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Procedures for the Collection, Analysis, and Interpretation of Explosion-Produced Debris

Department of Defense Explosives Safety Board

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14. ABSTRACT

Explosion-produced debris can be a major contributor to many aspects of explosives safety. This document discusses procedures for the collection, analysis, and interpretation of such data. It is based on the authors' many years of collective experience working in these areas. The original version of this document was released in 1999 and Revision 1 in 2007. This new document, Revision 2, updates the information contained in Revision 1, describes, advances to the state-of-the- art, includes specific recommendations regarding collection and analysis procedures, and includes as an attachment a bibliography of reports and publications of explosion-produced debris that have been published since 1962.

15. SUBJECT TERMS

Explosion-Produced-Debris	Debris Density	Inhabited Building Distance	Actual Debris Density
Debris	Debris Analysis	Pseudo-Trajectory Normal	
Debris Collection	Hazardous Fragment Distance	Modified Pseudo-Trajectory Normal	

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FOREWORD

Department of Defense Explosives Safety Board (DDESB) Technical Paper (TP) 21 Revision 2 provides guidance and recommendations for the collection and analysis of explosion produced debris. This document represents a revision of the previous version of this document released in 2007. Because this document was originally derived from a NATO document, the International System of Units (SI) has been used throughout.

This document will be kept current and will be updated as new methodologies are developed. The most recent version of the document can be found on these Web pages:

http://www.ddesb.pentagon.mil and https://www.denix.osd.mil/ddes/ddes-technical-papers/

This Technical Paper has been reviewed by the DDESB Staff and the Voting Board Members.

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1.0 INTRODUCTION

1.1 Background/History

In 1997, Michael Swisdak from the Naval Surface Warfare Center/Indian Head Division in the United States and Michael Gould from the United Kingdom Defense Ordnance Safety Group were asked by the Ad Hoc Technical Working Party of the NATO AC/258 Storage Sub-Group to "generate a paper on the overall subject of debris collection and analysis" [Reference 1-1]. The result of this effort was a paper that was ultimately released as a NATO D/Document in 1999 [Reference 1-2]. Subsequent to its release there were numerous improvements in both collection techniques and analysis methodologies, so in 2006 a revision to this document was deemed not only timely, but also necessary, and members of the NATO debris analysis community requested that a review of the 1999 document be undertaken in order to update or revise it as necessary [Reference 1-3]. The result was released in 2007 as Revision 1 to DDESB Technical Paper 21 [Reference 1-4].

Since 2007, there have been several testing programs that have incorporated debris cataloging and recovery efforts. The lessons learned from those programs have contributed significantly to the current state-of-the-art. In addition, existing analysis techniques have been refined, new techniques developed, and several analysis techniques have been standardized. As a result of all of these elements, it was decided that an update to Revision 1 of TP-21 was warranted.

As a background example as to why this paper was originally developed, the following hypothetical scenario, based on the experience of the original paper's authors (Gould and Swisdak), can be considered:

> An earth-covered explosives storage magazine (ECM) is filled to a high loading density with Hazard Division (HD) 1.1, mass detonating material. An accident occurs, causing the initiation of all of the structure's contents. As a result, the ECM is completely destroyed and the surrounding structures sustain varying amounts of damage. An examination of the damage shows that it has been caused not only by the airblast from the event but also by the impact of the primary fragments from the HD 1.1 material and the secondary fragments from the ECM debris. At the extant magazine separation distances, the current U.S. and NATO regulations consider that the major damage mechanism should be blast (pressure and impulse). However, it is obvious that debris from the ECM and fragmentation from its contents have generated a significant proportion of the observed consequences
>
> As a result of the investigation of this accident, it was found that the density of hazardous debris did not fall below an acceptable level of less than one hazardous fragment per 55.7 m^2 until beyond a range of 1200 meters (3937 ft). Current NATO Standards [Reference 1-5] state in paragraph 1.3.7.3.d.3:
>
> *There is a minor hazard from projections at 400 m. This hazard is tolerable for:*

- *Main public traffic routes or when the traffic is dense and when the Potential Explosion Site (PES) is a heavy-walled or earth-covered building*
- *Built-up areas when the PES is an open stack or a light structure*
- *All "Inhabited Buildings" when the PES is a heavy-walled or earth-covered building*

It is apparent from this that the current explosives safety standards are not necessarily adequate and that a greater knowledge of the explosives generation of debris is required. While not affecting current explosives safety standards, other debris-related processes may affect the results that are obtained. For instance, in some cases with a barricaded (traversed) donor, the hazard from projections may be lower at intermediate ranges. Close in, the debris density may still be high due to barricade (traverse) debris, and in the far field it may increase again due to the high angle debris, which cleared the barricade.

Internationally, there are several recent as well as on-going test series that are designed to study various aspects of the debris generated by explosions inside test structures. These test programs include but are not limited to the following:

- UK
  - 40 Tonne Trial
  - 27 Tonne Trial
- US
  - SciPan Test Series
  - ISO Test Series
- Klotz Group
  - Kasun Test Series
  - ISO-Klotz Test Series
- Singapore
  - Scaled High Performance Magazine Test
  - Model ECM Test Series

In addition, on both a national and international basis, analyses have been made of such debris data from these trials and from explosives accidents. From these trials and accident investigations, improvements to both national and international standards have been made, new models developed, and existing models improved to support better prediction of explosion effects.

A bibliography of references relating to explosion-produced debris [Reference 1-6] was developed in conjunction with the 2007 publication of Revision 1 to TP-21. At that time, the bibliography contained over 475 entries, dating back over 45 years. Updates to this bibliography have continued after its initial publication with the latest published version dated October 2011 [Reference 1-7].

The attachment at the end of this document provides the most up-to-date version of this bibliography.

1.2 Objectives

Based on the consequence information obtained after an accident or planned test, quantitative probabilistic risk assessments may be carried out, deterministic safety distances evaluated, and/or predictive models developed. In all cases, knowledge of the spatial and energy distributions of the debris is necessary. In an ideal world, a complete, detailed description of the debris field in terms of mass versus velocity versus debris number density is needed as a function of distance from and orientation to the explosion source; however, this is usually not achievable in practice due to time and/or cost constraints. What may be achievable is a measurement of mass versus number of debris versus range and bearing and an estimate of the distribution of initial velocities. The prediction of velocity-time histories of individual debris pieces is, at best, conjectural due to the indeterminacy of initial velocity, randomness of shape (drag) and the effects of bounce, skid, roll and shatter. The objective, therefore, must be to achieve the best information practicable, approaching the ideal, to describe the debris field.

During debris data gathering, be it from an accident or a planned experiment, consistency, definitions, and format are very important. The need for consistency in the gathering of the data should also be extended to the analysis. Many of the problems in the analysis of historical explosion effects data lie in the incompatibility or inconsistency of the data collected and the analyses performed. In this document, attempts are made to provide a framework for this consistency of approach.

This paper discusses the following topics:

- Planning for planned events (tests)
- Post event data collection
- Debris pick-up data analysis
- Planning for unplanned events (accidents), i.e., planning how to collect and analyze the debris generated by an accidental event
- Test and analysis standardization

Advice is provided on the need to consider and define the specific objectives to satisfy the immediate test requirement(s), while bearing in mind the broader long-term needs of the safety community. Various methodologies for the collection of debris data are described and several techniques for debris location are also considered. Several data analysis methodologies are described in detail, including Pseudo-Trajectory Normal (PTN) and Modified Pseudo-Trajectory Normal (MPTN) techniques to obtain the debris inhabited building distance. The paper concludes by describing several methods/techniques that are recommended to become standard in the collection and analysis of explosion-produced debris data.

The explosives safety community needs to continually investigate new and improved analysis methods, but still agree on one or more preferred methods for the analysis of both test and accident data. Because the outcome of these analyses can and often are used to update or change explosives safety quantity-distance standards, the analysis techniques utilized need to be transparent and reproducible.

1.3 Units

The original authors of this document (Swisdak and Gould) made a conscious decision to use SI or Metric units as the primary units throughout this document. Whenever a number is given in SI units, its Imperial (English) equivalent is given immediately after. This decision led to the following choice: Instead of the term Net Explosive Weight (NEW), its SI equivalent of Net Explosive Quantity (NEQ) is utilized throughout this document. These decisions are continued in this current revision of this document.

2.0 PLANNING FOR PLANNED EVENTS (TESTS)

2.1 Pre-Test Preparation

Careful preparation and planning for any test that involves the collection of explosion-produced debris is essential to the successful achievement of its objectives. Every aspect of the test plan and its translation into practice must be considered in the light of the test objectives and their optimal satisfaction. The test objectives should be well defined and documented. Criteria for any decisions that are part of the objectives must be clear and unambiguous. The test objectives should, where possible, include the capture of additional information that may not be directly relevant to the test objectives but that do not add significantly to the cost or resource bill of the test. These additional data may become invaluable at a later date. Examples of such information might include data on the debris generated by the formation of the crater or measurement of the launch angles of the debris generated by the failure of a PES.

Pre-test preparation should include as a minimum the prediction or estimation of the following:

- Maximum debris range—both horizontal and vertical. Although maximum vertical debris range has not always been predicted, it should be, since this will determine the minimum acceptable altitude for low flying aircraft over the test site,
- Debris density vs range and azimuth,
- Debris shape,
- Debris size/mass distribution,
- Debris initial velocity, and
- Debris impact velocity.

The results of these predictions will help determine the debris collection techniques that will be utilized during the testing process.

Over the last few years there have been several empirical models and accompanying software tools that could be used to address various portions of the list shown in the last paragraph. These include, but are not limited to the following:

- Technical Paper 13 and its associated software--MUDEMIMP/DISPRE/DISPRE2 [References 2-1, 2-2]: This paper and its associated software presents methodologies for calculating building break-up, debris throw and fragment hazards; it is used to calculate the inhabited building distances for select types of PES over a fairly narrow range of explosive weights and buildings.
- TRAJ_CAN [Reference 2-3]: This software is used to perform trajectory analyses.
- Klotz Group Engineering Tool (KG-ET) [References 2-4, 2-5]: This tool calculates detailed results--structural break-up, debris launch angles and velocities, debris ranges, debris densities for explosions occurring inside the structure. Version 1.5 addresses reinforced concrete structures while Version 2.0 addresses ISO containers.

- Technical Paper 16 and its associated software (GEQ and MPTNC) [Reference 2-6]: This paper presents methodologies used to calculate primary fragment hazardous fragment distance and maximum fragment range for munitions. The GEQ software automates this process for generic munitions (known weight/diameter and description—robust, non-robust, extremely heavy cased). The MPTNC software calculates Modified Pseudo-Trajectory Normal debris density as a function of range and angle for input debris data.
- IMESAFR Technical Manual and its associated software, IMESAFR [Reference 2-7]: IMESAFR is a commercial software program that calculates risks and consequences from explosives operations. The consequences include building break-up, debris density, airblast, and prediction of both fatalities and major and minor injuries.
- Technical Paper 14, Rev 4A and its associated software SAFER [References 2-8, 2-9]: The methods and algorithms described in this paper are used to calculate risks and consequences from Department of Defense explosive operations. The consequences include building break-up, debris density, airblast, and prediction of both fatalities and major and minor injuries. Currently, this is the only model/tool that is approved for generating DDESB risk-based site plans.
- HAZX [Reference 2-10]: A tool developed by the Army that can be used to perform qualitative and quantitative risk assessments and consequence modeling. It is currently used to perform Service-level risk management studies.
- UFC 3-340-02 [Reference 2-11]: Protective construction guidelines are found in this manual.
- UFC 3-340-01 [Reference 2-12]: Response of hardened structures to conventional weapons effects are found in this manual.
- DOE/TIC 11268 [Reference 2-13]: A compendium of methodologies and techniques that can be used to predict the consequences from explosions in or near structures.

Empirically-based models that estimate the effects of shatter as well as bounce, skid, and roll have been proposed and are under development [References 2-14, 2-15] in several countries. Although some of these models have been implemented, they still require further validation.

2.2 Test Site Requirements

It is important that the test range should be sufficient in size and condition to meet the needs of the test. Ideally, the area to be used for the test should be flat and clear of obstacles such as structures, trees, other vegetation, widely varying terrain, etc., over a circle (unless a more specific shape such as a cruciform or quatrefoil pattern can be reliably predicted) centered on the test structure; it should have a radius greater than the predicted maximum debris range. Experience has shown that a safety factor of 20% should be applied to the predicted maximum debris range when determining the size of the test area. When test range distance is limited in some directions, careful orientation of the test structure can sometimes be used to reduce the required distance.

Experience has shown that structural debris tends to be projected farther along the normals to the walls of the structure and that there is generally less debris off the corners of the structure. However, if the structure has a concrete roof, strengthened corners, or is non-rectangular in shape, there may be a stronger diagonal contribution from these elements that could distort or eliminate the quatrefoil pattern. A quatrefoil pattern might also be distorted or eliminated by the presence of barricades (traverses).

In smaller test venues, it may be necessary to limit the maximum debris ranges in specified directions. However, in the directions of interest, it is important that there is sufficient distance to ensure an uninterrupted debris throw. If necessary, the non-measurement directions may be protected by simple, expedient barricades.

2.2.1 Terrain

While it is difficult to advise absolutely on the required flatness of the test area, it is clear that sloping ground will enhance the debris ranges downhill and reduce them uphill. It will also lead to skewing of the debris distributions in the cross-slope directions. In order to minimize these effects, it is recommended that ground slope should be less than 1% over the test area. Again, some alleviation may be gained by careful control of test orientation on sites where there are local slope variations.

Inevitably, the test site will be strewn with stones, natural rubble, lumps, and hollows. The degree to which these should be cleared, flattened or filled is dependent on the test and the predicted debris characteristics, the availability of financial resources, and the local environmental considerations and regulations. Clusters of large boulders that might act as barricades (traverses) and significantly distort the debris throw need be moved. In a similar vein, holes or depressions with the same potential should be filled.

2.2.2 Soil/Geology

It is important that the test site surface is firm enough that debris or fragments landing on it are not lost, i.e., buried in sand or submerged in mud or water. While it is normally impractical to remedy the situation, differences in soil properties should be noted if the variation is not isotropic within the test area. For example, if one direction is significantly sandier (and thus softer), while another side is rockier (and thus harder) than the average soil condition, this information should be recorded. Such differences may well affect test results in at least two ways:

1. Concrete or masonry debris will more likely, and more dramatically, shatter upon impact with harder surfaces, and
2. Different soil conditions will affect bounce and roll of the debris.

2.2.3 Vegetation

There may be a carpet of vegetation over all or part of the test area. This vegetation should not be so dense as to impede the scatter of debris or reduce the efficiency of the post-test debris search phase. The degree to which the test area should be cleared (mowed, scraped, or burned) will be dependent upon the type of debris recovery techniques to be used and the rules governing to test site. If aerial photography is to be used rather than a ground search to locate debris, then the amount of clearing required could be greater. Debris recovery techniques are described later in this document). Care must be taken, however, to not overly disturb the surface layer of soil as a disturbed surface layer is more susceptible to dust entrainment by the passing shockwave.

In addition to the ground cover type vegetation, there may also be small pockets of larger items such as shrubs or trees. Generally, these more substantial items cannot be removed prior to a test. If they are few in number or cover only a small portion of the recovery area, then they should not have a significant impact on the results. If this is not the case, the ground zero should be oriented such that these effects would be minimized.

2.2.4 Existing Debris

The test site will, in all probability, have been used for testing previously and may be littered with old debris. It is essential that there should be no confusion between old debris and debris being generated in the planned test. If there is any chance of confusion, the old materials should be cleared. If clearance is not practical, an alternative is to either mark the old debris with spray paint, color code the source of the new debris being produced on the test (high temperature paint for metallic debris and colored concrete for concrete debris), or both. A problem with the *paint the old debris* solution is when there is so much old debris that search personnel begin to ignore or miss the new debris that they are trying to find.

2.2.5 Environmental Coordination

It is the authors' experience that early communication with the environmental and/or conservation authorities responsible for the test area is vital to reduce or avoid conflict where there is a need to clear or modify the topography of the test site. Such conflict, if it is allowed to occur, could delay or jeopardize the trial.

2.3 The Potential Explosion Site (PES)/Donor Structure

2.3.1 PES Design and Construction Specifications

A complete PES description and construction specifications (e.g., material types, dimensions, thicknesses, rebar size and location, ASTM material testing results, etc.) must be included in any test report. This information is vital to any modeling effort and may also be necessary in the interpretation of observed results. Location and shape of the energetic material within the PES is also necessary to allow for accurate modeling.

A qualified structural engineer should inspect the PES both during and after construction (but prior to testing) in order to assure that the as-built structure meets all of the construction requirements. Prior to test execution, all debris recovery personnel should familiarize themselves with the construction drawings and conduct a personal inspection of the PES in order to better understand all of the types of debris that might be generated by the structure.

2.3.2 PES Design Considerations

The PES clearly has to be representative, in terms of building codes and standards, of existing or planned buildings. However, much can be done in the detailed design to improve or extend the debris information gathered. The requirements of model development, risk analysis, or safety-distance determination can generally be met with knowledge of the total debris field from the whole structure and its contents. However, when it comes to the development of predictive models or quantitative risk assessment tools, there is a need to identify the source of the individual debris—wall, roof, floor, structure contents, etc.

A choice of bright or unique colors or dyes can also be a simple aid to the efficient location of debris after the event. However, when selecting a color scheme, there are several additional factors that must be considered:

- Care must be taken to select colors that do not blend with the surrounding terrain and vegetation.
- If the test site has been used previously used for similar testing, care must be taken to not assign the same colors to the same materials on the new test as done on the previous test. If the same colors must be assigned to the same materials, then the orientation of the structure should be changed to that the same color new material does not land on the old material.
- Roof material generally goes in all directions and could, potentially, mask other materials.

It is the authors' opinion that the incorporation of this type of measure (color-coding of potential debris), which maximizes information retrieval and costs little (in terms of the full test cost), is worth doing even if it goes beyond the immediate aims of the experiment.

For concrete buildings, color-coding of potential debris might be accomplished by adding coloring agents to the concrete mix of various components. Care must be taken, however, to ensure that the addition of these materials does not significantly alter the structural properties of the concrete. It is recommended that pre-test screening be conducted to ensure that the concrete mixes have the desired properties; in addition, test cylinders should be poured at the time of PES construction. These cylinders should then be tested to verify that the concrete has the desired properties both at 28 days (after pouring the concrete) and at test time.

Paint might also be used to color different parts of the structure. In those areas that would be exposed to high temperatures, a paint that is resistant to the effects of such temperatures must be used. A disadvantage to this technique is that the applied color is only skin deep. If the structure is reduced to aggregate-size pieces, as is sometimes the case, the paint may not be helpful.

The design of the PES, and indeed any exposed sites (ES), may have to be in accordance with local building codes and regulations—including requirements for seismic hardening. If this is the case, variances or exceptions may have to be obtained in order to complete the test structure as required at the test site.

2.3.3 PES Ancillary Equipment and Fixtures

Consideration must be given to the choice of ancillary equipment and fixtures to be included in or on the structure. The simple question to ask for each item is: Does its exclusion detract significantly from the debris to be generated, or will its absence affect the generation of the debris? If the answer is *no*, then its inclusion in the structure is unnecessary. When addressing this question, there is a need to distinguish between the debris generation and the debris throw mechanisms. For instance, the shock might affect the number of fragments and their mass distribution, whilst the venting could affect the debris throw (note that the two phenomena are not mutually exclusive).

An example might be a personnel door. If the door were not present, the opening might represent a vent that could reduce the gas pressures inside the structure. If the NEQ or the loading density (the NEQ divided by the internal volume of the PES) is such that the direct shockwave is the dominant debris generation mechanism, then the presence of a door will not significantly affect the debris generation. If, on the other hand, the quasi-static gas pressure is a major contributor to the debris generation, then a door should be included.

A recent study [Reference 2-16] has shown that for the storage of small quantities, the door hazard is typically dominant compared to other explosion effects and that in many cases door impact takes place outside the established Inhabited Building Distance (IBD). Thus, the inclusion or omission of a door could affect the final debris ranges in the direction of the opening.

A possible exception is the inclusion of lightning protection. A lightning protection system would not affect or add materially to the debris. However, if there is any intention to store explosives in the structure prior to the test event, even on a temporary basis or if the trials authority considers it necessary for the test, then it must be included. The requirement for a grounding system within the PES is at the discretion of the local safety authorities.

2.4 Exposed Site(s) (ES)/Target(s)

Tests may also include one or more ES/targets which may be included to investigate the interaction of the PES blast wave and/or the PES debris with the target structures. One example of this is the vehicle targets which were placed on SciPan 3 [Reference 2-17]. The locations of the ES structures that were placed on SciPan 1 [Reference 2-18] and SciPan 3 were selected to minimize the effects of the PES debris on the ES.

2.4.1 ES/Target Description

An ES/target may be designed to study only one or a few aspects of the behavior of the structure that it is representing. All unique aspects of its design should be documented in writing with accompanying drawings and/or photographs. Where appropriate, construction specifications (e.g., material types, dimensions, thicknesses, rebar size and location, ASTM material testing results, etc.) must be included in any test report. This information is vital to any modeling effort and may also be necessary in the interpretation of observed results.

After construction is completed, but before the test, all ES/targets should be inspected by a qualified structural engineer in order to assure that their as-built condition meets test requirements.

2.4.2 ES/Target Design Considerations

An ES/Target does not have to be designed to represent a particular type of building; rather, it may be designed to test typical design or construction details such as tilt-up walls or doublewythe masonry construction. The structure should be designed in such a way that its construction details will not compromise what is being tested. This might be as simple as completely enclosing the rear of a structure so that the airblast that wraps around the structure does not prematurely reduce the loading on the front surface.

