ISO-3: 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 and in conjunction with ongoing ISO container trials conducted by the United Kingdom, the U.S. has conducted the ISO-3 test series in Woomera, Australia. Whereas previous ISO container tests in this program have utilized a non-fragmenting source, ANFO, this testing consisted of two experiments to study the airblast and debris effects produced by the detonation of 1054 kg (2,324 lbs) Net Explosive Quantity (NEQ) of M1 105 mm projectiles and their associated propellant cartridges inside a standard ISO container. ISO-3 actually consisted of two tests. The first involved the detonation of these munitions inside an ISO container. The second tested the detonation of an identical amount of material with the same configuration in the open. A full 360° debris recovery was accomplished on each event outside a 100 m (328 ft) radius from ground zero. The setup of the ISO-3 test series and the types of data that were collected are described. In addition, the test data and information regarding the container breakup and debris generation are presented.

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14. ABSTRACT
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Introduction

In a quantitative risk assessment (QRA), the ability to accurately model real-world situations is obviously critical. In the end, the model must be able to represent the effects produced by the detonation of the donor and the consequences on the target. The science that goes into such a model must be carefully thought-out and based on as much data as possible.

In a semi-empirical QRA model, conservatism is inversely related to the amount of available data. That is, if there are very few (or no) data points available to anchor an algorithm, the model typically must err on the side of caution. However, when an algorithm can be readily corroborated by test and/or accident data, the model does not need to include conservatism. This is important because the inclusion of conservatism would prevent model results from comparing well with the empirical data anchor points.

One of the benefits of a QRA is the quantification of relative risk from different hazards. One of the potential explosion sites (PES) that is of current interest is a standard ISO shipping container of explosives.

An important aspect of modeling a PES is how the structure behaves under explosive loading:

- How much debris is produced?
- What is the mass distribution of the debris?
- How far does the debris get thrown?
- What is the azimuthal distribution of the debris?
- How much external airblast attenuation is provided by the structure?
- How does the presence of the PES affect the primary fragments (if fragment-producing explosives are present)?

To begin addressing these issues, the U.S. Department of Defense Explosives Safety Board (DDESB) Science Panel suggested that an additional test be added to the UK/Australian Defence Trial 859 held in Woomera, South Australia as a part of Project ESKIMORE[1]. This test became Test 5 in the Trial 859 test sequence and was alternatively referred to as the ISO container or ISO-1 event[2].

The ISO-1 event was detonated on 18 May 2006. It had a Net Explosive Quantity (NEQ) of 1,054 kg (2,324 lb) of non-fragmenting material ,ammonium nitrate / fuel oil (ANFO), configured as a nominal 1.1-meter cube.

As the results of the ISO-1 trial became available, several interesting questions were raised regarding aspects of the data:

- What are the appropriate scaling algorithms for the debris distribution; i.e., how should the ISO-1 data be scaled or adjusted for a higher (or lower) NEQ event?
- For “out-of-area” military operations, the maximum NEQ that can be stored in ISO containers is limited to approximately 4 tonnes. How can the ISO-1 results be applied to this situation?
- Are these results directly applicable to transportation scenarios?

In order to address these questions, a follow-up trial (ISO-2)[3] was proposed and added to ADF Trial 859 as Trials 7 and 8. In Trial 7, ANFO inside an ISO container was detonated at 1015 Australian Central Daylight Time on 21 March 2007. Trial 8, an open-air ANFO calibration shot, occurred at 1000 Australian Central Standard Time on 2 April 2007.

As the ISO-2 data were being analyzed, additional questions arose: "How much would the results change if the ammunition and explosives (AE) being detonated were fragmenting munitions rather than ANFO? Would the results change if the ISO container were on the ground rather than on a truck?"

To address these issues, another ISO container trial (ISO-3) was proposed as part of the ADF 868 series in Woomera in 2009. The specific differences between the proposed ISO-3 event and the previous ISO-1 test include:

- Fragmenting AE rather than bare explosives
- An energetic material with a higher TNT equivalence and greater brisance than ANFO
- ISO container on the ground rather than on a truck

Because of these potential differences between ISO-3 and ISO-1, it was decided that a calibration shot, consisting of the same number of projectiles detonated in the open should also be conducted.

It should be noted that the analyses presented in this paper are preliminary and are still undergoing further scrutiny. Therefore, the results shown are not final and should not be considered a complete set.

Organization and Funding

Funding for the ISO-3 test was provided by the following organizations:

- U. S. Department of Defense Explosives Safety Board
- U. S. Army Technical Center For Explosives Safety (USATCES)

Personnel from or provided by the following organizations participated in the post-detonation debris mapping:

- U. S.
  - Indian Head Division/Naval Surface Warfare Center
  - Naval Facilities Engineering Service Center
  - USATCES
  - Army Engineering and Support Center, Huntsville
  - DDESB
  - Naval Air Warfare Center—Weapons Division
  - A-P-T Research, Inc. (APT)
- UK
  - Defense Ordnance Safety Group
- Australia
  - Directorate of Trials
  - Australian Defence Forces

    - CR Kennedy, Surveyors
- Singapore
    - Defense Science and Technology Agency (DSTA)

Test Objectives

There were several objectives for the ISO-3 test:

1. Determine the debris distribution/characteristics produced by a detonation inside a standard ISO container with a typical explosive load of fragmenting AE
2. Determine the external airblast attenuation provided by a detonation inside a standard ISO container with a typical explosive load of fragmenting AE
3. Determine the debris IBD arc for an ISO container of fragmenting AE
4. Quantify the differences between the ISO-1 and ISO-3 events
5. Compare the primary fragment behavior of a stack inside an ISO container to an identical stack in the open

Event Description

The ISO-container testing that was part of the ADF 868 series consisted of four detonations: two sponsored by the United Kingdom (UK) and two by the United States (US). The US detonations consisted of the following two events: a primary event (Test 3/Site 3/GZ 3/ISO-3) and a calibration shot (Test 4/Site 4/GZ 4/ISO-3 Calibration). Both detonations were conducted on Range G (Spantech Site) within the Woomera Prohibited Area (WPA).

ADF 868 Test 3. The event consisted of the detonation of 1,054 kg (2,324 lb) NEQ of fragmenting AE (M1 105 mm cartridges) located inside of an ISO container resting on the ground. The active instrumentation consisted of regular and high-speed videos and airblast transducers. Post-detonation, the effort concentrated on preparing a 360° debris catalog (range, azimuth, weight, source for each piece) for all material beyond 100 m (328 ft) of ground zero. This test will be referred to as "ISO-3" throughout this paper.

ADF 868 Test 4. The purpose of this event was to characterize (calibrate) the output of the M1 105 mm projectiles that were used in the primary event. To that end, the charge was constructed, located and detonated in the open but otherwise in a manner identical to the ISO-3 test. The active instrumentation consisted of regular and high-speed videos and airblast transducers. Post-detonation, the effort concentrated on preparing a 360° debris catalog (range, azimuth, weight, source for each piece) for all material beyond 100 m (328 ft) of ground zero. This test will be referred to as "ISO-3Cal" throughout this paper.

ISO Container Description

The term ISO is not an acronym; it comes from the Greek word *ίσος* (*isos*), meaning "equal."

ISO containers are steel shipping containers used around the world. Their standard design specifications ensure their compatibility with handling equipment, storage areas, and replacement parts in almost any country. ISO containers are 2.44 m (8 ft) wide and 2.44 meters high (external dimensions), and come in two lengths: 6.1 m (20 ft) and 12.2 ms (40 ft). A 6.1 m container was used on this test. The top, bottom, and sidewalls of the container were made of corrugated steel panels 1.5 mm thick, joined to steel structural members at the panel intersections. Double-leaf steel panel doors were located at one end of the container. The specifications for the 6.1 meter ISO container are shown in Table 1.

Table 1. ISO Container Specifications

Maximum Gross Weight	Maximum Payload	Tare Weght	Internal Capacity	Interal			Door Opening	
				Height	Width	Length	Height	Width
30,480 kg (67,200 lb)	28,080 kg (61,910 lb)	2,400 kg (5,290 lb)	33.2 m^3 (1,172 ft^3)	2,393 mm (7.85 ft)	2,350 mm (7.71 ft)	5,897 mm (19.35 ft)	2,127 mm (6.98 ft)	2,343 mm (7.69 ft)

At the corners of the container there are large steel blocks, each with a weight of over 10 kg; these provide extra support for stacking the containers.

Potential Explosion Site (PES)

The PES consisted of a standard 2.4 m x 2.4 m x 6.1 m ISO container located on the ground. Figure 1 shows front and side views of the ISO container.

Figure 1 PES (ISO Container)

Charge Description

The donor charge consisted of Australian-produced M1 105 mm cartridges in wooden packaging boxes. The M1 105 mm cartridge is a semi-fixed, high explosive artillery round. The projectile body is fabricated from forged steel and weighs approximately 11.7 kg (25.8 lb). The propelling charge consists of approximately 1.4 kg (3.1 lb) of M1 propellant contained in a brass case. Each propelling charge case weighs approximately 2.1 kg (4.6 lb). Each projectile body contains approximately 2.2 kg (4.9 lb) of Composition B high explosive. The cartridges were packaged two to a wooden box.

Previous testing[4] has indicated that M1 propellant can react with a TNT equivalence approaching 100%. Thus, the NEQ for each cartridge was taken as 3.6 kg (HE weight plus propellant weight). Therefore, the desired NEQ for these tests, 1,050 kg (2,315 lb), was achieved by using 144 boxes (288 cartridges) with about 20 kg (44.1 lb) of plastic explosive arranged in eight uniform stacks of 18 boxes each. The plastic explosive was placed in the nose fuze well of every projectile and all projectiles were detonated simultaneously in their design mode via detonation cord transfer lines. Figure 2 shows photographs of the actual ISO-3Cal charge arrangement. For ISO-3, this same arrangement was placed inside of the ISO container shown in Figure 1.

In order for the center of gravity of the stack on ISO-3Cal to be at the same height as on ISO-3, additional bracing was placed under each pallet on ISO-3Cal to compensate for the lack of the ISO container floor that was present on ISO-3.

As shown in Table 1, the internal volume of the container is 33.2 m^3 (1172.4 ft^3). With a total NEQ of 1,054 kg (2,324 lb), the effective loading density of the event was 31.7 kg/m^3 (2.0 lbs/ft^3).


Figure 2 Actual Charge Arrangement

Data Collection

The following data were collected for both ISO-3 and ISO-3Cal:

- Airblast
- Debris catalog (range, bearing, mass, source) over 360º of azimuth
- Multiple views with high speed (500 to 3000 frames per second (fps)) video
- Multiple views with normal speed video
- 3-D laser scan of Ground Zero (GZ) area

Test Layout

The coordinate system shown in Figure 43 was used to locate the airblast transducers, the cameras, and the debris pieces that were produced on both ISO-3 and ISO-3Cal. GZ was taken as the center of the coordinate system, which was located on the ground under the center of the ISO container.

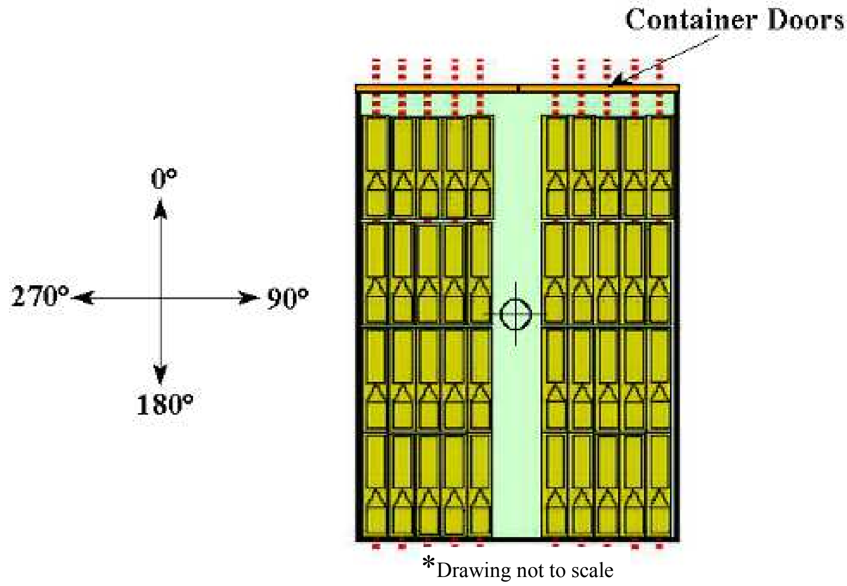


Figure 3 ISO-3 Coordinate System

<u>Airblast</u>

Using the coordinate system shown in Figure 3, three lines of airblast transducers were established (instrumentation was identical for ISO-3 and ISO-3Cal):

- Line 1 (normal to door of ISO container) at 0º azimuth
- Line 2 (normal to side of ISO container) at 270º azimuth
- Line 3 (normal to rear of ISO container) at 180º azimuth

Transducers were located at the following intervals (as measured from GZ):

- 30 m (98 ft)
- 50 m (164 ft)
- 100 m (328 ft)
- 200 m (656 ft)
- 300 m (984 ft)

At each transducers location, the following airblast information was recorded:

- Time of arrival
- Peak pressure
- Impulse
- Pressure profile

At the 30, 50, and 100 m distances, ground mounted gauges were utilized, as shown in Figure 4, due to the significant number of primary fragments that were produced on both ISO-3 and ISO-3Cal.

