PREFACE

Applied Research Associates, Inc. (ARA) conducted high-explosive tests on August 2 and August 5, 2002, in order to evaluate the hazard mitigation characteristics of window systems developed by G.E. Plastics. Two high-explosive tests were conducted, with four windows evaluated in each test. This report documents the findings of these tests.

The test series was performed at the Energetic Materials Research and Testing Center (EMRTC) located in Socorro, New Mexico. This test site is jointly operated by the New Mexico Institute of Mining and Technology, and Applied Research Associates, Inc.

The Security Engineering Group of ARA, under the direction of Mr. Joseph L. Smith (ARA Director of Security Consulting Services), provided test structures, test design, test planning and documentation of the results. Mr. James T. Brokaw was the principal investigator and the field test engineer for this effort. The ARA team assigned to this project also included Mr. Kenneth W. Herrle. The Shock Physics Division of ARA, under the direction of Mr. Donald Cole, was responsible for test bed preparation, construction, test instrumentation, data collection and test execution. Dr. Sue Babcock was the test director for this effort.

This work was sponsored by G.E. Plastics. The support and efforts of Mr. Dennis Furlano (G.E. Plastics point of contact) are acknowledged and greatly appreciated.
EXECUTIVE SUMMARY

In response to the heightened concern about terrorism, the US Government and private industry are developing and testing new technologies to mitigate hazards to people in the vicinity of a terrorist bombing. Propelled by the forces of a terrorist bomb, glass fragments cause large numbers of serious injuries.

The US General Services Administration developed comprehensive security criteria (GSA Security Criteria, October 8, 1997) that includes physical security, electronic security, and many other criteria for blast considerations. This criteria formed the basis for the Interagency Security Committee (ISC) Security Criteria (May 28, 2001). The GSA has indicated that manufacturers must test their window products against the criteria to evaluate the performance of these products in blast if they want to be considered for use in GSA buildings. Actual window designs are then performed with the GSA computer program WINGARD (Window Glazing Analysis Response and Design).

G.E. Plastics commissioned ARA to perform open-air high explosive tests on August 2 and August 5, 2002. Two high-explosive tests were conducted with four windows evaluated in each test. The tests used the GSA standard test protocol included in Appendix A. The windows were mounted in enclosed concrete reaction structures. The response of each window was captured with high-speed film and still photography. An exterior, high-speed camera and an exterior, normal-speed video camera were used to capture the views of the structures and the explosive detonation for each test. The reaction structures were instrumented with pressure gages to measure the exterior reflected pressure on the specimens and the internal pressure in the structures.

The test charge was 600 lb of Ammonium Nitrate and Fuel Oil (ANFO), which is equivalent to 500 lb of TNT. The standoff distance to the structure remained constant for both tests at 170 ft.
A test matrix was developed to explore the effect of various pane configurations on the window response. The nominal total window size for the tests was 4 ft by 5-1/2 ft. Various configurations were tested, including panes constructed of LEXAN® MARGARD® Sheet, LEXGARD® Laminates, and laminated annealed glass (AG). The windows were tested in aluminum frames, as well as steel frames.

The ISC performance conditions for windows are presented graphically in the figure below and are described in the table provided on the next page. The ISC approach compares potential hazards based on the type and location of glass fragments interior and exterior to the test cubicle. These criteria indirectly reflect the velocity (hence hazard level) of fragments based on their distance from the original window position.
<table>
<thead>
<tr>
<th>Performance Condition</th>
<th>Protection Level</th>
<th>Hazard Level</th>
<th>Description of Window Glazing Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Safe</td>
<td>None</td>
<td>Glazing does not break. No visible damage to glazing or frame.</td>
</tr>
<tr>
<td>2</td>
<td>Very High</td>
<td>None</td>
<td>Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.</td>
</tr>
<tr>
<td>3a</td>
<td>High</td>
<td>Very Low</td>
<td>Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.</td>
</tr>
<tr>
<td>3b</td>
<td>High</td>
<td>Low</td>
<td>Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.</td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
<td>Medium</td>
<td>Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>High</td>
<td>Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.</td>
</tr>
</tbody>
</table>

The results of the tests are documented in the following tables and photographs. Properly designed and installed windows can be developed which may provide a very high level of protection against the GSA level C (ISC Medium) loading of 4 psi and 28 psi-msec. Quality control during installation is very important and could drastically affect window response.
## TEST 1 SUMMARY

Date: 2 August 2002  
Nominal Charge Weight, lb ANFO: 600  
Standoff to each structure, ft: 170  
Avg. Measured Peak Pressure, psi: 4.3  
Avg. Measured Positive Impulse, psi-msec: 29.9  
Time of Detonation: 1:25 pm  
Ambient Temperature, deg F: 77  

<table>
<thead>
<tr>
<th>Specimen Description</th>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
<th>Window 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4&quot; LEXAN® MARGARD® Sheet, wet-glazed (4-sided); Norshield aluminum frame, center horizontal mutton</td>
<td></td>
<td>3/8&quot; LEXAN® MARGARD® Sheet, wet-glazed (4-sided); Norshield aluminum frame</td>
<td>1/4&quot; LEXAN® MARGARD® Sheet, 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (GEP-BL011PC insulated unit), wet-glazed (4-sided); Norshield aluminum frame</td>
<td>1/4” LEXAN® MARGARD® Sheet (outer), 1/2” air gap, 1/4” laminated AG (inner) (GEP-BL011 insulated unit), wet-glazed (4-sided); Norshield aluminum frame</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Damage Description</th>
<th>V2</th>
<th>V1</th>
<th>V2</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing remained intact, but landed outside of structure. Permanent inward deformation ≈ 3.25” on center mullion.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edges of glazing pulled out of frame and bowed ≈ 2.25” inward on right’ side and ≈ 1” outward on left’ side.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper section of glazing pulled out of frame bowing outward ≈ 2” on right’ side and ≈ 13” on left’ side.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right’ upper corner of glazing pulled out of frame and bowed ≈ 12.5” outward.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Window Glazing Response</th>
<th>V2</th>
<th>V1</th>
<th>V2</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing left frame and landed 66” outside of structure. No fragments evident inside of structure. No impacts evident on witness panel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glazing (with the exception of two bowed edges) remained in frame. No fragments evident inside or outside of structure. No impacts evident on witness panel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glazing (with the exception of bowed areas) remained in frame. No fragments evident inside or outside of structure. No impacts evident on witness panel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glazing (with the exception of the bowed corner) remained in frame. No fragments evident outside of structure. Light dusting on sill and in 3a/3b region. No impacts evident on witness panel.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>V2</th>
<th>V1</th>
<th>V2</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Low</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Protection Level</th>
<th>V2</th>
<th>V1</th>
<th>V2</th>
<th>V2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very High</td>
<td>Very High</td>
<td>Very High</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance Condition</th>
<th>V2</th>
<th>V1</th>
<th>V2</th>
<th>V2</th>
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<tbody>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3b</td>
<td></td>
</tr>
</tbody>
</table>

Test Notes:  
1) All window units had a 1” nominal bite.  
2) Windows were mounted in aluminum frames: pane = 64.5” x 46.5”; clear opening = 62.5” x 44.5”.  
3) AG = annealed glass.  
4) Witness panels were located 120” behind window.  
6) Panes were unintentionally transposed in frame when Window 4 was constructed; LEXAN® MARGARD® Sheet was intended as inner pane.  
7) Window edges (top, bottom, left, right) are based on a person standing to the exterior side of the window looking inward.  
8) GE Construction 1200 silicone sealant was used for wet glazing. It should be noted that the silicone was not fully cured when the test occurred (as noted during the posttest inspection). Minimum silicone depth was 1/4”. Wet glazing details are shown in Appendix C (Page C-25).  
9) The test bed is situated at an altitude of 6200 ft above sea level.  
10) Windows were mounted to the structure using 1/2” diameter, Grade 8 bolts spaced at 6” on center.  
Test 1, Window 1,
4.32 psi – 29.85 psi-msec
• 1/4” LEXAN® MARGARD® Sheet, wet-glazed (4-sided).
• Glazing landed 66” outside of structure.
No fragments evident inside of structure.
No impacts evident on witness panel.