2.5 Energetic Materials

2.5.1 Selection of Energetic Materials

The type of energetic material selected for the test should reflect the goals of the experiment. Whatever material is selected and used, its output should be well characterized. If it is not, a calibration shot should be conducted under similar conditions (charge shape, height of burst, initiation system, etc.) to the test event. Regardless of the characterization of the explosive donor through the use of one or more calibration tests, time-resolved pressure measurements both internal and external to the PES should be taken during the test to confirm the explosive output for that test and to provide additional diagnostic information.

2.5.2 Means of Initiation

The means of initiation of the explosives must be in accord with the aims of the test and meet an acceptable standard. If the test is intended to simulate an accidental fire environment, then a fire meeting the requirements of the UN Test 6c [Reference 2-19] should be arranged. Examples of this are the HD 1.2 tests in igloos carried out in 1993 and 1995 [References 2-20, 2-21]. An HD 1.1 test that is designed to represent simultaneous detonation of all the AE within the PES may require multi-point initiation throughout the stack to ensure complete and simultaneous initiation. One method of achieving such initiation is to use a single detonator that initiates a branching network of equal length detonating cords. For example, on a large stack of MK 82 bombs stored on six-bomb pallets, one bomb per pallet could be primed and initiated. Other items might require additional priming. An alternative method might involve using individual detonators in each AE item.

It should be pointed out, however, that multi-point initiation, though potentially conservative, ensures that a worst-case scenario in terms of initiation is obtained. In some scenarios, simultaneous initiation of all rounds, while conservative, may not be realistic in terms of real-world expectations. Cognizance of local range safety regulations must be maintained, as the desired or proposed initiation mechanism may be deemed unsafe under certain circumstances. Whatever method is ultimately employed for initiation, it should be documented and its description included in any test report that is generated.

2.6 Meteorological Effects

Meteorological effects such as wind, rain, humidity, etc., will have an effect on the test site and may have to be taken into account and test schedules altered or revised as necessary.

Too much or too little rain can both cause problems. It is obvious that periods of excessive rain may cause the test site to become unacceptably muddy or flooded. Other consequences of too much rain may be more difficult to anticipate. Excessive rain may cause local vegetation to flourish and become denser than usual. Should this vegetation be producing pollen during the planned test, it is possible for that pollen to act like the material in a cloud chamber and produce an opaque layer that could obscure some or all of the test structures in the videos taken at the time of the test.

In some places (e.g., Woomera, South Australia) periods of dry weather can bring their own problems. The dust clouds generated by the expanding blast wave can and often do occlude the fields of view of cameras, thus reducing their data collection capability. This is difficult to combat. One possible countermeasure is the thorough wetting of the ground zero area with water or petroleum-based products. Even this, however, may do little to ameliorate matters. At many locations, the dumping of petroleum-based products directly onto the ground is prohibited by environmental regulations.

Wind may, of course, exacerbate the dust problem. In addition, wind can also apply bias to the debris distribution, when times of flight are long (seconds) and/or in the case of light debris with large surface areas, where the wind may significantly affect the maximum throw range. Wind biasing of debris is a special problem for vertically launched debris (e.g., roof debris).

As a broad guide, a wind-induced displacement of 0.5 meters (1.7 ft) can be expected for each knot (1 knot = 0.514 m/s (1.69 ft/s)) of wind and each second of travel. It is recommended that debris testing should not take place in wind strengths greater than 5.14 m/s (10 knots or 12 mph).

Test site conditions (temperature, wind speed and direction, barometric pressure) will also have an effect on any airblast that is recorded on the test. The relations between the airblast recorded under test site conditions and that same airblast at standard conditions (sea level atmospheric pressure and a temperature of 15º C (59º F)) is provided by the Sach's scaling relationships [Reference 2-22] provided in Table 2-1.

Table 2-1. Sachs Scaling Factors

Sea Level	Test Site	Factor
Distances at sea level	Distances at test site/S_d	$S_d = (P_0/P_z)^{1/3}$
Pressures at sea level	Pressures at test site/S_p	$S_p = (P_z/P_0)$
Time at sea level	Time at test site/S_t	$S_t = (P_0/P_z)^{1/3} * (T_0/T_z)^{1/2}$
Impulse at sea level	Impulse at test site/S_i	$S_i = (P_z/P_0)^{2/3} * (T_0/T_z)^{1/2}$

P_0 = 101.33 kPa (14.696 psi)
T_0 = 15°C (59°F)

Because of their effects on both the debris and the airblast, the shot time meteorological conditions (temperature, barometric pressure, wind speed, and wind direction) should be recorded and included in all reports. This information could later be necessary to estimate any meteorological effects on the results obtained.

2.7 Instrumentation

Any instrumentation that is to be included on the test should be described in detail. For each sensor or transducer, the description should include:

- Exactly what is being measured
- Location
- Expected maximum and minimum values
- Frequency response or temporal resolution required

2.7.1 Optical Instrumentation

Optical instrumentation includes video cameras, cine cameras, and flash X-ray. The following information should be recorded and reported for each optical instrument:

- Designation/identifier
- Description, camera type, etc.
- Location/coordinates (range and bearing from ground zero)
- Lens description (type, aperture, etc.)
- Measured field of view (X meters by Y meters centered on point Z)
- Equivalent frame rate (pictures per second)

Commercially available software such as SolidWorks [Reference 2-23] has been used by several organizations to help visualize and demonstrate the fields of view for each camera/optical instrument. However, it will be almost inevitable that local site conditions will dictate last-minute changes; prior to each test, all fields of view, as set up, must be agreed upon and documented.

Some basic terminology and techniques are defined in this section to provide insight into topics discussed throughout this section.

The *image plane*, as used in this section, is the imaginary plane that the camera is focused upon. In other words, it's the part of the world that appears in focus in the camera. It is important to consider, since any measurements too far from the image plane will have to be corrected. In general, the camera layout is designed so the cameras are focused on areas of interest. The *image plane* of the cameras is the area that objects of interest move through.

The *field of view* is the area of the world that the camera can "see." The *field of view* dictates the area of the *image plane* and is the entire subject that the camera records.

While not strictly necessary, the individual frames of a video are usually used in analysis instead of a continuous video file. The camera software itself may capture data in that fashion at any rate and most software tools are set up to handle the frames in that fashion. It also simplifies processing segments of the “video” rather than having to manipulate one large video file.

The collection of points (or positions) of a fragment in the image is the *fragment track*.

In general, the analysis process is to gather image registration and calibration information, trace fragments across the image, and then process the track data for each fragment. This process requires planning to ensure appropriate calibration objects are in the image before the test and careful measurement of those objects before the test occurs. This is discussed in further detail later in this section.

2.7.1.1 Calibration Objects

When planning high-speed video use in a test, there must be objects of known location and dimensions within the cameras field of view. Typically, these are posts, called fiducial markers, (with a known physical size and/or a color pattern of known size) or a screen (usually referred to as a velocity screen, with known dimensions) to help distinguish fragments from the background. Fiducial markers and velocity screens can both be used in the same frame of reference. An example from a test is shown in Figure 2-1. Experience has shown that fiducial markers should be placed on or near the center line of the field of view in order to minimize calibration errors.

Figure 2-1. Fiducial Markers and Velocity Screens

2.7.1.2 Image Plane Markers

It is difficult if not impossible to determine if objects are traveling mostly in the image plane. Since fragments could be moving away from or toward the camera, it’s important to plan the location of any objects used as markers. By strategically placing marker objects, it is possible to determine if fragments are traveling inside a particular angular deviation from the image plane.

This can be accomplished many different ways. A few examples are shown in Figure 2-2. A sample camera plan is provided as Figure 2-3.

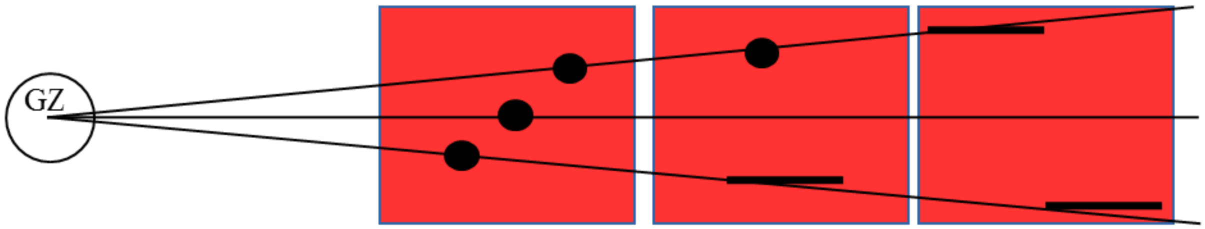
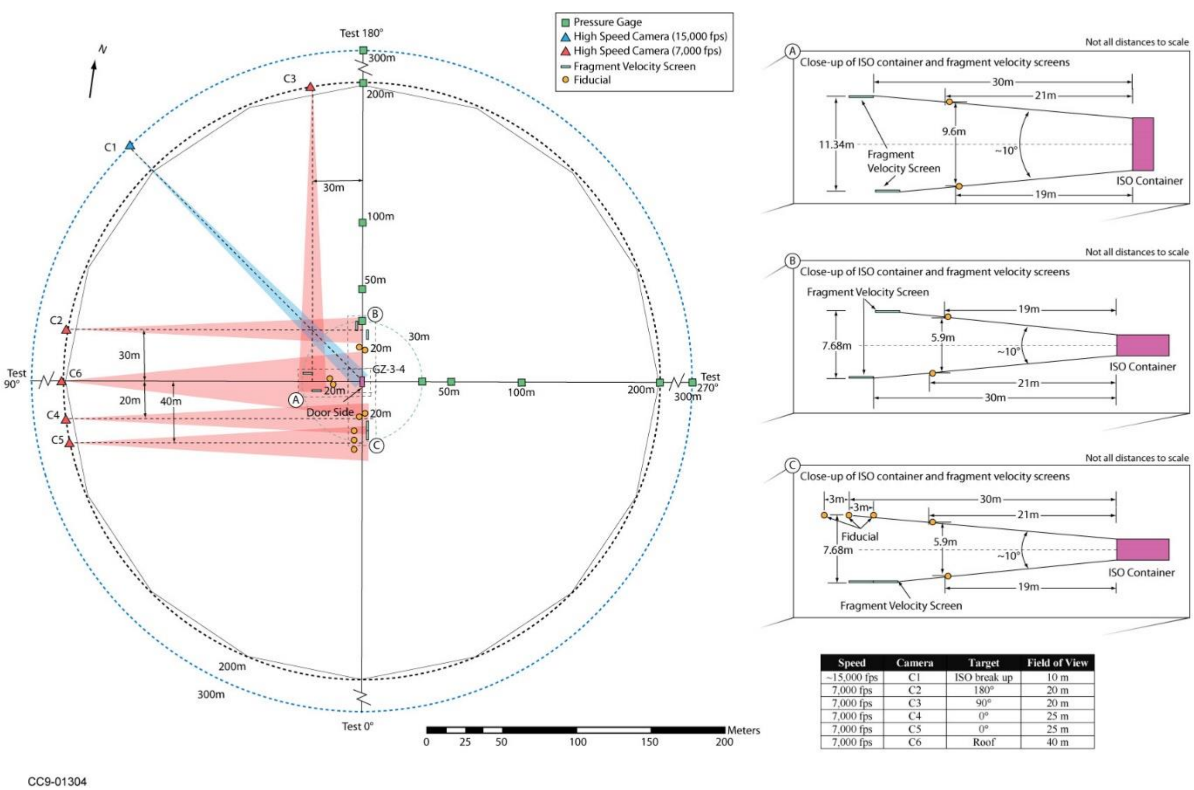


Figure 2-2. Marker Objects Set-up Example



Speed	Camera	Target	Field of View
~15,000 fps	C1	ISO break up	10 m
7,000 fps	C2	180°	20 m
7,000 fps	C3	90°	20 m
7,000 fps	C4	0°	25 m
7,000 fps	C5	0°	25 m
7,000 fps	C6	Roof	40 m

Figure 2-3. Sample Camera Plan

2.7.2 Common Time Base

Experience has shown that it is practically essential to have a common time base across <u>all</u> instrumentation, including cameras. A continuously running time base, such as IRIG timing, will be acceptable so long as Time Zero (the time of initiation of the charge) is recorded such that it may be superimposed on all other records.

2.7.3 New/Novel Concepts and Techniques

Predicting which concepts or techniques might mature to the point that they can be utilized on future tests is difficult to predict. Some examples of this include:

- Novel camera locations; i.e., buried with upward fields of view. This technique has been used on at least one trial series with some success.
- Use of mirrors to enhance the field of view of cameras.
- Small, disposable video cameras placed at strategic locations within the structure. This technique has been used with some success on several recent tests.
- Doppler radar. This technique has been used on some specialized trials with limited success.
- LIDAR. This technique has been discussed for inclusion on several trials; however, as yet, it has not been implemented.
- Embedded sensors. It may be possible to embed sensors within the walls/roof of the PES structure as it is being constructed. The sensors would have to be small enough to likely survive and cheap enough to be placed in multiple locations.

2.8 Pre-Event Site Survey

2.8.1 Requirements and Accuracy

A pre-event survey of the site is required for the following reasons:

1. Determine the location of all cameras, scaling screens/poles and instrumentation
2. Determine the location, orientation, and spatial relationship of all test structures
3. Facilitate debris collection and cataloging by sub-dividing the debris collection area into azimuthal sectors and radial zones

All pre-event survey points should be located to accuracy no worse than 0.1° in azimuth and 0.1% in linear dimension (minimum 0.1 m (0.33 ft)).

2.8.2 Camera Locations

To optimize the quality of the data generated from the analysis of video or cine records, it is essential to determine the positions of the cameras and their scaling screens and/or photo-poles relative to a fixed datum.

Where possible, cameras which are to be used to determine debris characteristics (launch velocity and launch angle), should have the camera axis either in the plane of or perpendicular to the normal of any wall of any structure being observed. Thus, it is essential to locate the position of the structures relative to the fixed datum and define the perpendicular bisectors of each of the walls. All debris cameras should include a known reference point in their field of view.

Other cameras being used to document the event or the behavior/response of targets are often located away from the normal to the PES walls.

Unless they are considered expendable, all cameras should be protected from the effects of the PES debris and blast waves. The specifics of the protective design are left to the testing organization. Figure 2-4. shows a typical armored camera housing.

Figure 2-4. Armored Camera Shelter

2.8.3 Debris Cataloging

The survey requirements for debris collection and cataloging will be highly dependent on the scale of the test and the planned debris data recording method. Debris cataloging methodologies generally fall into two categories:

1. Within azimuthally and radially defined zones ***(Section 2.8.3.1 (Collection within Zones))***.
2. By individual debris piece location (identifier, range and azimuth) ***(Section 2.8.3.2 (Location of Individual Debris Pieces))***

Both of these techniques assume that the debris collection area has or will be marked into azimuthal and radial zones and sectors. However, neither technique addresses a problem that is endemic to the entire process: *All that is known is the final resting place of the debris, not how it came to be at that location*.

In many cases, individual fragments will translate (bounce, skid, or roll) after their initial impact with the ground, rather than forming an impact crater. In some cases, this translation may mean that the initial impact point is at one location but the final position (i.e., where it came to rest) is in a different one. This leads to the question of where the fragment should be positioned in the recording of the data (*first impact point or final location when or if this distinction can be made; for many situations involving concrete debris, it may be impossible to make this distinction*). While several arguments can be made for or against one philosophy or the other, at the very least, it is clear that this is an important decision that should be consistently applied to the data and that should be documented in the test report.

Another issue, which is of particular importance when the donor material is concrete or brick, involves the break-up or shattering of pieces either in flight or upon impact. If a single large fragment shatters when it first hits the ground, it may scatter hundreds of smaller pieces. Where should these data points be recorded, and as how many pieces? Again, the manner in which this issue is treated must be consistently applied and should be recorded in the test report. This issue is especially a problem with concrete debris, where it may not be possible to reconstruct the shatter process of the original piece.

2.8.3.1 Collection within Zones

If debris is to be collected within pre-defined zones, these areas should be surveyed in prior to the test. Often, these zones will be defined as elements of a radial coordinate system, the origin of which will be at the center point of the PES and the originating axis will be related to the perpendicular bisector of one wall. Radials should be marked at the desired angular intervals, thus defining the angular width of each sector. The authors have found that a 5° sector width is suitable in most cases; however, allowance should be made for further sub-division after the event where it is clear that the angular debris density variation is large within the pre-defined interval. In order to standardize the post event data analysis, it is recommended that sector width be standardized at 5°. When using radial zones, care must be taken to ensure that the area of each zone is properly computed and taken into account when computing debris density.

Also of importance is the exact choice of the originating axis position. The first option is to use the normal to the structure wall as a sector divider as shown in Figure 2-5. The second option, as shown in Figure 2-6, is to have the normal to the structure wall bisect the sector.

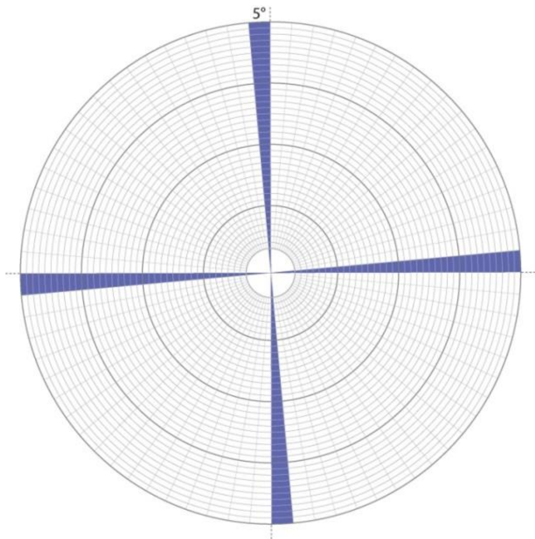


Figure 2-5. Collection within Zones: Offset Sectors (Example)

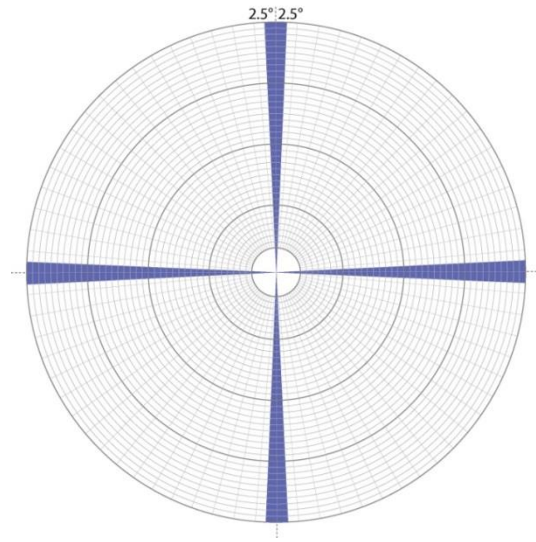


Figure 2-6. Collection within Zones: Symmetric Sectors (Example)

The zonal definition shown in Figure 2-6 is generally more advantageous and it is recommended that this technique be used in lieu of the one shown in Figure 2-5, unless there is a compelling reason to do otherwise. This is because the defined sectors are centered on the normal to the PES walls and would, therefore, be expected to contain the peak density. In the configuration shown in Figure 2-5, the normal forms the sector boundary; therefore, no single sector can be expected to contain the peak.

Having set the angular width, each sector may be marked at intervals to define the depth of the sector and, thus, the individual search areas. The sector depths will be a function of the scale of the trial and the predicted maximum debris throw distance, coupled with the practical limitations of carrying out the debris search. The search area should be marked out to about 1.2 to 1.3 times the maximum predicted debris throw. Typically, sector depths of about 5 to 30 m (15 to 100 ft) have been used. To aid in the standardization of the analysis of the debris information, it is recommended that a sector depth of 10 m be chosen unless there is a compelling reason to select some other depth. An example of a compelling reason to do otherwise is for tests where the maximum fragment distance is expected to be less than 100 meters, and thus a smaller sector depth would be desired to generate greater fidelity in the debris collection data.

2.8.3.2 Location of Individual Debris Pieces

If a post-test survey technique is to be used to locate each individual debris piece, there may be no need to establish sector depths. However, it is strongly recommended that prior to the test an angular division be surveyed in over the test site to assist in the management of the search operation with survey markers placed at 5° intervals around ground zero located at a minimum of at least two distances.

Ropes or lines can be used to temporarily mark off azimuths that have been searched and those that have not. It is not critical for these angles to be accurate; rather just used as a frame of reference to designate what areas have been cleared and the boundaries of the current search area. The origin and orientation of the search area is not as important but is probably best if it is defined as elements of a polar coordinate system, the origin of which will be at the center point of the PES.

2.9 Debris Collection Techniques

Debris collection methodologies generally fall into two categories, as described in Section 2.8.3:

1. As a group within azimuthally and radially defined zones. Within each zone, the following information is recorded:
    a) The coordinates (range and azimuth) of the center of the zone
    b) As a function of material type, the number of pieces found in each mass bin or preferably the mass of each piece
2. As individual debris pieces. For each debris piece, the following information is recorded:
    a) The coordinates of each piece (range and azimuth)
    b) A descriptor that gives its origin
    c) The mass of the piece

Both techniques have been successfully used. It is recommended, however, that the second method be utilized whenever possible. If, instead, the first option is selected, it is recommended that the weight of each individual piece still be determined.

2.10 Documentation

2.10.1 General Debris Information

It is essential that documentation extends from the test manager's search control techniques to the labeling of individual debris (either singly or collectively, dependent on the technique used). It is crucial that the search be carried out methodically with a high confidence in its completeness and consistency. The debris collectors need to be briefed at the start of the collection phase (and possibly at regular intervals during the process) on the debris collection technique being employed and also on the importance of accuracy/fidelity during the collection process. This helps to maintain confidence in the completeness of the data.

A test diary/log should be maintained. This will provide chronological notes of all actions, observations, and decisions made on the test site and again forms an essential part of the test record.