Figure 4 Ground Mount Gage

At the 200 and 300 m distances, at a height of approximately 2 m (6.6 ft) , above-ground pencil gauges were used, as shown in Figure 5.

Figure 5 Pencil Gage

Photographic Coverage

The events utilized a variety of conventional and high-speed grayscale and color video cameras running at rates between 30 fps and 3000 fps. Most cameras were mounted inside protective structures as shown in Figure 6. Many were located within 220 m (722 ft) of GZ, as shown in Figure 7.

Figure 6 High Speed Camera Shelter

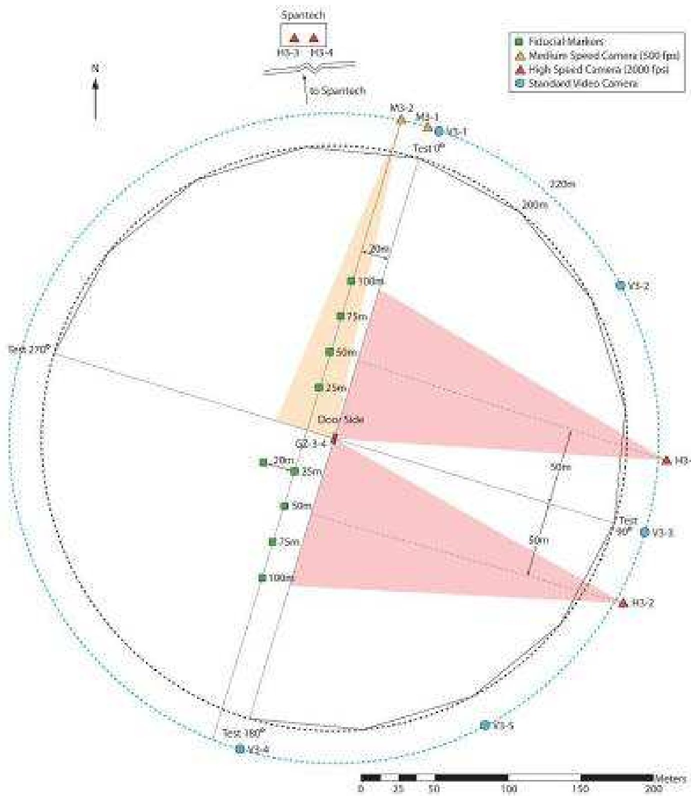


Figure 7 Camera Layout

Preliminary video analysis has been completed. An example of the initial video analysis can be seen in Figure 8, in which the stack effects of the fragmenting munitions are observed (the dark outline on the ISO container). More information on the video analysis is available upon request.

Figure 8 ISO-3 Video Analysis

Debris Catalog

For both ISO-3 and ISO-3Cal, the debris collection area was divided into two zones: *Near Field* and *Far Field*. Near Field was defined as the area within approximately 100 m of GZ. Far Field was defined as the area beyond a range of 100 m from GZ.

To facilitate the debris collection process, survey markers were positioned in the Far Field prior to detonation. These markers were placed at the following locations, as shown schematically in Figure 9.

- 100 m radius—marker every 5° (2.5° to 357.5°)
- 300 m radius—marker every 5° (2.5° to 357.5°)
- 500 m radius—marker every 5° (2.5° to 357.5°)
- 1000 m radius—markers placed at the following angles: 87.5°, 92.5°, 267.5°, and 272.5°

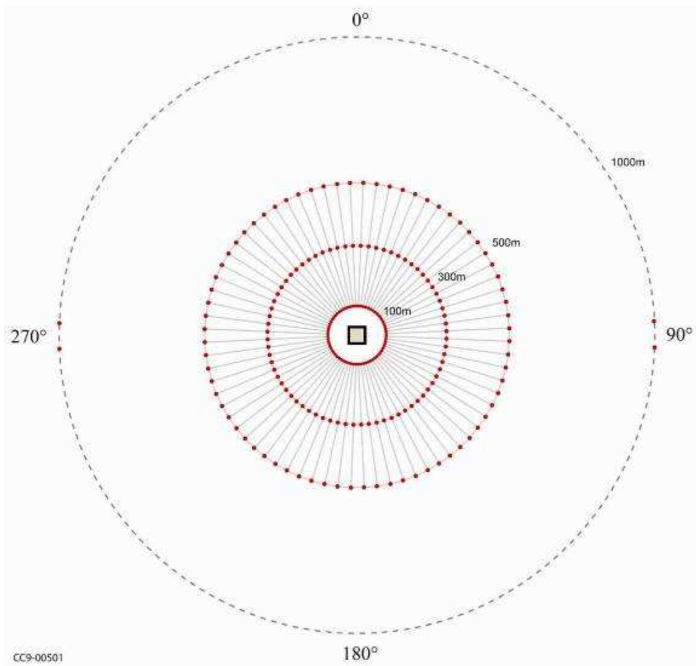


Figure 9 ISO-3 Debris Collection Zones

Around the outside of the ISO container, on each corner, are heavy steel blocks. These blocks each weigh over 10 kg (22 lb) and form unique and easily identifiable pieces of debris. A post test photograph of one of the blocks is shown in Figure 10.

Figure 10 ISO Container Corner Block

To facilitate post-test identification, each corner block had a unique number stamped on its surface, as shown in Figure 11.

Figure 11 ISO Container Corner Block With Number

The numbering scheme applied in the ISO-3 test was not consistent with that of the previous ISO tests due to some confusion when communicating the test plan to test setup engineers. The actual numbering scheme that was applied in the field, based on pre-test photographs, is shown in Figure 12.

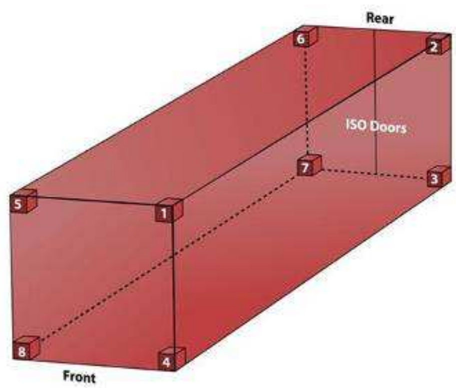


Figure 12 Actual Corner Block Numbering

After each detonation, the cataloging effort consisted of two concurrent tasks:

- Debris location and marking
- Determination of range, bearing, weight and source of each debris piece

Three location (or "flagging") teams were established and utilized for the effort. As many as four survey (or "cataloging") teams were formed to capture and record the debris data. Once the pertinent information for each piece was recorded, the material was transported to a central location for disposal. Figure 13 shows a portion of one of the flagging teams and Figure 14 shows a flagged area that has yet to be cataloged.

Figure 13 Flagging Team

Figure 14 Flagged Area

A Leica 1200 Series Differential GPS system was used to locate and catalog each debris piece. A base station was established near the large Spantech igloo; each of the survey teams had a set of portable equipment that consisted of a GPS 1200 SmartTrack Antenna and Receiver and an electronic scale.

During the cataloging process, each piece of debris was assigned a Category Code to describe its origin. These codes are shown in Table 2. In hindsight, the authors of this paper regret not designating an additional code to distinguish between the brace and skin of the ISO container itself. Doing so would have significantly reduced the effort required to develop detailed empirically-based mass distributions from the test data. Also of great interest for future ISO testing is the ability to distinguish between the roof and wall of the ISO container to allow for a more complete picture of the horizontal debris distribution. One method that has been considered to help facilitate the distinction between roof and wall debris is to apply a high temperature-resistant paint to each surface. Both of these distinctions would provide considerable aid in understanding and characterizing the breakup of ISO containers.

Table 2. Debris Category Codes

Category Code	Source
I	ISO Container
P	Projectile, cartridge case, packaging
U	Unknown
F	Crater ejecta, star picket
G	Instrumentation transducer

The mass bins that were defined for the SciPan program[5] and that were used on the previous ISO tests[2,3], were again used to characterize the debris. Table 3 provides the characteristics for material in each of the mass bins that were collected.

The instruction to flagging teams was to locate and mark material that was the size of a postage stamp or larger (mass of approximately five grams). This corresponded to material in Mass Bin 10 or larger. Because the interpretation of the collection threshold varied from individual-to-individual, significant amounts of material that was smaller than Mass Bin 10 were collected. These were placed into an additional bin with the designation “g”, with characteristics as shown in Table 3.

Table 3. Mass Bin Characteristics

Bin Number	STEEL WEIGHT (lbs)	STEEL WEIGHT (oz)	STEEL SIZE* (in)	STEEL WEIGHT (kg)	STEEL WEIGHT (g)	STEEL SIZE* (mm)
1	>26	>416	>5.5	>11.8	>11,793	>140
2	10 - 26	160 - 416	4.1 - 5.5	4.54 - 11.8	4,536 - 11,793	104 - 140
3	4.5 - 10	72 - 160	3.1 - 4.1	2.04 - 4.54	2,041 - 4,536	79 - 104
4	1.8 - 4.5	28.8 - 72	2.3 - 3.1	0.82 - 2.04	816 - 2,041	58 - 79
5	0.8 - 1.8	12.8 - 28.8	1.8 - 2.3	0.36 - 0.82	363 - 816	46 - 58
6	0.3 - 0.8	4.8 - 12.8	1.3 - 1.8	0.14 - 0.36	136 - 363	33 - 46
7	0.14 - 0.3	2.24 - 4.8	1.0 - 1.3	0.06 - 0.14	64 - 136	25 - 33
8	0.06 - 0.14	0.96 - 2.24	0.7 - 1	0.03 - 0.06	27 - 64	18 - 25
9	0.025 - 0.06	0.4 - 0.96	0.56 - 0.7	0.01 - 0.03	11.3 - 27	14 - 18
10	0.013 - 0.025	0.21 - 0.40	0.28 - 0.56	0.006 - 0.01	5.9 - 11	7.1 - 14
g	<0.013	<0.21	<0.28	<0.006	<5.9	<7.1

*Assumes spherical shape

Near Field. Within 100 m of GZ, only large or interesting pieces were cataloged, weighed, and their locations (range and bearing) determined. In addition, a three-dimensional laser scan of the crater area was performed immediately after each detonation.

Far Field. Debris pieces that fell between 100 m and 500 m were located, their position (range, bearing, and elevation) and mass determined, and their source described. The boundaries of each sector were marked using a rope stretched between the 100 m stake and the 500 m stake. It should be noted that these boundaries were only used to guide the flagging teams; the actual debris position was determined by GPS. A thorough search process was employed to carefully scan each 5° sector out to 500 m, with a flag placed at the location of each individual fragment. Generally, each sector was swept laterally in increments, and then a quality control check was performed to ensure a very low "miss rate" in this region. Additional quality control measures were executed by independent survey teams, who re-investigated selected areas to try to quantify average miss rates in terms of time of day, type of terrain, and location on the test bed.

After the ISO-3 detonation, the area between 500 m and 1000 m was searched in a less formal manner with the goal of locating any large debris pieces that may have fallen in this region (NB: Small debris would not be expected to be thrown beyond a range of about 500 m). A group of about 30 individuals were spaced logarithmically (approximately) between 500 and 1000 m. The line marched around the full 360° to locate and catalog each piece that landed beyond 500 m.

In order to best utilize the available manpower, the Far Field debris recovery process was modified after the ISO-3Cal detonation. The same general procedure was used out to a distance of 300 m. The majority of the area between 300 and 1000 m, however, was swept and cataloged by a single, dedicated survey team.

General Results

ISO-3 was detonated at 0950 Australian Central Daylight Time on 10 March 2009. Debris Collection and Cataloging (DCC) began immediately after the detonation and concluded on 23 March. The calibration event (ISO-3Cal) occurred at 1000 Australian Central Daylight Time on 24 March 2009. DCC began immediately after the detonation and concluded on 3 April 2009.

Crater Results

Both craters were of similar shape and size (relatively shallow and shaped like the charge outline). Figure 15 shows the crater formed on ISO-3Cal. At the time of this writing, the 3-D laser scan results of the GZ area have been received but they have not been analyzed, so further crater details are not currently available.

Since crater ejecta data was not a priority for either ISO-3 or ISO-3Cal and since primary fragments from the M1 105 mm projectiles and secondary fragments from the ISO container dominated the debris field, only a few crater ejecta points were recorded.

Figure 15 ISO-3Cal Crater

Airblast Results

The analysis of the airblast data is at a preliminary stage. Therefore, it will not be discussed in this paper. Initial analysis is available in a separate paper[6] and final results will be presented in the ISO-3 final report.

Debris Catalog Results

All of the debris data shown and discussed in this report have been modified from the raw data files that were provided post-event. These modifications were made in order to accomplish the following:

- Remove duplicate entries
- Locate and correct items that were shown as having zero mass
- Locate items that were not weighed onsite and enter estimated mass
- Locate and correct entries from ISO-3 that were mis-identified as projectile (Category Code P) when they should have been identified as ISO (Category Code I)

- Locate items identified as “Crater Ejecta” or “Star Picket” and assign them Category Code F
- Convert angular units from degrees/minutes/seconds to decimal degrees
- Correct any other obvious errors.