Test 1, Window 2,
4.32 psi – 29.85 psi-msec
• 3/8” LEXAN® MARGARD® Sheet, wet-glazed (4-sided).
• Side edges of glazing pulled out of frame. No fragments evident inside or outside of structure.
No impacts evident on witness panel.
Test 1, Window 3,  
4.32 psi – 29.85 psi-msec  
- GEP-BL011PC insulated unit.  
- Upper section of glazing pulled out of frame bowing outward. No fragments evident inside or outside of structure. No impacts evident on witness panel.

Test 1, Window 4,  
4.32 psi – 29.85 psi-msec  
- GEP-BL011 insulated unit.  
- Right upper corner of glazing pulled out of frame bowing outward. No fragments evident outside of structure. Light dusting of glass on sill and in 3a/3b region. No impacts evident on witness panel.
### TEST 2 SUMMARY

**Date:** 5 August 2002  
**Nominal Charge Weight, lb ANFO:** 600  
**Standoff to each structure, ft:** 170  
**Avg. Measured Peak Pressure, psi:** 4.3  
**Avg. Measured Positive Impulse, psi-msec:** 28.7  
**Time of Detonation:** 9:41 am  
**Ambient Temperature, deg F:** 71

<table>
<thead>
<tr>
<th>Specimen Description</th>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
<th>Window 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/8” MPC-375 LEXGARD® Laminate; steel frame (GEP-STFR)</td>
<td>1/4” laminated AG (exterior), 3/4” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit); aluminum frame (44-600)</td>
<td>7/8” HP-875 LEXGARD® Laminate (UL Level 2 Rated); aluminum frame (44-600)</td>
<td>1/4” laminated AG (exterior), 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit); steel frame (GEP-STFR)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Damage Description</th>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
<th>Window 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small area on left side pulled out of frame. Glazing remained intact. Unit bowed inward approximately 2”.</td>
<td>Exterior pane cracked. Interior pane remained intact. Bottom left side and top right corner pulled out of frame (displaced approximately 4-1/2” and 12-1/4” outward respectively).</td>
<td>No noticeable damage or deformation of glazing. Glazing remained entirely in frame.</td>
<td>Exterior pane cracked. Interior pane remained intact. Right side pulled out of frame (displaced approximately 7-3/4” outward).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Window Glazing Response</th>
<th>Window 1</th>
<th>Window 2</th>
<th>Window 3</th>
<th>Window 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.</td>
<td>Several small fragments to the exterior of the structure. Light dusting of glass on sill. No impacts evident on witness panel.</td>
<td>No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.</td>
<td>Light dusting of glass to the exterior of the structure. No fragments evident on the interior of the structure. No impacts evident on witness panel.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hazard Level</th>
<th>None</th>
<th>None</th>
<th>None</th>
<th>None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protection Level</td>
<td>Very High</td>
<td>Very High</td>
<td>Safe</td>
<td>Very High</td>
</tr>
<tr>
<td>Performance Condition</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

Test Notes:
1) Window units had: 1” nominal bite using steel frames; 13/16” nominal bite using aluminum frames.
2) Windows mounted in steel frames: pane = 45-1/8” x 63-1/8”; clear opening = 43-1/8” x 61-1/8”.
   Windows mounted in aluminum frames: pane = 45-1/8” x 63-1/8”; clear opening = 43-1/2” x 61-1/2”.
3) AG = annealed glass
4) Witness panels were located 120” behind window.
6) Window edges (top, bottom, left, right) are based on a person standing to the exterior side of the window looking inward.
7) Lightning damaged some of the data acquisition equipment in the time span between tests 1 and 2. As a result, data obtained from gages 2, 3, 4, 6, and 9 was flawed and therefore not included in the averages.
8) The test bed is situated at an altitude of 6200 ft above sea level.
9) Windows were mounted to the structure using 1/2” diameter, Grade 8 bolts spaced at 6” on center.
11) MPC-375 LEXGARD® Laminate: 3/16” LEXAN® MARGARD® Sheet, 0.015 laminate interlayer, 3/16” LEXAN® MARGARD® Sheet.
12) HP-875 LEXGARD® Laminate: 3/16” LEXAN® MARGARD® Sheet, 0.015 laminate interlayer, 1/2” acrylic sheet, 0.015 laminate interlayer, 3/16” LEXAN® MARGARD® Sheet.
Test 2, Window 1,  
4.33 psi – 28.71 psi-msec  
- 3/8” MPC-375 LEXGARD® Laminate.  
- Small area on left side pulled out of frame bowing inward. No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.

Test 2, Window 2,  
4.33 psi – 28.71 psi-msec  
- GEP-BL011 insulated unit.  
- Bottom left side and top right corner pulled out of frame (bowing outward). Several small fragments found to the exterior of the structure. Light dusting of glass on sill. No impacts evident on witness panel.
Test 2, Window 3, 
4.33 psi – 28.71 psi-msec
• 7/8” HP-875 LEXGARD® Laminate (UL Level 2 Rated).
• No noticeable damage or deformation of glazing. Glazing remained entirely in frame. No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.

Test 2, Window 4, 
4.33 psi – 28.71 psi-msec
• GEP-BL011 insulated unit.
• Right side pulled out of frame bowing outward. Light dusting of glass to the exterior of the structure. No fragments evident on the interior of the structure. No impacts evident on witness panel.
Non-SI units of measurement used in the report can be converted to SI units as follows:

<table>
<thead>
<tr>
<th>Multiply:</th>
<th>By:</th>
<th>To Obtain:</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees (deg)</td>
<td>0.01745329</td>
<td>radians (rad)</td>
</tr>
<tr>
<td>miles (U.S. statute)</td>
<td>1.609347</td>
<td>kilometers (km)</td>
</tr>
<tr>
<td>feet (ft)</td>
<td>0.3048</td>
<td>meters (m)</td>
</tr>
<tr>
<td>inches (in)</td>
<td>25.4</td>
<td>millimeters (mm)</td>
</tr>
<tr>
<td>mil</td>
<td>0.0254</td>
<td>millimeters (mm)</td>
</tr>
<tr>
<td>pounds (lb)</td>
<td>4.448222</td>
<td>newtons (N)</td>
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<td>0.4535924</td>
<td>kilogram (kg)</td>
</tr>
<tr>
<td>kips per square inch (ksi)</td>
<td>6.894757</td>
<td>megapascals (mPa)</td>
</tr>
<tr>
<td>pounds per square inch (psi)</td>
<td>6894.757</td>
<td>pascals (N/m$^2$ or Pa)</td>
</tr>
<tr>
<td>pounds per square inch (psi)</td>
<td>6.894757</td>
<td>kilopascals (kPa)</td>
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<td>pounds per square inch (psi)</td>
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<td>megapascals (mPa)</td>
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</tbody>
</table>
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Chapter</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREFACE</td>
<td>ii</td>
</tr>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>iii</td>
</tr>
<tr>
<td>CONVERSION FACTORS</td>
<td>xii</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>1-1</td>
</tr>
<tr>
<td>1.1 BACKGROUND</td>
<td>1-1</td>
</tr>
<tr>
<td>1.2 OBJECTIVES</td>
<td>1-2</td>
</tr>
<tr>
<td>1.3 ISC CRITERIA</td>
<td>1-2</td>
</tr>
<tr>
<td>2 TEST CONFIGURATION</td>
<td>2-1</td>
</tr>
<tr>
<td>2.1 TEST RANGE</td>
<td>2-1</td>
</tr>
<tr>
<td>2.2 TEST STRUCTURES AND TEST BED</td>
<td>2-1</td>
</tr>
<tr>
<td>2.3 INSTRUMENTATION</td>
<td>2-2</td>
</tr>
<tr>
<td>2.4 TEST CHARGE</td>
<td>2-2</td>
</tr>
<tr>
<td>2.5 INSTALLATION DETAILS</td>
<td>2-3</td>
</tr>
<tr>
<td>2.6 TEST MATRIX</td>
<td>2-3</td>
</tr>
<tr>
<td>3 TEST RESULTS</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1 TEST 1 RESULTS</td>
<td>3-1</td>
</tr>
<tr>
<td>3.1.1 Window 1</td>
<td>3-2</td>
</tr>
<tr>
<td>3.1.2 Window 2</td>
<td>3-2</td>
</tr>
<tr>
<td>3.1.3 Window 3</td>
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</tr>
<tr>
<td>3.1.4 Window 4</td>
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</tr>
<tr>
<td>3.2 TEST 2 RESULTS</td>
<td>3-10</td>
</tr>
<tr>
<td>3.2.1 Window 1</td>
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</tr>
<tr>
<td>3.2.2 Window 2</td>
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</tr>
<tr>
<td>3.2.3 Window 3</td>
<td>3-11</td>
</tr>
<tr>
<td>3.2.4 Window 4</td>
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</tr>
<tr>
<td>4 RESULTS SUMMARIES AND MAJOR FINDINGS</td>
<td>4-1</td>
</tr>
<tr>
<td>4.1 IMPLICATION OF RESULTS AND GSA SECURITY REQUIREMENTS</td>
<td>4-1</td>
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<td>4.2 CONSOLIDATED RESULTS</td>
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<td>4.3 MAJOR FINDINGS</td>
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Appendix

A  GSA TEST METHOD................................................................. A-1
B  MEASURED PRESSURE DATA............................................... B-1
C  FRAME DETAILS .................................................................... C-1
CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

When an explosion is detonated in an urban environment, window breakage is typically widespread and can occur over several city blocks. The window glass fragments generated by such an event are either driven into the buildings or drawn outside the buildings resulting in injury to building occupants and people on the street. For example, over 500 people in Oklahoma City sustained injuries (many due to window glass failure) and required medical attention due to the bombing of the A.P. Murrah Building in 1995. To reduce the window glass fragment hazards generated by blast, several technologies have emerged, including security window films, laminated glass, blast curtains, blast louvers, and new energy absorbing technologies.

The US General Services Administration (GSA) oversees design and construction of new facilities and manages the existing real property inventory for a large portion of the US Government. After the Oklahoma City bombing, the President issued a directive for government agencies to take action toward protecting government facilities. In response to this presidential directive, the GSA published a security criteria document (GSA Security Criteria, October 8, 1997), which specifically addresses blast protection issues for both new and existing GSA facilities. This criteria was followed by the Interagency Security Committee (ISC) Security Criteria which was signed and officially adopted on May 28, 2001. Part of the criteria addresses window glazings and the associated hazard generated by blast. This portion of the criteria was based in part on a series of blast tests on windows performed by the GSA and other blast test data. The glazing criteria are performance based. The glass fragment hazard generated by windows is graded based on the post-blast location of glass fragments in a blast test. The GSA has indicated that manufacturers of glass fragment mitigating products must test their products to be considered for use in ISC Medium and Higher (GSA Level C and D) facilities.

G.E. Plastics commissioned ARA to perform two high-explosive blast tests in order to evaluate the performance of various window systems. The test data collected in this effort will provide useful information for many government and civilian entities that are responsible for security planning of building facilities.
The explosive tests were conducted at the Energetic Materials Research and Testing Center (EMRTC) in Socorro, New Mexico on August 2 and August 5, 2002. The test procedure was designed in accordance with the procedure adopted by the GSA. The GSA test procedure is included in Appendix A. The test used 600 lb of ANFO, which is equivalent to 500 lb of TNT. The window sizes were approximately 4 ft by 5-1/2 ft. The windows were mounted in enclosed concrete reaction structures for testing. The test was conducted using a standoff distance to the charge of 170 ft.

1.2 OBJECTIVES
The primary objective of this test series was to evaluate the performance of G.E. Plastics window systems subjected to a blast environment. The effect of various test specimen parameters was investigated to evaluate the effect of these variances on performance.

1.3 ISC CRITERIA
The ISC security criteria glass fragment hazard rating scheme is presented graphically in Figure 1.1 and described in Table 1.1. The approach compares potential hazards based on the location of glass fragments interior and exterior to the test cubicle. These criteria indirectly reflect the velocity of fragments based on their distance from the original window position.

Figure 1.1 GSA window glazing hazard rating scheme.
Table 1.1 GSA/ISC glass hazard rating scheme.

<table>
<thead>
<tr>
<th>Performance Condition</th>
<th>Protection Level</th>
<th>Hazard Level</th>
<th>Description of Window Glazing Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Safe</td>
<td>None</td>
<td>Glazing does not break. No visible damage to glazing or frame.</td>
</tr>
<tr>
<td>2</td>
<td>Very High</td>
<td>None</td>
<td>Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.</td>
</tr>
<tr>
<td>3a</td>
<td>High</td>
<td>Very Low</td>
<td>Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.</td>
</tr>
<tr>
<td>3b</td>
<td>High</td>
<td>Low</td>
<td>Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.</td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
<td>Medium</td>
<td>Glazing cracks. Fragments enter space and land on floor and impact a vertical witness panel at a distance of no more than 10 ft. from the window at a height no greater than 2 ft. above the floor.</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>High</td>
<td>Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.</td>
</tr>
</tbody>
</table>
CHAPTER 2
TEST CONFIGURATION

2.1 TEST RANGE

The test series was performed at the Energetic Materials Research and Testing Center (EMRTC) located in Socorro, New Mexico. The test site is jointly operated by the New Mexico Institute of Mining and Technology and Applied Research Associates, Inc.

2.2 TEST STRUCTURES AND TEST BED

Three concrete reaction structures were used for this test. Reaction structures were enclosed and sealed to prevent airblast engulfment effects that occur in open frame blast tests. When a window or other specimen is blast tested in an open frame, the airblast engulfs the specimen before it can completely respond. The result is an airblast loading from both the front and the back of the window. The net load driving the specimen is the difference between the load on the front of the specimen and the back of the specimen. This net differential load is much less than that which is obtained by using an enclosed reaction structure. To best simulate the loads that can be expected on typical buildings, the enclosed reaction structure is required.

Three reaction structures were used during testing. Two of the reaction structures housed one window per test. The third reaction structure housed two individual window specimens per test. An interior partition wall separated this structure into two rooms, preventing any potential engulfment effect that could occur if one window failed before the other window in this structure.

The three structures were placed in a semi-circular pattern at approximately 30 ft on center with windows facing toward the charge. The modular structure was located in the center with the two smaller boxes to either side. Window nomenclature and orientations are shown in Figure 2.1.

The charge standoff to each structure was 170 ft for both tests. The nominal reflected pressure levels for both tests was 4.3 psi. The placement of these structures for this test series is as shown Figure 2.2.

