 150 lbs	500 ft	250 ft	250 ft
< 68 kg	*152.4 m*	*76.2 m*	*76.2 m*
150 to 450 lbs	700 ft	250 ft	250 ft
68 to 204.1 kg	*213.6 m*	*76.2 m*	*76.2 m*
[illegible]	[illegible]	…250 ft	1,250 ft
[illegible]	[illegible]	*…1 m*	*381 m*
[illegible]	[illegible]	…5/50	K25/50
[illegible]	[illegible]	*….9/19.8*	*K_m9.9/19.8*

Hastings & Navajo Testing

- **Hastings – barricaded front**
- **Applicability to all ECM designs questionable**

U.S. QDs for ECMs

ESKIMO 1 and SPANTECH indicate debris IBD may be as high as K65 (K_m25.8) for larger NEWs

		Side	Rear
		250 ft	250 ft
		76.2 m	*76.2 m*
		250 ft	250 ft
68 to 204.1 kg	*213.6 m*	*76.2 m*	*76.2 m*
450 to 45,000 lbs	1,250 ft	1,250 ft	1,250 ft
204.1 to 20,412 kg	*381 m*	*381 m*	*381 m*
> 45,000 lbs	K35/50	K35/50	K25/50
> 20,412 kg	*K_m13.9/19.8*	*K_m13.9/19.8*	*K_m9.9/19.8*

ECM Test Program

- **Goals**
  - ➢ **Debris characterization**
    - ✓ **Arch and box-type designs**
    - ✓ **Large and small NEWs**
    - ✓ **Azimuthal variations**
  - ➢ **Validate or determine design blast loading for flat-roof ECMs**
- **Data developed would be used to update U.S. explosives safety standards**
  - ➢ **Increased debris IBDs would probably lead to revaluation of debris IBD criteria (density and impact energy)**

ECM Test Program

- **For small NEW testing**
  - ➢ **Series of tests in the 100 to 450-lb [45.4 to 204.1 kg] range**
  - ➢ **No new construction – would depend upon identifying suitable “abandoned” ECMs**
- **For large NEW testing**
  - ➢ **Two tests proposed**
  - ➢ **ECM-1 test would have ECM-2 as an acceptor**
  - ➢ **New or existing construction not yet decided**

Large NEW ECM Testing

- **Existing construction – two SPANTECHs at Woomera, South Australia**
  - **Large SPANTECH (pictured) is significantly larger than most U.S. ECMs**
  - **Refurbishment required**
  - **Both are arch designs**
  - **Would probably have to build replacement “range support” structures**

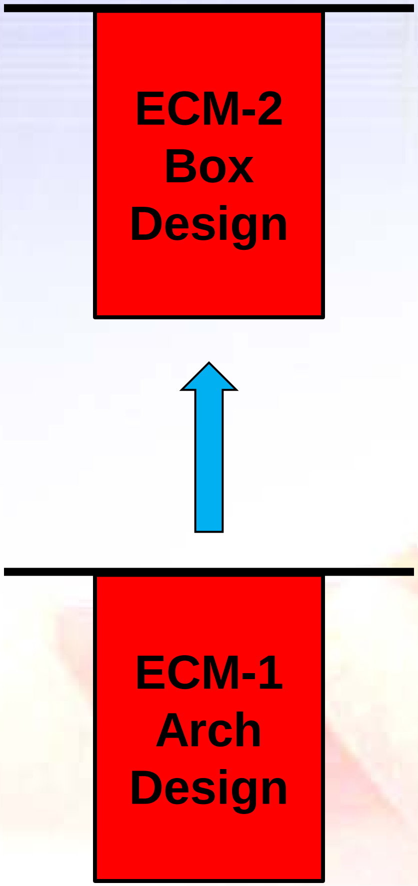
Large NEW ECM Testing

- **New construction**
  - ➢ **Try to match majority of existing structures?**
  - ➢ **Try to match designs used most often for new construction projects?**

- **"Popular" designs for new projects**
  - ➢ **COE 421-80-06**
  - ➢ **COE 33-15-74**
  - ➢ **NAVFAC Type C**