Beyond 100 meters, over 67,200 separate pieces of debris were located and cataloged for ISO-3. For ISO-3Cal, there were approximately 65,300 pieces beyond 100 m. Because the debris catalog is so extensive (hundreds of pages), it will not be included in this paper. Copies of the debris catalog can be requested from the DDESB. Included in the ISO-3 totals are points that were collected for quality control (QC) purposes. There are a total of 232 QC points — seven ISO container and 225 non-container (primary fragment) pieces.

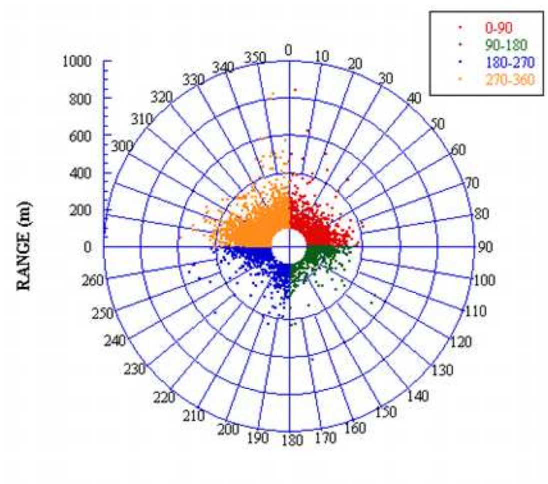
In order to facilitate comparisons between the primary (projectile) fragments recorded on the two detonations, all ISO-3 material not identified as coming from the ISO container, with the exception of items identified as category code F (ejecta, star picket), were counted as projectile fragments. Table 4 provides a summary of the debris information that has been collected on the two events.

Table 4. Summary Statistics

Statistic	ISO-3*				ISO-3Cal **	
	ISO (I)		Primary (P)		Primary (P)	
	Mass Bins 1--10 + G	Mass Bins 1--10	Mass Bins 1--10 + G	Mass Bins 1--10	Mass Bins 1--10 + G	Mass Bins 1--10
Piece Count	7,064	5,694	60,134	50,149	65,334	56,178
Mean Mass (grams)	223.2	275.9	20.1	23.2	19.6	22.1
Mode Mass (grams)	5	6	5	6	6	6
Minimum Mass (grams)	1	6	1	6	1	6
Maximum Mass (grams)	75,000	75,000	2,693	2,693	2,562	2,562
Mass Range (grams)	74,999	74,994	2,692	2,687	2,561	2,556

*Does not include 41 pieces in other Category Codes
**Does not include 2 pieces in other Category Codes

Figure 16, Figure 17, and Figure 18 are scatter plots of all of the debris data collected on both events. Figure 16 shows only the ISO container material from ISO-3; Figure 17 shows the non-ISO container material (primary fragments) produced by this detonation. Figure 18 shows the non-ISO container material (primary fragments) from the ISO-3Cal detonation. On ISO-3, there was a significant wind, gusting up to 8.3 m/s (27.2 fps), from the SSE, blowing towards the 320º azimuth. This wind seemed to bias the debris density in this direction. The wind had a less pronounced effect on ISO-3Cal as its speed, 3.6 m/s (11.8 fps), was less that half of that on ISO-3.



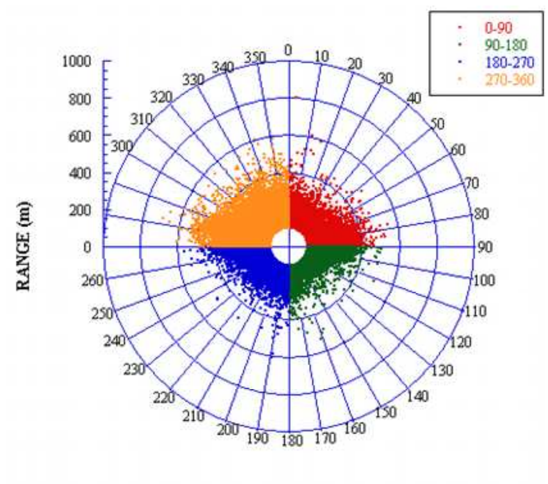


Figure 16 ISO-3 Container Debris Scatter Plot

Figure 17 ISO-3 Non-Container Debris Scatter Plot

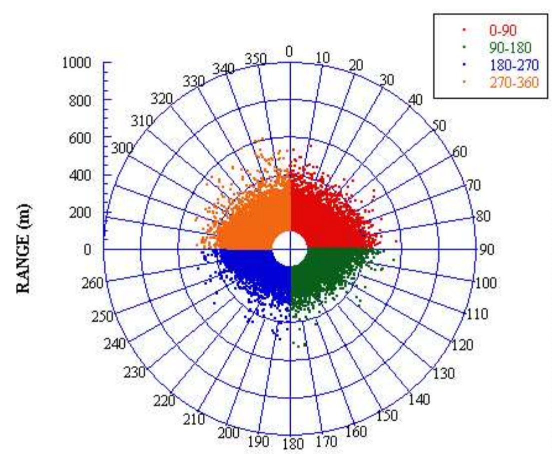


Figure 18 ISO-3Cal Non-Container Debris Scatter Plot

During the ISO-3 DCC process, ten items were identified as corner blocks, when, physically, there are only eight blocks present. Two blocks were described as "CB 3" and one was simply described as "*Corner Block"* with no number. The two blocks identified as coming from Position 3 are listed as CB3 A and CB3 B. The block with no number is listed as CB X.

One of the two previously described UK tests had a ground zero located near where the suspect corner blocks were cataloged. As part of their test program, a full debris catalog was supposed to be prepared. Once their debris was cataloged, it was to be removed from the test area and taken to a recycling bin. The route that would be taken by a truck carrying this debris was through the area in which CB3 B and CB X were located. It was postulated that either these two pieces were missed during their cataloging effort or that they bounced off of the truck on the way to the recycling area. For this reason, it was decided that CB3 B and CB X should be removed from the data set.

The catalog information for all of the items identified as corner blocks is shown in Table 5. Their locations are shown in Figure 19. Additionally, other anomalies of interest are the locations of CB1 and CB5. These corner blocks appear to have gone backwards, apparently due to the wind, as their position on the ISO container was on the opposite side of their final resting location.

Table 5. Corner Block Information

ID	East	North	Elevation (m)	Code	Description	Weight (grams)	Mass Bin	Azimuth (°)	Range (m)
B4	669,346.68	6,567,849.93	137.118	I	CB X	21200	1	343.93	503.93
A7002	669381.20	6567344.38	135.878	I	CB1	11600	2	72.62	65.99
B6447	669724.48	6567336.86	137.732	I	CB2 & Frame	75000	1	71.78	409.35
S5611	669372.43	6567489.11	135.683	I	CB3 A	51100	1	2.27	153.19
Y4320	668,966.32	6,567,694.92	136.430	I	CB3 B	62000	1	295.27	492.76
C7762	669393.89	6567094.10	137.055	I	CB4	12500	1	143.09	264.83
A7000	669289.70	6567328.00	136.513	I	CB5	12200	1	214.04	31.74
A9101	669,343.32	6,567,582.46	135.825	I	CB6	16300	1	347.15	237.14
A9100	669,366.95	6,567,524.41	135.721	I	CB7	12200	1	356.60	184.80
T3324	669186.00	6567268.63	137.119	I	CB8	11500	2	219.13	151.16

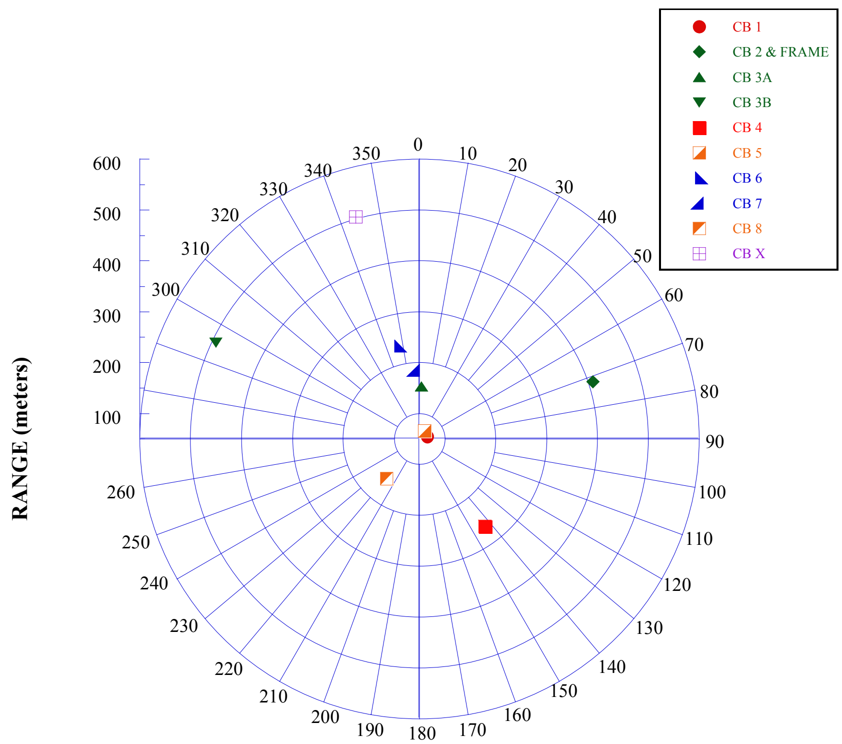


Figure 19 ISO-3 Corner Block Locations

Figure 210 shows the locations of the 50 farthest pieces of ISO container from ISO-3. The Maximum Fragment Distance (MFD) for a piece of container debris was 842.5 m (2,764.1 ft) at an azimuth of 2.4º. The three farthest pieces that were found were all parts of the closing/locking mechanism for the doors of the container.

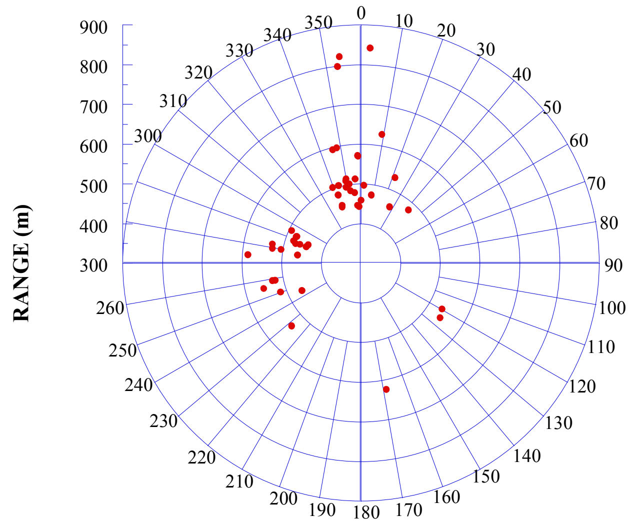


Figure 20 ISO-3 ISO Container Debris MFD

Figure 21 shows the locations of the 50 farthest primary fragments from both ISO-3 and ISO-3Cal. The MFD for a piece of non-container debris was 802.3 m (2,632.2 ft) at an azimuth of 3.0º. After this fragment, the next eight pieces were all from the projectile bodies themselves. The maximum range for a projectile body piece was 691.8 m (2,268.7 ft) at an azimuth of 282.9º.

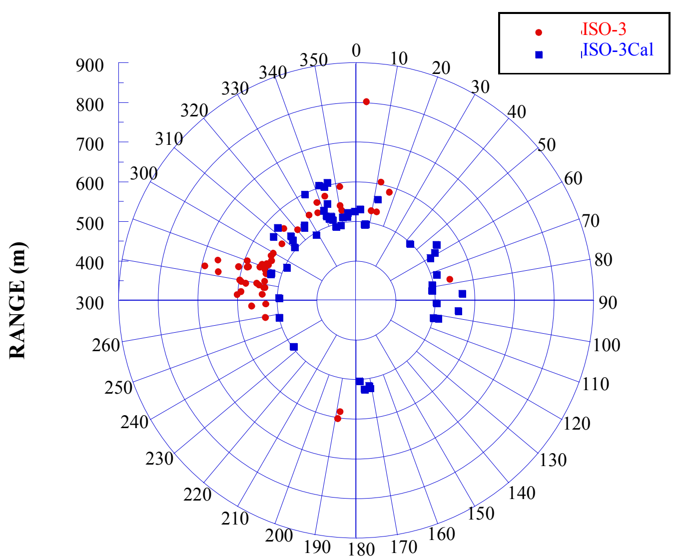


Figure 21 Primary Fragment MFD (ISO-3 and ISO-3Cal)

Debris Analysis Results

Debris Number Comparisons. Table 6 shows the number of ISO-3 ISO container pieces that were collected in each mass bin. Also shown on this table are the corresponding numbers recorded for ISO-1, which had the same nominal NEQ of 1054 kg (2,324 lbs). It should be remembered, however, that debris from only 185º of azimuth were collected on the ISO-1 event. Similar information is presented in Table 7, where the *Piece Count* data are presented as a percentage of the total number of pieces collected. The percentage information in this table is calculated relative to two debris totals – with and without Mass Bin G. The increased number of Mass Bin 10 pieces on ISO-3 versus ISO-1 can partly be attributed to the influence of primary fragments that seemed to have acted like a shredder, slicing the bottom portion of the ISO container, from what would have been Mass Bin 8 and 9 pieces, into a myriad of Mass Bin 10 pieces. A more detailed comparison of the ISO-1 and ISO-3 can be seen in a separate paper[7].