Rocks are abundant in the soil at the test site. In order to minimize the potential for rock impact of the specimens, the explosive charge was placed over a pit backfilled with sand, and the test bed was graded and raked between each test.
The test structures are nominally 10 ft deep from the window opening to the rear of the structure. Wood framed walls were erected in the rear of the structures for mounting of the rigid foam witness panels. These witness panels were located approximately 120 inches from the back of the windows in accordance with the GSA test method (criteria dictates ≤10 ft). The witness panels were 4 ft wide by 8 ft high and were located behind the window openings. Butcher paper was attached to the rigid foam witness panel and was examined after testing to determine if glass fragment impacts occurred.

2.3 INSTRUMENTATION

The reaction structures were instrumented with exterior pressure gages (Figure 2.3) to monitor the reflected pressures near the window specimens. Two exterior pressure gages were used for each window for a total of eight exterior pressure gages. These were located as close as possible to either side of the window specimens mounted in the concrete wall near the vertical center of the window.

Interior pressure gages were mounted on the witness panels for Windows 1 and 4, and on the back wall for Windows 2 and 3 (Figure 2.4) to monitor the infill pressures. Infill pressures from all tests were very small and would not likely pose a hazard to occupants. All measured pressure data is plotted in Appendix B along with statistical summaries for each test.

A high-speed video camera was located inside the structures behind each window and off to one side of the cubicle. The cameras used a Plexiglas screen to protect the lenses. In three of the structures, the cameras were rigid mounted to the structure floor on steel tube stands. The camera was placed on sandbags inside the structure containing Window 1.

A high-speed film camera and a normal-speed video camera were located on an embankment to the northeast of the test bed to capture exterior views of the explosion and the structures. See Figure 2.5 for all camera locations.

A weather station was used to monitor the ambient temperature, relative humidity, and barometric pressure for each test.

2.4 TEST CHARGE

The explosive charge for the test was 600 lb of ammonium nitrate and fuel oil which is equivalent to 500 lb of TNT. The charge was built in a 30-inch diameter cardboard Sonotube
with two PETN boosters located in the center of the charge. The charge standoff distance was measured with a measuring tape and an iterative process was used to locate the charge the same distance from each window.

2.5 INSTALLATION DETAILS

The windows were tested in three different frame types. All four windows in test 1 were mounted in Norshield aluminum frames (2” x 4-1/2” aluminum frame with snap covers). Windows tested in these frames had a pane size of 64.5” x 46.5”, a clear opening a 62.5” x 44.5”, and a nominal bite of 1”. Windows 1 and 4 in test 2 were mounted in frame type GEP-STFR (2-11/16” x 4” steel frame). Windows tested in these frames had a pane size of 45-1/8” x 63-1/8”, a clear opening a 43-1/8” x 61-1/8”, and a nominal bite of 1”. Windows 2 and 3 in test 2 were mounted in frame type 44-600 (2-1/2” x 6” aluminum “field glazed” frame). Windows tested in these frames had a pane size of 45-1/8” x 63-1/8”, a clear opening a 43-1/2” x 61-1/2”, and a nominal bite of 13/16”. All windows were mounted using 1/2” diameter, Grade 8 bolts spaced at 6” on center. Frame details are shown in Appendix C.

2.6 TEST MATRIX

A test matrix (Table 2.1) was designed by G.E. Plastics in an attempt to get the most useful information from the limited number of specimens to be evaluated. Windows were tested in both aluminum and steel frames.
Table 2.1  Test article matrix.

<table>
<thead>
<tr>
<th>Standoff /Measured Peak Pressure</th>
<th>Win. #</th>
<th>Test Articles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test 1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>standoff = 170 ft</td>
<td>1</td>
<td>1/4” LEXAN® MARGARD® Sheet, wet-glazed (4-sided), center horizontal mutton</td>
</tr>
<tr>
<td>peak pressure = 4.3 psi</td>
<td>2</td>
<td>3/8” LEXAN® MARGARD® Sheet, wet-glazed (4-sided)</td>
</tr>
<tr>
<td>peak impulse = 29.9 psi-msec</td>
<td>3</td>
<td>1/4” LEXAN® MARGARD® Sheet, 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (GEP-BL011PC insulated unit), wet-glazed (4-sided)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1/4” LEXAN® MARGARD® Sheet (outer), 1/2” air gap, 1/4” laminated AG (inner) (GEP-BL011 insulated unit), wet-glazed (4-sided)</td>
</tr>
<tr>
<td><strong>Test 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>standoff = 170 ft</td>
<td>1</td>
<td>3/8” MPC-375 LEXGARD® Laminate</td>
</tr>
<tr>
<td>peak pressure = 4.3 psi</td>
<td>2</td>
<td>1/4” laminated AG (exterior), 3/4” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit)</td>
</tr>
<tr>
<td>peak impulse = 28.7 psi-msec</td>
<td>3</td>
<td>7/8” HP-875 LEXGARD® Laminate (UL Level 2 Rated)</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1/4” laminated AG (exterior), 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit)</td>
</tr>
</tbody>
</table>

Note: “®” designates a Registered Trademark of the General Electric Company.

Note: Panes were unintentionally transposed in frame when Window 4, Test 1, was constructed. The LEXAN® MARGARD® Sheet was intended as the inner pane.
Figure 2.1 Structure orientation and window nomenclature.
Reaction structures were centered on charge at 170 ft with center-to-center spacing of approximately 30 ft.

Figure 2.2 Radial orientation of structures (not drawn to scale).
Figure 2.3 Exterior pressure gage locations.
Figure 2.4 Interior pressure gage locations.
Figure 2.5 Camera locations.
CHAPTER 3
TEST RESULTS

3.1 TEST 1 RESULTS

The explosive was detonated on August 2, 2002 at 1:25 pm. The charge was located at a standoff of 170 ft from the structures for a pretest nominal target pressure of 4.6 psi. A typical airblast waveform is shown in Figure 3.1, and the average airblast values from the exterior gages are given in Table 3.1. Statistical analysis was performed on the test data and is included in Appendix B.

![Figure 3.1 Typical airblast waveform from test 1.](image)

**Table 3.1 Average airblast values for test 1.**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.46</td>
<td>29.49</td>
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<tr>
<td>2</td>
<td>4.31</td>
<td>30.73</td>
</tr>
<tr>
<td>3</td>
<td>4.20</td>
<td>28.44</td>
</tr>
<tr>
<td>Avg.</td>
<td>4.32</td>
<td>29.85</td>
</tr>
</tbody>
</table>
3.1.1 Window 1

Description: 1/4" LEXAN® MARGARD® Sheet, wet-glazed (4-sided); Norshield aluminum frame, center horizontal mutton

Rating: GSA Condition 2

Glazing remained intact, but landed outside of structure. Permanent inward deformation of approximately 3.25” on center mullion. Glazing left frame and landed 66” outside of structure. No fragments evident inside of structure. No impacts evident on witness panel.

A pretest photo is included in Figure 3.2. Posttest photos are located in Figure 3.3 and Figure 3.4.

3.1.2 Window 2

Description: 3/8" LEXAN® MARGARD® Sheet, wet-glazed (4-sided); Norshield aluminum frame

Rating: GSA Condition 2

Edges of glazing pulled out of frame and bowed approximately 2.25” inward on right side and approximately 1” outward on left side. Glazing (with the exception of two bowed edges) remained in frame. No fragments evident inside or outside of structure. No impacts evident on witness panel.

A pretest photo is included in Figure 3.5. Posttest photos are located in Figure 3.6 and Figure 3.7.

3.1.3 Window 3

Description: 1/4" LEXAN® MARGARD® Sheet, 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (GEP-BL011PC insulated unit), wet-glazed (4-sided); Norshield aluminum frame

Rating: GSA Condition 2

Upper section of glazing pulled out of frame, bowing outward approximately 2” on right side and approximately 13” on left side. Glazing (with the exception of bowed areas) remained in frame. No fragments evident inside or outside of structure. No impacts evident on witness panel.