2.10.2 Photography (Still and Video)

It is essential that all aspects of the setup of the test, the test structures (both PES and ES) and the explosive charge be recorded using still photography and video. Of particular importance are views of the test structure (internal and external) and details of the energetic materials. It is better to discard excess records after the event than to regret not having them. All photographs should include a scale reference in the field of view of each picture.

Particularly when there are multiple tests, it is important to include in each picture/video sequence an indication of the event number, date, etc. Photographs in particular get displaced from their original locations and then one piece of structure or test site looks much the same as others.

At a minimum, the following information should be reported for all video cameras utilized on a test:

- Location
- Type of camera
- Frame Rate
- Aperture

2.10.3 Instrumentation

All aspects of the electronic instrumentation should be documented and reported. This includes, but is not limited to, location, description, calibration, how recorded, and overall frequency range of the system (sensor to recorder).

2.10.4 Energetics

All details of the test explosives, such as configuration, dimensions, masses, lot/stock numbers, origins, history, and location within the PES must be documented and reported. Details of camera and instrumentation locations, calibrations, fields of view, frame rates, etc., must be logged and reported. If these are changed during the course of the testing, the changes must also be recorded.

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3.0 POST-EVENT DATA COLLECTION

Post-event data collection involves four processes:

1. Finding each debris piece
2. Determining the location, mass, and description of each piece
3. Cataloging of the information associated with each piece
4. Site remediation, including removal of all test-related debris pieces

3.1 Saturation Zone

An examination of the recovery area post-event will often show that within some**,** to be defined**,** distance from ground zero, the number of debris pieces becomes so high that it may be impractical to count or catalog individual bits. This region is known as the *debris saturation zone*. Anecdotal evidence indicates that whether or not such a *debris saturation zone* occurs may be a function of the loading density, with the formation of such zones occurring at the higher loading densities. However, the authors have never seen a loading density so low as to fail to produce a saturation zone with a concrete PES. Prediction models and/or previous test data may be used to estimate the location of this region.

Debris located within an identified saturation zone should be treated in the following manner:

1. Significant pieces, as defined in the test plan or determined by the Debris Cataloging Team Leader, should be cataloged and photographed
2. Depending upon the symmetry of the distribution, one or more sampling areas should be identified, and all debris pieces within that area should be treated individually and their description, location (range and bearing) and mass determined and cataloged
3. All remaining debris (not cataloged as part of #1 or #2) within the saturation zone should be collected and its aggregate mass measured or estimated.

3.2 Test Site Assessment

In all cases, however, the first step in the post-event data collection process is an overall test bed assessment. This is, essentially, a scouting effort to determine the overall extent of the debris throw. Historically, this process would involve a search by personnel who were either on foot or in vehicles. Because of the chance of missing or not locating items, vehicular search is appropriate only when large debris may have been thrown more than, say, one kilometer. When this is thought to have occurred, it is better to use vehicles to transport personnel and equipment to the search area and then conduct the actual search on foot.

In addition to debris location, a thorough examination of the recovery area can produce other useful information. If a fragment has penetrated into other materials, an estimate can often be made of its impact velocity. Likewise, when debris impacts other objects or structures (trees, buildings, etc.) and leave marks indicating the point of impact, information such as trajectory directions can also be deduced. For example, if after an accident, a metal fragment is found embedded in the trunk of a tree, the depth and angle of penetration can be related to its impact velocity and its position relative to the explosion site gives an indication of its direction of throw. Subsequent controlled experiments may, of course, be needed to quantify its speed.

3.3 Search Techniques

An orderly, repeatable procedure, such as those described in Sections 2.8.3 and 2.9, is strongly recommended for locating the debris. The exact method employed will depend on the circumstances, notably the:

- Debris density,
- Recovery area conditions,
- Number of people available to form one or more debris location teams,
- Experience/capability/motivation of such teams, and
- Time available to complete the effort.

3.3.1 Width Walk

A proven, deliberate method is to form a line of recovery personnel along the side of the sector and sweep across the sector from side to side. Although the personnel line up along the length of the sector, the search path is across the width of the sector. For this reason, this method is called a *width walk*. This method is depicted in Figure 3-1, and can be adjusted to fit the specific circumstances of any debris recovery effort (if there is sufficient time available).

The actual path followed by each searcher should be serpentine, as shown in Figure 3-1. The pace of the effort should be slow enough to ensure that few pieces are missed; ideally, the spacing of the personnel should be such that one searcher would be able to spot a piece missed by a searcher to either side. However, this will depend upon the vegetation, as well as the density of pieces and the size of the debris. In addition to checking their neighbors, the search crews should be advised to periodically look behind themselves to check for pieces obscured by terrain, vegetation, or shadows. The ability to spot debris thus obscured is a function of the sun angle/time of day.

Because the area being covered by each searcher remains relatively constant, and the back-and-forth pattern avoids long, uninterrupted paths that can cause searchers to lose focus, this technique is quite effective. However, it is labor intensive and time-consuming.

3.3.2 Length Walk

An alternate search technique, shown in Figure 3-2, is a *length walk* through each sector. Here, the recovery personnel line up across the width of the sector and sweep the length of the sector. This method may not be practical if there are not enough people to adequately span the width of the sector. This technique may also be less thorough. If the search direction is away from ground zero, the search area for which each individual is responsible increases as the search progresses along the length of the sector. At some point, the width of each person's search path may exceed that which can be searched with a high expectation of locating all of the debris. It is particularly difficult to achieve success if the search is directly into or away from a bright, low sun.

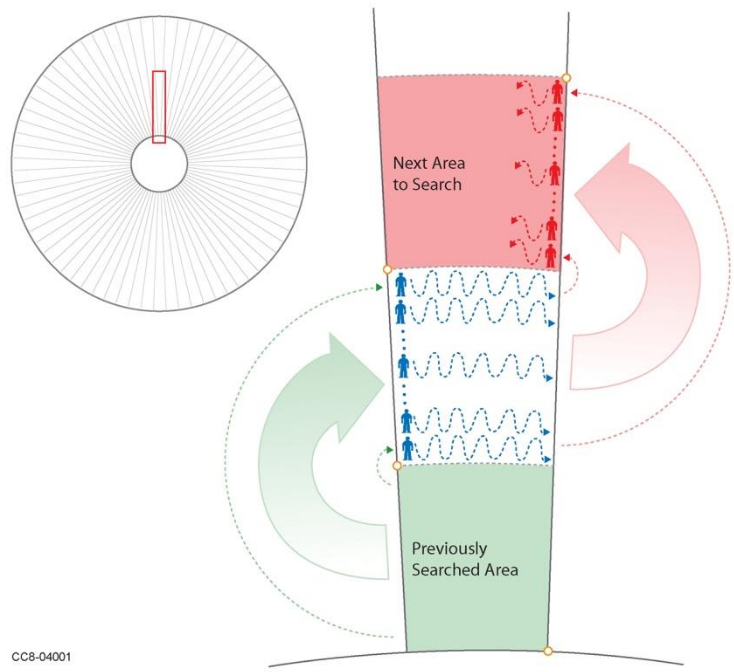

Figure 3-1. Width Walk Search Technique

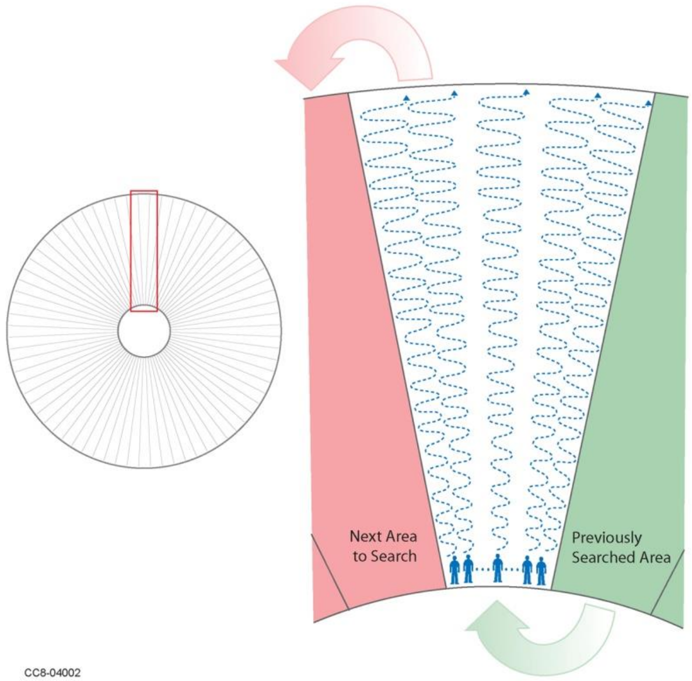

Figure 3-2. Length Walk Search Technique

The length walk technique is typically much faster, because there is less wasted movement between the current search area and the next area to be searched. This speed should be balanced, however, by the fact that this search technique generally has a higher miss rate, often leading to less reliable data.

3.3.3 Search Technique Caveats

It is inevitable that there will be multiple teams performing the search. It is critical that the same techniques, thoroughness, speed, etc. are employed by all of the teams. Although it is not recommended, it's better to perform the search consistently "sloppy" rather than inconsistently throughout. With a consistent technique utilized, you can apply your quantified miss-rate evenly throughout the entire search area.

All debris collection teams should be briefed daily as to methodology updates or changes to ensure thorough processing of the scene and changes in processing protocols due to changing conditions etc.

Regardless of the search technique, the requirements of prolonged concentration without break, even a break as short as just 20 seconds, results in a measurable drop off in collection efficiency.

3.3.4 Aerial Photography

There exists another technique, which can be used as a backup to the two search techniques discussed in the previous two sections: aerial mapping/photogrammetry. As was demonstrated after the Distant Runner Test Series [References 3-1, 3-2], conventional aerial photography and stereo photogrammetry techniques can be used to generate position information and size estimates for any debris piece with a size that is resolvable in the photograph. The use of such an independent method is doubly useful. First, it can serve as a check on the results obtained by the other methods and, second, it can be used to identify/locate any debris that may have been missed on the initial survey. There are several limitations to this technique;

- Its inability to provide adequate debris identification (material type and original location on PES) for all pieces,
- The fact that only size estimates are available—not mass. Mass estimates would require assumptions about material type and shape, and
- No data are obtained for pieces smaller than the resolution limit of the photograph.

Distant Runner utilized conventional aerial mapping/photogrammetry. Conventional aerial surveying with manned aircraft requires significant resources and can be limited by cloud cover. Unmanned aerial systems (UAS) (drones) and computing power have evolved to such an extent that the use of UAS equipped with high resolution digital cameras can be considered.

The use of UAS on DoD or other government installations is generally at the discretion of the installation commander. Within the U.S., the Federal Aviation Administration recently approved regulations to implement the use of UAS into the United States' National Airspace [Reference 3-3].

UAS can provide visual perspectives of the shot that are otherwise unattainable because of cost or safety. They also have the potential to increase the debris collection efficiency, reduce test costs and provide new analysis capabilities.

UAS can survey the debris field and provide data for photogrammetry, just as in Distant Runner. Hundreds of aerial images can be collected over dozens of acres with UAS in very short amount of time and processed quickly using gaming laptop computers into a detailed 3D model and orthomosaics [Reference 3-4]. The accuracy of a photogrammetry survey is limited to the size of a pixel in the images.

The use of UAS in debris collection and analysis efforts is in its infancy. New techniques and new platforms are being announced on a regular basis. It is believed that in the future UAS use will greatly increase efficiency while also reducing test costs.

3.4 Collection Methodologies

The collection methodology that is ultimately used will be selected on the basis of the pre-event planning process and an assessment of the on-site conditions present post-event. Under ideal conditions, the location, mass, and description of every debris piece would be noted and recorded (Section 2.8.3.2, *Individual Location*). This is the recommended practice. However, this may not always be practical. When it is not, the methodology referred to as *Collection by Zone* in Section 2.8.3.1 may be used. In the zonal method, two techniques with variations predominate. The first uses pre-determined (pre-event prepared) fixed recovery zones. The second involves recovering data in pre-selected areas, then determining their location, mass, and description. This selection process may be as simple as choosing all material ejected in preferred directions.

It could also be as complete as selecting and cataloging all debris located beyond the edge of the debris saturation zone.

3.4.1 Collection by Zone

In this approach, collection zones will have been defined (Section 2.8.3.1) and their boundaries located prior to the start of the data. Each zone is searched by a recovery team. The number of personnel required for this operation will be determined by the size of the recovery zones and the amount of time allocated for the operation. Assuming favorable terrain conditions and a location outside the saturation zone, one person can adequately search an area that extends approximately two meters to either side of his/her location; however, for effective, 100% pickup, especially in high debris density zones or within the saturation zone, this may be reduced to as little as one meter. Often, more than one pass through a zone will be required in order to completely cover the area.

During the search, each debris piece located within the zone is identified, picked up, and transported to a zone collection area (usually one corner of the zone). If further analysis is to be performed later, an identification tag is prepared and the material bagged. The identification tag should contain the zone identifier, the zone location, and the number of pieces collected within the zone.

After collection there are two options for cataloging the collected material:

1. With a portable system that is transported to each zone, or
2. With a permanent system that is set up out of the weather, away from the collection grid. Each bag of collected material would be transported to this central location for cataloging.

There are pros and cons to both options (field analysis versus analysis at a central location). Operating at a central location may be more efficient because weather delays are eliminated and information is typed directly into a computer, saving time and reducing possible transcription errors. One con to transporting to a central location is that concrete and masonry pieces could be further damaged or further shattered during transportation. The pros probably outweigh the cons, but care should be taken to minimize damage during transit.

With either option, the cataloging process would be the same;

- For each piece, determine the weight and assign a descriptor, or
- Sort the collected material by type/source and then sort each material type into mass bins; then for each type, count the number of pieces in each mass bin

It should be emphasized that all large debris should be photographed in situ with a scale reference in the field of view before they are moved or disturbed.

A historical variation on this method is the use of collection pans or debris traps. These are areas or structures of known dimension that are placed at selected locations around the test area.

Because their dimensions are known, these provide point estimates of the debris density at that location. In theory, if enough of these traps are placed around the test area, then these point estimates can be used to estimate the total debris distribution. This method has the theoretical advantage that it appears inexpensive and easy to apply. In practice, however, this is usually not the case. In order to adequately sample the debris distribution, large numbers of collection boxes are required. Further, in some situations, the debris density is changing rapidly with range and/or azimuth; such changes may be missed or inadequately represented by a simple sampling technique. An additional problem with using this type of technique is that the pan or trap may interfere and modify the debris cloud and thus give incorrect information. Because of the problems associated with the use of such traps, it is recommended that this method not be used on future tests.

3.4.2 Individual Piece Location

In this approach (Section 2.8.3.2), a pre-event survey will have located azimuthal markers at pre-determined, usually 5°, intervals around ground zero at a minimum of at least two distances. Ropes or lines can be used to temporarily mark off azimuths that have been searched and those that have not. It is not critical for these angles to be accurate; rather the ropes just used as a frame of reference to designate what areas have been cleared and the boundaries of the current search area. The origin and orientation of the search area is not as important but is probably best if it is defined as elements of a polar coordinate system, the origin of which will be at the center point of the PES.

The search team performs two tasks within each search area:

- Each debris piece is located and
- A survey flag is placed next to each piece.

Once the area has been completely searched and all debris locations flagged, the boundary lines are removed and taken to the next sector to be searched.

Cataloging teams follow behind the search teams to complete the process. A cataloging team performs the following functions for each piece of flagged debris within the search zone:

- Photographs in situ any unique or unusual pieces
- Determines its coordinates (bearing and range) relative to ground zero, as described in Section 3.5
- Determine its weight
- Provide an identifier that gives the source (type of material and/or where on the PES the piece originated)
- Enter all of this information into an electronic database
- Removes the debris piece from the test bed
- Remove the flag for reuse

3.5 Coordinate Determination

Once it has been decided that the location and description of each piece will be obtained, there are several options that can be used to achieve the location portion of this goal. These include, but are not limited to, the following:

- compass and tape
- the use of special binoculars that have a built-in range finder and compass
- conventional transit-based surveying techniques
- Global Positioning System (GPS)

3.5.1 Non-GPS Systems

Historically, the first two listed techniques have been used when there is a relatively small amount of debris, up to a few hundred pieces, and they are located relatively close to ground zero. In its simplest form, the tape is used to measure the range of each piece from ground zero. The compass is used to estimate the bearing of each piece, also with respect to ground zero. While simple and easy to use in concept, this method has the highest potential for error—especially in the estimation of the bearing.

Another technique which has been used in this scenario is the use of, special binoculars or laser range finders. These instruments have a built-in range finder and compass that can simply be used to point and measure a distance. If measurements must be taken from a location other than ground zero, then multiple distances to structures or landmarks with known bearings and ranges from ground zero must be recorded. These multiple readings can later be resolved into a range and bearing for each debris location. Otherwise, direct measurements of the range and bearing of each piece with respect to ground zero is preferred. It should also be noted that the accuracy of laser range finder/binoculars is often limited to only ± 1 meter in range and ± 1° in bearing.

Conventional survey techniques are appropriate for debris numbers up to a few thousand. Their main disadvantage is the amount of time required to complete each measurement. If a test generates a significant amount of debris (over a few thousand pieces), the time required to conduct the survey may become prohibitive; for this case, the use of a GPS system is recommended. This disadvantage can be reduced using more sophisticated surveying systems. Using conventional techniques, a small crew (less than eight), and a moderate debris density, about one thousand points can be surveyed in an average day. However, in terms of total data retrieval, this efficiency will be reduced, as debris mass and description information are included against each item.

For these methods and other transit-based surveying techniques all data must be recorded using other equipment (e.g., laptop, note book, etc.).

3.5.2 GPS Systems

The following discussion is based on information contained on the website of the USGS Global Position Application and Practice web site [Reference 3-5]. GPS based systems are currently available in two grades (based on their complexity and resolution):

- Mapping Grade
- Survey Grade

3.5.2.1 Mapping Grade GPS Systems

Mapping grade systems are further divided into two sub-categories:

- Commercial Grade
- Differential Grade

Handheld units available are generally considered Commercial Grade. They are designed for recreation or general commercial use. These units are good for general location and navigation with simple waypoint marking. Commercial Grade units are small and easy to use. They have an average horizontal accuracy of about 3 meters.

Differential grade GPS (DGPS) equipment differ from commercial grade GPS units by incorporating higher quality antennas and implementing differential corrections that greatly improves the accuracy of the location. Differential grade GPS equipment incorporating high quality antennas can receive information from a greater number of satellites at once, some can receive information from the satellites in several frequencies (L1 and L2), and some can receive information from satellites in different satellite systems (primarily GPS and GLONASS). Differential grade antennas receive corrections from either a satellite based augmentation system (SBAS) or ground based augmentation systems (GBAS).

All Differential-grade GPS receivers have a horizontal positional accuracy of less than 1 meter. Most new GPS receivers with differential corrections from SBAS such as WAAS (wide area augmentation system) and low level subscriptions or from GBAS such as beacons typically have accuracies from 0.3 to 1.0 meter, depending on the quality of the receiver. Some systems with improved corrections have an accuracy of 5 – 30 cm. Currently, the highest quality differential GPS receivers available are dual frequency units that utilize both GPS and GLONASS satellites. These coupled with a very accurate differential correction subscription will give the best differentially corrected position possible. Vertical accuracies for these GPS units are 2 – 3 times that of the horizontal accuracy, and should be used only for informational purposes.

3.5.2.2 Survey Grade GPS Systems

Requirements for survey-grade GPS receivers are that they record the full-wavelength carrier phase and signal strength of the L1 and L2 frequencies and they track at least eight satellites simultaneously on parallel channels. These dual-frequency receivers limit the effects of ionospheric delay and, increase the reliability of processed results over long baselines.

Real Time Kinematic (RTK) is a term applied to GPS surveying methods where receivers are in continuous motion; however, for relative positioning (the situation for debris location), the more typical arrangement is a stop and go technique. This approach involves using at least one stationary reference receiver and at least one moving receiver called a rover. RTK procedures do not require post processing of the data to obtain a position solution. A radio at the reference receiver broadcasts the position of the reference position to the roving receivers. This allows for real-time surveying in the field and allows the surveyor to check the quality of the measurements without having to process the data. The typical accuracy for these systems is the following:

- Horizontal: 1 cm + 2ppm
- Vertical: 2 cm + 2 ppm

This means that the accuracy is a function of the separation between the reference station and the measurement point. If a separation distance of 1000 meters between these two points is assumed, then the accuracy becomes:

- Horizontal: 1 cm + $(2x10^{-6})$ x $(1x10^{5}$ cm) = 1.2 cm
- Vertical: 2 cm + $(2x10^{-6})$ x $(1x10^{5}$ cm) = 2.2 cm

3.5.2.3 Collection Caveats

Care should be taken when selecting any system for determining debris locations. This is especially true with many hand-held GPS systems. Their relative accuracy may be inadequate for the situation, thus precluding their use. DGPS and Survey grade systems are equipped with data collectors that can be used to catalogue any information about the debris at a given location. Depending on the processing power of the data collector and amount of debris characteristics recorded, one GPS crew (consisting of 3-4 people) can catalogue 500-2,000 points per day. A GPS crew typically consists of one person operating the GPS and 2-3 people who find, weigh and characterize each piece, and load the piece for removal from the search area.

3.5.3 Collection Efficiency

The use of GPS has greatly increased the efficiency of the debris cataloging process. ISO-1 [Reference 3-6] used a theodolite based system. Subsequent collection efforts including ISO-2 [Reference 3-7], ISO-3 [Reference 3-8], ISO-3 Cal [Reference 3-8] (ISO-3 Cal was a repeat of the ISO-3 shot with the change that the ISO container was not present for the Cal), SciPan 4 [Reference 3-9] and SciPan 5 [Reference 3-10] have all utilized GPS systems. The efficiency of the cataloging process has increased on each event. A measure of this efficiency is the number of points cataloged per man hour of effort expended. The number of man hours expended has two parts: (1) the time spent locating and flagging each point and (2) the number of man hours expended surveying, weighing, cataloging and removing each debris piece. Table 3-1 taken from Reference 3-8 presents the collection efficiency for several previous debris collection efforts.

