ARA-TR-03-16095.1

Explosive Tests for the Evaluation of 3M Corporation Window Systems

Prepared by:
Applied Research Associates, Inc.
Security Engineering Group
119 Monument Place
Vicksburg, MS 39180

November 2003

Prepared for:
3M Corporation
Consumer Safety & Light Management Department
3M Center, 223-2S-24
Saint Paul, MN 55144-2222

PREFACE

Applied Research Associates, Inc. (ARA) conducted high-explosive tests from September 24 to September 25, 2003, to evaluate the hazard mitigation characteristics of window systems developed by 3M Corporation. Five 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 and Applied Sciences Sector, under the direction of Mr. Joseph L. Smith, 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 3M Corporation. The support and efforts of Mr. Jim Mannix (3M Corporation's 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.

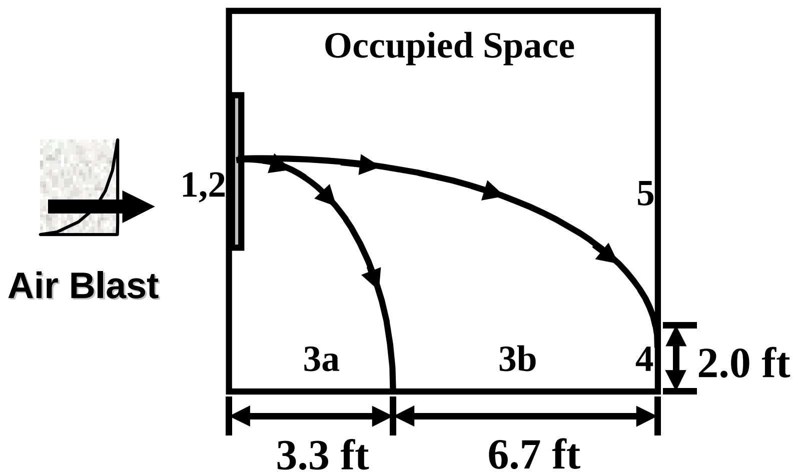
The US General Services Administration developed comprehensive security criteria (GSA Security Criteria, October 8, 1997) that includes physical security, electronic security, and many other criteria for blast considerations. This criteria formed the basis for the Interagency Security Committee (ISC) 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).

3M Corporation commissioned ARA to perform open-air high explosive tests from September 24 to September 25, 2003. Five high-explosive tests were conducted, with four window units evaluated in each test. The test series 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 charge size for all tests was 600 lb of Ammonium Nitrate and Fuel Oil (ANFO), which is equivalent to 500 lb of TNT. The standoff distance to the structures remained at 170 ft for all tests.

A test matrix was developed to explore the effect of various security film thickness and film attachment combinations on the windows' response. The nominal window size for the tests was 4 ft by 5-1/2 ft. The glass types used for the five tests consisted of both annealed glass (AG) and thermally tempered glass (TTG). The windows were tested in typical commercial aluminum 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.



Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	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.
5	Low	High	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.

The results of the tests are documented in the following tables and photographs. Properly designed and installed windows can be developed which provide a 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 can drastically affect window response.

At the request of 3M Corporation, ARA saved and weighed glass in zones 3a and 3b for each window and each test. While this information is not required to meet the GSA test requirements, other tests performed to other standards have recorded this information. The fragment weights are included in the appendix for reference.

TEST 1 SUMMARY

Date:	24 September 2003
Nominal Charge Weight, lb ANFO:	600
Standoff to each structure, ft:	170
Avg. Measured Peak Pressure, psi:	4.19
Avg. Measured Positive Impulse, psi-msec:	28.96
Time of Detonation:	12:34 pm
Ambient Temperature, deg F:	75

	Window 1	Window 2	Window 3	Window 4
Specimen Description	1/4" monolithic AG, wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, mechanically attached 4-mil security film (4-sided batten bar attachment)	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
Damage Description	Glazing left frame and landed 90 inches to the exterior of the structure. Right side[6] of frame deformed into window opening approximately 1 inch.	Glazing left frame and landed 103 inches to the exterior of the structure. No visible frame deformation.	Batten bar attachment screws failed along lower left side[6], and film tore in lower left hand corner[6]. Bottom of frame deformed into window opening approximately 3 inches.	Outer pane failed with fragments landing outside of structure. Inner pane film remained attached to frame. No visible frame deformation.
Window Glazing Response	Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Film remained attached to the frame, but most of the glass was stripped from the film and landed to the exterior of the structure. One glass fragment impacted the witness panel in Region 4.	Inner pane film remained attached to the frame, but some of the glass was stripped from the film and landed to the exterior of the structure. Light dusting of glass on sill. No impacts evident on witness panel.
Hazard Level	Low	Low	Medium	None
Protection Level	High	High	Medium	Very High
Performance Condition	3b	3b	4	2

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in commercial aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by “sandwiching” the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.
10) 2-sided mechanical attachments were connected along the jambs of the window frame.

Test 1, Window 1
4.19 psi – 28.96 psi-msec

- 1/4" monolithic AG, wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)
- Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

Test 1, Window 2
4.19 psi – 28.96 psi-msec

- 1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
- Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

Test 1, Window 3
4.19 psi – 28.96 psi-msec

- 1/4" monolithic AG, mechanically attached 4-mil security film (4-sided batten bar attachment)
- Film remained attached to the frame, but most of the glass was stripped from the film and landed to the exterior of the structure. One glass fragment impacted the witness panel in Region 4.

Test 1, Window 4
4.19 psi – 28.96 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
- Outer pane failed with fragments landing outside of structure. Inner pane film remained attached to frame, but some glass was stripped from the film and landed to the structure exterior. Light dusting of glass on sill. No impacts evident on witness panel.