A pretest photo is included in Figure 3.8. Posttest photos are located in Figure 3.9 and Figure 3.10.
3.1.4 Window 4

Description: 1/4” LEXAN® MARGARD® Sheet (outer), 1/2” air gap, 1/4” laminated AG (inner) (GEP-BL011 insulated unit), wet-glazed (4-sided); Norshield aluminum frame

Rating: GSA Condition 3b

Right upper corner of glazing pulled out of frame and bowed approximately 12.5” outward. Glazing (with the exception of the bowed corner) remained in frame. No fragments evident outside of structure. Light dusting of glass on sill and in 3a/3b region. No impacts evident on witness panel.

A pretest photo is included in Figure 3.11. Posttest photos are located in Figure 3.12 and Figure 3.13.

For the four window descriptions listed above, the window edges (left, right) are oriented based on a person standing to the exterior of the window looking inward.

Figure 3.2 Exterior pretest view of window 1. (DSC00140.jpg)
Figure 3.3 Exterior posttest view of window 1. (IMG_5525.jpg)

Figure 3.4 Interior posttest view of window 1. (DSC00172.jpg)
Figure 3.5  Exterior pretest view of window 2.  (IMG_5502.jpg)

Figure 3.6  Exterior posttest view of window 2.  (IMG_5542.jpg)
Figure 3.7 Interior posttest view of window 2.  (IMG_5553.jpg)

Figure 3.8 Exterior pretest view of window 3.  (IMG_5513.jpg)
Figure 3.9  Exterior posttest view of window 3.  (DSC00205.jpg)

Figure 3.10  Interior posttest view of window 3.  (IMG_5573.jpg)
Figure 3.11  Exterior pretest view of window 4.  (DSC00159.jpg)

Figure 3.12  Exterior posttest view of window 4.  (IMG_5583.jpg)
Figure 3.13  Interior posttest view of window 4.  (IMG_5609.jpg)
3.2 TEST 2 RESULTS

The explosive was detonated on August 5, 2002 at 9:41am. The charge was located at a standoff of 170 ft from the structures for a pretest nominal target pressure of 4.6 psi. A typical airblast waveform is shown in Figure 3.14, and the average airblast values from the exterior gages are given in Table 3.2. Statistical analysis was performed on the test data and is included in Appendix B.

![Figure 3.14 Typical airblast waveform from test 2.](image)

Table 3.2 Average airblast values for test 2.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.57</td>
<td>27.74</td>
</tr>
<tr>
<td>2</td>
<td>4.20</td>
<td>29.40</td>
</tr>
<tr>
<td>3</td>
<td>4.41</td>
<td>28.14</td>
</tr>
<tr>
<td>Avg.</td>
<td>4.33</td>
<td>28.71</td>
</tr>
</tbody>
</table>
3.2.1 Window 1

**Description:** 3/8” MPC-375 LEXGARD® Laminate; steel frame (GEP-STFR)

**Rating:** GSA Condition 2

Small area on left edge pulled out of frame. Glazing remained intact. Unit bowed inward approximately 2”. No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.

A pretest photo of window 1 is included in Figure 3.15. Figure 3.16 and Figure 3.17 contain posttest photos of the window.

3.2.2 Window 2

**Description:** 1/4” laminated AG (exterior), 3/4” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit); aluminum frame (44-600)

**Rating:** GSA Condition 2

Exterior pane cracked. Interior pane remained intact. Bottom left edge and top right corner pulled out of frame (displaced approximately 4-1/2” and 12-1/4” outward respectively). Several small fragments found to the exterior of the structure. Light dusting of glass on sill. No impacts evident on witness panel.

A pretest photo of window 2 is included in Figure 3.18. Figure 3.19 and Figure 3.20 contain posttest photos of the window.

3.2.3 Window 3

**Description:** 7/8” HP-875 LEXGARD® Laminate (UL Level 2 Rated); aluminum frame (44-600)

**Rating:** GSA Condition 1

No noticeable damage or deformation of glazing. Glazing remained entirely in frame. No fragments evident on the interior or exterior of the structure. No impacts evident on witness panel.

A pretest photo of window 3 is included in Figure 3.21. Figure 3.22 and Figure 3.23 contain posttest photos of the window.
3.2.4 Window 4

Description: 1/4” laminated AG (exterior), 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit); steel frame (GEP-STFR)

Rating: GSA Condition 2

Exterior pane cracked. Interior pane remained intact. Right edge pulled out of frame (displaced approximately 7-3/4” outward). Light dusting of glass to the exterior of the structure. No fragments evident on the interior of the structure. No impacts evident on witness panel.

A pretest photo of window 4 is included in Figure 3.24. Figure 3.25 and Figure 3.26 contain posttest photos of the window.

For the four window descriptions listed above, the window edges (left, right) are oriented based on a person standing to the exterior of the window looking inward.

Figure 3.15 Exterior pretest view of window 1. (IMG_5626.jpg)
Figure 3.16 Exterior posttest view of window 1. (IMG_5663.jpg)

Figure 3.17 Interior posttest view of window 1. (IMG_5677.jpg)
Figure 3.18  Exterior pretest view of window 2.  (IMG_5637.jpg)

Figure 3.19  Exterior posttest view of window 2.  (IMG_5682.jpg)
Figure 3.20  Interior posttest view of window 2.  (IMG_5697.jpg)

Figure 3.21  Exterior pretest view of window 3.  (IMG_5639.jpg)
Figure 3.22 Exterior posttest view of window 3. (IMG_5716.jpg)

Figure 3.23 Interior posttest view of window 3. (IMG_5714.jpg)
Figure 3.24  Exterior pretest view of window 4.  (DSC00029.jpg)

Figure 3.25  Exterior posttest view of window 4.  (IMG_5719.jpg)
Figure 3.26  Interior posttest view of window 4.  (DSC00091.jpg)
CHAPTER 4
RESULTS SUMMARIES AND MAJOR FINDINGS

4.1 IMPLICATION OF RESULTS AND GSA SECURITY REQUIREMENTS

The ISC (GSA) Security Criteria for window response requires that windows meet a certain level of performance for a particular design threat. This is true for GSA buildings with ISC protection levels of Medium and Higher (GSA Levels C and D). Buildings at the Low and Medium/Low levels of protection, which are lower in security classification than the Medium and Higher buildings, require no specific performance criteria though use of certain window types is discouraged.

For ISC Medium (GSA Level C) buildings, the typical design blast load is a triangular pulse that instantaneously rises to 4 psi and decays linearly to zero over a duration of 13.9 milliseconds (msec). The impulse that the specified design blast load generates is 28 psi-msec. The performance required for ISC Medium (GSA Level C) buildings is a Condition 4 or lower. The average impulses generated during current testing were 28.7 to 29.9 psi-msec with average peak pressures of 4.3 psi. Thus, window specimens that performed to a Condition 4 or better from this test series can be considered for use in ISC Medium (GSA Level C) buildings. Only window systems of the tested size and smaller in a similar configuration (framing and support conditions) can be directly compared to the test data from this test series. Other configurations must be designed by a qualified blast consultant for the specific application.
4.2 CONSOLIDATED RESULTS

The results of the tests are consolidated into the tables below.

Table 4.1 Summary of results for Test 1.