Table 3-1. Cataloging Efficiency

Event	Points	Time (man-hours)	Efficiency (points/man-hour)	Reference
ISO-1	4,585	950	4.8	3-6
ISO-2	25,144	2,205	11.4	3-7
SciPan 4*	22,472	1,757	12.8	3-9
ISO-3	66,915	2,410	27.8	3-8
ISO-3 Cal	65,197	3,022	21.6	3-8

*SciPan 4 Collection Efficiency does not reflect additional points collected on DIRT 4.1 and DIRT 4.2

Although the size of the collection area is not shown in Table 3-1, given knowledge of the tests, some interesting information may be inferred. For example, from the test reports it can be seen that the collection area for ISO-2 was roughly the same as that for ISO-3. The number of man-hours required for the debris recovery effort was also roughly the same, which can be seen in the table. However, the number of points recovered for ISO-3 is much greater than the total for ISO-2. This is very apparent when comparing the reported efficiency values for these two tests. From this information, the authors conclude:

1) The amount of time it takes to complete the debris recovery effort is more a function of the area to be searched rather than the number of points in the data set.
2) The collection efficiency of a test that produces fewer debris elements, but scattered over the same area, can never be as high as a test producing more pieces.

This second point may temper the conclusion that the authors also feel to be true: the efficiency of debris recovery efforts has improved as the methods have been standardized, the equipment has improved, and the crews have become seasoned to such tasks.

With this comparison in mind, can the same conclusions be reached when considering ISO-3 and ISO-3 Cal? The test areas were identical, as was the equipment used, but the only difference between the tests was that the ISO-3 test placed the stacked munitions in an ISO container whereas ISO-3 Cal conducted the test with the munitions in the open. ISO-3 Cal took more man-hours to recover slightly fewer points than ISO-3. This can be seen when comparing the efficiencies of these two tests. One could argue that the efficiency of ISO-3 Cal suffered because the crew had been working for as much as almost two months straight, as the ISO-3 Cal test was conducted immediately after ISO-3, with a series of other tests prior to that. However, this must not be telling the whole story – consider the piece counts in the two tests. Why would the ISO-3 Cal shot produce almost as many pieces as the ISO-3 shot, despite the fact that ISO-3 included ISO container debris as well as primary fragments? Could it be that some of the primary fragments recovered in the ISO-3 Cal shot were really pieces produced by the ISO-3 test, but missed by the debris recovery crew the first time around? This seems to be the most logical explanation, and is supported, at least anecdotally, by the evidence at the time of the tests. This conclusion might suggest that there is a maximum speed that the crews can be expected to work, and trying to do anything faster may result in a higher miss rate, despite what the efficiency value would suggest.

The information in Table 3-1 is presented as a historical record to aid in any future debris collection efforts. As discussed, there are multiple factors affecting the duration required to conduct a comprehensive debris collection. The information provided in Table 3-1 and the associated test reports is intended to provide a baseline for future test planning efforts.

3.5.4 The Future

As technology develops it is important to keep in mind what methods are feasible and applicable to a given test. New technologies, that are not considered here, could be applied to advantageously affect the viability of recording individual debris locations.

For example, infrared and ultraviolet imaging could offer unknown opportunities. The former is dependent upon temperature differences between the individual debris pieces and the surrounding terrain; these differences may be small and will decay rapidly. Metal pieces however, may stand out brightly when heated by the sun. Ultraviolet imaging would require painting the PES with a material that would fluoresce in ultraviolet light, or embedding such a material within the PES structure. Care must be taken to ensure that such materials would survive the effects of the detonation.

The applications of UAS to large scale testing are still emerging and must be proven, but UAS could bring many benefits and become routine. The ultimate goal would be to use UAS to reduce the resources necessary the conduct a large scale test and obtain better data. Potentially, UAS surveying could dramatically improve manual debris collection.

3.6 Error Checking/Search Process

While the accuracy of other test data acquisition systems is dependent upon calibration and technical specifications, the debris collection effort is almost entirely dependent upon the human element, and as such is highly affected by human error. Fatigue, inexperience, and lack of motivation are three factors that can severely compromise the test data, even to the point where the data become useless. It is much easier for a tired or unmotivated crew member to simply walk the debris field without actively searching for debris than it is for them to utilize the physical and mental energy to perform a proper search. The authors have found from experience that maintaining proper focus and technique of the debris recovery crew is absolutely critical to generating quality data from the test, and therefore shall be focused on in detail in this section.

3.6.1 Quality Control (QC)

Quality Control (QC) is the effort made, during the debris collection effort, to ensure that fragments have been noticed and marked by the recovery crew. This is usually achieved by having one or more persons following the rest of the search crew, checking behind them for missed pieces. This QC assignment is normally given to a more experienced member of the crew, and the assignment includes “coaching” the others on mistakes (such as failing to check in bushes, not being careful of shadows, not “helping neighbors” to find pieces, drifting out of alignment, etc.).

The QC person will generally “snake along” behind the crew, and must balance the attempt to be thorough with the goals for the pace of the recovery effort. This typically involves more physical exertion than the rest of crew, so it may be advisable to rotate this assignment.

Although styles vary, it usually is a good idea to keep the QC process from being adversarial. However, if the crew performance is deteriorating noticeably, perhaps due to conditions (such as extreme weather, or just being late in the day), the QC person may decide to make unavoidably public changes. These changes could include postponing the debris recovery effort for the day, slowing the spacing or pace of the crew, or reconfiguring crew members to increase efficiency.

It is imperative to note that the QC person cannot be expected to find every piece that the rest of the search crew misses. If that were possible, then logically the rest of the crew would not be needed. The QC job is designed to help season the newer members of the crew, identify (and hopefully correct) recurring mistakes, and to give some sense of accountability to the flaggers (personnel performing the debris location operation).

3.6.2 Quality Assurance (QA)

Quality Assurance (QA) is the attempt to characterize the thoroughness of the crew, which must therefore come after the crew has finished a section (or all sections) of the recovery. The QA team is typically made up of 3-5 people that have participated in some part of the recovery effort, and are therefore familiar with the terrain and the fragments in question. It is critical that the QA team is looking for the same thing that the original search team was; otherwise the process is flawed. For example, if the search team was told to look for fragments down to 10 grams, but the QA is looking for pieces down to 5 grams, the QA effort is not fairly grading the quality of the original search.

The QA process itself usually involves setting up some selected search sectors and thoroughly scouring them for missed debris. A typical QA sector might be a 10m by 10m square. Often it is desirable to set up several such squares, located in different parts of the original search area. For instance, it might be prudent to search a high density area (such as the normal of a wall) and a low density area (such as a corner). The areas could also be setup by distance: a close-in area to cover the high density spots, and an area much farther out to consider low density zones. It may also be important to check “boundary regions” in the collection area, such as along the dividing line between teams or sectors – a common place for missed debris.

The QA will normally record the number and size of the missed pieces, but the exact location may not be important. It may be informative to note trends in the misses, such as pieces often found in vegetation, or that more pieces were noted when the terrain was more uneven (or even just darker, or closer to the color of the debris). The QA process may conclude that most areas had fewer missed pieces than special regions (such as boundary areas).

It should be noted that the goal of the QA effort is to establish a “miss rate” for the test, or several rates for different areas. This is as opposed to rejecting the test results, which would only apply if the miss rate was extreme. Although all search teams should have performed the search in a consistent manner, it may also be useful to establish different miss rates for different search teams, so the data can be reviewed accordingly.

3.6.3 QC vs QA

In addition to the difference in timing of the two efforts, the inherent distinction is that the QC process is part of the debris recovery effort, and consequently the debris noticed by the QC person is counted the same as any other piece surveyed. Conversely, the debris found during the QA effort is a subset of the pieces missed, since the area searched was a subset of the total recovery area. Therefore, the test results would be skewed if the QA pieces are counted as part of the data set, so this is not normally done. Instead, the QA data can be used to scale the regularly-collected data to account for the estimated miss rate(s).

3.7 Debris Mass Determination

As has been previously indicated, the mass of each debris piece is usually required. In most situations, this will be determined by weighing the individual pieces. For rebar, in addition to the piece weight, the size of the rebar and its length should also be recorded. However, in those situations where the piece is too large to weigh easily, the piece should be assigned an identification number, photographed with a size scale and the identification number in the field of view, and its maximum dimensions (length, width, and height) and its mass should be estimated and recorded. Other alternatives include:

- Transporting the piece to a central location for subsequent weighing on a weight bridge/truck scales
- Carefully breaking the debris piece into smaller components, weighing the components, and then summing the masses of the components

For all other pieces, the resolution of the scales that are used should be better than 1% of the total mass of the item or 1 gram, whichever is smaller. The minimum measurement increment that is normally required is usually 1 gram. There are commercially available, portable, battery-operated scales with the required resolution, often with a computer interface.

When it is not practical or necessary to determine the exact mass of each piece, a binning technique can be used. Each piece of debris is categorized by a mass bin, rather than its actual mass. A recommended set of mass bins is shown in Table 3-2. An alternative approach that has also been used is the sorting of debris by dimension rather than mass. The size bands, also shown in Table 3-2 have been chosen to represent selected mass bands for steel and concrete. The size ranges shown for each mass bin were calculated by assuming that each debris piece was spherical in shape with a density of either 2,307 kg/m^3 (144 lb/ft^3) for concrete or 7,849 kg/m^3 (490 lb/ft^3) for steel.

Table 3-2 provides a description (size, mass, and impact kinetic energy) for each mass bin for both steel and concrete debris. The impact kinetic energies were calculated by assuming that the material was falling at terminal velocity at the time of impact. These bins are based on the mass bins that were originally defined for the United States risk-based explosives safety siting program described in DDESB Technical Paper 14 [Reference 3-11].

Table 3-2. Mass Bin Characteristics

Bin Number	Concrete			Steel		
	Mass (kg)	Size (mm)	Energy (J)	Mass (kg)	Size (mm)	Energy (J)
1	>24.5	>274	>136,920	>11.8	>140	>140,093
2	9.75 – 24.5	201 – 274	40,081 – 136,920	4.54 – 11.8	104 – 140	39,160 – 140,093
3	4.31 – 9.75	152 – 201	6,703 – 40,081	2.04 – 4.54	79 – 104	13,497 – 39,160
4	1.81 – 4.31	114 – 152	4,252 – 6,703	0.82 – 2.04	58 – 79	3,975 – 13,497
5	0.77 – 1.81	86 – 114	1,359 – 4,252	0.36 – 0.82	46 – 58	1,348 – 3,975
6	0.27 – 0.77	64 – 86	339 – 1,359	0.14 – 0.36	33 – 46	365 – 1,348
7	0.136 – 0.27	48 – 64	134 – 339	0.064 – 0.14	25 – 33	132 – 365
8	0.054 – 0.136	36 – 48	39 – 134	0.027 – 0.064	18 – 25	42 – 132
9	0.023 – 0.054	25 – 36	12 – 39	0.011 – 0.027	14 – 18	13 – 42
10	0.011 – 0.023	13 – 25	5 – 12	0.006 – 0.011	7.1 – 14	6 – 13
G	<0.011	<13	<5	<0.006	<7.1	<6

Since their definition, they have been used on at least two DoD trial programs to characterize the debris that was collected [References 3-12, 3-13]. Such use, however, pre-dates the general availability of GPS technology. Since then, the importance of obtaining the mass of each piece of collected debris has been recognized and the use of mass bins as a collection technique is no longer recommended.

3.8 Debris Descriptors

Each piece of debris that is cataloged should be assigned a unique descriptor. This descriptor should as a minimum include the following information:

- Piece number
- Material Type, e.g., concrete, masonry, steel, aluminum, etc.
- Where piece originated on PES; e.g., roof, wall, door, skin, bracing, engine, cab, etc.

The descriptors utilized on a particular test series should be standardized; i.e., with multiple cataloging crews working simultaneously, the same descriptor set should be utilized by all personnel. For a test series with multiple events, the same descriptor set should be applied to all of them. Doing this will facilitate data comparisons between shots in the same test series.

3.9 Cataloging/Sample Data Sheets

When the collected data are to be entered directly into pre-determined catalog pages, then the format and data categorization (e.g., debris type identifiers) must be agreed upon. Generic, site specific, and/or more detailed specific descriptors are appropriate and can be used. However, these must be well defined and each should be a sub-set of the more generic descriptors.

The practice of using GPS with built-in data logging has begun to preclude the use of such cataloging techniques. However, there may be situations or scenarios where their use is appropriate. For those situations, the reader is referred to earlier versions of this publication [Reference 3-14] for sample data sheets.

3.10 Site Remediation

In order to reduce site contamination by material from previous tests, it is imperative that site remediation become an integral part of any post-event data collection process. The two primary collection methods (*Collection By Zone* and *Individual Piece Location*) both include post-catalog removal of material from the test bed. Arrangements should be made with the test site owner for disposal of all material collected during the site remediation.

Generally, un-cataloged debris that is located during the site remediation process is not added to the debris catalog. However, if the recently-located debris is considered significant or important, adding it to the debris catalog will be considered if it is found to be feasible.

4.0 DEBRIS DATA ANALYSIS

4.1 General

A general aim of the analysis of the debris pickup data from tests or accident investigations is the generation of debris mass and number distributions and their defining functions, as well as the launch angles and launch velocities of the debris. When considering accidents and tests, although the aim of the debris pickup data and analysis may be similar, the focus may be quite different. After an accident, the goal would likely be to help determine the size (e.g., 5 versus 50 kg), type (e.g., high order versus low order versus pressure rupture), and location (e.g., mix kettle versus fill hopper) of the event that occurred, with the goal of identifying where and how the accident happened. With a planned test, these are all initially known. According to the test or accident investigation circumstances, the degree to which this aim can be fulfilled will vary.

Care should be taken that situations do not arise that could mask or hide trends in the data. Two potential issues are:

- The sheer amount of debris may preclude more than a few sampled distributions
- The zonal dimensions used in the debris collection effort may conceal some detail of the spatial distribution

An example of the first issue arose during tests in Australia [Reference 4-1] in which the debris distributions from explosions in small buildings were determined. Most of the debris was sorted to discard material that had no dimension greater than 50 mm (2 in) (deemed at the time to be equivalent to an object with a mass of 100 grams (0.22 lb)). The remainder was simply counted. Only along two, orthogonal, 10° rays was a full mass analysis carried out. Mass distributions as a function of range were produced in those directions. The report authors indicated that to do more would have been prohibitively time-consuming.

The information gathered in any collection effort is generally a description of the piece, to include its source, its mass, and its position or zone at or in which it was found, i.e., the point at which it came to rest. To arrive at that point, following its initial acceleration, it will have followed a ballistic trajectory defined by its velocity, mass and dimensions/shape (which determine the drag) to its first point of impact. Upon impact, it may have shattered, buried itself, bounced, skidded or rolled. Dependent on which occurred, further ballistic, burial, bounce, skid, and roll phases may have followed.

For consistency, the following definitions are provided:

- <u>Bounce</u> (synonymous with ricochet)--piece hits ground but does not stop; piece leaves contact with ground; piece hits ground again

- <u>Skid</u>--piece hits ground but does not stop; piece never leaves contact with ground, and skids/slides on the same surface (of the piece) until zero velocity achieved

- Roll--piece hits ground but does not stop; piece tumbles along ground, so the contact surface may change, but the piece doesn't "bounce" into the air; tumbling motion may generate new component of velocity post-impact

At any point, its passage from PES to final resting place may have been perturbed by in-flight collision with other pieces of debris and/or being pushed by the shock front followed by travel through the negative phase of the wave. Furthermore, at any impact point the piece of debris may break up and, thus, what is found at the pick-up point is only a part of something that was larger as it traveled over most of its journey.

As a result of all this, consideration of the debris data, in its *as-collected form* and in terms of measuring its potential damaging interaction with personnel or materiel targets must be considered as conservative (in terms of distance) for the following reason: Except for vertical debris falling straight down and forming a crater, along the final stages of its passage from the PES to pick-up point, any piece of debris will be lower in energy and thus not as harmful as at its initial impact with the ground.

For many years this conservatism was accepted and all debris analysis was performed on the as-collected form of the data. In recent times, consciousness of the non-realistic treatment of the data coupled with a drive, for economic reasons, to control or minimize the degree of conservatism in consequence analyses has led to a re-examination of the methodology.

Looking simplistically at a storage or operating structure, most projected debris originates from three sources—the walls, the roof, and the floor. In general, each of these debris sources has a characteristic launch direction.

Roof debris is mostly projected upward over a small angle about the normal to the ground; hence, it rises high into the air and returns to earth at a high, nearly vertical, angle. As a result, roof debris will have a consequence only at or near where it lands.

Floor debris is mostly projected downward over a small angle about the normal to the ground; the majority of this debris tends to remain in and around the crater area. There are two scenarios where some of the floor material may be projected to some distance away from the ground zero area:

- Some of the floor material, however, rebounds or ricochets off the crater walls and may be projected to some distance away from the ground zero area

- Some of the floor material located just outside the footprint of the charge can be lifted up and out by the blast wave rebounding up from the crater; as before, this material may be projected to some distance away from the ground zero area.

Because of this behavior, the floor will generally only have a consequence at or near where it lands.

Debris from the walls is generally projected over a small angle about the normal to the walls, along a vector that is nearly parallel to the ground. As it leaves the PES, it can sweep across the ground at a relatively low altitude and may, therefore, interact with any target (personnel or structures) as it passes. It is essential, therefore, that the contribution to consequence of low-angle debris be integrated over its entire path length. Methods that address this scenario are described in Sections 4.4 and 4.5.

As might be expected, in practice the picture is not so simple:

- Some debris pieces will be projected at intermediate launch angles and will only contribute to the consequences over parts of the passage to their final locations, and
- Debris from roof, floor, and walls may not be separable and thus cannot be treated independently.

Until recently, the requirement for a debris mass analysis was dependent upon the end use of the data. The current thinking, however, is that a debris mass analysis is important for all aspects of explosives safety.

Historically, whether or not a full debris mass analysis was carried out, debris with low mass was removed from the analysis. In general, this was done to expedite the process and reduce costs. There are at least two downsides to this procedure:

- Once the data collection is completed with small pieces of debris not being collected, there is no way to recover this data. Small debris may be potentially hazardous near the PES, but its kinetic energy decreases as it moves away from the PES.
- This procedure also prevents the determination of the total percentage of mass recovered.

It is always better to collect as much information as is practical from the beginning, since there is no way of predicting what future analyses may require or desire.

4.2 Hazardous Fragment Distance (HFD)/Debris Inhabited Building Distance (IBD)

The Debris Hazardous Fragment Distance (HFD), also known as the Debris IBD, is the range at which the density of hazardous fragments falls below a value of 1 per 55.7 m^2 (1 per 600 ft^2). Currently, a hazardous fragment is defined [References 1-5, 4-2] as a fragment that has an impact kinetic energy of 79 Joules (58 ft-lb) or greater.

Depending on the analysis methodology utilized, for specific azimuths, the debris density versus range curve may become non-monotonic and cross the IBD density on multiple occasions. If this occurs, it is suggested that the crossing at the farthest (greatest) distance be used as the HFD/Debris IBD.

4.2.1 Probability of Fatality

It is frequently a requirement to relate the impact kinetic energy of a piece of debris to its probability of fatality, given that the debris hits the target. Figure 4-1 presents a curve of kinetic energy versus probability of fatality. This curve is based on the *Average Body Position* data described in Reference 4-3 and is for blunt force trauma, not penetration. The curve is a cumulative lognormal distribution fit to the data shown in Table 4-1.

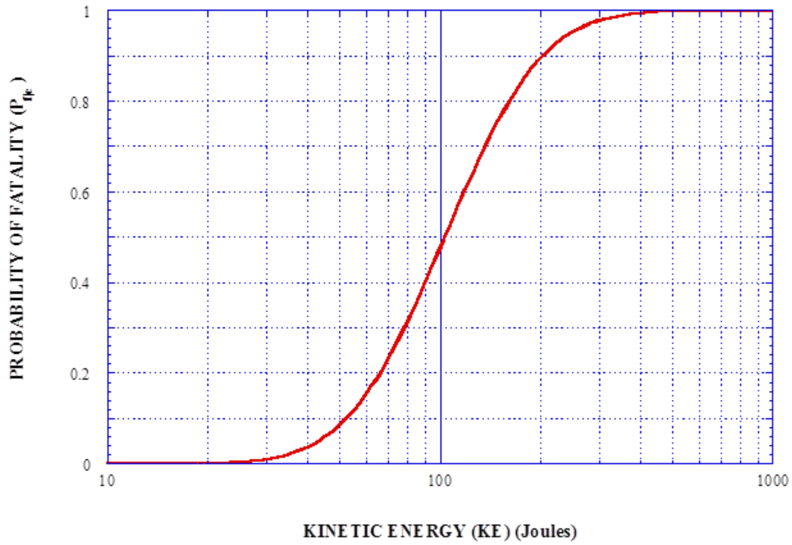

Figure 4-1. Kinetic Energy versus Probability of Fatality

Table 4-1. Impact Kinetic Energy Data

Probability of Fatality Given an Explosive Event and Exposure (P_{fle})	Kinetic Energy (KE) (Joules)
0.1	51.5
0.5	103.0
0.9	203.4

The direct formula for the cumulative lognormal distribution function does not exist in a closed form; however, Microsoft Excel does provide a function for its computation (LOGNORMDIST (X, Mean, Sigma)).