TEST 2 SUMMARY

Date:	24 September 2003
Nominal Charge Weight, lb ANFO:	600
Standoff to each structure, ft:	170
Avg. Measured Peak Pressure, psi:	4.15
Avg. Measured Positive Impulse, psi-msec:	29.08
Time of Detonation:	3:47 pm
Ambient Temperature, deg F:	79

	Window 1	Window 2	Window 3	Window 4
Specimen Description	1/4" monolithic AG, mechanically attached 8-mil security film (2-sided batten bar attachment)[10]	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment) [10]	1/4" monolithic AG, mechanically attached 6-mil security film (2-sided batten bar attachment) [10]	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
Damage Description	Glazing left frame and fell just outside of structure. Batten bar attachment screws failed along left side[6], and film tore along right side[6] batten bar. Sides of frame deformed into window opening up to 1-3/4 inches.	Glazing left frame and landed 36 inches to the exterior of the structure. Film tore along both left and right batten bars. Sides of frame deformed into window opening up to 1-3/4 inches.	Glazing remained in window opening due to mechanical attachment of film, although the film tore along a significant length of the batten bars. Sides of frame deformed into window opening up to 2 inches.	Outer pane failed with fragments landing outside of structure. Inner pane remained attached to frame. Slight deformation at bottom of frame.
Window Glazing Response	Glazing landed outside of structure. Glass fragments landed inside of structure. One glass fragment impacted the witness panel in Region 5.	Glazing landed outside of structure. Glass fragments landed inside of structure. Two glass fragments impacted the witness panel in Region 4.	Film remained attached to the frame in just two small areas along the batten bars, but glazing did not fall. Two glass fragments impacted the witness panel in Region 4.	Inner pane cracked but remained intact. No fragments visible inside structure. No impacts evident on witness panel.
Hazard Level	High	Medium	Medium	None
Protection Level	Low	Medium	Medium	Very High
Performance Condition	5	4	4	2

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in commercial aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by “sandwiching” the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.
10) 2-sided mechanical attachments were connected along the jambs of the window frame.

Test 2, Window 1
4.15 psi – 29.08 psi-msec

- 1/4" monolithic AG, mechanically attached 8-mil security film (2-sided batten bar attachment)
- Glazing landed outside of structure. Glass fragments landed inside of structure. One glass fragment impacted the witness panel in Region 5.

Test 2, Window 2
4.15 psi – 29.08 psi-msec

- 1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)
- Glazing landed outside of structure. Glass fragments landed inside of structure. Two glass fragments impacted the witness panel in Region 4.


Pre-test


Post-test


Post-test

Test 2, Window 3
4.15 psi – 29.08 psi-msec

- 1/4" monolithic AG, mechanically attached 6-mil security film (2- sided batten bar attachment)
- Film remained attached to the frame in just two small areas along the batten bars, but glazing did not fall. Two glass fragments impacted the witness panel in Region 4.


Pre-test


Post-test


Post-test

Test 2, Window 4
4.15 psi – 29.08 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
- Inner pane cracked but remained intact. No fragments visible inside structure. No impacts evident on witness panel.

TEST 3 SUMMARY

Date:	25 September 2003
Nominal Charge Weight, lb ANFO:	600
Standoff to each structure, ft:	170
Avg. Measured Peak Pressure, psi:	4.23
Avg. Measured Positive Impulse, psi-msec:	29.88
Time of Detonation:	10:38 am
Ambient Temperature, deg F:	67

	Window 1	Window 2	Window 3	Window 4
Specimen Description	1/4" monolithic AG, mechanically attached 8-mil security film (4-sided batten bar attachment)	1/4" monolithic TTG, daylight applied 8-mil security film	1/4" monolithic AG, daylight applied 8-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 4-mil security film (4-sided batten bar attachment)
Damage Description	Glazing remained in frame. Bottom of frame deformed into window opening approximately 3-1/4 inches. Sides of frame deformed into window opening approximately 1-1/4 inches.	Glazing left frame and landed 96 inches to the exterior of the structure. Minor deformation at bottom of frame. No other visible frame deformation.	Glazing left frame and fell just outside of structure. Slight deformation at bottom of frame. No other visible frame deformation.	Outer pane failed with fragments landing outside of structure. Inner pane remained attached to frame. No visible frame deformation.
Window Glazing Response	Film remained attached to the frame, but some of the glass was stripped from the film and landed to the exterior of the structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Inner pane cracked but remained intact. No fragments visible inside structure. No impacts evident on witness panel.
Hazard Level	Low	Low	Low	None
Protection Level	High	High	High	Very High
Performance Condition	3b	3b	3b	2

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in commercial aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by “sandwiching” the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.
10) 2-sided mechanical attachments were connected along the jambs of the window frame.


Pre-test


Post-test


Post-test

Test 3, Window 1
4.23 psi – 29.88 psi-msec

- 1/4" monolithic AG, mechanically attached 8-mil security film (4-sided batten bar attachment)
- Film remained attached to frame, but some glass was stripped from the film and landed to the exterior of the structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.


Pre-test


Post-test


Post-test

Test 3, Window 2
4.23 psi – 29.88 psi-msec

- 1/4" monolithic TTG, daylight applied 8-mil security film
- Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.