Table 6. ISO Container Debris—Piece Count Comparison

Mass Bin	Number of Pieces (Container Only)		Mass Bin	Number of Pieces (Container Only)	
	ISO-3	ISO-1*		ISO-3	ISO-1*
1	23	13	7	513	526
2	47	22	8	773	845
3	61	19	9	1,617	1,017
4	130	86	10	1,926	603
5	205	151	G	1,370	83
6	399	391	1--10 + G	7,064	3,756
			1--10	5,694	3,673

*Data collected over 185°

Table 7. ISO Container Debris—Percentage Comparison

Mass Bin	Percent of Total Pieces (Container Only)			
	ISO-3	ISO-1*	ISO-3	ISO-1*
1	0.33	0.35	0.40	0.35
2	0.67	0.59	0.83	0.60
3	0.86	0.51	1.1	0.52
4	1.8	2.3	2.3	2.3
5	2.9	4.0	3.6	4.1
6	5.6	10.4	7.0	10.6
7	7.3	14.3	9.0	14.3
8	10.9	23.0	13.6	23.0
9	22.9	27.7	28.4	27.7
10	27.3	16.4	33.8	16.4
G	19.4	2.3		
Total	100	100	100	100

*Data collected over 185°

Table 8 presents a comparison between the numbers of non-ISO container pieces (primary fragments) that were collected on ISO-3 and ISO-3Cal. Table 9 presents the same information as a percentage of the total numbers of pieces collected. The percentage information in this table is calculated relative to two debris totals – with and without Mass Bin G.

Table 8. Non-ISO Container Debris—Piece Count Comparison

Mass Bin	Number of Pieces (Weapon Fragments (P))		Mass Bin	Number of Pieces (Weapon Fragments (P))	
	ISO-3	ISO-3Cal		ISO-3	ISO-3Cal
1			7	1,807	1,816
2			8	8,038	8,726
3	3	2	9	19,360	22,040
4	8	2	10	20,533	23,230
5	199	200	G	9,985	9,156
6	201	162	1--10 + G	60,134	65,334
			1--10	50,149	56,178

Table 9. Non-ISO Container Debris—Percentage Comparison

Mass Bin	Percent of Total Pieces (Weapon Fragments (P))			
	ISO-3	ISO-3Cal	ISO-3	ISO-3Cal
1				
2				
3	0.005	0.003	0.006	0.004
4	0.013	0.003	0.016	0.004
5	0.33	0.31	0.40	0.36
6	0.33	0.25	0.40	0.29
7	3.0	2.8	3.6	3.2
8	13.4	13.4	16.0	15.5
9	32.2	33.7	38.6	39.2
10	34.1	35.6	40.9	41.4
G	16.6	14.0		
Total	100	100	100	100

The QRA software, SAFER[8], contains the mass distribution for an ISO container shown in Table 10. SAFER also defines an average value for the mass of steel in each mass bin. When this information is combined with the mass distribution, a Piece Count distribution can be defined. This is also shown in Table 10. This theoretical Piece Count distribution should be compared to the measured distribution shown in Table 6. This comparison is presented in Figure 22.

SAFER's ISO container distribution predicts no material in Mass Bins 1 or 2. Likewise, SAFER predicts no primary fragments in Mass Bins 1 through 5.

Table 10. SAFER ISO Container Distributions

PES Component	Mass (kg)	Percent Of Mass									
		Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
ISO-Container	2,232.1	0	0	5	5	5	15	20	25	15	10
PES Component	**Piece Count**	**Percent of Piece Count**									
		Bin 1	**Bin 2**	**Bin 3**	**Bin 4**	**Bin 5**	**Bin 6**	**Bin 7**	**Bin 8**	**Bin 9**	**Bin 10**
ISO-Container	75,426	0	0	0.05	0.12	0.29	2.1	6.6	19.1	25.8	45.9

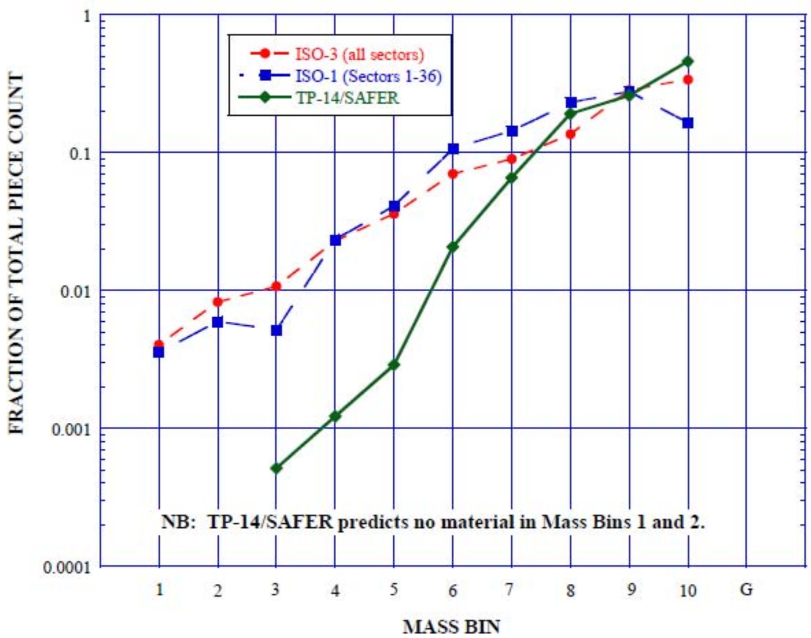


Figure 22 ISO Container Piece Count Distribution

Using the number of primary fragments in each mass bin shown in TP-14/SAFER for a single M1 projectile and the total number of projectiles used on each shot, the total number of primary fragments can be estimated. This predicted primary fragment piece count is given in Table 11 and should be compared with the measured results shown in Table 8 and Table 9. The results of this comparison are presented in Figure 23.

Table 11. Non-ISO Container Expected Number of (Primary) Debris Pieces

Debris Source	Mass Bin										Total
	1	2	3	4	5	6	7	8	9	10	
288 M1 Cartridges	0	0	0	0	0	576	5,760	28,512	64,512	115,488	214,848

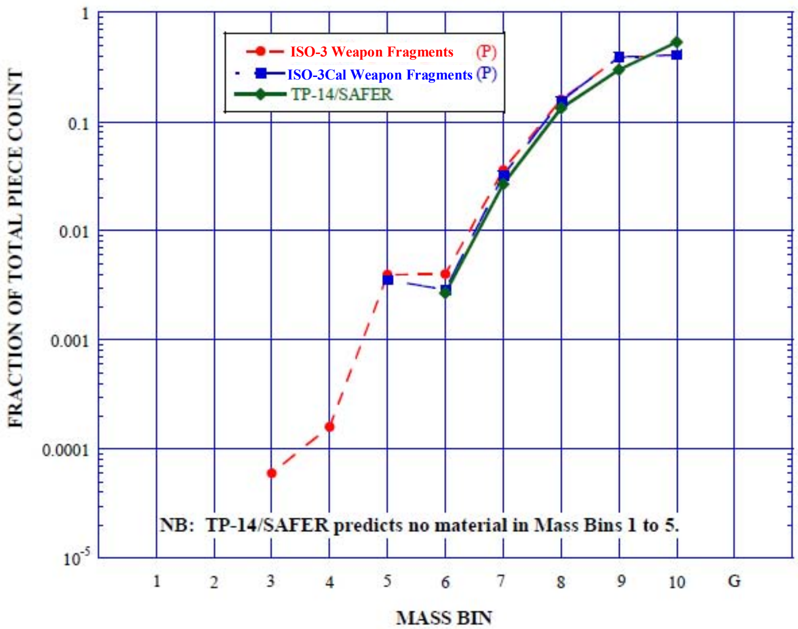


Figure 23 Non-ISO Container Debris Piece Count Distribution

Maximum Debris Range. U.S. DDESB Technical Paper 16 (TP-16)[9] gives the MFD for the U.S. 105 mm M1 projectile as 591 m (1,938.1 ft) for a single round detonation. It further indicates that the single round MFD should be multiplied by 1.33 to account for the increased range produced by the detonation of a stack of items. That would put the MFD for the stack configuration utilized on both ISO-3 and ISO-3Cal at 786 m (2,578.7 ft) (1.33*591). TP-16 further indicates that its methodology and algorithms "…do not address fragments produced by sections of nose plugs, base plates, boat tails, and/or lugs. These fragments from non-cylindrical portions of the case can travel to significantly greater distances …"

The TP-16 methodology is designed to produce an upper bound estimate for the MFD. The maximum range for a projectile body piece (i.e., a piece from the cylindrical portion of case) on either test was 691.8 m (2,269.7 ft). The maximum range for one of the cartridge case base plates was 802.3 m (2,632.2 ft). Figure 24 presents a comparison of the observed maximum ranges with these TP-16 estimates. Based on these results, the TP-16 methodology does appear to produce a satisfactory upper bound estimate.

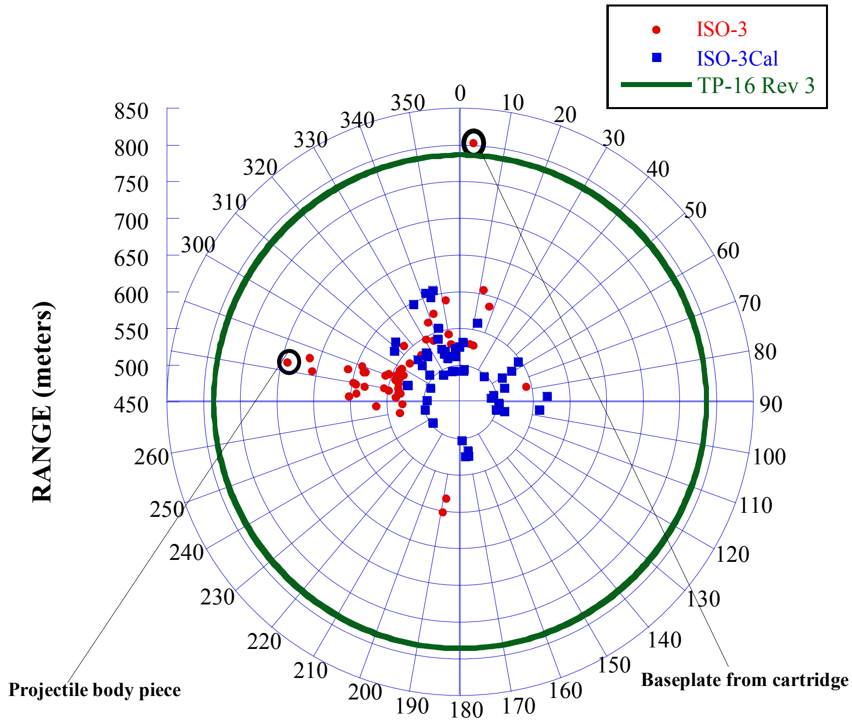


Figure 24 Non-Container Maximum Debris Ranges

Debris IBD. The debris data have been analyzed to estimate the Pseudo-Trajectory Normal (PTN) debris density[10] as a function of range for each azimuthal sector. The PTN debris IBD is defined as the range at which the PTN density of hazardous fragments falls below a value of 1 per 55.7 m^2 (600 ft^2). A hazardous fragment is defined as a fragment with an impact kinetic energy of at least 79 Joules (58 ft-lb).

In this analysis, the above criteria corresponds to all material in Mass Bins 1 through 7 and 20% of the material in Mass Bin 8. It should be pointed out, however, that this is an approximation based on several initial assumptions. Other initial assumptions would lead to the inclusion of a different percentage of material in Mass Bin 8. Figure 25 presents the *container only* debris IBD determined for ISO-3. Also shown on this figure is the debris IBD reported for the ISO-1 event, considering only the ISO container material, not the truck (NB: The same coordinate system was not used on these two events. The ISO-1 results that are shown have been converted to the ISO-3 coordinate system.)