Based on Figure 4-1, it can be seen that a fragment with an impact kinetic energy of 79 Joules only has a 31% probability of being lethal. In order to achieve a lethality probability of 50%, an impact kinetic energy of 103 Joules would be required. Reference 4-4 is another source of information on the probability of fatality information as a function of the impacted body area.

4.3 Incremental and Continuum Analysis

The positional debris information, whether collected in zones or as individual pieces, can be sorted and sub-divided into fixed polar zone populations of debris density, $N_{r\theta}$. The debris density for that zone is then given by one of two formulae:

$$D_{r\theta} = 360\ N_{r\theta}/[(\pi\ \Delta r\ \Delta\theta)(2r+\Delta r)] \quad (1)$$

$$D_{r\theta} = 180\ N_{r\theta}/(\pi\ r_c\ \Delta r\ \Delta\theta) \quad (2)$$

where

$D_{r\theta}$ = zonal debris density ($N_{r\theta}$/zone area)
$N_{r\theta}$ = number of pieces in zone (r,θ)
r_c = radial distance from ground zero to the center of the zone
r = radial distance from ground zero to the inner boundary of zone
θ = polar angle of the center of zone in degrees with respect to a coordinate system centered at ground zero
Δr = incremental zone depth
Δθ = angular width of zone in degrees

Fragment/debris density distributions as a function of range and polar angle can then be plotted. Two examples of such plots are shown as Figure 4-2 and Figure 4-3. Figure 4-2, taken from Reference 4-1, is based on UK small quantity trials. Figure 4-3 depicts the debris data collected on the SciPan 5 event [Reference 4-5]. It should be pointed out that the regions with no debris shown near the center of the plot (center circular region, two spokes pointing "up" and "left" from the center, and quadrant to the "right" of center) are regions where a different debris recovery technique was employed, or there was no debris recovery conducted. These voids do not represent regions were no debris was present.

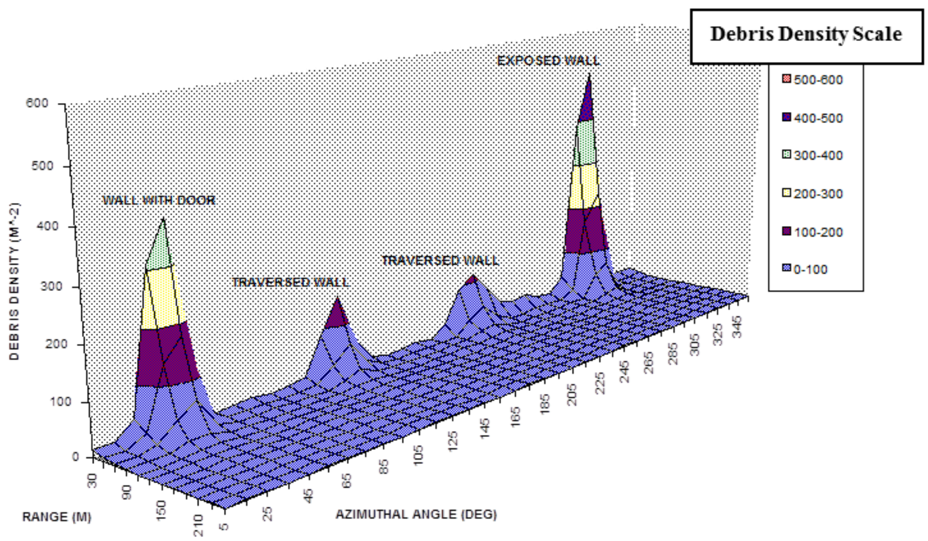

Figure 4-2. Debris Density Variation—Example 1

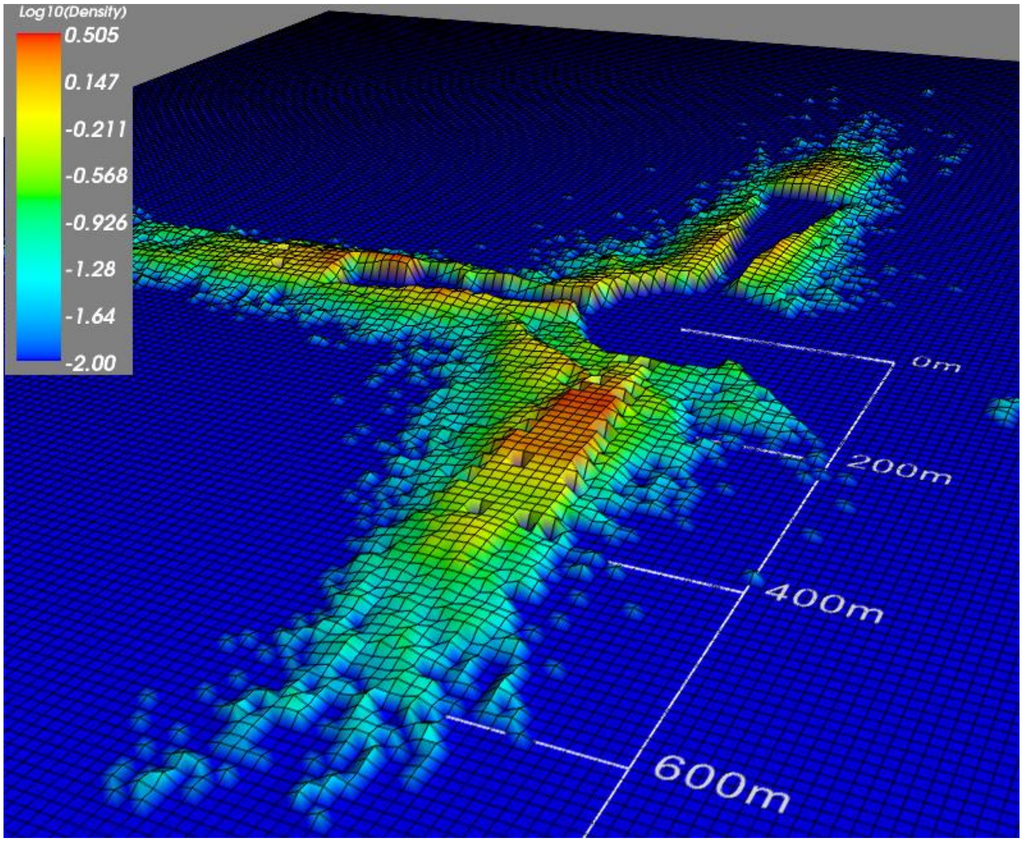

Figure 4-3. Debris Density Variation—Example 2

The collection of individual debris locations/masses for each piece of debris can result in dauntingly large amounts of data. An Australian trial [Reference 3-6] involving the collection of debris produced by a detonation inside an ISO container resulted in a data file with over 4,500 entries.

The collection of individual debris locations/masses for each piece of debris can result in dauntingly large amounts of data. An Australian trial [Reference 3-6] involving the collection of debris produced by a detonation inside an ISO container resulted in a data file with over 4,500 entries. Table 4-2 shows a portion of that data file. Subsequent trials have generated significantly larger amounts of data:

- ISO-2—over 25,000 entries
- ISO-3—over 65,000 data entries
- SciPan 5—over 102,000 entries

Table 4-2. Sample Data File

Day	Item Number	Angle (°)	Distance (m)	Mass (g)	Mass Bin	Source
1	1	358.97	100.90	220	6	I
1	2	358.97	100.86	100	7	I
1	3	358.56	101.81	33	8	T
1	4	358.49	101.47	66	7	I
1	5	357.60	104.16	21	9	I
1	6	358.87	106.59	9	10	I
1	7	359.45	106.46	91	7	T
1	8	359.94	106.78	7	10	I
1	9	1.14	107.38	18	9	T
1	10	2.00	104.54	9	10	I
1	11	2.59	105.50	22	9	T
1	12	2.64	105.79	12	9	U
1	13	2.40	107.00	130	7	T
1	14	2.89	108.33	60	8	U
1	15	1.87	110.05	25	9	T
1	16	2.43	113.04	16	9	I
1	17	1.68	112.65	51	8	I
1	18	1.35	112.70	19	9	T
1	19	0.40	111.53	1094	4	T
1	20	0.43	111.53	20	9	T

The type of data shown in Table 4-2 can be analyzed using one of several statistical techniques. One powerful technique is to utilize the *Pivot Table* function contained in Microsoft Excel. A pivot table enables the creation of frequency distributions and cross-tabulations of several different data dimensions. In addition, it allows the display of subtotals and any level of detail that is desired. A pivot table analysis was used on the full data set (from which Table 4-2 was extracted) to determine the number of debris as a function of sector (azimuth), range band, and mass bin. A portion of the results of this type of analysis is shown as Table 4-3.

.

Table 4-3. Pivot Table Analysis Of Debris Data (Sample)

Sector	Range Band (meters)	Mass Bin										
		1	2	3	4	5	6	7	8	9	10	g
01 357.5° - 2.5°	A 100-125				2	2	1	6	7	8	5	
	B 125-150					1	3	3	10	13	5	
	C 150-175						2	5	8	16	5	1
	D 175-200					1	2	7	7	6	1	
	E 200-225					1	1	5	2	5	3	
	F 225-250			2			1	3	6	2	1	
	G 250-275				1				2	2		
	H 275-300			1		2						
	I 300-325					1			1			
	J 325-350					2						
	K 350-375								1	1		
02 2.5°-7.5°	A 100-125		1			2	2	4	11	19	8	
	B 125-150					1	4	6	19	15	14	5
	C 150-175					1	2	6	14	12	6	3
	D 175-200				1		3	3	8	17	9	
	E 200-225					1	2	3	11	8	4	
	F 225-250						5	5	9	8	2	
	G 250-275				1		1	1	4	3	2	1
	H 275-300				1			2	3	1		
	I 300-325					2			1			
	J 325-350							1	1			
	K 350-375								1	1		
	M 400-425						1			1		
	N 425-450							1		1		

The pivot table analysis shown in Table 4-3 utilizes the Mass Bins defined in Chapter 3 to characterize the debris mass.

In 1994, as a method of improving the statistics associated with the debris analysis procedures and to correct problems that had been exposed in the fixed grid methodology, Jacobs and Jenus [Reference 4-6] proposed a new methodology for analyzing debris distributions. Their algorithm utilized a moving grid, using a procedure similar to that for calculating a sliding average. In this procedure, the analyst examines the radius-azimuth data and selects realistic bounds (minimum and maximum angles and distances) for analysis. Once a starting point is selected, a value for a sector of an annulus to be used as the "electronic debris collection pad" is also chosen. Their methodology calculated the area of this pad, counted the number of fragments on that pad and then calculated the fragment density at that point using Equations (1) or (2). It then created another sector of an annulus of the same angular width, some increment further away from ground zero and calculated the debris density for that sector. It continued in this manner until the leading edge of the sector of the annulus included the last fragment to be considered. As before, the coordinates of the sector are those of the center point of the annulus. A similar approach is being considered in the United Kingdom by their Defense Ordnance Safety Group within the Ministry of Defence.

4.4 Pseudo Trajectory Normal (PTN) Density

In 1990, the Secretariat of the DDESB recommended that all debris densities should be measured as *trajectory-normal*, i.e., a density measured in a plane perpendicular to the trajectory at any point. The motivation for this decision was not provided. However, it can be surmised that they were attempting to represent the actual hazard to targets such as people and structures. Trajectory-normal density is difficult, if not impossible, to determine experimentally. Ground surface collection data, on the other hand, are straightforward to obtain. In order to approximate *trajectory-normal* densities, it was proposed that a *pseudo-trajectory-norma*l (PTN) density be defined. At a given location, this density would be computed by defining the number of debris pieces to be considered as all hazardous debris material at that location plus all hazardous material that had to pass through that location to reach a greater range. One of the following two formulae can be used to compute these densities:

$$PTN_{r\theta}(i) = [360/(\pi\ \Delta r \Delta\theta\{2r + \Delta r\})]\sum_{i}^{i\max} N_{r\theta}(i) \quad (3)$$

$$PTN_{r\theta}(i) = [180\ /\ (\pi\ r_c \Delta\theta \Delta r)]\sum_{i}^{i\max} N_{r\theta}(i) \quad (4)$$

where $PTN_{r\theta}$ (i) is the PTN zonal debris density for the i-th zone, r, r_c, and θ are as previously defined and *i* max is the number of the zone that contains the furthest hazardous fragment. A more detailed discussion of trajectory-normal and pseudo-trajectory-normal distributions and their computation is presented in Reference 4-7.

4.5 Composite or Modified Pseudo-Trajectory-Normal (MPTN) Density

During the debris dispersion process, many pieces are thrown well above the ground surface at a given distance and, hence, would not interact with persons or structures in that zone. In order to make a more realistic estimate of the true trajectory normal density, the DDESB Secretariat started a task to re-examine the PTN algorithm and recommend updates or modifications. The results of this task may be summarized as follows. Instead of considering all debris passing through a zone as contributing to the density in that zone, the study found that only about 1/3 of such debris contributes to the hazard within the zone. It should be noted that this nominal value of 1/3 seemed to adequately represents an average of the scenarios considered; however, this estimation would be conservative for roof or other vertically launched debris.

Based on this analysis, it was decided that a Modified Pseudo-Trajectory-Normal (MPTN) density could be defined and used. This was defined for a particular location by considering all appropriate debris material at that location plus 1/3 of all material that had to pass through that point to reach a greater range. The appropriate modifications to Equations (3) and (4) are shown as Equations (5) and (6):

$$MPTN_{r\theta}(i) = [360/(\pi\ \Delta r \Delta\theta \{2r + \Delta r\})][N_{r\theta}(i) + (1/3)\sum_{i}^{\mathrm{imax}-1} N_{r\theta}(i+1)] \quad (5)$$

$$MPTN_{r\theta}(i) = [180/(\pi\ r_c \Delta\theta \Delta r)][N_{r\theta}(i) + (1/3)\sum_{i}^{i\max-1} N_{r\theta}(i+1)] \quad (6)$$

The “1/3” factor used in Equations (5) and (6) was corroborated by the following exercise. A series of trajectories for steel and concrete debris were calculated using the computer code TRAJ [Reference 4-8], the predecessor of the current code TRAJ_CAN mentioned in Section 2.1. The following assumptions were made about the debris:

- Two debris types: concrete and steel
- Debris shape: *chunky* (cuboid)
- Launch angles varied between 1º and 89.9º
- Concrete debris
  - Mass = 0.045 to 45.4 kg (0.1 to 100 lb)
  - Speed = 30.5 to 609.6 m/s (100 to 2000 ft/s)
- Steel debris
  - Mass = 0.009 to 4.54 kg (0.02 to 10 lb)
  - Speed = 60.7 to 2133.6 m/s (200 to 7000 ft/s)

For each combination of debris type, debris mass, and launch velocity, the fraction of fragments/debris that reach that location via high angle (launch angle >45º) and low angle (launch angle <45º) trajectories was computed. The average fraction reaching that location via low angles for the concrete debris was 0.223 ± 0.146. Based on this it was proposed that if a value of 1/3 were selected for the low angle fraction, it would provide an upper bound for nearly all of the scenarios analyzed and assessed.

This factor was substantiated by an independent assessment made by the DDESB Science Panel [Reference 4-9]. In any case, if the debris data and analyses are adequately documented, then the data can be re-analyzed by new methods for purposes of comparison and further improvement of methods.

4.6 Application to Test Data

The direct application of either the PTN or MPTN analysis procedure to test data will generally result in conservative estimates for the Debris IBD (HFD). Roof and floor debris would initially have been launched vertically upward or downward and would present a hazard only to those targets in the immediate vicinity of their impact points. The majority of wall debris will generally be projected nearly parallel to the ground and will interact with targets at all distances out to its final impact point. Thus a more realistic analysis procedure could be to apply no special procedure (PTN/MPTN) to the floor and roof debris, treat the wall debris with an MPTN analysis, and then sum or overlay the results.

4.7 PTN/MPTN Discussion

Because its use has increased significantly since its introduction, the PTN/MPTN concept has been examined by several investigators [References 4-10, 4-11, 4-12]. Independent of each other, at least three investigators reached the same conclusion—that the methodology was potentially flawed. The absolute value of the IBD that is determined is dependent upon the zone size selected. As discussed in Reference 4-10, engineering judgment is often used to determine the sector length. The document further states that using a constant increment biases the fragment density as the radius increases. As the sector depth approaches zero, the density could approach infinity.

Another example of this potential problem is illustrated in the following example, taken from Reference 4-11. Consider three test scenarios for debris data collected between 90 and 250 meters (295 and 820 ft). Each describes a different manner to assess the same test data.

- Scenario 1
  - Sector depth = 20 meters (65.6 ft)
  - Sector width = 10º
  - Calculated Debris IBD = 231 meters (758 ft)
- Scenario 2
  - Sector depth = 20 meters (65.6 ft)
  - Sector width = 5º
  - To account for the change in collection area (1/2 of the sector width), the number of debris in each sector was reduced by a factor of 2
  - Calculated Debris IBD = 213 meters (699 ft)
- Scenario 3
  - Sector depth = 5 meters (16.4 ft)
  - Sector width = 10º
  - Number of debris adjusted to account for collection area change
  - Calculated Debris IBD = 246 meters (807 ft)

Based on the data utilized in this study, there is a noticeable variation in the calculated IBD value with changes in the collection zone dimensional parameters. An independent theoretical analysis by van der Voort [Reference 4-13] demonstrated that PTN and MPTN density were independent of sector width but were dependent upon the value selected for the sector depth. References 4-11 and 4-13 appear to reach conflicting conclusions:

- Reference 4-11: IBD is dependent on both the zone width and zone depth selected
- Reference 4-13: IBD is dependent on the zone depth selected but us independent of the zone width

Reference 4-11 was based on an analysis of actual test data that had inherent directionality. Reference 4-13 assumed a theoretical uniform distribution. The difference is the directionality present in the actual data.

At least two approaches have been proposed to resolve this problem. Both involve modifications to the MPTN procedure. The first approach, described by Parker in Reference 4-10 is to choose a sector length equal to the radial arc length. This gives the characteristic of having a nearly square analysis area approximating the area of a spherical segment. This is illustrated in Figure 4-4.

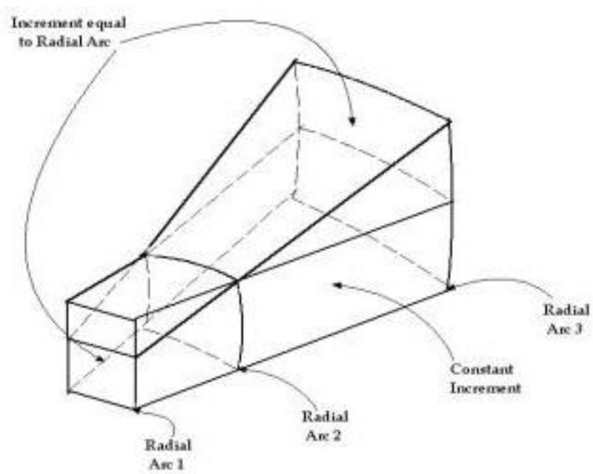

Figure 4-4. PTN Density Increment Illustration

In the second approach, described by Gould [Reference 4-11], the trajectory of the debris is considered. A virtual vertical zone is placed at the center of each sector. Debris passing through the sector could impact this virtual surface or could pass above it. If it passes above it, it would not present a hazard to personnel or structures within the zone. This is shown in Figure 4-5.

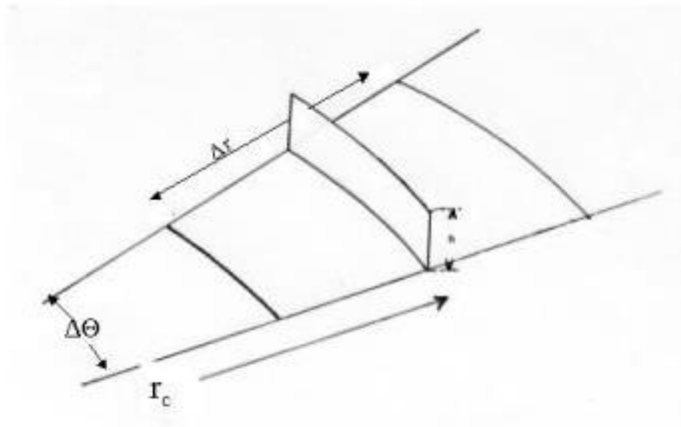

Figure 4-5. Vertical Sector Illustration

The density of pieces within the zone is the sum of the density of material landing in the zone added to the density of material passing through the virtual wall. The height of the virtual wall is obviously important. It should be chosen to be representative of the types of targets of interest, i.e., personnel or structures. If the only interest is personnel, then a height of 2 meters (6.6 ft) is suggested; if structures are involved, then a height of 5 meters is recommended. For most analyses, a value of 5 meters (16.4 ft) ensures conservatism. When using this technique, it should be noted that if the debris is projected at a high angle, it could drop such that it passes through the virtual wall and still lands within the zone, which could lead to double-counting some of the high angle debris. In practice this double counting issue will require some sort of software tool to resolve the problem.

These concerns could call into question the use of the PTN/MPTN methodology for comparison of tests as different test agencies often use different zone dimensions. A solution to this dilemma might be for agencies to agree to use the same or similar zonal dimensions in their analyses—angular widths of 5°-10° and sector lengths of 5-20 meters (16.4-65.6 ft). Further consideration of these concerns is ongoing.

4.8 HFD/Debris IBD Recommendations

The concepts of PTN and MPTN debris densities were developed to try to address the desire that calculated debris densities represent anticipated debris hazards. In addition to PTN and MPTN, yet another way to express the debris hazard at given location is to calculate the Actual Debris Density (ADD). The ADD only considers all appropriate debris material at that location, while ignoring all material that reached a greater range. This methodology is appropriate for debris launched at a high angle that is essentially traveling vertically downward at impact.