Pre-test


Post-test

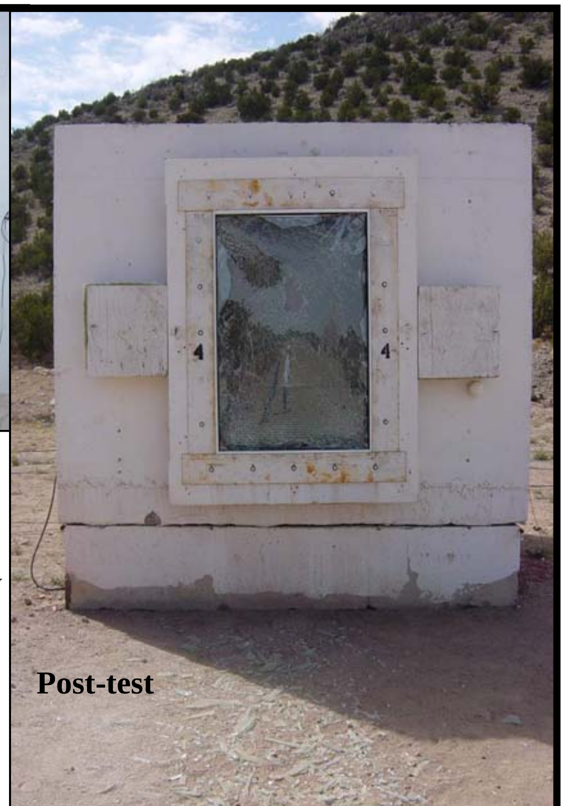

Post-test

Test 3, Window 3
4.23 psi – 29.88 psi-msec

- 1/4" monolithic AG, daylight applied 8-mil security film
- Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.


Pre-test


Post-test


Post-test

Test 3, Window 4
4.23 psi – 29.88 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 4-mil security film (4-sided batten bar attachment)
- Inner pane cracked but remained intact. No fragments visible inside structure. No impacts evident on witness panel.

TEST 4 SUMMARY

Date:	25 September 2003
Nominal Charge Weight, lb ANFO:	600
Standoff to each structure, ft:	170
Avg. Measured Peak Pressure, psi:	4.21
Avg. Measured Positive Impulse, psi-msec:	29.72
Time of Detonation:	1:30 pm
Ambient Temperature, deg F:	75

	Window 1	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 6-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 8-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 8-mil security film (4-sided batten bar attachment)
Damage Description	Outer pane failed with fragments landing outside of structure. Inner pane remained attached to frame. No visible frame deformation.	Outer pane failed with fragments landing outside of structure. Inner pane left the frame and fell just outside of structure. Minor deformation at bottom of frame. No other visible frame deformation.	Outer pane failed with fragments landing outside of structure. Top and bottom of inner pane pulled out of frame while the sides remained attached. Deformation occurred at bottom of frame. No other visible frame deformation.	Outer pane failed with fragments landing outside of structure. Inner pane did not leave frame, but small tears (approximately 8 to 11 inches in length) occurred in film at bottom corners. No visible frame deformation.
Window Glazing Response	Inner pane cracked but remained in frame. Light dusting of glass on sill. No impacts evident on witness panel.	Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Inner pane cracked but remained in frame and attached at the sides. One glass fragment impacted the witness panel in Region 4. Two glass fragments impacted the witness panel in Region 5.	Inner pane cracked but remained in frame. Fragments landed in 3a region inside of structure. No impacts evident on witness panel.
Hazard Level	None	Low	High	Very Low
Protection Level	Very High	High	Low	High
Performance Condition	2	3b	5	3a

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in commercial aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by “sandwiching” the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.
10) 2-sided mechanical attachments were connected along the jambs of the window frame.

Test 4, Window 1
4.21 psi – 29.72 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)
- Inner pane cracked but remained in frame. Light dusting of glass on sill. No impacts evident on witness panel.

Test 4, Window 2
4.21 psi – 29.72 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 6-mil security film
- Glazing landed outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

Test 4, Window 3
4.21 psi – 29.72 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 8-mil security film
- Inner pane cracked but remained in frame and attached at the sides. One glass fragment impacted the witness panel in Region 4. Two glass fragments impacted the witness panel in Region 5.

Test 4, Window 4
4.21 psi – 29.72 psi-msec

- 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 8-mil security film (4-sided batten bar attachment)
- Inner pane cracked but remained in frame. Fragments landed in 3a region inside of structure. No impacts evident on witness panel.

TEST 5 SUMMARY

Date:	25 September 2003
Nominal Charge Weight, lb ANFO:	600
Standoff to each structure, ft:	170
Avg. Measured Peak Pressure, psi:	4.21
Avg. Measured Positive Impulse, psi-msec:	30.07
Time of Detonation:	3:49 pm
Ambient Temperature, deg F:	77

	Window 1	Window 2	Window 3	Window 4
Specimen Description	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)[10]	1/4" monolithic TTG, mechanically attached 4-mil security film (4-sided batten bar attachment)	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
Damage Description	Film tore along entire left edge[6] and glazing folded into window opening, attached to frame only at the right edge[6]. Sides of frame deformed into window opening up to 1-1/2 inches.	Film tore throughout large center region of glazing with torn area falling to the exterior of the structure. Sides of frame deformed into window opening up to 1-1/2 inches.	Top, bottom, and right edge[6] of glazing pulled out of frame. Glazing attached to the frame only at left edge[6]. No visible frame deformation.	Glazing left frame and landed approximately 48 inches to the exterior of the structure. Sides of frame deformed into window opening up to 1 inches.
Window Glazing Response	Glazing hung half inside and half outside the structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Center area of glazing hung outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.	Glazing hung outside of structure. One glass fragment impacted the witness panel in Region 5.	Glazing landed outside of structure. One glass fragment impacted the witness panel in Region 4.
Hazard Level	Low	Low	High	Medium
Protection Level	High	High	Low	Medium
Performance Condition	3b	3b	5	4