Large NEW ECM Testing

- **First test – ECM-1 as donor**
  - ➢ **ECM-2 heavily instrumented**
- **Second test – ECM-2 as donor**
- **Both tests instrumented for overpressure and impulse beyond intermagazine distances**
- **Target structures – TBD**
  - ➢ **Impact to debris recovery must be considered**



Large NEW ECM Testing

Test	Tentative Donor Design	NEW (lbs) [kg]	AE Type	Blast IBD (ft) [m]	Scaled Debris IBD of 65 $ft/lb^{1/3}$ [25.8 $m/kg^{1/3}$]
ECM-1	33-15-74	44,900 [20,366]	234 MK 82 bombs (39 pallets)	1,250 [381]	2,310 [704]
ECM-2	421-80-06	100,000 [45,400]	522 MK 82 bombs (87 pallets)	2,320 [708]	3,000 [914]

Large NEW ECM Testing

- **Debris collection methods**
  - **Sector collection, sort by mass bin, count**
  - **Mark location of each piece using differential GPS, weigh, and then record mass and type (using a "non-collection zone")**

- **"GPS" method with 360-degree collection preferred, but may not be feasible or necessary**

Large NEW ECM Testing

- Using “GPS” method (25 pieces/hour)
- 100-m radius non-collection zone
- Mass bins 1 through 8 only
- Not counting earth-cover debris or crater ejecta
- 9-hour work day, 6-day work week

Test	Number of Pieces	Crew Size	Number of Weeks
ECM-1	750,000	50	11.7
		75	7.8
		100	5.8
ECM-2	1,000,000	50	15.5
		75	10.3
		100	7.7

Large NEW ECM Testing

- Using “GPS” method (25 pieces/hour)
- 100-m radius non-collection zone
- Mass bins 1 through 8 only
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Test	Number of Pieces	Crew Size	Number of Weeks
ECM-1	750,000	50	11.7
		75	7.8
		100	5.8
ECM-2	1,000,000	50	15.5
		75	10.3
		100	7.7

= 13.5 weeks
= ~ 3.5 months

Large NEW ECM Testing

- Using "GPS" method (25 pieces/hour)
- 100-m radius non-collection zone
- Mass bins 1 through 8 only
- Not counting earth-cover debris or crater ejecta
- 9-hour work day, 6-day work week

Test	Number of Pieces	Crew Size	Number of Weeks
ECM-1	750,000	50	11.7
		75	7.8
		100	5.8
ECM-2	1,000,000	50	15.5
		75	10.3
		100	7.7

= 27.2 weeks
= ~ 7 months

= 13.5 weeks
= ~ 3.5 months

Large NEW ECM Testing

Year	Activities
Year 1	• Solicit participation by other organizations/nations • Develop test requirements • Prepare cost benefit analysis for existing versus new construction • Prepare cost benefit analysis for debris collection approaches • Select ECM type(s)/design(s) and site arrangement • Prepare construction drawings
Year 2	• Prepare detailed test and instrumentation plans • Select test site • Prepare detailed construction and test cost estimates
Year 3	• Lay-out test site • Construct ECM-1 and ECM-2 • Install instrumentation • Update test and instrumentation plans
Year 4	• Conduct test of ECM-1 • Collect debris • Analyze ECM-2 response, and identify costs to refurbish ECM-2 • Analyze data
Year 5	• Prepare final report for ECM-1 test • Refurbish ECM-2 • Update test and instrumentation plans • Conduct test of ECM-2 • Collect debris
Year 6	• Restore test site • Analyze data • Prepare final report for ECM-2 test • Prepare report for recommended changes to U.S. QD standards

ECM Test Program

- **Funding**
  - ➢ **Not yet secured**
  - ➢ **Estimates range from $6M to $9M**
  - ➢ **Probably commence Year 1 effort in 2012**
- **Participation by other organizations/nations**
  - ➢ **WELCOME!**
  - ➢ **Large financial investment**
  - ➢ **"Once-in-a-lifetime" testing opportunity**
  - ➢ **Formal planning meeting in Year 1**

Project ESKIMORE

- Comprehensive, on-going test program
- Addresses knowledge gaps via testing and analysis efforts
- Results used to update standards and models
- Open to participation from other agencies and nations

Questions?