Given the different methods available to quantify the debris hazard, it is recommended that a combination of these quantified debris densities be employed to determine the debris IBD/HFD. The purpose of selecting one of the aforementioned analysis techniques for determination of debris IBD/HFD is typically for the purpose of defining the quantity-distance (QD) associated with it. With this in mind, the trajectory behavior of the debris being considered (if known) should be taken into account when selecting an analysis technique. Since the roof debris is typically launched at a high angle relative to the ground, the majority of roof debris is traveling vertically down and the ADD should be utilized. The appropriate technique to use for wall debris is not as straight-forward, as the wall debris typically departs the PES with a low launch angle relative to the ground. For small NEQs and/or loading densities that result in structural debris being thrown a minimal distance (e.g., less than 200 meters), it is likely that the maximum trajectory height achieved by the majority of wall debris is quite small and would be considered hazardous throughout its entire path. In this instance PTN should be applied to the wall debris to calculate the representative hazardous debris density. For larger NEQs and/or loading densities that result in structural debris being thrown a significant distance (e.g., farther than 600 meters), it is likely that the maximum trajectory height achieved by the majority of wall debris making it out to the anticipated debris IBD/HFD (e.g., > 400 meters) is quite large and would not be considered hazardous throughout its entire path. In this instance MPTN should be applied to the wall debris to calculate the representative hazardous debris density. Finally, for scenarios where the debris from the PES is not as bi-directional as roof versus wall or when the source of debris recovered on the ground is not known, MPTN should be applied to the debris, as it provides a sufficient upper bound as demonstrated in Section 4.5 of this document.

These recommendations are for determining debris IBD/HFD for QD purposes. If the debris data set is being analyzed for purposes other than determination of QD, consideration of the trajectory behavior of the debris in questions should be made when selecting the analysis technique used to quantify the hazard at the point of concern.

When a cruciform debris pattern is expected from structures, the debris IBD will vary with the azimuth around the structure. Because of this variation, a structure will have multiple HFDs: (1) An average value obtained by averaging the calculated HFDs over all azimuths, (2) A maximum value obtained by taking the maximum value for any azimuth and (3) A minimum value obtained by an average of the off-normal densities. Given that QD typically requires a single value to define the "circular" debris IBD/HFD which doesn't capture the variation of the quatrefoil pattern, there is some debate as to which HFD to use for QD purposes. Using any of the three HFD options listed is a valid approach, yet will always result in an erroneous estimate of the debris hazard in certain directions. The selection of the HFD value for QD purposes should keep this fact in mind.

4.9 Debris Initial Velocity Estimates

4.9.1 Preprocessing Images

The images from the video may need to be adjusted before analysis for maximum fragment visibility. This can be as simple as adjusting brightness and contrast, or as complicated as performing processing to highlight moving objects. Some tools may have image adjustment options built-in. The ultimate goal of any preprocessing is to make it easy to identify and track fragments through the field of view.

4.9.2 Coordinate System and Calibration

When starting the analysis, the first step is to choose a coordinate system that will remain constant throughout the images. The origin of the coordinate system is typically a fixed object in the image. It is better to fix it on an object rather than a corner of the image itself in case something, such as the blast wave, causes the camera to shift. The images can be reviewed beforehand to determine if that is a possible issue. It is also important to consider the angular orientation of the coordinate system, as it may be useful for the x or y axis to point in a particular direction. Typically, the x axis is parallel to the ground and the y axis is vertical, however, it could be useful to change this depending on what is being analyzed.

The concept of calibration is the same regardless of the software tools used. An object (or part of the object) of known size is measured in the image in pixels. Since the size is known in both length units and pixels, any length in pixels can be translated to the other unit of length. Software tools typically allow only one calibration measurement to be used, but multiple measurements can be averaged together and used after position data are collected. One important note is that the object used for calibration may be a distance from the image plane (closer or farther away from the camera). This affects the apparent size on the image and may need to be accounted for. An example of a defined coordinate system and calibration measurement is shown in Figure 4-6.

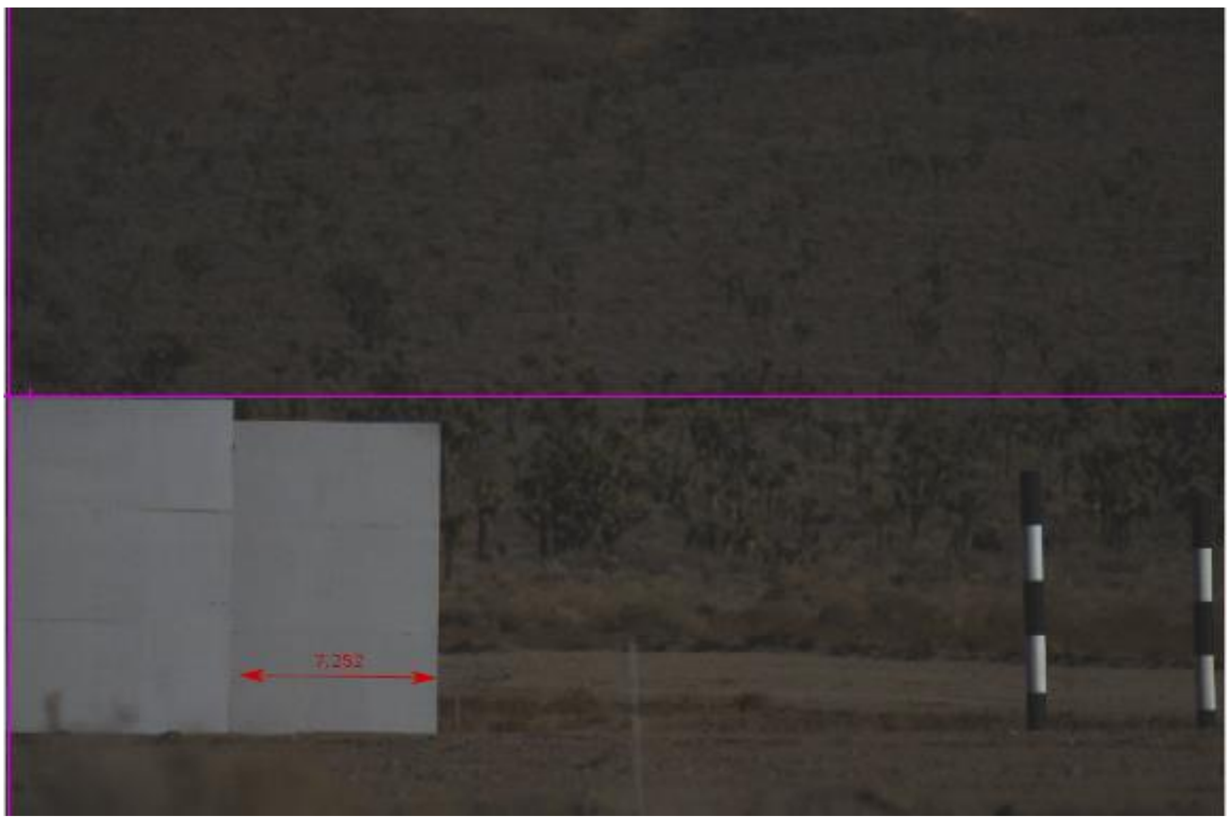

Figure 4-6. Coordinate System Designation and Calibration—Example

4.9.3 Record Fragment Position Data

To obtain fragment position data, a fragment candidate should be selected for recording that is easily discernable from the image background. Before recording a fragment’s position data, it is important to review the video segment to ensure that the fragment is traveling in the image plane. This is typically accomplished by tracking the fragment to see if it travels in between the object markers in the field of view, i.e., does the fragment pass in front of and behind the appropriate objects?

Once it is established that the fragment is traveling between the object markers, the position of the fragment on each frame is recorded. Specialized software is not generally required, but makes the process much more efficient. Each fragment's track can then be analyzed to obtain and extract useful information.

4.9.4 Data Analysis

Typically, the desired information from a high-speed video includes data on the fragment launch vector (velocity and angle). Launch angles are easily determined by fitting a line to the first few points in the fragment trace fragment trace (then rotating the coordinate system if necessary to adjust so zero degrees is parallel to the ground, recording the amount of rotation necessary to adjust to trace in this manner). Velocity can be determined in different ways, and should be calculated multiple ways to ensure data quality. The easiest is to pick a target with a known location and see how long it takes for a fragment to cross it. The average velocity during that time is calculated using Equation (7):

$$v_{avg} = \frac{(x_{end} - x_{start})}{(t_{end} - t_{start})} \quad (7)$$

where the *end* subscript indicates the position and time where the fragment crosses the end of the target object and *start* indicates the time and position at front of the target object.

Numerical differentiation can be used to find the horizontal and vertical components over time, which together determine the velocity vector in the image plane. A basic formula for differentiation uses two points as shown in Equation (8):

$$f'(t) = \frac{f(t+h) - f(t-h)}{2h} = v(t) = \frac{v_{i+1} - v_{i-1}}{t_{i+1} - t_{i-1}} \quad (8)$$

where *i* indicates the point at which velocity is being determined.

The collected position data may be noisy; smoothing and filtering techniques can be applied before or after calculations. In some cases, physics-based mathematical models can be used to fit the data, which could yield specific properties of the fragments. For example, it may be possible to fit a simple drag model to the velocity data to get an estimate of a fragment's ballistic coefficient.

4.9.5 Notes On Error

If the fragment is traveling at an angle to the image plane as shown in Figure 4-7, some error will be introduced.

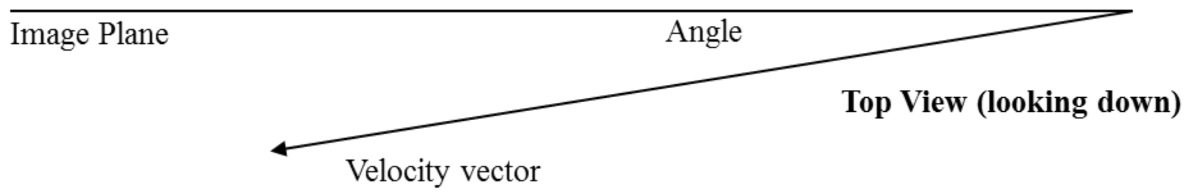

Figure 4-7. Velocity Relative to Image Plane

Since the image plane contains a projection of the actual velocity vector, that means the projected vector varies by the cosine of the angle between the vector and the image plane. This mainly impacts the horizontal velocity component (relative to the image plane)as shown in Equation (9):

$$v_{x-projected} = v_x * cos(\theta) \quad (9)$$

This means the fragment could have a direction of travel relative to the image plane of slightly over 18 degrees for there to be at least a 5% difference between the actual velocity and the measured velocity.

The inherent noise in measuring fragment locations in the images comes from three sources:

- The first and largest source of error is generated by the fragments themselves. The fragments are usually tumbling and are not regularly shaped, so choosing a location on the fragment (usually the center of the visible fragment) is difficult.
- The second source is the blast environment, both ahead of and behind the fireball from the explosion. Ahead of the fireball there are visual distortions caused by various physical effects that may make it hard to see fragments or could cause fragments to appear in slightly different locations over time (due to refraction). As the fire ball approaches, it may obscure some fragments or produce other effects that make it difficult to identify fragments traveling at the edge of the flame.
- The third and most minor source comes from using digital images. Since the images are a discretization of the actual image, there is a small amount of noise introduced from only being able to choose a pixel rather than a precise location. As camera resolution improves, this becomes less of an issue.

4.9.6 Estimating Initial Velocity From Debris Mass and Impact Location

After the debris has been collected and its mass determined, questions are often raised about the initial velocities of the debris. For the planned event, these questions may be answered by the optical and/or electronic instrumentation. What about the unplanned event or the situation where an independent estimate of velocity is needed or required?

The procedure described in this section can be used to make a crude estimate of the launch velocity of debris that is projected into the far field. This estimate is based upon three pieces of information:

1. The final range of the debris piece,
2. The mass/size of the debris piece, and
3. The type of debris.

This procedure ignores ricochet and roll, and assumes that they do not occur; i.e., the final impact point of each debris piece can be calculated by a purely ballistic trajectory. It should be noted that the trajectories that are computed assume the debris is launched at its optimum launch angle—maximizing range for the given launch velocity. The method further assumes that individual debris pieces do not shed mass over the course of the trajectory or break up upon impact. It also assumes that the debris pieces can be represented as compact, *chunky* shapes, rather than long rods or spheres. Strictly speaking, this methodology applies only to far-field debris.

To date, the procedure has been established for steel and concrete debris. The velocity estimates that are produced are not unique or absolute. If a debris piece reaches its final location by ricochet or roll, then the velocity that is calculated will be higher than the true launch velocity (assuming an optimum launch angle). Further, if the debris piece reaches its final location via a launch angle that differs from the optimum, then the velocity that is estimated will also differ from the actual velocity.

The following equations, which were derived for an earlier version of this document, may be used to estimate the velocity:

$$\text{Velocity (m/s)} = A_m e^{(Bm*R)} \qquad (10)$$

Equations (11) and (13) or (12) and (14) (depending on the type of material) are used to calculate A_m and B_m. With these coefficients and the range, Equation (10) may be used to estimate the velocity.

$$A_{m,concrete} = 5.41 + 1.79*[\ln (M)] + 0.049*[\ln (M)]^2 \qquad (11)$$

$$A_{m,steel} = 7.54 + 1.27*[\ln (M)] + 0.24*[\ln (M)]^2 \qquad (12)$$

$$B_{m,concrete} = 0.053*M^{-0.304} \qquad (13)$$

$$B_{m,steel} = 0.030*M^{-0.326} \qquad (14)$$

where

M = mass of the debris piece in grams
R = range in meters from the center of the PES to the debris in question

As an example, consider a piece of concrete debris that weighs 454 grams that is found 300 meters from the center of a PES. Using Equations (11) and (13), values of 18.2 and 0.00825 are obtained for $A_{m,concrete}$ and $B_{m,concrete}$, respectively. Inserting these values into Equation (10) with a range of 300 m, a velocity estimate of 216 m/s is obtained.

For concrete debris, the equations are valid for masses between 45 grams (0.1 lb) and 45,000 grams (99.2 lb). For steel debris, they are valid for masses between 10 grams (0.022 lb) and 4,500 grams (9.92 lb). The equations are valid for ranges between 50 and 1,400 meters (164 to 4,593 ft) for concrete and 100 to 2,000 meters (328 to 6,592 ft) for steel.

It should also be re-iterated that these equations provide approximations for the velocities and should only be applied to far-field debris.

4.10 Debris Mass Analysis

If full debris mass data have been collected, they should be sorted, most certainly, by polar angle and/or by polar zone. If individual components have been pre-marked (e.g., dyed concrete in the wall), then the mass analysis should be done by component. If the angular increment has not been preselected, it should be chosen with regard to the rate at which the debris pattern changes with angle. If, for example, the mass distribution in one lobe of a quatrefoil spatial distribution is required, then the polar angular increment should be chosen to encompass the whole lobe. If the mass distribution is to be examined as a function of angle then an incremental width should be chosen, which is sufficiently small so that it will not mask changes in distribution with angle.

If the mass data are analyzed into discretized bins of mass, it is recommended that the mass bands presented in Table 3-2 in Chapter 3 be used. These bands are logarithmic in kinetic energy, which is most directly a function of the mass (because the velocity is dependent on the mass). It should be pointed out that the use of these bands has become somewhat standard when performing debris mass analyses.

Either pre-test, post-test or at the data analysis stage, a decision may be made to limit the mass data collection or analysis. Very small debris will not be injurious, particularly at long ranges. However, its inclusion is often very useful in defining overall mass distributions.

Internationally, it has been the custom and practice to consider a debris kinetic energy of 79 Joules (58 ft-lb) as the threshold for potential fatal effects. This criterion had its origins in Napoleonic times [References 4-14, 4-15, 4-16] but much more recently has been shown to adequately envelope the many more sophisticated debris mass/velocity/fatality models that have been developed [Reference 4-17]. However, as previously described, 79 Joules (58 ft-lb) is not necessarily indicative of a 50% probability of lethality given impact.

If it is assumed that the debris is falling at terminal velocity and that an impact kinetic energy of 79 Joules (58 ft-lb) is required, it is possible to estimate the required mass (and size) of material necessary to achieve this energy. In making this estimate, the debris is assumed to be roughly spherical in shape; steel debris is assumed to have a drag coefficient of 0.5 and concrete or brick is assumed to have a drag coefficient of 0.6. These assumptions are considered as representative of types of debris. If there is a priori knowledge of the debris material and shape, then the factors appropriate to this information should be used. With these assumptions,

- Steel debris (density = 7849 kg/m^3 (490 lb/ft^3))
  - Mass > 43 grams (0.095 lb)
  - Diameter > 21.9 mm (0.863 in)
- Concrete debris (density = 2307 kg/m^3 (144 lb/ft^3))
  - Mass > 91 grams (0.20 lb)
  - Diameter > 42.3 mm (1.66 in)
- Brick debris (density = 2054 kg/m^3 (128 lb/ft^3))
  - Mass > 96.6 grams (0.22 lb)
  - Diameter > 444.9 mm (1.77 in)

It should be noted that this argument generally excludes primary fragments from detonating ordnance. This is not considered to be a problem since, in most cases, the more massive debris from structures is thrown to greater distances than small detonation fragments and the greatest interest from the safety community's point of view is usually in far-field effects. If the interest is the near-field, then low-angle, high velocity primary fragments tend to control the debris IBD. Although the shape factor would not be the same as for secondary debris, this information could be applied to the primary fragments with a relatively small error.

It is not recommended that mass data distributions be restricted; i.e., all debris should be collected, cataloged, and analyzed. If this is not practical, and collection or analysis efforts must be restricted, then the following lower limits for debris mass are recommended:

- Metallic debris: 5 grams (0.011 lb)
- Non-metallic debris: 10 grams (0.0.022 lb)

A typical set of mass distributions [Reference 4-1] for different ranges is shown in Figure 4-8.

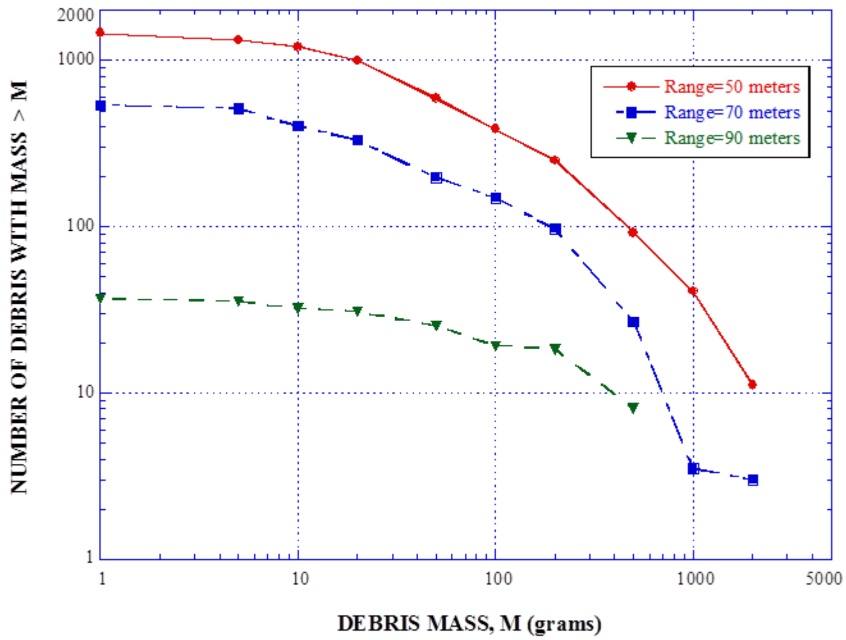

Figure 4-8. Debris Mass Distribution—Example 1

Continuous mass distribution plots, also known as cumulative piece count plots, are another effective method of illustrating the relative characteristics of a test data set. In this type of figure, the cumulative number of debris pieces is plotted across a range of mass values (or characteristic length values), on a double-logarithmic scale. The number of pieces larger than or equal to the mass on the x-axis is plotted. An example of this is shown in Figure 4-9. The shape of the plot can provide insight into the breakup of the test article or structure. If additional detail is required, Mass Bins 1 and 10 can be further discretized.