<table>
<thead>
<tr>
<th>Specimen Description</th>
<th>Test 1 Description</th>
<th>Test 2 Description</th>
<th>Test 3 Description</th>
<th>Test 4 Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4” LEXAN® MARGARD® Sheet, wet-glazed (4-sided), center horizontal mutton</td>
<td>3/8” LEXAN® MARGARD® Sheet, wet-glazed (4-sided)</td>
<td>1/4” LEXAN® MARGARD® Sheet, 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (GEP-BL011P insulated unit), wet-glazed (4-sided)</td>
<td>1/4” LEXAN® MARGARD® Sheet (outer), 1/2” air gap, 1/4” laminated AG (inner) (GEP-BL011 insulated unit), wet-glazed (4-sided)</td>
</tr>
<tr>
<td>Pressure</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Impulse</td>
<td>29.9</td>
<td>29.9</td>
<td>29.9</td>
<td>29.9</td>
</tr>
<tr>
<td>GSA Performance Condition</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3b</td>
</tr>
</tbody>
</table>

Table 4.2 Summary of results for Test 2.

<table>
<thead>
<tr>
<th>Specimen Description</th>
<th>Test 1 Description</th>
<th>Test 2 Description</th>
<th>Test 3 Description</th>
<th>Test 4 Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3/8” MPC-375 LEXGARD® Laminate</td>
<td>1/4” laminated AG (exterior), 3/4” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit)</td>
<td>7/8” HP-875 LEXGARD® Laminate (UL Level 2 Rated)</td>
<td>1/4” laminated AG (exterior), 1/2” air gap, 1/4” LEXAN® MARGARD® Sheet (interior) (GEP-BL011 insulated unit)</td>
</tr>
<tr>
<td>Pressure</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Impulse</td>
<td>28.7</td>
<td>28.7</td>
<td>28.7</td>
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<tr>
<td>GSA Performance Condition</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
4.3 MAJOR FINDINGS

This test series investigated the response of G.E. Plastics window systems exposed to blast loadings. Each of the four windows in Test 1 contained a wet glazed attachment. As the tables above show, for loads of approximately 4 psi, these systems may provide up to a performance condition 2 for the tested window sizes. It should be noted, however, that the posttest inspection revealed that the glazing silicone was not fully cured at the time of the test. It is therefore not known if these systems reacted as typical wet glazed systems. It is imperative that good quality control be used in developing the wet glazed window systems. Even without a fully cured wet glazed attachment, each of these wet glazed systems appear adequate to meet the ISC medium (GSA Level C) protection requirements for the window sizes and configurations tested.

Each of the four windows in Test 2 contained a dry glazed attachment. As the tables above show, for loads of approximately 4 psi, these window systems may provide up to a performance condition 1 for the tested window sizes. These systems appear adequate to meet the ISC medium (GSA Level C) protection requirements for the window sizes and configurations tested.

The G.E. Plastics technologies used in this test series can all be engineered to meet the performance requirements for the ISC medium (GSA Level C) protection. As with all blast resistant products, good quality control during design, manufacturing, and installation will increase the overall performance of any system to blast loads.
APPENDIX A

GSA TEST METHOD
Historical records show that fragments from glazing that has failed as the result of intentional or accidental explosions present a serious threat of personal injury. Glazing failure also allows blast pressure to enter the interior of buildings thus resulting in additional threat of personal injury and facility damage. These risks increase in direct proportion to the amount of glazing used on the building façade. This test method addresses only glazing and glazing systems. It assumes that the designer has verified that other structural elements have been adequately designed to resist the anticipated airblast pressures.

1. Scope
1.1 This test method sets forth procedures for the evaluation of the resistance of glazing or glazing systems against airblast loadings.
1.2 This test method allows for glazings to be tested with or without framing systems.
1.3 This test method is designed to test all glazings and glazing systems, including those fabricated from glass, plastic, glass-clad plastics, laminated glass, glass/plastic glazing materials, and film-backed glass.
1.4 The values stated in inch-pound units are to be regarded as the standard.
1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. See Section 8 for specific hazards statements.

2. Referenced Document
2.1 GSA Security Document:
2.2 ISC Security Criteria:
2.3 ASTM Standard:
E 997 Test Method for Structural Performance of Glass in Exterior Windows, Curtain Walls, and Doors Under the Influence of Uniform Static Loads by Destructive Methods

3. Terminology
3.1 Definitions:
3.1.1 ambient temperature - 75 ± 25° F.
3.1.2 blast mat—a steel or concrete pad upon which high explosive may be detonated to reduce the incidence of ejection.
3.1.3 effective positive phase duration (T)—the duration of an idealized triangular positive phase reflected airblast pressure time history, having an instantaneous rise to the measured P, with a linear decay to ambient, such that the impulse of the idealized pressure time history equals I of the measured positive phase of the reflected airblast time history.
3.1.3.1 Discussion—The idealized triangular airblast wave is considered to provide a reliable standard measure of the positive phase airblast intensity.
3.1.4 glazing—transparent materials used for windows, doors, or other panels.
3.1.5 glazing system—the assembly comprised of the glazing, its framing system, and anchorage devices.
3.1.6 peak positive pressure (P)—the maximum measured positive phase reflected airblast pressure, pounds per square inch.
3.1.7 positive phase impulse (I)—the integral of the measured positive phase reflected airblast pressure time history, pounds per square inch-milliseconds (more correctly called the specific positive phase impulse).
3.1.8 reflected airblast pressure—the pressure increase that a surface, oriented other than parallel to the line from the detonation point to the surface, experiences due to the detonation of a high explosive charge.
3.1.8.1 Discussion—The reflected airblast pressure time history, as measured at a point on the surface, consists of two separate phases. The positive phase is characterized by a nearly instantaneous rise to a maximum pressure followed by an exponential decay to ambient pressure. In the negative phase, which follows immediately the positive phase, the pressure decreases below ambient for a period of time before returning to ambient.
3.1.9 simply supported glazings—glazings supported in accordance with Test Method E 997 with the edges of the glass extending to a minimum of 1/8 in. beyond the neoprene supports.
3.1.10 test director—the individual identified by the independent testing laboratory as being responsible to complete the specified tests as required and to document the results in accordance with this test method.
4. Summary of Test Method
4.1 This test method prescribes the required apparatus, procedures, specimens, and other requirements necessary to determine the airblast resistance capacity of a glazing or glazing system.

5. Significance and Use
5.1 This test method provides a structured procedure to establish the airblast resistance capacity and fragmentation characteristics of glazings and glazing systems. Such evaluations will allow comparison of the relative benefits of the glazings and glazing systems on mitigating hazards to building occupants. Knowing the airblast resistance capacity reduces the risk of personal injury and facility damage.

5.2 The airblast resistance capacity for a glazing or glazing material does not imply that a single specimen will resist the specific airblast for which it is rated with a probability of 1.0. The probability that a single glazing or glazing construction specimen will resist the specific airblast for which it is rated increases proportionally with the number of test specimens that successfully resist the given level of airblast.

6. Performance Criteria
6.1 The performance of the glazing or glazing system shall be rated according to the GSA performance criteria as illustrated in the following figure and table based on the fragment hazard generated by the test specimen. The tested article is given a fragment hazard rating based on the location of fragments in and around the test reaction structure. The GSA scheme was adopted from a similar scheme developed in the United Kingdom for rating the hazard from glazing fragmentation. A witness panel is required no more than 10 ft behind the window to survey fragment impacts.