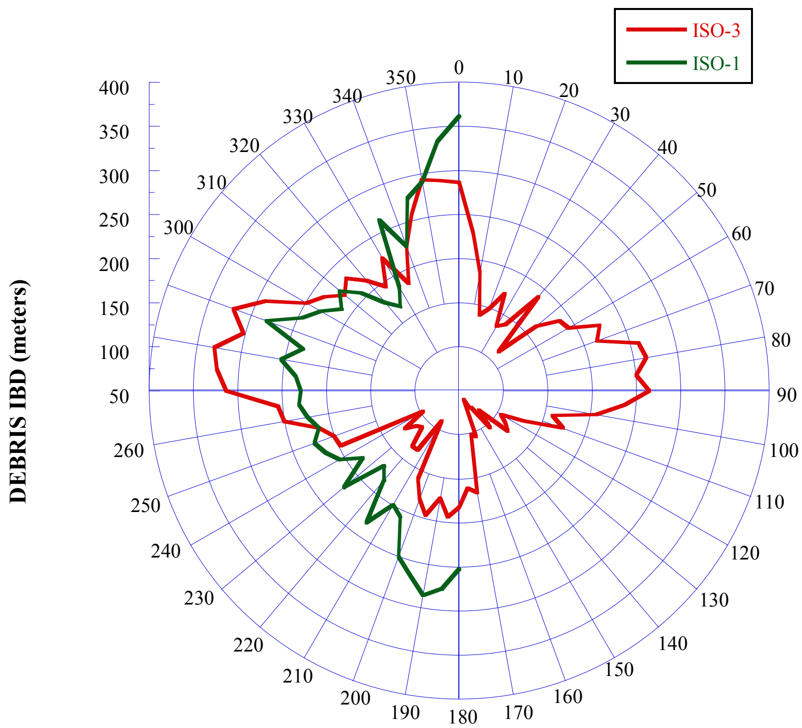


Figure 25 ISO Container PTN Debris IBD

If the ISO-1 data shown in Figure 25 are averaged over an azimuth range of 182.5º to 2.5º (the extent of the ISO-1 data), an average PTN debris IBD of 234.4 m (762.5 ft) is obtained. When the ISO-3 *container only* data are averaged over the same range, a debris IBD of 215.7 m (707.7 ft) is calculated. When the ISO-3 *container only* data are averaged over the full 360º of azimuth, a value of 189.4 m (621.4 ft) is obtained.

Figure 26 compares the *non-container* debris (primary fragment) IBD determined from the ISO-3 results with the debris IBD calculated for the ISO-3Cal event. When these data sets are averaged over the full 360º of azimuth, a value of 270.9 m (888.8 ft) is obtained for ISO-3 *non-container* debris IBD and 277.3 m (909.8 ft) for ISO-3Cal debris IBD.

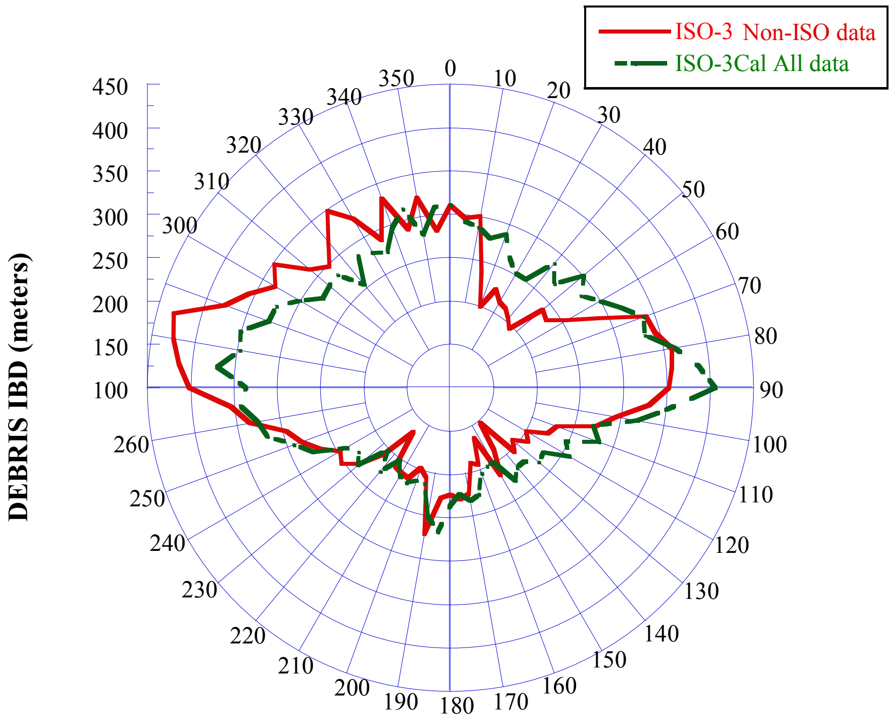


Figure 26 Non Container PTN Debris IBD

The single item Hazardous Fragment Distance (HFD) for the M1 projectile is 103.9 m (340.9 ft) (NB: The HFD can be considered as being the same as the debris PTN IBD). For the stack configuration shown in Figure 2, the number of items on the side of the stack is 24 and the number of items on the top layer is 48. Based on this geometry, the side of the stack is defined as the azimuths between 35º and 145º and 215º to 325º. Using the TP-16 procedures, the HFD for a stack such as that shown in Figure 2 is 290.5 m (953.1 ft). When the ISO-3 and ISO-3Cal data are averaged over the azimuths of 35º-145º and 215º to 325º, a PTN IBD of 285.0 m (935.0 ft) is calculated for ISO-3 and 290.0 m (951.4 ft) for ISO-3Cal.

It has been proposed, in a separate paper[11], that for many types of structures, the cube root of the PTN IBD may be a function of only the explosive loading density within the structure. Since this hypothesis was originally proposed, additional data including the most recent ISO-3 results have become available. These are shown in Figure 27. The ISO-3 debris data can also be used to determine what contribution each element makes to the total debris IBD; i.e., what is the contribution of the ISO container debris and what is the contribution of the ISO container contents? These elements can be seen in Figure 28. The average overall debris IBD is 284.3 m (932.7 ft). The *non-container* debris is the largest contributor—270.9 m (888.8 ft). The *container only* debris IBD was just 189.4 m (621.4 ft). Thus, the apparent controlling factor in this scenario is the primary fragments produced by the projectiles.

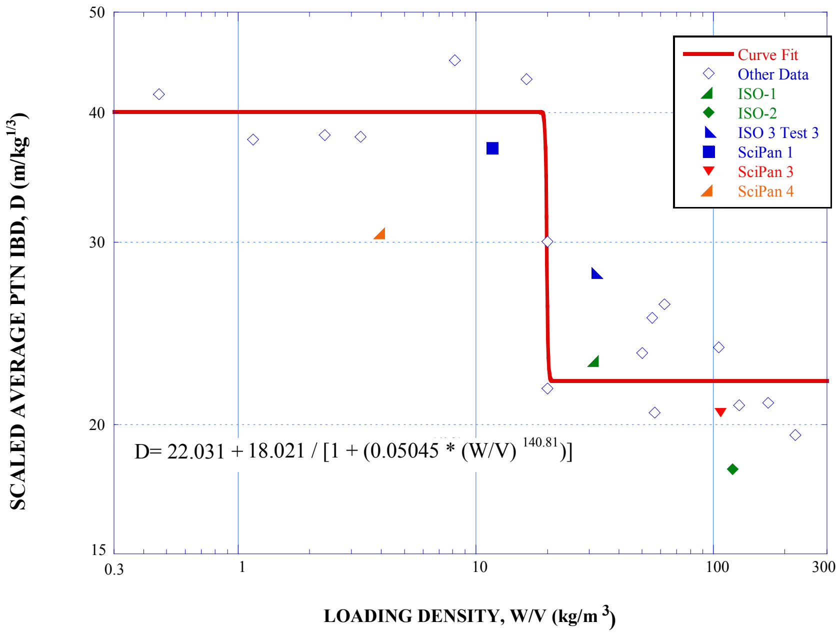


Figure 27 Scaled PTN Debris IBD

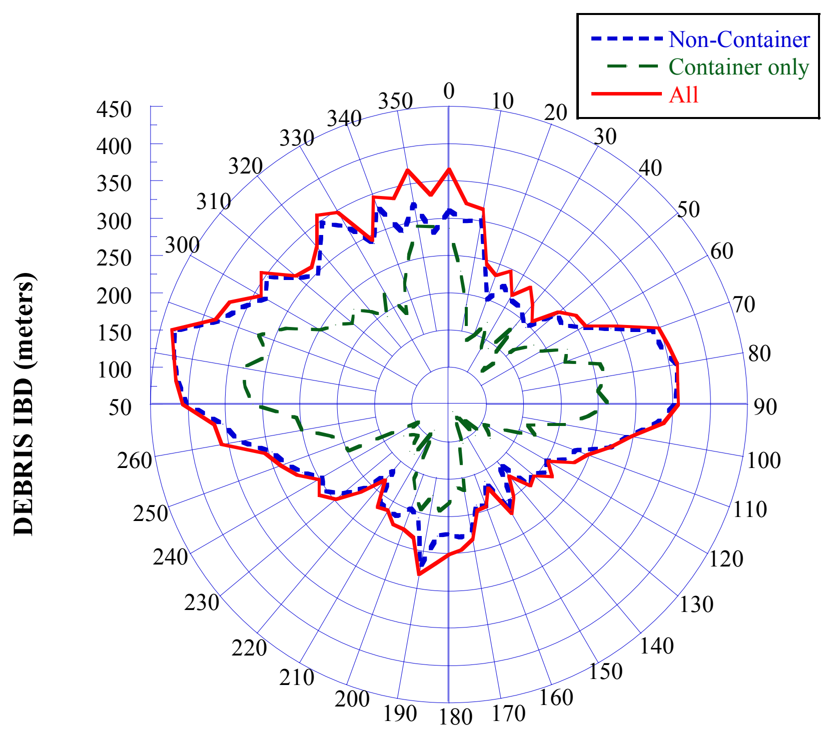


Figure 28 Debris IBD PTN Components—ISO-3

Collection Efficiency.

Both DCC efforts were scheduled to last ten working days. The ISO-3 effort had to be completed so that the ISO-3Cal charge could be assembled and detonated on time. The ISO-3Cal collection was required to be completed by Friday, 3 April 2009, so that personnel could be released for the Easter holidays. The estimated collection efficiencies are shown in Table 12. Previous test efficiencies are included for reference purposes. The collection pace on the ISO-3 event was slightly slower than for ISO-3Cal. This could be correlated to the slightly higher miss rate that was observed for ISO-3Cal.

Table 12. DCC Efficiency

EVENT	Points	Time (man-hours)	Efficiency (points/man-hour)
ISO-3Cal	65,739	2,410	27.3
ISO-3	67,865	3,022	22.5
SciPan 4*	22,472	1,757	12.8
ISO-2	25,144	2,205	11.4
ISO-1	4,585	950	4.8

* SciPan 4 efficiencies do not reflect additional points collected on DIRT 4.1 and DIRT 4.2

Another measure of collection efficiency is to calculate the fraction of the total container mass that was recovered during the collection process. Combining mass collected in the Far Field and Near Field, a total of 1,679.9 kg (3,703.5 lb) of container material was recovered. Table 1 gives the empty weight of a container as 2,400 kg (5,290 lb). Therefore, about 75% of the total container mass was recovered. However, it was noted that the majority of the floor of the ISO container stayed in the crater. Assuming that the entire floor mass, approximately 650 kg (1433 lb), is accounted for within the crater means about 95% of the container material was recovered.

Summary and Conclusion

One of the chief goals of the ISO-3 event was to increase understanding of the effects of primary fragments on the breakup of ISO containers. More generally, the goal was to increase understanding of the characteristics of an explosive event inside of an ISO container. As was the case with ISO-1 and ISO-2, ISO-3 has provided a source of invaluable data that will help reach that goal and will lead to improved models and algorithms used in the field of explosives safety. For example, comparing the test results to the predictions generated from TP-14/SAFER can highlight areas in the model that need attention. Comparing the test results to TP-14/SAFER brings to light the need to improve predictions in the lower mass bins for both the ISO container and non-ISO container distributions. Comparing the non-ISO container test results to the TP-16 methodology, it can be noted that TP-16 appears to produce an agreeable upper bound estimate for the maximum fragment distance.

While the results and analyses presented in this paper are still undergoing further refinement, it can be seen that the fragments produced by the M1 projectiles dominates the debris IBD and heavily influences the generation of smaller sized debris pieces. However, it should be noted that although more primary fragments were generated and went the farthest, the largest pieces, which are therefore the most energetic and dangerous to people in sturdy structures, were all ISO container pieces. This means that while being inside of a building or structure would afford protection from the smaller primary fragments, the larger ISO container debris pieces would still pose a significant risk to people inside of the building. The ISO-3 events also demonstrated the repeatability of debris produced from the detonation of stacks of M1 munitions. Furthermore, the ISO-3 tests have afforded insight into several ways to improve data collection in the field. The most important of these is the need to add debris category codes to distinguish between the ISO container skin and brace, which will yield greater data fidelity to develop more accurate models. In addition, being able to distinguish between the roof and walls of the ISO container would also greatly improve model accuracy.