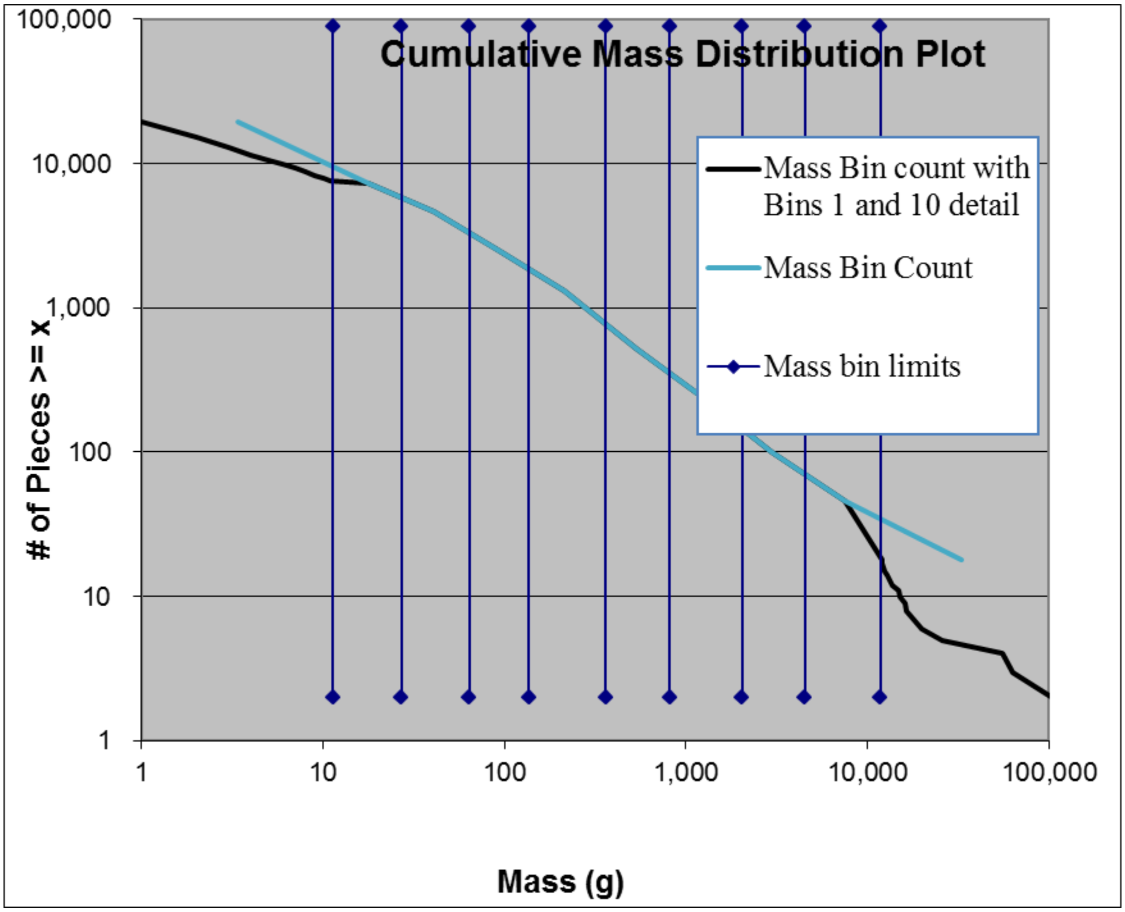

Figure 4-9. Debris Mass Distribution—Example 2

5.0 UNPLANNED EVENTS (ACCIDENTS)

5.1 Planning

The dictionary provides the following definition for *accident*: "An unforeseen and unplanned event or circumstance" [Reference 5-1]. An accident in an explosives facility is an unplanned event for which contingency plans must be made. In order to determine acceptable consequence levels and minimize the risk to personnel and property, an understanding of the potential consequences from the initiation of the explosives within a facility is essential. Currently, there is a reasonable understanding of the effects and consequences of blast in such circumstances but significantly less knowledge exists on the effects of weapon fragments and building debris (hereafter referred to simply as debris).

The consequences of the impact of debris on personnel and property are dependent on the debris mass, velocity, material, shape, number, and impact location. The characteristics of primary fragmentation from the explosion source may be estimated using the methodologies described in Reference 5-2. Corresponding methods for the estimation of secondary fragmentation from structures are not as mature [References 5-3, 5-4, 5-5]. Moreover, these methods do not determine the interaction of that fragmentation with the containing or intervening structure. Debris from the containing structure is generated and projected by the interaction of both the explosion products, i.e., shock and quasi-static gas pressure, and the primary fragmentation with the elements of the structure. Thus, the fragment and debris cloud that is projected into the field around the explosion site is complex and not readily calculable. In practice, therefore, it has been, and will continue to be, necessary to perform testing and modeling in order to quantify these effects.

Clearly, in the deduction of tangible data from accidental events, the information to be gained is primarily only that available after the fact. The majority of this information will be descriptors of location (range and bearing), mass, and characteristics. Some secondary evidence may be available to provide estimates of debris velocity, such as the depth of penetration in trees, soil, or other materials.

For many accident investigations, there may be insufficient funds available to perform as complete a debris collection effort as may be desired from a scientific or historic perspective. If this is the case, then the search parameters must be well defined prior to the start of the effort. The collection effort should extend outward to a range where the density of hazardous fragments, defined as a fragment having an impact energy of 79 Joules (58 ft-lb) or greater falls below a value of 1 per 55.7 m^2 (1 per 600 ft^2). Based on historical evidence, this distance can exceed a scaled range (actual range divided by the cube root of the NEQ) of 40 $m/kg^{1/3}$ (101 $ft/lb^{1/3}$) (based on the known or estimated amount of energetic material involved in the event) for many types of donor structures [Reference 5-6]. The azimuthal search limits should be established after an on-site inspection of the area.

5.2 Accidents

The collection and analysis of the debris produced by accidental explosions generally proceeds in a similar manner to that described for planned events. However, because it is an unplanned event, none of the pre-event planning can be performed. Generally, for accident situations, the location, mass, and description of each debris piece should be noted and recorded. The investigator should be aware that the accident scene might already include secondary debris that has nothing to do with the accident. An assessment of the site needs to be done to ensure that the debris is gathered with respect to the overall objective of the accident investigation.

The primary focus of any unplanned/unintentional explosion investigation is to determine if the explosion is *accidental or criminal*. This will entail a thorough examination of the scene to identify debris or evidence that would be associated with a criminal act. If the explosion is considered *criminal*, then the site is an *active crime scene,* (i.e., the *cause* of the accident is then usually classified as either vandalism, sabotage, terrorism or other criminal activity). In this case, the (non-evidentiary) debris collection effort may need to be postponed until the criminal investigation (scene processing) is complete.

At some sites, the crater and debris that were generated by the explosion may be, unavoidably, disturbed or compromised by the first responders entering the area. Such occurrences should be noted and documented in any post-event reporting. Interview of these first responders is often extremely helpful in the determination of the cause of the explosion. In some instances, there may be multiple explosions and the first responder's information may assist in the determination of which explosion occurred first. This is relatively easy to determine based on debris patterns associated with multiple explosion incidents but debris scatter from multiple explosions can potentially cause significant issues in the determination of a *cause.*

Commonly, crime scene investigators use a variety of tools to examine and document the scene. The data from these tools may be of significant assistance in processing the non-evidentiary debris. These include a GPS total station or similar equipment that is able to document the GPS location of the debris.

With most unplanned explosions it would be important for the analyst (investigator) who is examining the scene to closely coordinate with the post-blast law enforcement investigators. In a scene of this type, the non-evidentiary debris will usually be collected and placed in a debris pile away from this scene. This action would negatively impact the post-blast (crime) scene examination of debris (i.e., concrete, glass, metal) from the structure. Post-blast scene management includes initial and ongoing coordination of the scene with law enforcement and other investigating entities. This coordination and collaboration will assist in the proper documentation and complete processing of both evidentiary and non-evidentiary debris.

The generic descriptors used in test situations should be expanded to be more descriptive of each item. Because of the nature of the event, the interest in the results is often more than scientific. For this reason, every debris piece should be photographed if feasible. Included on each photograph should be a unique identification number that ties the photograph to an entry in a debris description catalog. Also, each photograph should contain an in-focus scale referent. Because of size, shape, or special features, some debris may require more than one photograph. Debris may have to be retained and stored until the completion of all accident investigations and litigations.

The choice of an appropriate collection methodology will depend upon an on-site assessment of the situation. Because it is an accident and not a planned event, the terrain around ground zero will probably not be flat or level. There may be hills, valleys, vegetation, barricades or other structures in locations that could influence the debris cloud. For this reason, a topographic map of the area that gives the locations of such items should be included with the debris catalog. The map should extend out to a range to include the farthest piece of debris. The contour scale of the map should be chosen such that all prominent terrain features in the vicinity can be resolved.

As previously noted, aerial photography and mapping and/or the use of unmanned aerial systems (drones) may be useful in locating debris pieces and in being able to assess the symmetry of the debris field.

Care should be taken that any debris results that are obtained have not been altered or skewed by the response or investigation process itself. If it is suspected that the results may have been skewed, then all factors that may have contributed to causing the results to be skewed should be identified and documented.

6.0 TEST AND ANALYSIS STANDARDIZATION

This document has historically not made specific recommendations regarding test design, test conduct, measurement accuracy, analysis methodology and assumptions or analysis techniques. However, it is the authors' observation that standardization in these areas if often lacking. In order to provide a starting point for future work that could involve the collection and analysis of explosion-produced debris, this chapter will attempt to aggregate all of the recommendations and suggestions that have been made in all of the previous chapters of this document.

6.1 Test Site

- Test should be at least 20% larger than the maximum predicted debris range
- Test site should slope less than 1% over test area
- Test site surface should be firm enough that debris or fragments landing on it are not lost, i.e., buried in sand or submerged in mud or water
- Existing debris from previous testing should either be removed or marked in some way so that it can be distinguished from debris generated on the current test

6.2 Pre-Event Survey

- Debris Collection sectors should be 5º wide; if a larger sector width is used, it is recommended that it should be no more than 10º
- Normal to PES walls should bisect sectors
- When debris collection within sectors is planned (not recommended), a sector depth of 5 to10 m is recommended

6.3 Test Conduct

- Wind speed at time of test less than 10 knots (5.14 m/s) or 18.5 kilometers/hour (11.5 miles/hour)
- Meteorological conditions at test site at the time of the test must be recorded and reported
  - Temperature
  - Barometric pressure
  - Wind speed
  - Wind direction
  - Relative Humidity
- Utilize a common time base, such as IRIG timing, across all electronic instrumentation

6.4 Post-Event Data Collection

- If a debris saturation zone exists, the following steps should be undertaken:
    - Catalog and photograph all major pieces
    - Depending on symmetry, define one or more sampling areas
    - Catalog (determine coordinates, mass, weight and identification) of all pieces within each sampling area
    - Collect all remaining debris within the saturation zone but outside the sampling areas and determine or estimate an aggregate mass
- Unless there is a compelling reason to do otherwise, it is recommended that Individual Piece Location rather than Collection By Zones be utilized
- Regardless of the collection technique used it is recommended to record the individual mass of collected debris.
- Use of debris traps is not recommended
- A survey-grade or a mapping-grade GPS-based system is recommended for determining all debris coordinates
- Regardless of the search technique (Collection by Zone or Individual Location), a robust QA/QC procedure must be in place and utilized
- Portable scales with a resolution of at least 1 gram should be used to determine the debris weight

6.5 Data Analysis

- If debris mass analysis is to be discretized, it is recommended that the SAFER Mass bins with the addition of a “G” division (< 11 grams (0.39 ounces) concrete and < 6 grams (0.21 ounces) steel) be used to define the divisions
- HFD/Debris IBD should be calculated using the MPTN methodology applied to wall debris and ADD applied to roof debris with the following assumptions:
    - 5º sector width but never more than 10º
    - 5 m sector depth but never more than 10 meters
    - Hazardous fragment:
        - Steel, mass > 43 grams (1.52 ounces)
        - Concrete, mass > 91 grams (3.21 ounces)
        - Brick, mass > 98 grams (3.46 ounces)
- Calculate three HFD/Debris IBDs for a structure:
    - Average calculated HFD/Debris IBD over all azimuths to give an average value
    - A maximum value obtained by selecting the maximum value calculated for all azimuths

   - A minimum value obtained by taking an average of the off-normal densities

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7.0 SUMMARY

This document should be used by a wide variety of professionals. Of course, the program manager, test engineer, safety professional, and test support personnel lead the list. The list also includes the funding source and prediction modelers. Accident investigators should also be aware of the valuable debris data that can be obtained after an accident. The safety policy makers need to be aware of how the data they use to establish policy are gathered and evaluated.

By following the guidance provided in this document, it is hoped that data obtained through safety test and accident debris analysis will be able to be used to better predict the hazard from debris from an explosive test, accident or incident and, ultimately, improve explosive safety standards.

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LIST OF ACRONYMS

ADD	actual debris density
AE	ammunition and explosives
ASTM	American Society for Testing and Materials
ºC	degrees Celsius
Cal	California
cm	centimeter
DDESB	Department of Defense Explosives Safety Board
DGPS	differential grade global positioning system
DIRT	Debris Investigation and Recovery Task
DOE	Department of Energy
ECM	explosives storage magazine
ES	exposed site
ºF	degrees Fahrenheit
ft	foot/feet
ft/s	feet per second
g	gram
GBAS	ground based augmentation systems
GLONASS	global navigation satellite system
GPS	global positioning system
HD	hazard division
HFD	hazardous fragment distance
IBD	inhabited building distance
IMESAFR	Institute of makers of Explosives Safety Analysis for Risk
in	inch
IRIG	inter-range instrumentation group
ISO	International Organization for Standardization
J	joule
KE	kinetic energy

KG-ET	Klotz Group Engineering Tool
kg	kilogram
kg/m^3	kilogram per cubic meter
kPa	kilopascal
lb	pound
lb/ft^3	pound per cubic feet
LIDAR	light detection and ranging
LOGNORMDIST	log normal distribution
m	meter
mm	millimeter
m^2	square meter
m/s	meter per second
mph	miles per hour
MPTN	modified pseudo-trajectory normal
NATO	North Atlantic Treaty Organization
NEQ	net explosive quantity
NEW	net explosive weight
PES	potential explosion site
ppm	parts per million
psi	pounds per square inch
PTN	pseudo-trajectory normal
QA	quality assurance
QC	quality control
QD	quantity distance
RTK	real time kinematic
SAFER	Safety Assessment of Explosives Risk
SBAS	satellite based augmentation system
SciPan	science panel
SI	system of units
TP	technical paper
UAS	unmanned aerial system

UFC	Unified Facilities Criteria
UK	United Kingdom
UN	United Nations
US	United States
USGS	United States Geological Survey
WAAS	wide area augmentation system

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12. Reeves, H. J., "Revised Quantity-Distance Criteria For Earth-Covered Igloos"

13. Roth, Julius, “Dependence Of Flyrock Range On Shot Conditions”
14. Swisdak, Michael M., “Determination Of Safe Handling Arcs Around Nuclear Attack Submarines”

20th Explosives Safety Seminar, 24-26 August 1982.

1. Connor, Joseph G., “Half-Scale Submarine Tender Workshop Explosion Hazards”
2. Flory, Robert A., “DISTANT RUNNER Results: A 5 Event High Explosives Test Series Involving U.S. Air Force 3rd Generation Aircraft Shelters”
3. Huang, Louis, “Probabilistic Model For Debris Hazards From Explosions”
4. Janser, Paul W., “Lethality Of Unprotected Persons Due To Debris And Fragments”
5. Johansen, Per Wollert, “Consequence Analysis For A Rock Underground Explosives Storage With Insufficient Overburden”
6. Longinow, A., Waterman, T. E. and Napadensky H. S., “Modeling Debris Effects Produced By A High Yield Explosion”
7. Marsh, John and Talmon, Ted, “Aerial Photography Applications In Debris Studies”
8. Moseley, P. K. and Whitney, M. G., “Prediction Of Human Injury Levels For Accidental Explosion Inside Aircraft Shelters”
9. Ward, Jerry M., “DISTANT RUNNER—Debris Recovery And Analysis Program For Events 4 and 5”

21st Explosives Safety Seminar, 28-30 August 1984.

1. Bowman, F., Henderson, J., Rees, N. J. M., and Walker, J., “Joint Australian/UK Stack Fragmentation Trials”
2. Huang, Louis C. P., “Prediction Of Debris Hazards From Explosions In Buildings”
3. Jager, Ernst H., “Velocity Of Debris From Bursting Explosives Storage Bunkers With Soil Overburden”
4. Mattern, Steven F., “Peacekeeper Quantity-Distance Verification Program Part I: Analytical And Experimental Program For Quantity-Distance Evaluation Of Peacekeeper Missiles In Minuteman Silos”
5. Reeves, H. J., and Robinson, W. T., “HASTINGS IGLOO Hazards Tests For Small Explosive Charges”
6. Sussholz, Benjamin, “Peacekeeper Quantity-Distance Verification Program Part II: Technical Evaluation Of Quantity-Distance Criteria For Peacekeeper Missiles In Minuteman Silos”

1st Australian Department of Defence Explosives Safety Seminar, 18-20 November 1985.

1. Henderson, J., “Joint Australian UK Stack Fragmentation Trials Phase 2”

22nd Explosives Safety Seminar, 26-28 August 1986.

1. Boisseau, F. X., Houdussee, D. and Kent, R., “Technical Evaluation Of The Limits Of The Hazardous Areas As To Projections”
2. Bowles, Patricia Moseley and Polcyn, Michael A., “Debris Hazard At A Rocket Motor Test Cell Facility—An “Accidental” Study”

3. Bulmash, G, Kingery, C. N., and Coulter, G. A., “Velocity Measurements Of Acceptor Wall Fragments From The Mass Detonation Of A Neighboring Aboveground Barricaded Munition Storage Magazine Model”
4. Henderson, J., Walker, J., Rees, N. J. M. and Bowe, R. A., “Joint Australian/UK Stack Fragmentation Trials Phase Two Report”

3rd International Symposium on the Interaction of Conventional Munitions with Concrete Structures, March 1987.

1. Bulmash, G., Coulter G. A., Kingery, C. N. and Aray, U.S., “A Direct Measurement Technique To Obtain Acceptor Wall Fragment Velocities In The Severe Environment Near An Aboveground Magazine”
2. Hartwig, R., “Eine Neue Messeinrichtung Zur Emittlung Von Splitterflugzeiten Und Splittergeschwindigkeiten Fuer Erst- Und Folgesplitter”
3. Marchand, K. A., Ross, C. A., and Prendergast, J. E., “The Resistance Of Sand Barrier Walls To Simultaneous Fragment And Blast Loadings”
4. Swisdak, Michael M. and Ward, Jerry, M., “Aircraft Shelter Model Test Program"

2nd Australian Department of Defence Explosives Safety Seminar, 30 November-2 December 1987.

1. Rees, N. J. M. and Henderson, J., “UK Collaborative Explosives Safety Test Programme”

23rd Explosives Safety Seminar, 9-11 August 1988.

1. Bowles, Patricia Moseley, Whitney, Mark G. and Polcyn, Michael A., “Q-D Requirements For New Norwegian Aircraft Shelter Design”
2. Henderson, J. and Rees, N. J. M., “Joint Australian/UK Stack Fragmentation Trials Preliminary Phase 3 Report”
3. Lawrence, William, “Storage Of Mixed Munitions In CONEX Containers”
4. Rees, N. J. M. and Henderson, J., “UK Collaborative Explosives Safety Test Programme”
5. Swisdak, Michael M. and Montanaro, Paul E., “Analysis Of The Debris Produced By Explosions In Tunnels”
6. Swisdak, Michael M., “Analysis Of The Debris Produced By A Processing Building Accident”
7. Vretblad, Bengt E. and Eriksson, Siwert E., “Results Of An Explosion In A Swedish Munition Storage”

4th International Symposium on the Interaction of Conventional Munitions with Concrete Structures, 1989.

1. Kossover, D., Dobbs, N. and Caltagirone, J., “Engineering Quantity-Distance Analysis Of Ammunition And Explosives Operations”
2. Mosley-Bowles, P., “Fragment And Debris Hazard Evaluation—A Need For New Q-D Criteria For DOE Facilities”

24th Explosives Safety Seminar, 28-30 August 1990.

1. Bowles, Patricia M., Vargas, Luis M. and Oswald, Charles J., "Building Debris Hazard Evaluation Test Program"
2. Bowles, Patricia M. and Oswald, Charles J., "Building Debris Hazard Prediction Model"
3. Bowles, Patricia M., Marchand, Kirk A. and Strybos, John W., "Scaled Debris Throw Of Third
Generation Norwegian/US Aircraft Shelters"
4. Held, Manfred, "Fragment Mass Distribution of Debris"
5. Henderson, J., "Joint Australian/UK Stack Fragmentation Trials Phase 4 Preliminary Report"
6. Joachim, Charles E., "Ejecta Hazard Ranges From Underground Munitions Storage Magazines"
7. Lawrence, William, "Test Data On The Storage Of Mixed Munitions In CONEX Containers"
8. McCleskey, Frank, Wilson, Lee, and Baker, Rose, "An Investigation Of Fragment Stopping Barricades"
9. McCleskey, Frank, Neades, D. N. and Rudolph, R. R., "A Comparison Of Two Personal Injury Criteria Based On Fragmentation"
10. Montanaro, Paul E., "TRAJ -A Two Dimensional Trajectory Program For Personal Computers"
11. Oswald, Charles J., "Development Of Predictive Methods From Test Data For Breakup Of Building Components and Debris Roll"
12. Swisdak, Michael M., "Procedures For The Analysis Of The Debris Produced By Explosion Events"

Consequences Analysis Workshop, Ad Hoc Technical Working Party NATO AC/258, Storage Sub-Group, 31 August-1 September 1990.

1. Allain, Laurent, "DENSECLA"
2. Byrns, J. P. and Franks, A. P., "The Simulation Of Building Debris Hazard –The Estimation Of Fatality Probabilities"
3. Ingebrigtsen, Karl Ove, "AMMORISK"
4. Keenan, William A., "The Navy's NOHARM System"
5. Kongehl, H. F., "Feasibility Study Of The Construction Of An Ammunition Storage Site On An Air Base Making Use of AMMORISK"
6. Opschoor, G., "Risk Analysis On Explosives And Ammunition Storage In The Netherlands"
7. Swisdak, Michael M., "TRAJ, DEBRIS, and FRAGHAZ – Analysis And Prediction Software For Explosion Produced Fragments And Debris"
8. Tancreto, James E., "Probabilistic Model For Debris Hazards From Explosions MUDEMIMP"

5th International Symposium on the Interaction of Conventional Munitions with Concrete Structures, 1991.

1. Held, M., "Splittermassenverteilung Der Truemmer Von Gesprengten Flugzeugsheltern"

25th Explosives Safety Seminar, 18-20 August 1992.