Test Notes:
1) All window units had a 1/2 inch minimum bite.
2) Windows were mounted in commercial aluminum frames: clear opening = 46.00 inches x 64.00 inches.
3) AG = annealed glass, TTG = tempered glass.
4) Witness panels were located 120 inches behind window.
5) The test bed is situated at an altitude of 6200 ft above sea level.
6) Window edges (left and right) are based on a person standing to the exterior of the window looking inward.
7) All wet glazed systems contained 1/2 inch (glazing edge) x 3/4 inch (frame edge) silicone contact lengths.
8) 3M Ultraflex was used for all wet-glazed attachments.
9) Windows were mounted by “sandwiching” the frame between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame.
10) 2-sided mechanical attachments were connected along the jambs of the window frame.

Test 5, Window 1
4.21 psi – 30.07 psi-msec

- 1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)
- Glazing hung half inside and half outside the structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

Test 5, Window 2
4.21 psi – 30.07 psi-msec

- 1/4" monolithic TTG, mechanically attached 4-mil security film (4-sided batten bar attachment)
- Center area of glazing hung outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

Test 5, Window 3
4.21 psi – 30.07 psi-msec

- 1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
- Glazing hung outside of structure. One glass fragment impacted the witness panel in Region 5.

Test 5, Window 4
4.21 psi – 30.07 psi-msec

- 1/4" monolithic AG, wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
- Glazing landed outside of structure. One glass fragment impacted the witness panel in Region 4.

CONVERSION FACTORS
(NON-SI TO SI UNITS OF MEASUREMENT)

Non-SI units of measurement used in the report can be converted to SI units as follows:

Multiply:	**By:**	**To Obtain:**
degrees (deg)	0.01745329	radians (rad)
miles (U.S. statute)	1.609347	kilometers (km)
feet (ft)	0.3048	meters (m)
inches (in)	25.4	millimeters (mm)
mil	0.0254	millimeters (mm)
pounds (lb)	4.448222	newtons (N)
pounds (lb)	0.4535924	kilograms(kg)
kips per square inch (ksi)	6.894757	megapascals (mPa)
pounds per square inch (psi)	6894.757	pascals (N/m^2 or Pa)
pounds per square inch (psi)	6.894757	kilopascals (kPa)
pounds per square inch (psi)	0.006894757	megapascals (mPa)

TABLE OF CONTENTS

Chapter		Page
	PREFACE	ii
	EXECUTIVE SUMMARY	iii
	CONVERSION FACTORS	xxi
1	INTRODUCTION	1-1
	1.1 BACKGROUND	1-1
	1.2 OBJECTIVES	1-2
	1.3 ISC CRITERIA	1-2
2	TEST CONFIGURATION	2-1
	2.1 TEST RANGE	2-1
	2.2 TEST STRUCTURES AND TEST BED	2-1
	2.3 INSTRUMENTATION	2-2
	2.4 TEST CHARGE	2-2
	2.5 INSTALLATION DETAILS	2-3
	2.6 TEST MATRIX	2-3
3	TEST RESULTS	3-1
	3.1 TEST 1 RESULTS	3-1
	3.1.1 Window 1	3-2
	3.1.2 Window 2	3-2
	3.1.3 Window 3	3-2
	3.1.4 Window 4	3-3
	3.2 TEST 2 RESULTS	3-10
	3.2.1 Window 1	3-11
	3.2.2 Window 2	3-11
	3.2.3 Window 3	3-11
	3.2.4 Window 4	3-12
	3.3 TEST 3 RESULTS	3-19
	3.3.1 Window 1	3-20
	3.3.2 Window 2	3-20
	3.3.3 Window 3	3-20
	3.3.4 Window 4	3-21
	3.4 TEST 3 RESULTS	3-28
	3.4.1 Window 1	3-29
	3.4.2 Window 2	3-29
	3.4.3 Window 3	3-29
	3.4.4 Window 4	3-30

3.5 TEST 3 RESULTS 3-37
3.5.1 Window 1 3-38
3.5.2 Window 2 3-38
3.5.3 Window 3 3-38
3.5.4 Window 4 3-39

4 RESULTS SUMMARIES AND MAJOR FINDINGS 4-1

4.1 IMPLICATION OF RESULTS AND GSA SECURITY REQUIREMENTS 4-1
4.2 CONSOLIDATED RESULTS 4-2

Appendix

A GSA TEST METHOD A-1
B MEASURED PRESSURE DATA B-1
C FRAME AND GLAZING DETAILS C-1
D GLASS FRAGMENT DISTRIBUTION D-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 hazard 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.

3M Corporation commissioned ARA to perform a series of five high-explosive blast tests in order to evaluate the performance of window systems containing various security film thickness and film attachments configurations. 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) located in Socorro, New Mexico on September 24 and 25, 2003. The test procedure was designed in accordance with the procedure adopted by the GSA. The GSA test procedure is included in Appendix A. All five tests 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. All five tests were 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 3M Corporation's 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.