References

1. Swisdak, Michael M., Conway, Robert, and Cotton, Lea Ann, "Project ESKIMORE—The DDESB Long-Term Testing Initiative," Minutes of 33rd DDESB Seminar, 12-14 August, 2008.
2. Swisdak, Michael M. and Tatom, John W., "Characterization Of An Explosion Inside An ISO Container Located On A Truck," IHTR 2837, 22 Feb 2007.
3. Swisdak, Michael M., Conway, Robert, Tatom, John, and Davis, Jesse, "ISO-2: Program Description and Data Summary," IHTR 3000, 1 March 2009.
4. Swisdak, Michael M., "TNT Equivalence Of Selected U.S. Army Gun Propellants," IHTR 1741, 2 December 1994.
5. Swisdak, Michael, Tancreto, James, and Tatom, John, "SciPan 1 and SciPan 2 Response of Reinforced Concrete Tiltup Construction to Blast Loading," NAVFAC ESC TM-2371-SHR, July 2004.
6. Swisdak, Michael M., Conway, Robert, and Tatom, John W., "ISO-3 Quick-LookReport," PFP (AC/326-SG5&6)(US)IWP 09-2009, 16 October, 2009.
7. Davis, Jesse D, Tatom, John W., Swisdak, Michael M., and. Conway, Robert T, "ISO-3 Debris Data Visualization and Comparison to ISO-1 Results," Minutes of 9th Australian Ordnance Symposium, PARARI 2009, November, 2009.
8. Hardwick, Meredith J., Hall, John, Tatom, John W., and Baker, Robert G., "Approved Methods and Algorithms for DoD Risk-Based Explosives Siting," DDESB Technical Paper 14 Revision 4, 21 July 2009.
9. Swisdak, Michael M., Crull, Michelle M., and Hamilton, Susan D., "Methodologies For Calculating Primary Fragment Characteristics," DDESB Technical Paper 16 Revision 3, 1 April 2009.
10. Swisdak, Michael M., Tatom, John W., and Hoing, Craig, "Procedures for the Collection, Analysis, and Interpretation of Explosion-Produced Debris—Revision 1," DDESB Technical Paper 21, 22 October 2007.
11. Swisdak, Michael, "Debris Based Inhabited Building Distances for Aboveground Structures," Minutes of 31st DoD Explosives Safety Seminar, August 2004.

ISO-3 Program Summary and Results

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Background

Event	ISO-1
Date	May 18, 2006
PES Type	ISO Container (on Truck)
Donor Material	Ammonium Nitrate/Fuel Oil (ANFO)
Net Explosive Weight (kg)	1054
Type of Debris Collection	185 degree recovery

Event	ISO-2
Date	March 21, 2007
PES Type	ISO Container (on Truck)
Donor Material	Ammonium Nitrate/Fuel Oil (ANFO)
Net Explosive Weight (kg)	4000
Type of Debris Collection	360 degree recovery

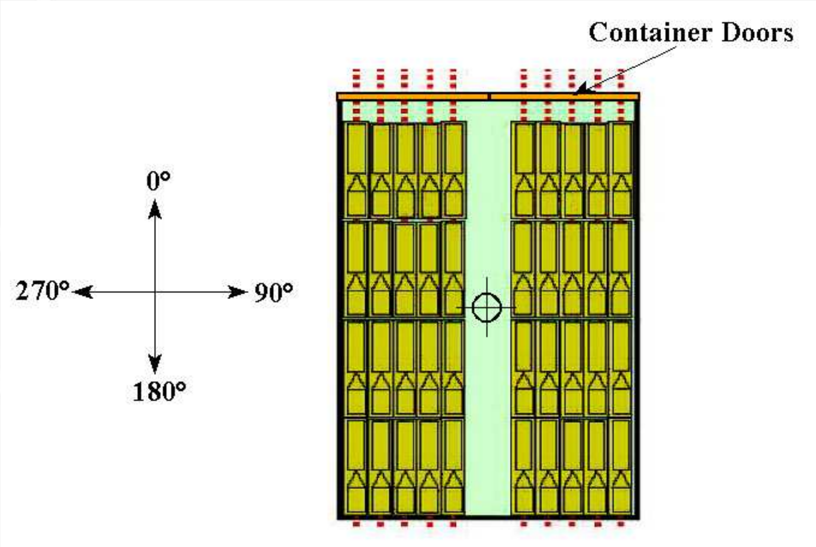
Event	ISO-3 / ISO-3 Cal
Date	March 08, 2009 / March 24,2009
PES Type	ISO Container / Open
Donor Material	M1 105mm projectiles and their associated propellant cartridges
Net Explosive Weight (kg)	1054
Type of Debris Collection	Full 360 degree recovery

ISO-3 / ISO-3Cal Overview

ISO-3 PES


Actual Charge Arrangement


Coordinate System



Charge Description:

Australian-produced M1 105 mm cartridges (288) in wooden packaging boxes (18).

NEQ of round = 3.6kg (HE + Propellant)

Sponsors and Partners

Funding for this test was provided by the following organizations:

- U. S. Department of Defense Explosives Safety Board
- U. S. Army Technical Center For Explosives Safety (USATCES)
- Personnel from or provided by the following organizations participated in the post-detonation debris mapping:
  - U. S.
    - Indian Head Division/Naval Surface Warfare Center
    - Naval Facilities Engineering Service Center
    - USATCES
    - Army Engineering and Support Center, Huntsville
    - DDESB
    - Naval Air Warfare Center—Weapons Division
    - A-P-T Research, Inc. (APT)
  - UK
    - Defense Ordnance Safety Group
  - Australia
    - Directorate of Trials
    - Australian Defence Forces
    - CR Kennedy, Surveyors
  - Singapore
    - Defense Science and Technology Agency (DSTA)

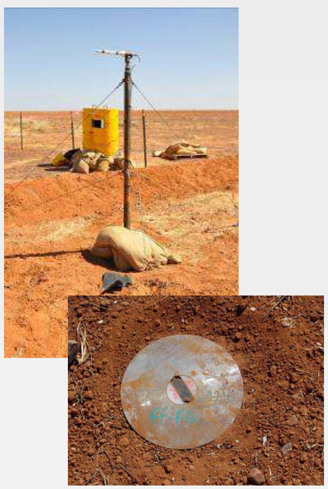
Objectives

- Determine the debris distribution/characteristics produced by a detonation inside a standard ISO container with a typical explosive load of fragmenting AE
- Determine the external airblast attenuation provided by a detonation inside a standard ISO container with a typical explosive load of fragmenting AE
- Determine the debris IBD arc for an ISO container of fragmenting AE
- Quantify the differences between the ISO-1 and ISO-3 events
- Compare the primary fragment behavior of a stack inside an ISO container to an identical stack in the open

ISO-3 Detonation Sequence

Data Collection

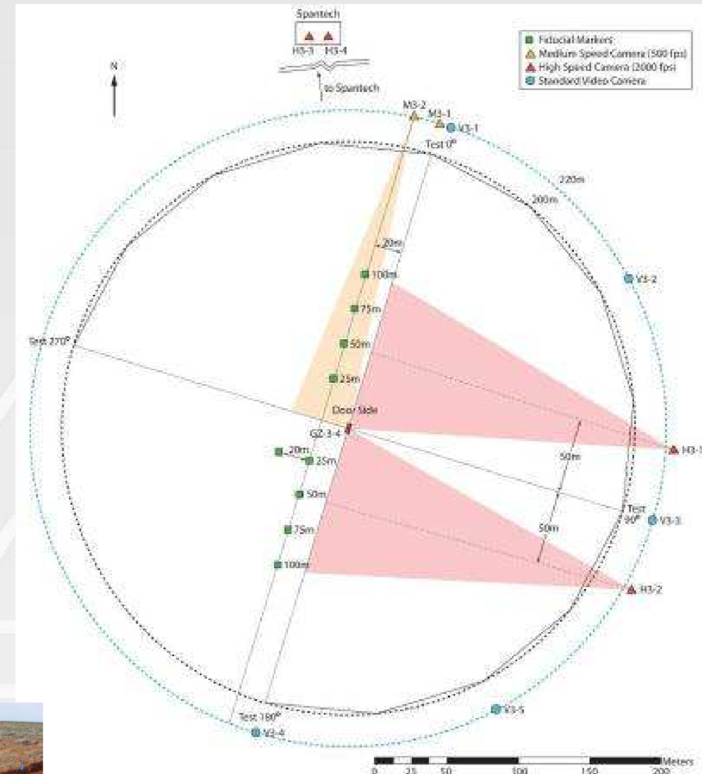
- The following data were collected for both ISO-3 and ISO-3Cal:
  - Airblast (analysis is preliminary and still undergoing further scrutiny)
  - Debris catalog (range, bearing, mass, source) over 360º of azimuth
  - Multiple views with high speed (500 to 3000 frames per second (fps)) video
  - Multiple views with normal speed video
  - 3-D Laser Scan of Ground Zero (GZ) Area



Pencil and Ground Mount Gauge

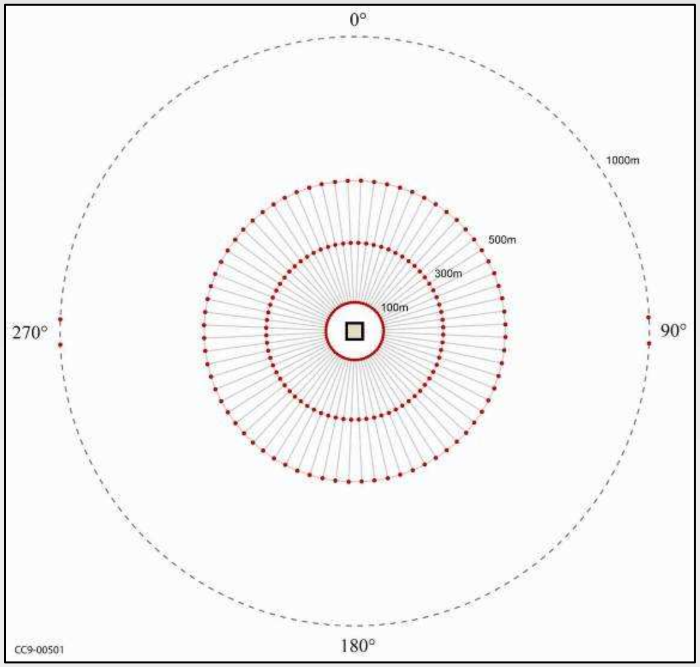
Video Analysis

Camera Shelter



Camera Layout

Debris Catalog – Collection Grid



Collection Grid

Category Code	Source
I	ISO Container
P	Projectile, cartridge case, packaging
U	Unknown
F	Crater ejecta, star picket
G	Instrumentation transducer

Debris Category Codes

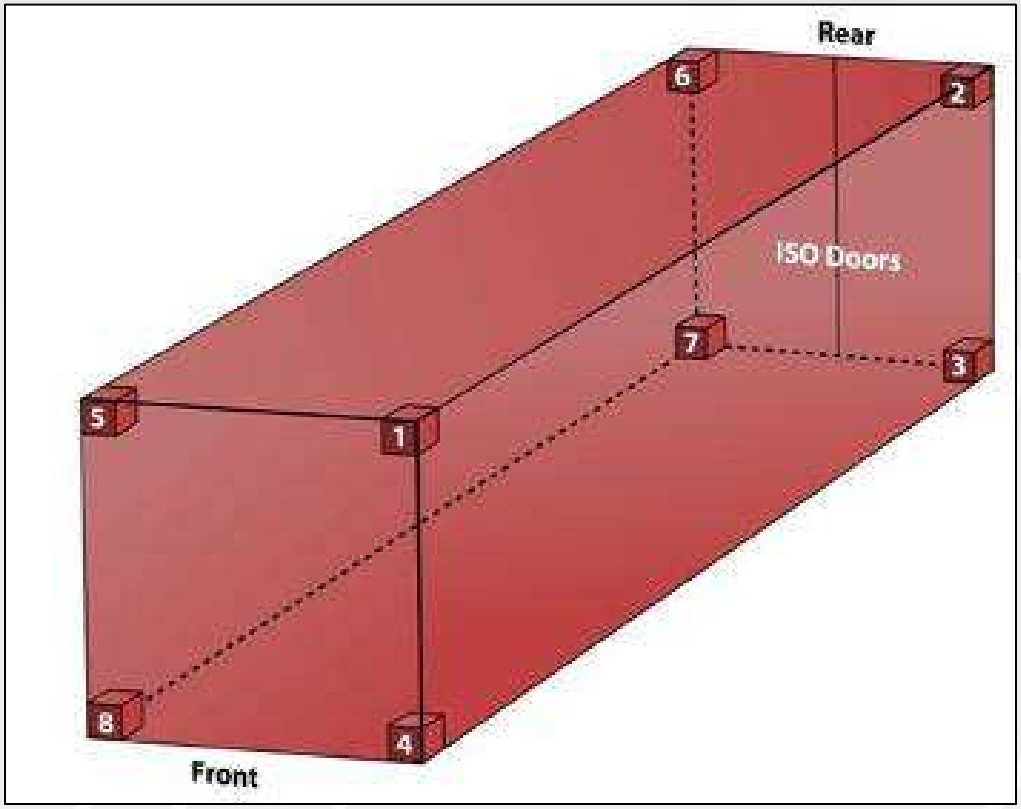
Flagging Team

Flagged Area

Debris Catalog – Corner Blocks

Corner Block

Number on Corner Block



Corner Block Numbering Scheme

Debris Catalog – Mass Bins

Bin Number	STEEL WEIGHT (lbs)	STEEL WEIGHT (oz)	STEEL SIZE* (in)	STEEL WEIGHT (kg)	STEEL WEIGHT (g)	STEEL SIZE* (mm)
1	>26	>416	>5.5	>11.8	>11,793	>140
2	10 - 26	160 - 416	4.1 - 5.5	4.54 - 11.8	4,536 - 11,793	104 - 140
3	4.5 - 10	72 - 160	3.1 - 4.1	2.04 - 4.54	2,041 - 4,536	79 - 104
4	1.8 - 4.5	28.8 - 72	2.3 - 3.1	0.82 - 2.04	816 - 2,041	58 - 79
5	0.8 - 1.8	12.8 - 28.8	1.8 - 2.3	0.36 - 0.82	363 - 816	46 - 58
6	0.3 - 0.8	4.8 - 12.8	1.3 - 1.8	0.14 - 0.36	136 - 363	33 - 46
7	0.14 - 0.3	2.24 - 4.8	1.0 - 1.3	0.06 - 0.14	64 - 136	25 - 33
8	0.06 - 0.14	0.96 - 2.24	0.7 - 1	0.03 - 0.06	27 - 64	18 - 25
9	0.025 - 0.06	0.4 - 0.96	0.56 - 0.7	0.01 - 0.03	11.3 - 27	14 - 18
10	0.013 - 0.025	0.21 - 0.40	0.28 - 0.56	0.006 - 0.01	5.9 - 11	7.1 - 14
G	<0.013	<0.21	<0.28	<0.006	<5.9	<7.1