1. Bowles, Patricia Moseley, "Practical Use Of The Building Debris Hazard Prediction Model, DISPRE"
2. Cain, Maurice R. and Sharp, Douglas E., "Pressure Vessel Burst Test Program: Progress Paper No. 3"

3. Finnerty, Anthony E., Watson, Jerry L. and Peregino, Phillip J., “A Safer Method Of Storing ammunition In A CONEX Container”
4. Horoschun, G., “Design And Full Scale Trial Of A Large Span Arch Explosive Storehouse”
5. Manthey, James P., “Assessment Of Secondary Fragment Threats From Conventional DOD Building Construction”
6. Murtha, Robert, “Small-Scale High Performance Magazine Roof And Soil Cover Feasibility Test Results”
7. Oswald, Charles J., “Calculation Of Hazardous Soil Debris Throw Distances Around Earth Covered Magazines”
8. Perea, Aaron and Austin, Bryan S., “Structural Response and Resulting Quantity-Distance Debris Collection Techniques and Results”
9. Robey, Robert W., “Numerical Calculations of Explosive Charges Inside Scaled Aircraft Shelters”
10. Swisdak, Michael M., “Hazards Produced By Explosions Inside Earth-Covered Igloos”
11. Swisdak, Michael M., “Hardened Aircraft Shelter Test Program”
12. Swisdak, Michael M., “ESQD Arcs For Maritime Prepositioning Ships”
13. Twisdale, L. A. and Vickery P. J., “Comparison of Debris Trajectory Models For Explosives Safety Hazard Analysis”
14. Whitney, Mark G., Spivey, Kathy H. and Skerhut, Debra D., “Quantity-Distance Prediction Methodology For hardened Aircraft Shelters—QDRACS”

6th International Symposium on the Interaction of Conventional Munitions with Concrete Structures, 1993.
1. Sues, R. T. and Twisdale, L. A., “How to Select A Design Fragment For Protective Structure Design With Consistent Reliability”

1st Australasian Explosive Ordnance Symposium (PARARI ’93), 27-29 October 1993.
1. Gould, M. J. A. and Ward, J. M., “Quantity-Distance Criteria for Small Net Explosives Quantities”

26th DoD Explosives Safety Seminar, 16-18 August 1994.
1. Bakhtar, Khosrow, “Prediction of Fragment Range For Responding Magazines Based On The Bakhtar Explosives Safety Criteria”
2. Bowles, Patricia Moseley and Oswald, Charles J., “Earth Covered Ammunition Storage Magazines, Quantity-Distance Model, DISPRE2”
3. Cain, Maurice R. and Hail, Robert J., “Progress Report: Pressure vessel Burst Test Study”
4. Dutch, Duke, Bakhtar, Khosrow, and Stewart, Daryl, “Automated Mapping of Fragments In MSM Test at UTTR”
5. Gilbert, S. M., Lees, F. P., and Scilly, N. F., “A Model for Injury from Fragments Generated By The Explosion Of Munitions”
6. Goold, J. J., Gould, M. J. A., and Ward, J. M., “Quantity-Distance Criteria for Small Net Explosives Quantities”
7. Guerke, Gerhard H., “Secondary Fragments From Accidental Explosions in Above Ground Ammunition Storage Houses at High Loading Densities”
8. Jacobs, Edward M. and Jenus, Joseph, “Proposed Methodology for Determining Hazardous Fragment Distance”

9. Jenus, Joseph, “Quantity-Distance Determination for Third Generation Aircraft Shelters (TGAS)”
10. Murtha, Robert N., “Tests and Analysis For Safe Distances From High Performance Magazine Overpressure and Debris”
11. Rytz, Hansjorg E., Kummer, Peter O., Jenus, Joseph, and Bakhtar, Khosrow, “Accident Investigation At The Swiss Steingletscher Installation”
12. Swisdak, M. M., Jacobs, E. M., and Ward, J. M., “Hazard Ranges For Small Net Explosive Quantities In Hardened Aircraft Shelters”

<u>7th International Symposium on the Interaction of Conventional Munitions with Concrete Structures</u>, March 1995.

1. Guerke, G., “Debris Throw From Accidental Explosions At High Loading Situations”
2. Hulton, F. G. and Jenkinson, R. J., “Bosnian Bunker Trial”

<u>2nd Australian Explosive Ordnance Symposium (PARARI ’95)</u>, 25-27 October 1995.

1. Gould, Michael J. A. and Cuthbertson, Kevin, “UK/Australian Trials To Determine The Effects Of The Accidental Initiation Of Small Quantities OF Explosives In Brick Wall Buildings With Concrete And Light Roofs”

<u>27th DoD Explosives Safety Seminar</u>, 20-22 August 1996.

1. Absil, L. H. J., Kodde, H. H., and Weerheijm, J., “Evaluation of Safety Distances For UXO Disposal Operations”
2. Bakhtar, Khosrow and Jenus, Joseph, “Comparison of Full Scale and Scaled-Model KLOTZ Tunnel Explosion Test Results”
3. Barker, Darrell D. and Baker, Quentin A., “Investigation of OTTO fuel Explosion Accident”
4. Bowles, Patricia Moseley, “Validation and Expansion of DISPRE2 Quantity-Distance Model”
5. Gould, M. J. A., Goold, J. J. and Cuthbertson, K., “UK/Australian Trials to Determine The Effects of the Accidental Initiation of Small Quantities of Explosives inside Brick Wall Buildings with Concrete and Light Roofs”
6. Gould, M. J. A., “The Analysis of Debris Data from UK/Australian Small Quantities Brick Cubicle Tests”
7. Guerke, Gerhard H., “Debris Throw from Overloaded Concrete structures at Internal Detonation Under Shock, Blast Impulse and Gas Pressure”
8. Kummer, Peter O., “Evaluation of the Debris Throw From the 1992 Explosion in the Steingletscher Installation in Switzerland”
9. Opsvik, Frode, Holm, Knut Bratveit, and Rollvik, Svein, “Adit Debris Projection Due To An Explosion In An Underground Ammunition Storage Magazine”
10. Oswald, Charles J. and Barker, Darrell D., “An Experimental Study of Methods For Mitigating Blast And Fragment Hazards From A Large Exploding Tank”
11. Rytz, Hansjorg and Bakhtar, Khosrow, “Analysis and Documentation of the “Mitholz” Underground Ammunition Storage accidental Explosion in Switzerland”
12. Swisdak, M. M. and Montanaro, P. E., “Non-Thermal Effects From Hazard Division 1.3 Events Inside Structures”

13. Swisdak, M. M., "A Brief Discussion of Two Recent Magazine Accidents at the Naval Surface Warfare Center"

<u>3rd Australian Explosive Ordnance Symposium (PARARI '97)</u>, 12-14 November 1997.

1. Gould, M. J. A. and Cuthbertson, K., "UK/Australian Small Quantity Explosion Effects Tests And their Analysis"
2. Gould, Michael J. A. and Swisdak, Michael M., "The Measurement And Analysis Of Explosion-Produced Debris And Fragments Following An Accident Or A Test Representative Of An Accident"

<u>28th DoD Explosives Safety Seminar</u>, 18-20 August 1998.

1. Bowles, Patricia Moseley and Crull, Michelle, "Refinement Of DISPRE 2 Quantity-Distance Software"
2. Dutch, Duck and Bakhtar, Khosrow, "Fragment Recovery Using GPS And Automated Mapping Techniques"
3. Gould, M. J. A. and Gouldstone, Frank G., "The Development Of A UK Structural Debris Throw Model"
4. Gould, Michael J. A. and Swisdak, Michael M., "Procedures For The Collection, Analysis, And Interpretation Of Explosion-Produced Debris"
5. Gould, M. J. A., "The Development Of Debris Related Quantity Distance Relationships From The UK Trials Database For Brick Wall Buildings"
6. Guerke, Gerhard, "Debris Launch Velocity From Internally Overloaded Concrete Structures"
7. Houchins, W. D., "Effects Of Barricade Placement On Debris Density"
8. Kummer, Peter, "Crater Debris Throw from Explosions in Underground Storage Installations; Revision of the Manual of NATO Safety Principles for the Storage of Military Ammunition and Explosives," AASTP-1, Part III
9. Merrifield, Roy and Myatt, Stewart, "The Risks Associated With The Storage Of Small Quantities Of Gunpowder And Shooters Powders In Containers and Buildings"
10. Murtha, Robert N., "High Performance Magazine Certification Test No. 3: Planning And Results"

<u>9th International Symposium on the Interaction of Conventional Munitions with Concrete Structures</u>, 1999.

1. Fairlie, G. E. and Livingstone, I. H. G., "Analysis Of Fragment Throw Distances From High Explosive Detonations In Masonry Structures"

<u>4th Australian Explosive Ordnance Symposium (PARARI '99)</u>, 10-12 November 1999.

1. Gould, Michael J. A., Gouldstone, Frank G., and Scott, Frank C., "Further Development Of A UK Structural Debris Throw Model"

<u>29th DoD Explosives Safety Seminar</u>, 18-20 July 2000.

1. Allahdadi, Firooz A., Price Paul D., Jakes, Edward M, and Campbell, Mark, M., "Reconstruction Of An Accidental Detonation"
2. Bowles, Patricia Moseley, "Data Enhancement And Refinement Of DISPRE2 Quantity-Distance Software"

3. Gould, M. J. A., "The 1998 Multi-National 40 Tonne Donor/Acceptor Test"
4. Gould, M. J. A., "The 1998 Multi-National 40 Tonne Donor/Acceptor Test -Fragment And Debris Collection And Analysis"
5. Gould, Michael J. A., Gouldstone, Frank G. and Scott, Frank C., "The UK Structural Debris Throw Model"
6. Grundler, Johannes, Guerke, Gerhard and Corley, John, "A Method To Characterize HE Charges According To Their Potential To Produce Debris Throw"
7. Grundler, Johanes and Guerke, Gerhard, "Debris Launch Velocity – A New Approximation Formula"
8. Kummer, Peter O., "Adit Debris Throw From Explosions In Underground Storage Installations"
9. Langberg, Helge and Kummer, Peter O., "Presentation Of The KLOTZ Group—An International Body Of Explosives Safety Experts"
10. Merrifield, Roy and Moreton, Peter Allan, "The Debris Hazard From Portable Steel Magazines"
11. Pexa, Wolfgang, "Intermediate scale Trials For The Evaluation Of The Efficiency Of A Special Blast Trap Configuration In Underground Ammunition Storage Facilities"
12. Rose, Stephen J., "Predicting Weapon Primary Fragmentation And Secondary Debris Using Modeling"
13. Swanson, Norrell, "40 Tonne Receptor Trial Australia September 1999"
14. Van Dongen, Philip, Hardwick, Meredith, Hewkin, David, Kummer, Peter, and Øiom, Hans, "Comparison Of International QRA Models On The Basis Of The "Setup And Results Of The Joint UK/Australian 40 Tonne Donor/Acceptor Trial"
15. Vretblad, Bengt, Weerheijm, Jaap, and Guerke, Gerhard, "The KLOTZ Group's Debris Dispersion Program-Developing A Prediction Tool For Debris Throw"
16. Whitney, Mark G. and Clutter, J. Keith, "Explosion Incident Investigation Methodology"

5th Australian Explosive Ordnance Symposium (PARARI '01), 31 October-2 November 2001.

1. Langberg, Helge, "Presentation Of the Klotz Group—An International Body Of Explosives Safety Experts"
2. Tatom, John W., Newton, Kristy L., Pfitzer, Tom, and Swisdak, Michael M., "Comparison Of 40 Tonne Test Debris Data To The Safety Assessment For Explosives Risk (SAFER) Model Predictions"

30th DoD Explosives Safety Seminar, 13-15 August 2002.

1. Doerr, Andreas, Guerke, Gerhard, and Ruebarsch, Dieter, "Experimental Investigation Of The Debris Launch Velocity From Internally Overloaded Concrete Structures"
2. Gan, Wenshui, Bogosian, David, and Chrowstowski, Jon D., "Evaluation Of Occupant Vulnerability To Explosive Building Debris: Computational Kernel of HULC"
3. Kummer, Peter O., "Adit Debris Throw From Explosions In Underground Storage Installations"
4. Michot, C., Kordek, M.A., and Bourdeaux, T., "Toulouse Ammonium Nitrate Disaster 21 September 2001 'Grande Paroisse' Plant France"
5. Moreton, Peter Allan and Merrifield, Roy, "Risk-Based Quantity Distances For Commercial Magazines"

6. Olson, Eric, Tancreto, James E., Swisdak, Michael M., and Tatom, John W., "Full Scale Testing For PES Debris Hazard And ES Response"
7. Swisdak, Michael M., Tatom, John W. and Newton, Kristy L., "Comparison Of SAFER Debris Predictions With Various Test Data"
8. Swisdak, Michael M., Gould, Michael J. A., and Henderson, Jonathan, "Proposed Inhabited Building Distances Based On Debris For Aboveground Structures"
9. Van Doormaal, J.C.A.M., Van den Berg, A. C. and Weerheijm, J., "Theoretical And Numerical Support Of The Debris Launch Velocity"
10. Weerheijm J., van Wees, R. M. M., Bruyn, P.C.A.M. and Karelse, J. W., "The Fireworks Disaster In Enschede Part 1: Overview And Reconstruction"
11. Weerheijm, J., Van Doormaal , A.,Guerke, G., and Lim, H. S. "The Break-up Of Ammunition Magazines Failure Mechanisms And Debris Distribution"
12. Whitney, Mark G., "Quick-Assessment Method For DDESB/TP-13 Situations"

Joint NATO AC/258 AND KLOTZ Group Debris Workshop, 16 August 2002.

1. Bowles, Trish, "DISPRE AS Software"
2. Dörr, Andreas, "Experimental Investigation Of The Debris Launch Velocity From Internally Overloaded Concrete Structures"
3. Weerheijm, Jaap, "The Breakup of Ammunition Magazines: Failure Mechanisms and Debris Distribution"

6th Australian Explosive Ordnance Symposium (PARARI '03), 28-31 October 2003.

1. Lim, Heng Soon, Tan, Su Chern, Lu, Yong, and Xu, Kai, "Comparison Of DISPRE 2 Debris Prediction With 40T Trial And Numerical Simulation Data"
2. Swisdak, Michael M., Tancreto, James E. and Tatom, John W., "SciPan 1—Test Description And Debris Characterization For Typical Aboveground, Non-Earth-Covered Structures"
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 (US DoD)"

International Symposium On Interaction Of The Effects Of Munitions With Structures (ISIEMS) May 2003.

1. van Doormaal, J. C. A. M, Dörr, A., Forsén, R.,"Debris Launch Velocity Program DLV"

31st DoD Explosives Safety Seminar, 24-26 August 2004.

1. Crull, Michelle, Bullock, Billy and Hlavsa, Gary, "Explosive Testing Of Multiple Round Containers"
2. Doerr, Andreas and Forsén, Rickard, "Experimental Investigation Of The Debris Launch Velocity"
3. Doerr, Andreas, Guerke, Gerhard, Ruesbarsch, Dieter, "The Debris Throw Model DHP"
4. Ellis, Sam, "DALAB – A Toolbox For Calculation And Assessment Of Danger Areas For Ballistic And Explosive Events,"
5. Gouldstone, Frank G. and Hoing, Craig A., "The UK Structural Debris Throw Model"
6. Henderson, J., "Effects Of Multi-Tonne Explosions On Commercial Structures"

7. Henderson, J., “Empirically Based Explosion Damage Assessment Model For Modern Housing Structure Types”
8. Langberg, Helge and Christensen, Svein O., “Air Blast And Debris Throw From Explosions In Small Ammunition Houses”
9. Swisdak, Michael M., Tancreto, James E., and Tatom, John W., “SciPan 1 and SciPan 2 Response Of Reinforced Concrete Tilt-Up Construction To Blast Loading”
10. Swisdak, Michael M., “Debris-Based Inhabited Building Distances For Aboveground Structures”
11. Tan, Su Chern, Lu, Yong, Xu, Kai, and Weerheijm, Jaap, “Development Of Debris Breakup Model And Its Initial Verification Against DLV Clamped Test”
12. Tatom, John W., Swisdak, Michael M., and Tancreto, James E., “Status Of Testing Program To Benefit Explosives Safety Standards Development In The United States Department Of Defense”
13. Tatom John W., Swisdak, Michael M. and Newton, Kristy, “Comparison of SAFER Debris Density Results To Test Data,”
14. Weerheijm, Jaap, Van der Voort, Martijn and Wentzel, Cyril, “Break-up Of Ammunition Magazines And The debris Inhabited Building Distance”

<u>Pilot MSIAC Workshop on Debris From Explosions</u>, 27 August 2004.

1. Bowles, Patricia, “DISPRE2 Predictions For SciPan 1 Test”
2. Doerr, Andreas and van Doormaal, J. C. A. M., “Mass Distribution”
3. Forsén, Rickard, “Calculated Debris Velocity For SciPan Test With INVEX”
4. Henderson, J., “An Overview Of The UK Debris Programme 1982-2002”
5. Kummer, Peter, “Debris Launch Angle: Debris Throw From RC Walls Due To Explosions”
6. Langberg, Helge, “Debris Throw From Explosions In Small Ammunition Houses”
7. Robertson, Norman, Fairlie, Greg, Glanville, Jonathan, Barnes, Ian, and Hoing, Craig, “Hydrocode Modeling Of Debris From Explosions”
8. Swisdak, Michael, “Effects Of Loading Density On Debris”
9. Tan, Su Chern, “SIN Debris Breakup Project”
10. Tancreto, James, Swisdak Michael and Tatom, John, “SciPan and SPIDER Testing To Characterize Debris Hazards”
11. Tatom, John, Swisdak, Michael and Newton, Kristy, “Comparison Of SAFER Debris Density Results To Test Data”
12. Weerheijm, Jaap, “KG Engineering Tool For Debris Throw Prediction: The Methodology”
13. Weerheijm, Jaap, “KG Engineering Tool For Debris Throw Prediction: The Initial Launch Velocity”

<u>TNO Workshop On Small Quantities</u>, 13-15 October 2004.

1. Doerr, Andreas, “Consequence Models For Small Net Explosive Quantities”
2. Gould, M. J. A., “Small Quantities—An Alternative Approach To IBD”
3. Madsen, Erik, “Danish Trials On Storage Of Readiness Ammunition In Field Camps”
4. Swisdak, Michael, “Effects Of Loading Density On Debris”
5. van der Voort, Martijn, “Determination Of The Debris IBD: The PTN Method And An Alternative Approach”
6. van Doormaal, Ans, “KG Engineering Tool For Debris Throw Prediction—Launch Velocity”

7. Verolme, Ellen, “Prediction Models And Quantity-Distance Relations For Small Quantities NEQ”
8. Weerheijm, Jaap and van Doormaal, Ans, “A Proposed Approach To Debris-Related Quantity-Distances”

7th Australian Explosive Ordnance Symposium (PARARI ’05), 8-10 November 2005.

1. Conway, Robert, Tancreto, James, Swisdak, Michael, and Tatom, John, “Comparison Of Risk Based Explosives Safety Criteria Team (RBESCT) Predictions With UK/Australian Defence Trial ADF 845/03 Results”
2. Grønsten, Geir Arne, “Small Quantity Storage In Soil Covered Ammunition Storage Magazines”
3. Langberg, Helge, Christensen, Svein O., and Skudal, Ståle, “Test Program With Small Concrete “Kasun” Houses”
4. Kummer, Peter, “Penetration and Perforation Of Brick Walls By Debris: Results From Test Series 1 and 2”
5. Richards, Jason, “Devastation Scene Mapping and Modelling in 3D, Bali I-Site 3D Laser Scanning System”
6. Swisdak, Michael, Tatom, John, and Tancreto, James, “SCIPAN—A Program To Determine The Effects Of Blast Loading On Typical Structures--Update”
7. Tatom, John, Tancreto, James, and Swisdak, Michael, “SPIDER - A Test Program To Determine The Response Of Typical Wall And Roof Panels To Debris Impact”

MSIAC Workshop on Debris Data, Analysis and Modeling, 7-9 February 2006.

1. Deschambault, Eric, J., “Minutes of the Workshop on Debris Data, Analysis, and Modeling,” MSIAC Report L-123, February 2006
2. Forsén, Rickard, “Parametric Sensitivity Study of Debris Launch Velocity with INVEX”
3. Grønsten, Geir Arne, “Planned Break-up Tests with Small Ammunition Houses”
4. Henderson, J., “UK Debris Trials 1982 - 2006”
5. Hoing, Craig, "DOSG Trials/Analysis of ESH Breakup”
6. Hoing, Craig, “Presentation by Debris Data and Analysis WG”
7. Kummer, Peter, “Launch Angle Of Debris From Magazine Walls”
8. Kummer, Peter, “Break Up Of Magazine Walls Due To Explosions: Debris Launch Angle”
9. Martel, Filip, “70 kg NEQ Container Trial, Tests 1 and 2”
10. Nielsen, Thomas, “Overview Of Denmark Tests In Containers and Concrete Structures: DNK Test 500 kg HD 1.1, DNK Test 1000 kg HD 1.1, and DNK Test Report Rømø 2004”
11. Norman, Paul, “Numerical Simulation Of Debris Generation From ESH Breakup”
12. Norman, Paul, “27 Tonne Fragment Trajectory Analysis Using AUDODYN Simulations and DEBDIS V1.2”
13. Øiom, Hans, “Mitigating Debris And Why Debris Mapping Is Important”
14. Swierk, Thomas, “Technical Investigation of Off-Range Fragment Event”
15. Swisdak, Michael, “Debris Collection and Testing in the United States”
16. Tancreto, James, “Modeling for Initial Debris Characteristics”
17. Tatom, John, “SCIPAN 3 Debris Data: Debris Plots”
18. Tatom, John, “SCIPAN 3 Debris Data: Debris Data Base”
19. Tatom, John, “Presentation by Analysis and Modeling WG”

20. van Doormaal, Ans, "Klotz Group Engineering Tool: Development And Application"
21. Weerheijm, Jaap, "Break up of Concrete Roof Slabs Under Internal Explosions; Explosion Box Tests"

<u>32nd DoD Explosives Safety Seminar</u>, 22-24 August 2006.

1. Crull, Michelle, "Design Of Barricades To Prevent Prompt Propagation"
2. Deschambault, Eric J., and Swisdak, Michael, "MSIAC Workshop On Debris Data, Analysis, And Modeling"
3. Grønsten, Geir Arne and Øiom, Hans., "Norwegian Scaled Field Storage Tests"
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