<table>
<thead>
<tr>
<th>Performance Condition</th>
<th>Protection Level</th>
<th>Hazard Level</th>
<th>Description of Window Glazing Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Safe</td>
<td>None</td>
<td>Glazing does not break. No visible damage to glazing or frame.</td>
</tr>
<tr>
<td>2</td>
<td>Very High</td>
<td>None</td>
<td>Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.</td>
</tr>
<tr>
<td>3a</td>
<td>High</td>
<td>Very Low</td>
<td>Fragments enter space and land on floor no further than 3.3 ft. from the window.</td>
</tr>
<tr>
<td>3b</td>
<td>High</td>
<td>Low</td>
<td>Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.</td>
</tr>
<tr>
<td>4</td>
<td>Medium</td>
<td>Medium</td>
<td>Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.</td>
</tr>
<tr>
<td>5</td>
<td>Low</td>
<td>High</td>
<td>Glazing cracks and window system fails catastrophically. Fragments enter space impacting a vertical witness panel at a distance of no more than 10 ft. from the window at a height greater than 2 ft. above the floor.</td>
</tr>
</tbody>
</table>

7. Apparatus
7.1 Test Facility—The test facility for qualifying a product shall consist of either a shock tube or an open-air arena. Subsequent development tests may use open-air explosives or shock tubes or both. Open-air arenas should be sited on clear and level terrain. The test facility shall be situated, and be of sufficient size, to accommodate the detonation of the required amount of explosives to provide the desired peak positive pressure and positive phase impulse. The test director shall ensure that potential environmental impact issues are determined and resolved prior to testing. The test director shall ensure that testing is conducted at ambient temperature in accordance with Section 3.1.1.

7.2 High Explosive (HE) Charge—A high explosive charge shall be used to generate the desired peak pressure and the positive phase impulse on the test specimen. The charge shall be hemispherical and detonated at ground level. Other charge configurations can be used. The effects of using other charge configurations must be accounted for and documented.

7.3 Blast Mat—If there is a possibility likelihood of crater ejecta interfering with the test, the high explosive charge shall be placed on a blast mat. The decision to use a blast mat shall be at the discretion of the test director.
7.4 Test Frame—A test frame suitable for supporting glazings or glazing systems shall be used. Glazing tested without a specific framing system shall be supported in a simple support subframe that is attached to the test frame. If a glazing system is tested, the glazing system shall be mounted to the test frame in a manner that closely models the manner in which it will be mounted in the field. The test frame shall be capable of resisting the airblast with deflections that do not exceed L/360 along lines of support for the simple support subframe or the glazing system. The area immediately behind the test specimens shall be enclosed to prevent airblast pressure from wrapping behind the test specimens.

7.5 Simple Support Subframe—A subframe, attachable to the test frame, to support glazing in accordance with Test Method E 997.

7.6 Instrumentation:

7.6.1 Pressure Transducers—A minimum of two airblast pressure transducers shall be used on each test reaction structure to measure the reflected pressure for specimens tested in a face-on configuration and the incident pressure for specimens tested in a side-on orientation. That is, the pressure measured should be the pressure in direction of loading and response of the glazing. A minimum of one interior pressure transducer is required in each test structure. If interior partitions are used to isolate interior pressure environments for the test specimens, an interior pressure transducer shall be used in each partitioned volume containing one or more test specimens. The airblast pressure transducers shall be capable of defining the anticipated airblast pressure history within the linear range of the transducer. The transducers shall have a rise/response time and resolution sufficient to capture the complete event.

7.6.2 Data Acquisition System (DAS)—The DAS shall consist of either an analog or digital recording system with a sufficient number of channels to accommodate the pressure transducers and any other electronic measuring devices. The DAS must operate at a sufficiently high frequency to record reliably the peak positive pressure. The DAS shall also incorporate filters to preclude alias frequency effects from the data.

7.6.3 Photographic Equipment—Photographic equipment shall be available to document the test. High Speed Photography (500 to 1000 frames per second), normal speed video, and still photography is recommended.

7.6.4 Temperature Measuring Device (TMD)—A TMD shall be used to accurately measure glazing surface temperatures.

7.6.5 Witness Panels—Witness panels shall consist of a foam board with a thin aluminum sheet or paper to record fragment impacts. The witness panel shall be mounted no more than 10 feet from the pretest window location.

8. Hazards

8.1 Storage, handling, and detonation of high explosive material should be conducted in accordance with applicable state and federal statutes by experienced professionals.

9. Specimens

9.1 The test sponsor shall provide the test specimens. The number of specimens provided shall consist of the number of specimens to be tested. Extra samples should be prepared in case of breakage due to transportation and/or installation.

9.2 The test director shall ensure that the test specimens are handled and stored in compliance with manufacturer’s instructions.

9.3 Each specimen shall be marked with the manufacturer’s model and serial numbers and the date of manufacture.

9.4 Each specimen shall be marked clearly to indicate its proper orientation to the explosive charge to preclude improper installation in the test frame.

9.5 To ensure proper support of glazing system test specimens, the test director shall obtain engineering information on anchoring details from the manufacturer.

10. Preparation of Apparatus and Specimens

10.1 Instrumentation:

10.1.1 At least two pressure transducers shall be installed on the test structure. The pressure transducers shall be flush with the outer surface of the test structure. The transducers should be located on the horizontal centerline of the test specimens at a distance from the edge of the test specimens not to exceed one half the shortest dimension of the specimen. Alternate locations may also be used.

10.1.2 The pressure transducers shall then be connected to the DAS and tested to verify proper operation.

10.2 Test Frames:

10.2.1 The test specimens shall be installed in the test frame. The face of the test frame with the test specimens installed shall be approximately a plane surface. No openings shall exist in this surface through which airblast pressure can infiltrate behind the test specimens. The area immediately behind the test specimens shall be enclosed to prevent airblast pressure from wrapping behind the test specimens.

10.3 Specimens:

10.3.1 The test director shall assign a number, and mark accordingly, each test specimen.

10.3.2 Thickness measurements of the glazing material should be made at each corner, 1 in. in from the edges, and recorded. Measurements of the lengths of the edges of the specimens shall be made and recorded.

10.4 Photography:

10.4.1 Prior to the test, a photographic record that adequately portrays the test specimens, the test frame, and the test configuration shall be made. This photographic record shall consist of still photographs and may include motion pictures or video.

10.4.2 If a photographic record of the response of the test specimens during the test is desired, high speed motion picture cameras or high speed video cameras, or both, shall be set up.

10.5 Witness Panels:

10.5.1 Witness panels shall be put in place to record spalling fragmentation from the test specimen.
11. Report

11.1 Upon completion of a test of glazing specimen(s), the test director shall report the results of the test. Report the following mandatory information:

11.1.1 Description of test glazing or glazing system specimens, including pertinent dimensions, construction, and glazing materials.

11.1.2 Complete description of framing.

11.1.3 Number of specimens tested.

11.1.4 Ambient temperature should be measured immediately prior to clearing the test range before the test.

11.1.5 Temperature of the glazing should be measured immediately prior to clearing the test range before the test.

11.1.6 Peak positive pressure should be measured from each reflected airblast pressure transducer on the reaction structure supporting the test specimens.

11.1.7 Positive phase duration should be measured from each reflected airblast pressure transducer on the reaction structure supporting the test specimens.

11.1.8 Positive phase impulse, $I$.

11.1.9 The recorded airblast pressure history from each pressure transducer.

11.1.10 Condition of the test specimens immediately following the test.

11.1.11 Damage to the witness panels.

11.1.12 Status of the specimens (that is, the performance condition according with 6.1.)

11.2 The test report shall contain the photographic record of the test setup in accordance with 10.4. In addition, the test report shall contain detailed photographs of each test specimen following the test. Each specimen shall be labeled in the post-test photographs to allow for clear identification.

11.3 If any motion picture records are made of the performance of the test specimens, such motion picture records shall become part of the test report.

11.4 The original copy of the test report shall be furnished to the sponsor of the test. The test director shall keep a copy of the test report on file.

12. Precision and Bias

12.1 No statement is made concerning either the precision or bias of this test method since the result merely states the actual performance of a glazing or glazing system subjected to an airblast loading.

13. Keywords

13.1 airblast rating; effective positive phase duration; glazing; glazing systems; high explosive; peak positive pressure; positive phase impulse; airblast pressure.
APPENDIX B

MEASURED PRESSURE DATA
Pressure gauges were installed in all of the reaction structures in order to measure the pressure levels that the window systems experienced in each explosive test. There were a total of 12 gauges used during this series. Figure B.1 shows the location of each gauge.