*Assumes spherical shape

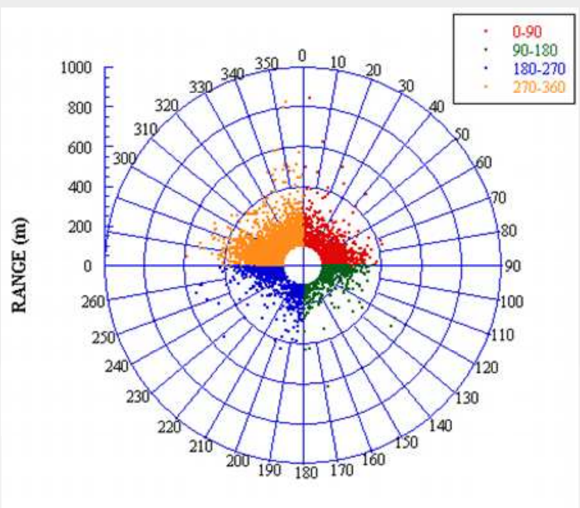
Debris Catalog Results – Pieces

Summary Statistics

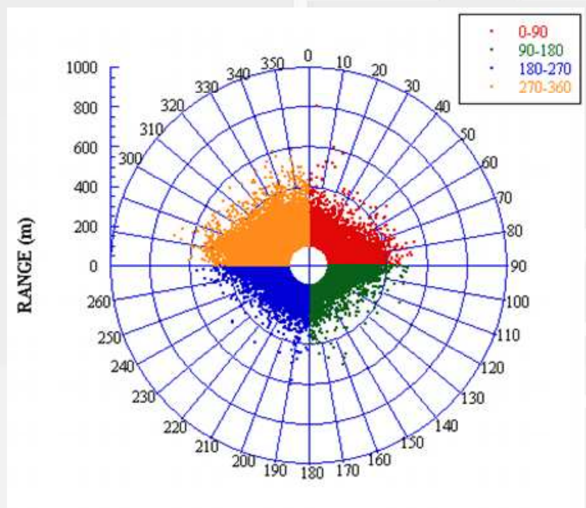
Statistic	ISO-3*				ISO-3Cal **	
	ISO (I)		Primary (P)		Primary (P)	
	Mass Bins 1--10 + G	Mass Bins 1--10	Mass Bins 1--10 + G	Mass Bins 1--10	Mass Bins 1--10 + G	Mass Bins 1--10
Piece Count	7,064	5,694	60,134	50,149	65,334	56,178
Mean Mass (grams)	223.2	275.9	20.1	23.2	19.6	22.1
Mode Mass (grams)	5	6	5	6	6	6
Minimum Mass (grams)	1	6	1	6	1	6
Maximum Mass (grams)	75,000	75,000	2,693	2,693	2,562	2,562
Mass Range (grams)	74,999	74,994	2,692	2,687	2,561	2,556

*Does not include 41 pieces in other Category Codes

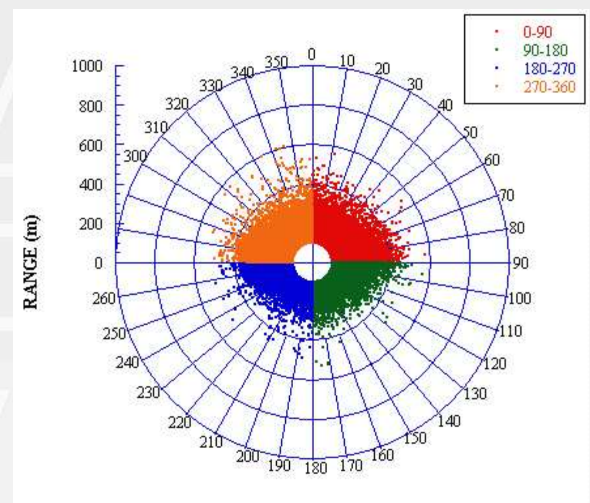
**Does not include 2 pieces in other Category Codes



ISO-3 Container Debris



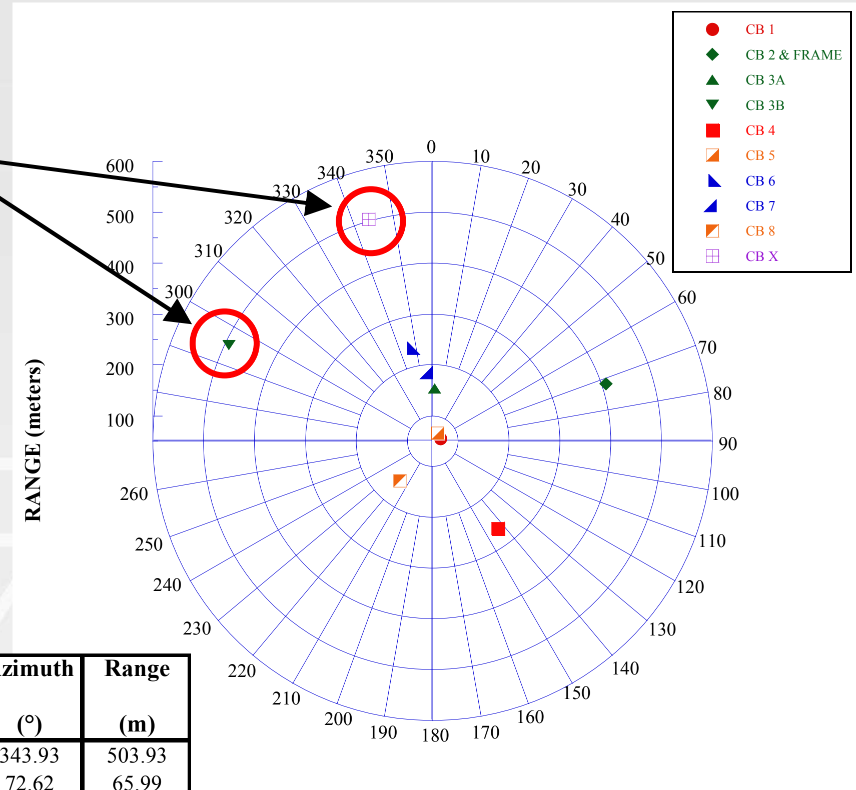
ISO-3 Non-Container Debris



ISO-3Cal Non-Container Debris

Debris Catalog Results – Corner Blocks

Removed from data set



Corner Block Locations

Corner Block Information

ID	East	North	Elevation (m)	Code	Description	Weight (grams)	Mass Bin	Azimuth (°)	Range (m)
B4	669,346.68	6,567,849.93	137.118	I	CB X	21200	1	343.93	503.93
A7002	669381.20	6567344.38	135.878	I	CB1	11600	2	72.62	65.99
B6447	669724.48	6567336.86	137.732	I	CB2 & Frame	75000	1	71.78	409.35
S5611	669372.43	6567489.11	135.683	I	CB3 A	51100	1	2.27	153.19
Y4320	668,966.32	6,567,694.92	136.430	I	CB3 B	62000	1	295.27	492.76
C7762	669393.89	6567094.10	137.055	I	CB4	12500	1	143.09	264.83
A7000	669289.70	6567328.00	136.513	I	CB5	12200	1	214.04	31.74
A9101	669,343.32	6,567,582.46	135.825	I	CB6	16300	1	347.15	237.14
A9100	669,366.95	6,567,524.41	135.721	I	CB7	12200	1	356.60	184.80
T3324	669186.00	6567268.63	137.119	I	CB8	11500	2	219.13	151.16

Debris Catalog Results – Piece Count Comparisons

How does the ISO-3 event compare to ISO-1?

Are the effects of primary fragments on the breakup of the ISO container noticeable?

ISO-3 / ISO-1 Container Piece Comparison

Mass Bin	Number of Pieces (Container Only)		Mass Bin	Number of Pieces (Container Only)	
	ISO-3	ISO-1*		ISO-3	ISO-1*
1	23	13	7	513	526
2	47	22	8	773	845
3	61	19	9	1,617	1,017
4	130	86	10	1,926	603
5	205	151	G	1,370	83
6	399	391	1--10 + G	7,064	3,756
			1--10	5,694	3,673

*Data collected over 185°

ISO-3 / ISO-1 Container Percent of Total Comparison

Mass Bin	Percent of Total Pieces (Container Only)			
	ISO-3	ISO-1*	ISO-3	ISO-1*
1	0.33	0.35	0.40	0.35
2	0.67	0.59	0.83	0.60
3	0.86	0.51	1.1	0.52
4	1.8	2.3	2.3	2.3
5	2.9	4.0	3.6	4.1
6	5.6	10.4	7.0	10.6
7	7.3	14.3	9.0	14.3
8	10.9	23.0	13.6	23.0
9	22.9	27.7	28.4	27.7
10	27.3	16.4	33.8	16.4
G	19.4	2.3		
Total	100	100	100	100

*Data collected over 185°

Debris Catalog Results – Piece Count Comparisons

ISO-3 / ISO-3Cal Non-ISO Container Piece Comparison

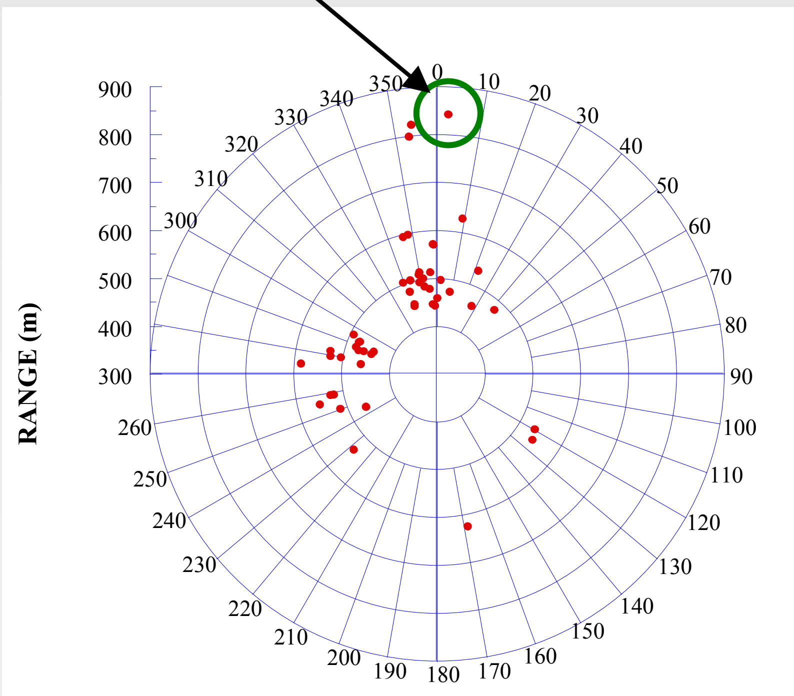
Mass Bin	Number of Pieces (Weapon Fragments (P))		Mass Bin	Number of Pieces (Weapon Fragments (P))	
	Test 3	Test 4		Test 3	Test 4
1			7	1,807	1,816
2			8	8,038	8,726
3	3	2	9	19,360	22,040
4	8	2	10	20,533	23,230
5	199	200	G	9,985	9,156
6	201	162	1--10 + G	60,134	65,334
			1--10	50,149	56,178

ISO-3 / ISO-3Cal Non-ISO Container Percent of Total Comparison

Mass Bin	Percent of Total Pieces (Weapon Fragments (P))			
	Test 3	Test 4	Test 3	Test 4
1				
2				
3	0.005	0.003	0.006	0.004
4	0.013	0.003	0.016	0.004
5	0.33	0.31	0.40	0.36
6	0.33	0.25	0.40	0.29
7	3.0	2.8	3.6	3.2
8	13.4	13.4	16.0	15.5
9	32.2	33.7	38.6	39.2
10	34.1	35.6	40.9	41.4
G	16.6	14.0		
Total	100	100	100	100