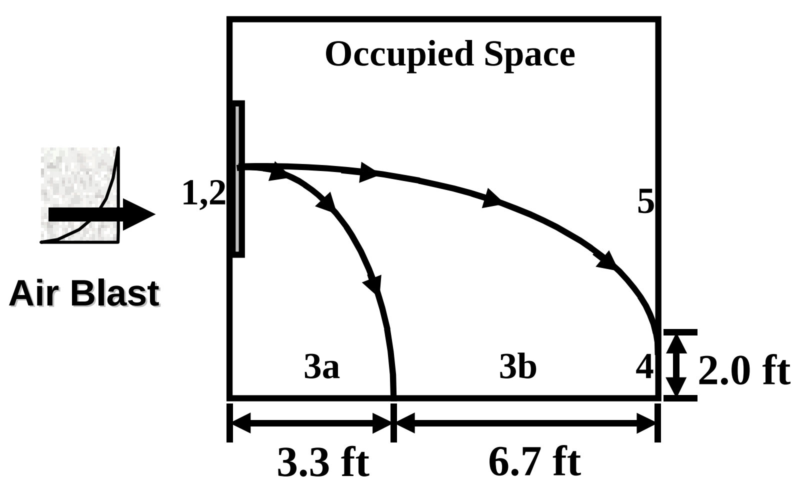


Figure 1-1 GSA window glazing hazard rating scheme.

Table 1.1 GSA/ISC glass hazard rating scheme.

Performance Condition	**Protection Level**	**Hazard Level**	**Description of Window Glazing Response**
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	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.
5	Low	High	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.

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 for all five tests was 170 ft. The maximum reflected pressure levels for tests 1, 2, 3, 4, and 5 were nominally 4.19 psi, 4.15 psi, 4.23 psi, 4.21 psi, and 4.21 psi respectively. 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 118-120 inches from the back of the windows in accordance with the GSA test method (criteria dictates $\leq$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 all five tests contained 600 lb of ammonium nitrate and fuel oil which is equivalent to 500 lb of TNT. The charge for each test was built in a 30-inch diameter cardboard Sonotube with three Pentalite boosters (total weight 2 lb) 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

All windows were tested in commercial aluminum frames. The frames were 2-inch by 4-1/2-inch storefront aluminum frames, with vision openings of nominally 46 inches by 64 inches. The aluminum frame windows had a 1/2" nominal bite. Windows were mounted by “sandwiching” the aluminum frames between steel plates (mounted to the outside of the window opening) and steel tubes (mounted to the inside of the window opening). The steel plates were mounted to the structure using 1/2 inch diameter bolts spaced at 12 inches on center while tube bolts were spaced at 6 inches on center. #10 self-tapping screws spaced at 12 inches on center connected the outer steel plates to the aluminum frame. Frame details are shown in Appendix C.

2.6 TEST MATRIX

A test matrix (Table 2.1) was designed by 3M Corporation in an attempt to get the most useful information from the number of specimens to be tested. All windows were tested in typical commercial aluminum frames. Glass configuration, glass type, film thickness and attachment were varied.

Table 2.1 Test article matrix.

Standoff /Measured Peak Pressure	Win. #	Test Articles
Test 1 standoff = 170 ft peak pressure = 4.19 psi	1	1/4" monolithic AG, wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)
	2	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
	3	1/4" monolithic AG, mechanically attached 4-mil security film (4-sided batten bar attachment)
	4	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
Test 2 standoff = 170 ft peak pressure = 4.15 psi	1	1/4" monolithic AG, mechanically attached 8-mil security film (2-sided batten bar attachment)
	2	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)
	3	1/4" monolithic AG, mechanically attached 6-mil security film (2- sided batten bar attachment)
	4	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
Test 3 standoff = 170 ft peak pressure = 4.23 psi	1	1/4" monolithic AG, mechanically attached 8-mil security film (4-sided batten bar attachment)
	2	1/4" monolithic TTG, daylight applied 8-mil security film
	3	1/4" monolithic AG, daylight applied 8-mil security film
	4	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 4-mil security film (4-sided batten bar attachment)

Table 2.2 (continued) Test article matrix.

Standoff /Measured Peak Pressure	**Win. #**	**Test Articles**
Test 4 standoff = 170 ft peak pressure = 4.21 psi	1	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)
	2	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 6-mil security film
	3	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 8-mil security film
	4	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 8-mil security film (4-sided batten bar attachment)
Test 5 standoff = 170 ft peak pressure = 4.21 psi	1	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)
	2	1/4" monolithic TTG, mechanically attached 4-mil security film (4-sided batten bar attachment)
	3	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
	4	1/4" monolithic AG, wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)