![Illustration of pressure gauge locations.](image)

Figure B.1. Illustration of pressure gauge locations.

The table below (Table B.1) summarizes the peak pressures and impulses. Waveforms for each of the gauges (for each test) follow this. It should be noted that when attempting to determine the peak pressure and impulses, obvious noise (spikes) in the waveforms were ignored.
Table B.1. Summary of the peak pressures and impulses.

Note: Lightning damaged some of the data acquisition equipment in the time span between tests 1 and 2. As a result, data obtained from gages 2, 3, 4, 6, and 9 was flawed and therefore not included in the averages for test 2.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Gauge Number*/ Average/ Standard Deviation</th>
<th>Peak Positive Pressure (psi)</th>
<th>Peak Positive Impulse (psi-msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>4.51</td>
<td>29.01</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.40</td>
<td>29.97</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.31</td>
<td>4.80</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>4.67</td>
<td>30.47</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>4.29</td>
<td>31.82</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.32</td>
<td>5.91</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>3.87</td>
<td>31.36</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4.42</td>
<td>29.26</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.41</td>
<td>6.60</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>4.11</td>
<td>27.31</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>4.29</td>
<td>29.56</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>0.15</td>
<td>3.31</td>
</tr>
<tr>
<td></td>
<td>Average External Gauge</td>
<td>4.32</td>
<td>29.85</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation External Gauge</td>
<td>0.25</td>
<td>1.42</td>
</tr>
</tbody>
</table>

| 2           | 1                                           | 4.57                         | 27.74                            |
|             | 2                                           | ---                          | ---                              |
|             | 3                                           | ---                          | ---                              |
|             | 4                                           | ---                          | ---                              |
|             | 5                                           | 4.27                         | 30.52                            |
|             | 6                                           | ---                          | ---                              |
|             | 7                                           | 3.87                         | 30.54                            |
|             | 8                                           | 4.48                         | 27.15                            |
|             | 9                                           | ---                          | ---                              |
|             | 10                                          | 4.30                         | 27.21                            |
|             | 11                                          | 4.51                         | 29.07                            |
|             | 12                                          | 0.15                         | 2.62                             |
|             | Average External Gauge                      | 4.33                         | 28.71                            |
|             | Standard Deviation External Gauge           | 0.26                         | 1.57                             |

*Pressure Gauges 1, 2, 4, 5, 7, 8, 10, and 11 are located on the on the exterior of the structures. Pressure gauges 3, 6, 9, and 12 are located on the interior of the structures. For reference see Figure B.1.
G.E. Plastics
Test 1 Comparison
Exterior Pressure Gages

![Graph showing pressure vs. time for different gages.]

Gage 1
Gage 2
Gage 4
Gage 5
Gage 7
Gage 8
Gage 10
Gage 11

Time (msec)
Pressure (psi)

Test Series Conducted
August 2 – August 5, 2002
G.E. Plastics
Test 1 Comparison
Interior Pressure Gages

![Graph showing comparison of interior pressure gages. Graph includes plots for Gage 3, Gage 6, Gage 9, and Gage 12. The x-axis represents time in milliseconds (80 to 240), and the y-axis represents pressure in psi (-3 to 3). The graph illustrates the pressure variations over time for each gage.]
G.E. Plastics
Test 2 Comparison
Exterior Pressure Gages

Time (msec)

Pressure (psi)

Gage 1
Gage 5
Gage 7
Gage 8
Gage 10
Gage 11

G.E. Plastics Test Report
Proprietary Information
Limited Distribution Only
Page B-8

Test Series Conducted
August 2 – August 5, 2002
G.E. Plastics
Test 2 Comparison
Interior Pressure Gages

![Graph showing impulse vs. time with data points marked for Gage 12.]

Time (msec)
80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240

Impulse (psi-msec)
-20 -15 -10 -5 0 5 10 15 20 25 30

Gage 12
APPENDIX C

FRAME DETAILS
Test 1, Windows 2, 3, and 4
Test 1, Window 1

- 1 1/4" ALUMINUM MUNTIN TUBE W/ 3/8" ALLTHREAD
- #1 1/4" SECURITY GLAZING
- 4 1/2" ALUMINUM FRAME W/ NS #443685 GLAZING STOP
- THIS AREA TO BE REMOVED TO ALLOW FOR MUNTIN INSTALLATION
- STEEL MOUNTING PLATE E/O
- HORSESHOE SHIMS

USE L-SHAPED BRACKETS TO SECURE ALUMINUM TUBE TO THE ALUMINUM FRAME. (4) REQUIRED.
Test Series Conducted
August 2 – August 5, 2002
Test 1, Window 3

G.E. Plastics Test Report

Proprietary Information
Limited Distribution Only
Page C-7

Test Series Conducted
August 2 – August 5, 2002
Test 1, Window 4
Test 2, Window 1
Test 2, Window 2

Test Series Conducted
August 2 – August 5, 2002
Test 2, Window 2

CONTINUOUS ALUMINUM EXTRUSION WITH (4) NO. 12 x 1" HEX WASHER HEAD SELF TAPPING SCREWS (18-8) ATTACHED TO EACH VERTICAL JAMB EXTRUSION

FRAME DIMENSION

1/2" DIA. FASTENER BY ARA ATTACHED TO SUBSTRATE Ø 12" o.c.

DAYLITE DIMENSION

CONTINUOUS ALUMINUM REMOVABLE HEAD BEAD

NEOPRENE GASKETS BOTH SIDES

1 1/4" C011 GLAZING
Test 2, Window 2

G.E. Plastics Test Report
Proprietary Information
Limited Distribution Only
Page C-15

Test Series Conducted
August 2 – August 5, 2002
Test 2, Window 3
(Note: Glazing changed to 7/8” HP-875)
Test 2, Window 3
(Note: Glazing changed to 7/8" HP-875)
Test 2, Window 3
(Note: Glazing changed to 7/8" HP-875)
Test 2, Window 4

CONTINUOUS 1/4" THICK STEEL PLATE x CONTINUOUS WELD

54 x 7.7# ALTERED STEEL I-BEAM (MITERED AT CORNERS WITH WELDS AS SHOWN w/ "X")

1 1/4" x 1 1/4" x 1/4" THICK STEEL ANGLE ATTACHED TO I-BEAM w/ 1/4-20 x 3/4" HEX HEAD MACHINE BOLTS @ 12" O.C.

1 1/2" DIAM. FASTENER BY ARA ATTACHED TO SUBSTRATE @ 12" O.C. (STAGGER HOLES TO OFFSET w/ 1/4-20 FASTENER)

FRAME DIMENSION

DAY-LITE DIMENSION
Test 2, Window 4

1 1/4" x 1 1/4" x 1/4" THICK STEEL ANGLE ATTACHED TO I-BEAM w/ 1/4-20 x 3/4" HEX HEAD MACHINE BOLTS @ 12" o.c.

1" IC GLAZING

CONTINUOUS 1/4" THICK COMPRESSIBLE DOUBLE FACED GASKET TAPE

1/2" DIA. FASTENER BY HOLE ATTACHED TO SUBSTRATE @ 12" o.c. STACER HOLES TO OFFSET w/ 1/4-20 FASTENER

S4 x 7.7# ALTERED STEEL I-BEAM (WIERED AT CORNERS WITH WELDS AS SHOWN w/ "x5")

CONTINUOUS 1/4" THICK STEEL PLATE x CONTINUOUS WELD
Typical Wet-Glazed Attachment
G.E. Construction 1200 Silicone
1/4” Minimum Silicone Depth