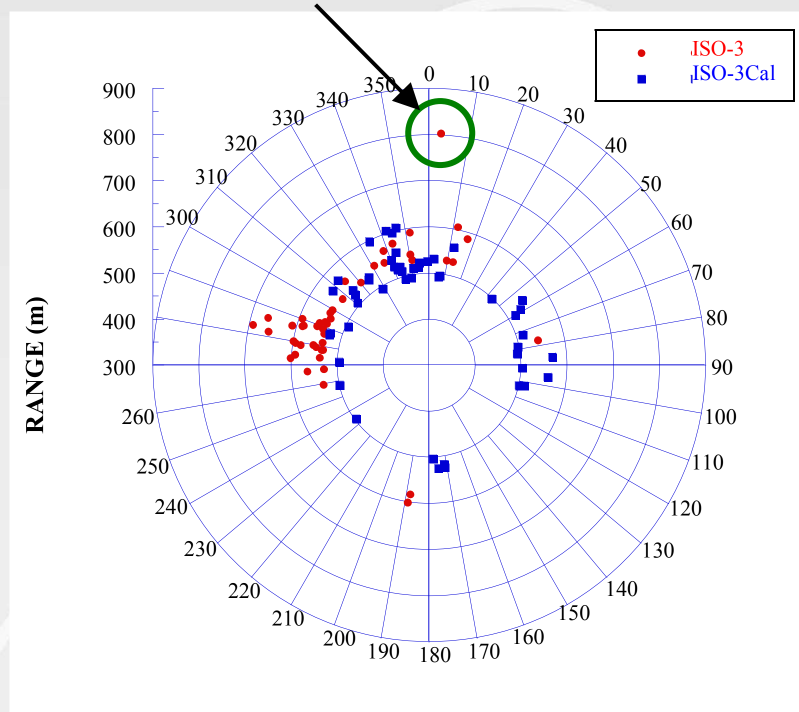
Debris Catalog Results – Maximum Fragment Distance

842.5 m



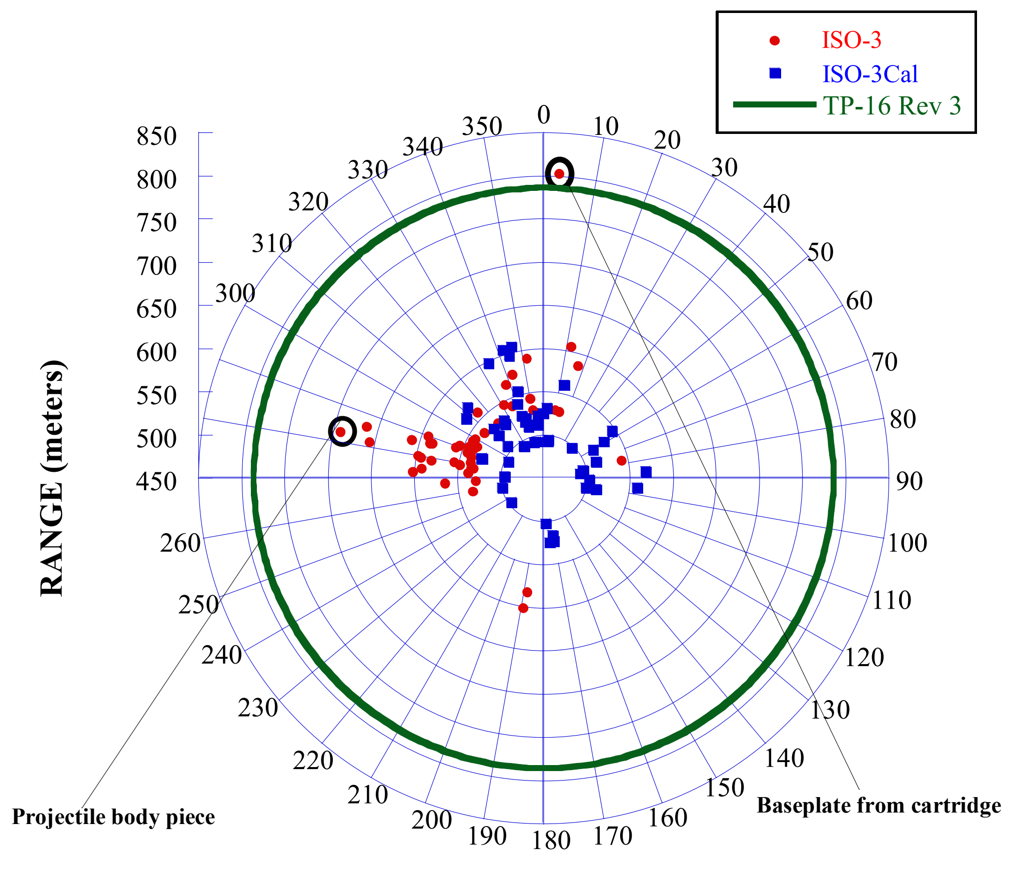
ISO-3 ISO Container MFD (50 Farthest Pieces)

802.3 m



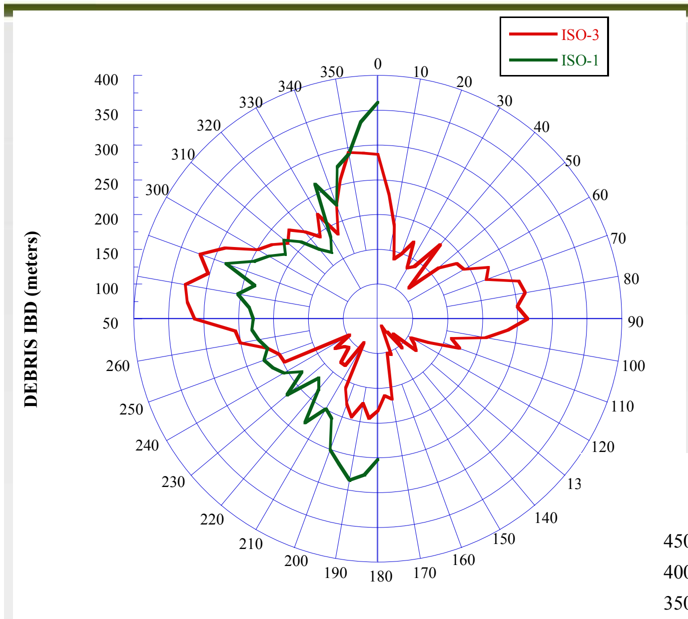
ISO-3 / ISO-3Cal Primary Fragment MFD (50 Farthest Pieces)

Debris Catalog Results – Maximum Fragment Distance

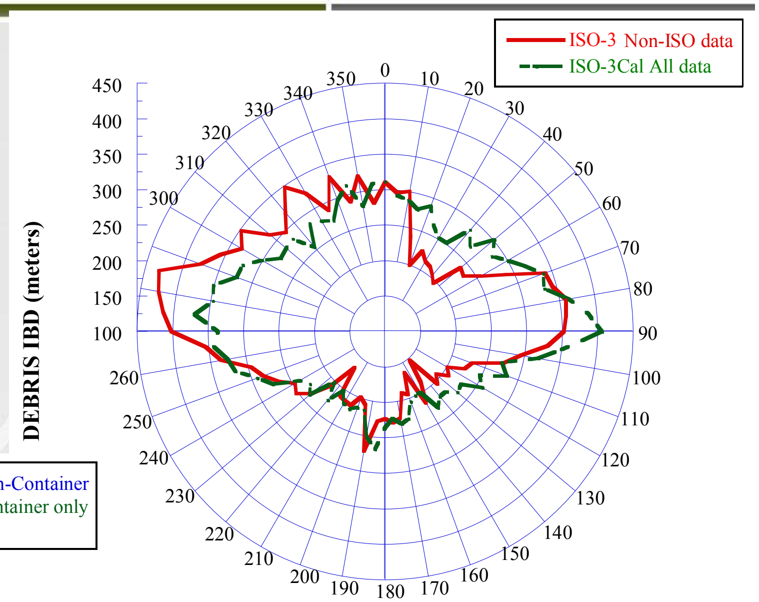


Primary Fragment Debris Ranges

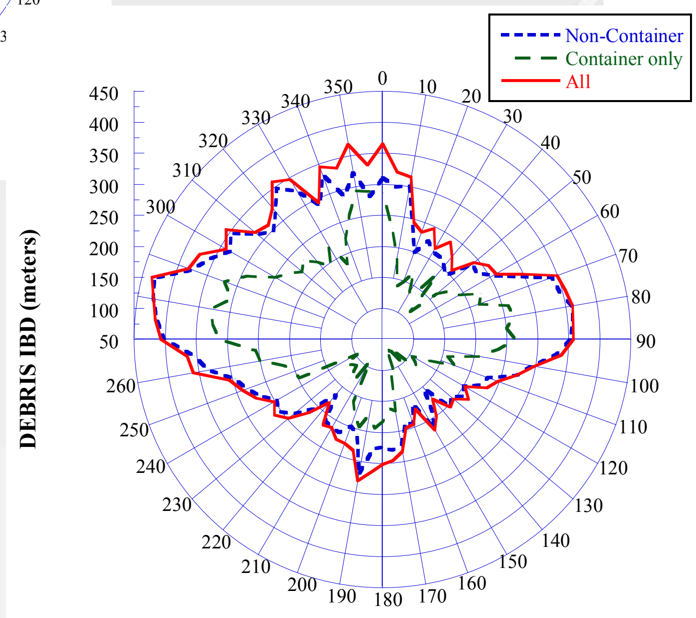
Debris Catalog Results – Debris IBD



ISO-3 / ISO-1 ISO Container Debris IBD

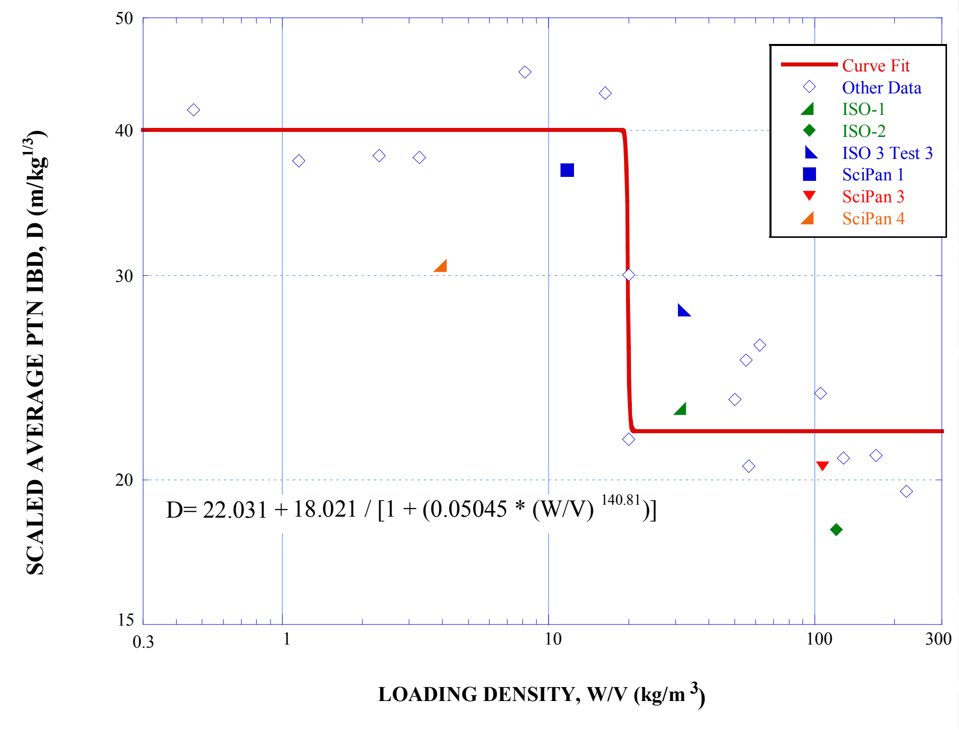


ISO-3 / ISO-3Cal Non-ISO Container Debris IBD



ISO-3 Average Overall Debris IBD

Debris Catalog Results – Scaled PTN Debris IBD



Debris Catalog Results – Collection Efficiency

Event	Points	Time (man-hours)	Efficiency (points/man-hours
ISO-3Cal	65,739	2,410	27.3
ISO-3	67,865	3,022	22.5
SciPan 4*	22,472	1,757	12.8
ISO-2	25,144	2,205	11.4
ISO-1	4,585	950	4.8

*SciPan 4 efficiencies do not reflect additional points collected on DIRT 4.1 and DIRT 4.2

Summary and Conclusions

- Fragments produced by the M1 projectiles dominates the debris IBD and heavily influences the generation of smaller sized debris pieces.
- Although more primary fragments were generated and went the farthest, the largest pieces, which are therefore the most energetic and dangerous to people in sturdy structures, were all ISO container pieces.
- The ISO-3 events also demonstrated the repeatability of debris produced from the detonation of stacks of M1 munitions.
- The ISO-3 tests have afforded insight into several ways to improve data collection in the field.
  - Add debris category codes to distinguish between the ISO container skin and brace.
  - Add debris category codes to distinguish between the roof and walls of the ISO container.