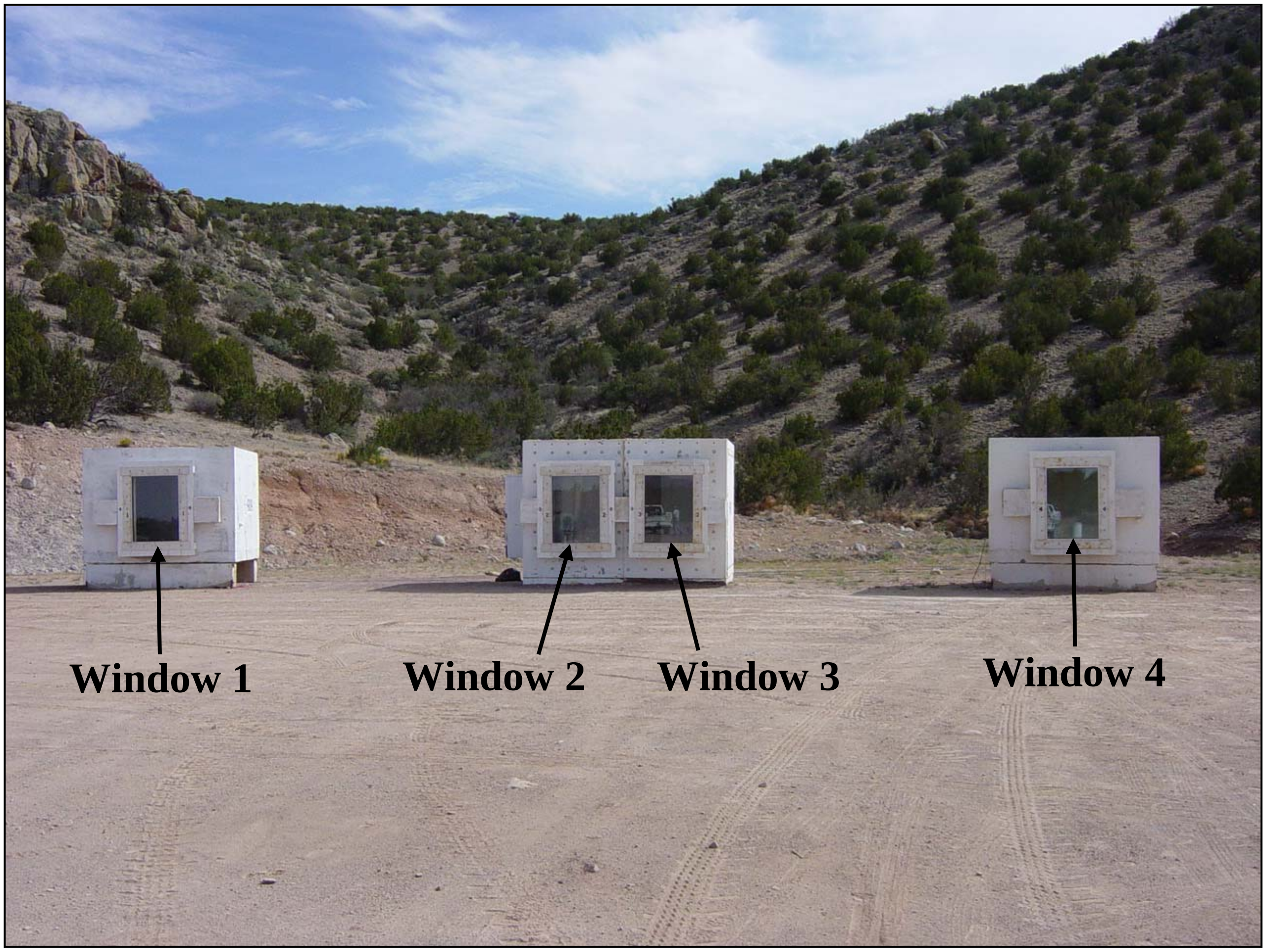


Figure 2-1 Structure orientation and window nomenclature.

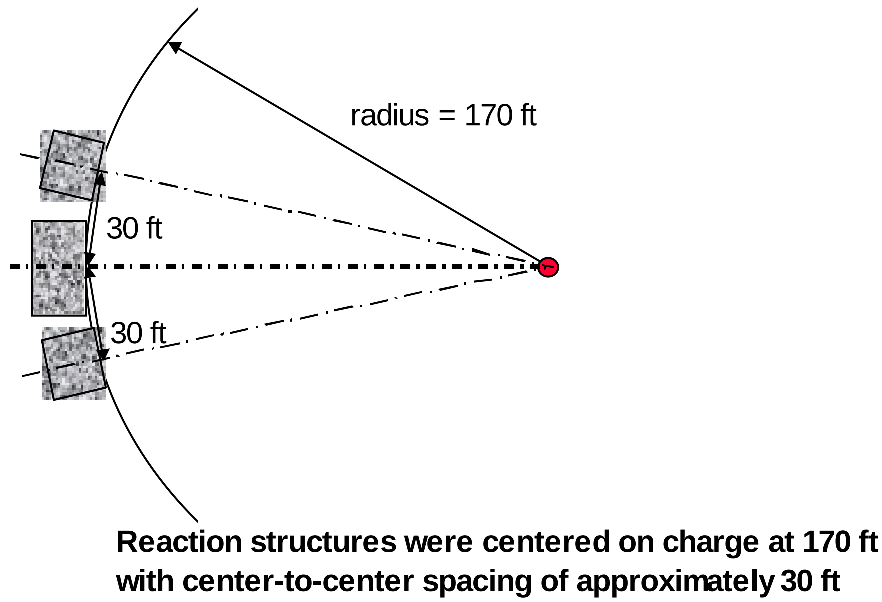


Figure 2-2 Radial orientation of structures (not drawn to scale).

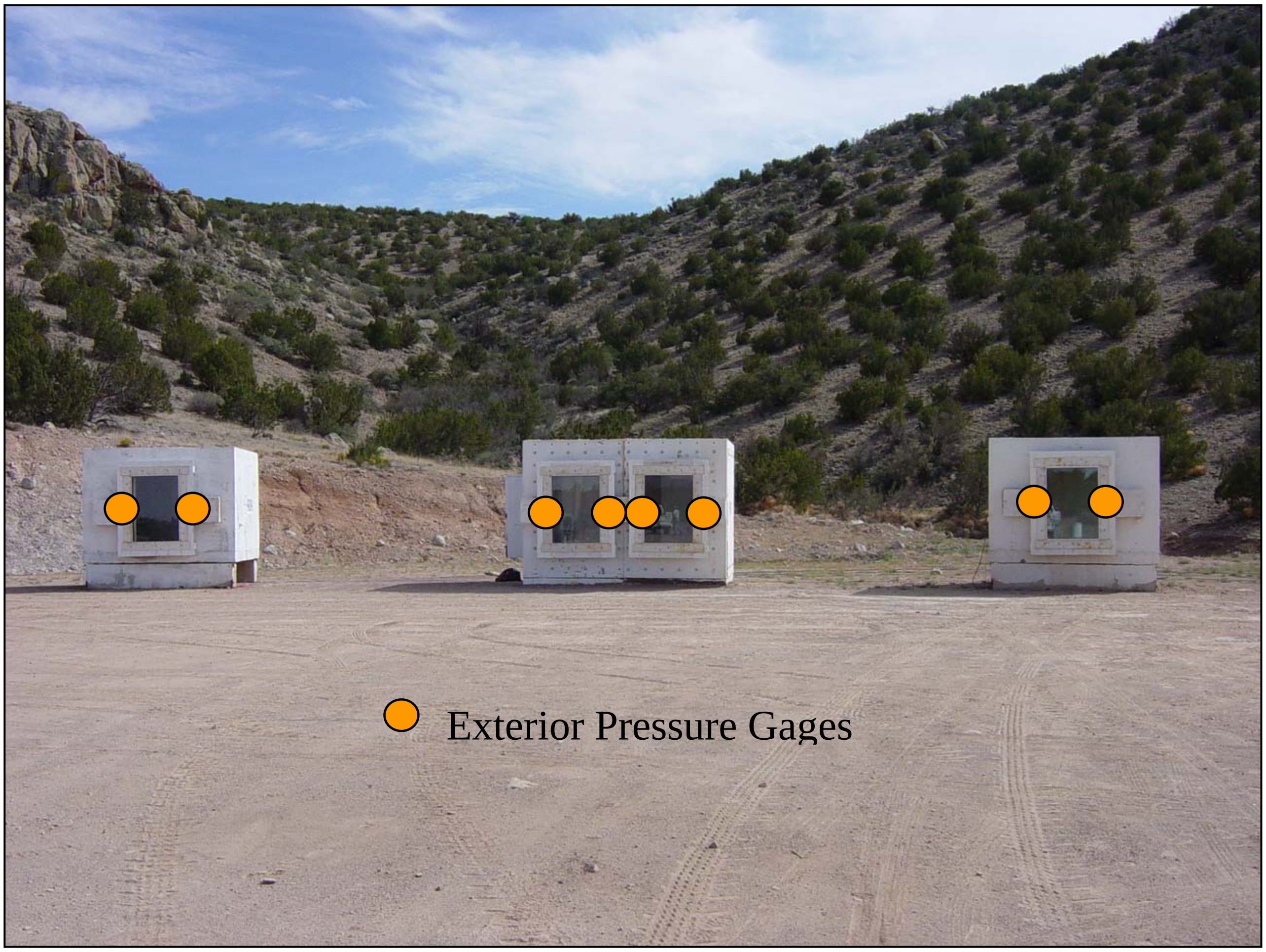


Figure 2-3 Exterior pressure gage locations.

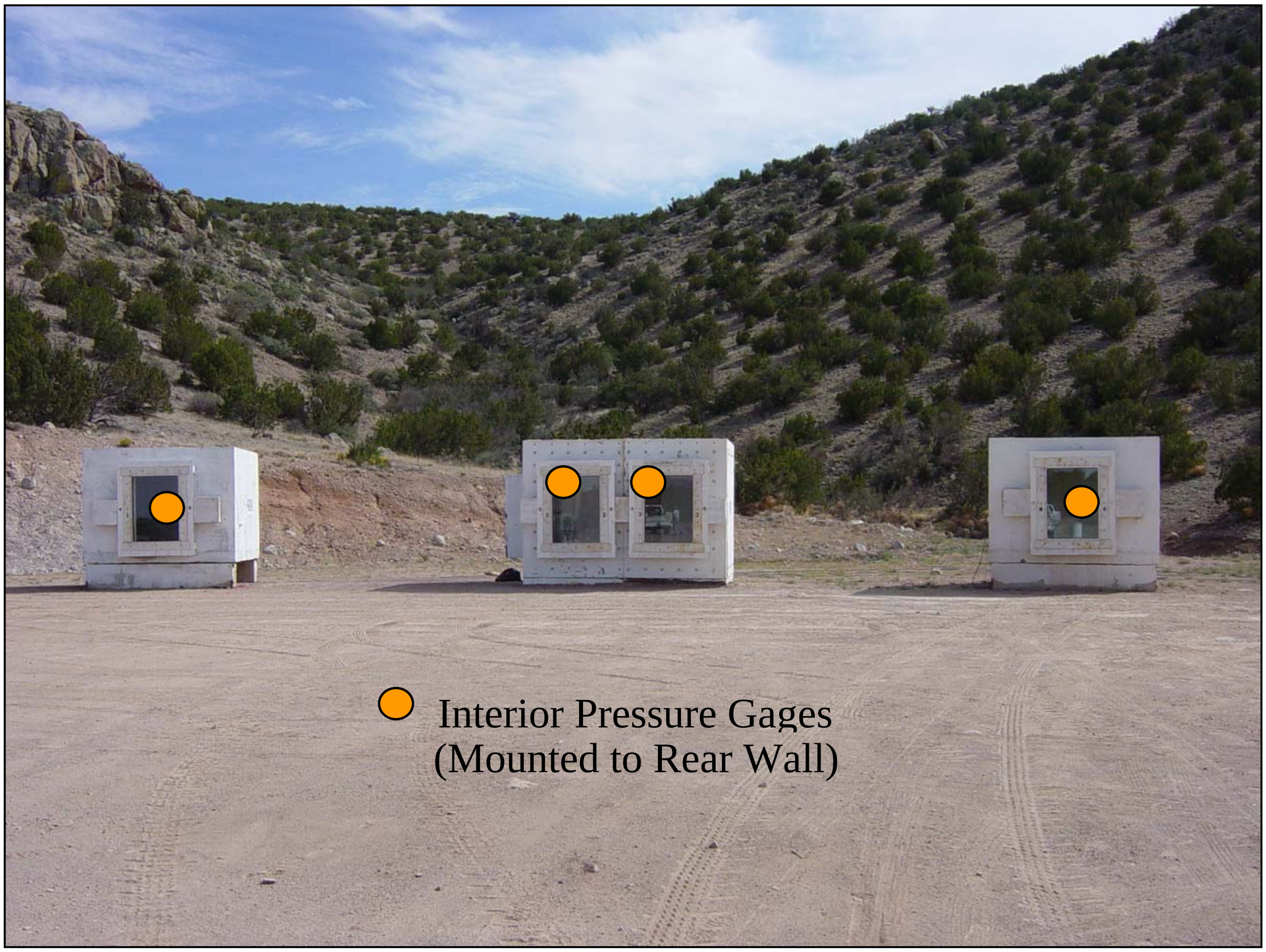


Figure 2-4 Interior pressure gage locations.

Figure 2-5 Camera locations.

CHAPTER 3
TEST RESULTS

3.1 TEST 1 RESULTS

The explosive was detonated on September 24, 2003 at 12:34 pm. The charge was located at a standoff of 170 ft from the structures for a pre-test nominal target pressure of 4.7 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.

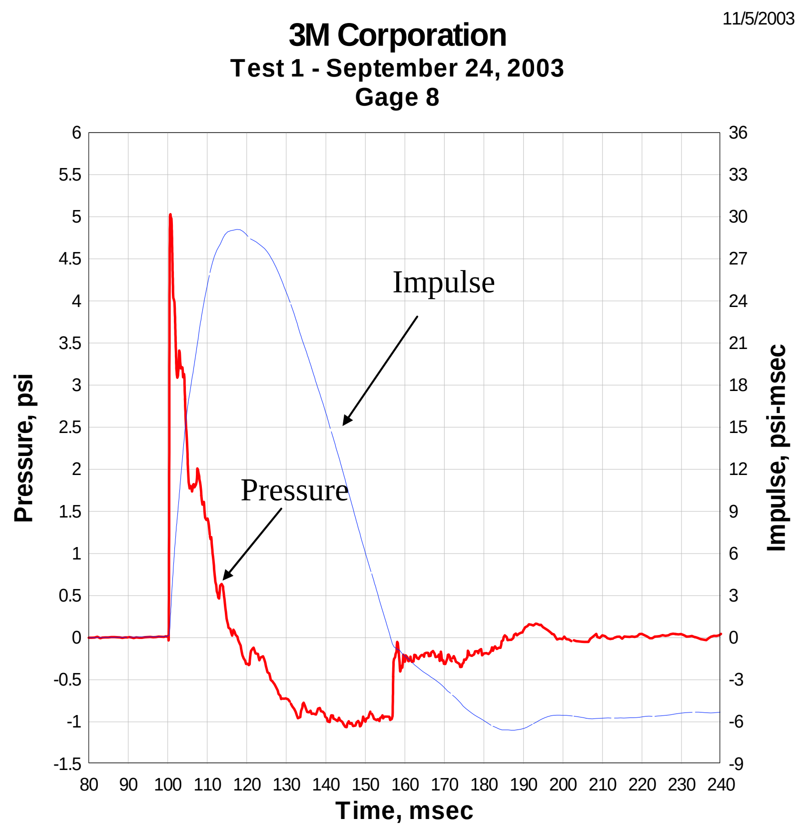


Figure 3-1 Typical airblast waveform from test 1.

Table 3.1 Average airblast values for test 1.

Structure	Avg. Peak Positive Pressure (psi)	Avg. Peak Positive Impulse (psi-msec)
1	4.15	27.48
2	4.18	28.73
3	4.34	32.63
Avg.	4.19	28.96

3.1.1 Window 1

Description: 1/4" monolithic AG, wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 3b

Glazing left frame and landed 90 inches to the exterior of the structure. Right side of frame deformed into window opening approximately 1 inch. Fragments landed in 3b region inside of structure. No impacts evident on witness panel. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo is included in Figure 3-2. Post-test photos are located in Figure 3-3 and Figure 3-4.

3.1.2 Window 2

Description: 1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 3b

Glazing left frame and landed 103 inches to the exterior of the structure. No visible frame deformation. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo is included in Figure 3-5. Post-test photos are located in Figure 3-6 and Figure 3-7.

3.1.3 Window 3

Description: 1/4" monolithic AG, mechanically attached 4-mil security film (4-sided batten bar attachment)

Rating: GSA Condition 4

Batten bar attachment screws failed along lower left side, and film tore in lower left hand corner. Bottom of frame deformed into window opening approximately 3 inches. Film remained attached to the frame, but most of the glass was stripped from the film and landed to the exterior of the structure. One glass fragment impacted the witness panel in Region 4. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo is included in Figure 3-8. Post-test photos are located in Figure 3-9 and Figure 3-10.

3.1.4 Window 4

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 2

Outer pane failed with fragments landing outside of structure. Inner pane film remained attached to the frame, but some of the glass was stripped from the film and landed to the exterior of the structure. Light dusting of glass on sill. No visible frame deformation. No impacts evident on witness panel.

A pre-test photo is included in Figure 3-11. Post-test photos are located in Figure 3-12 and Figure 3-13.

Figure 3-2 Exterior pre-test view of window 1. (DSC03991.jpg)

Figure 3-3 Exterior post-test view of window 1. (DSC04037.jpg)

Figure 3-4 Interior post-test view of window 1. (DSC04039.jpg)

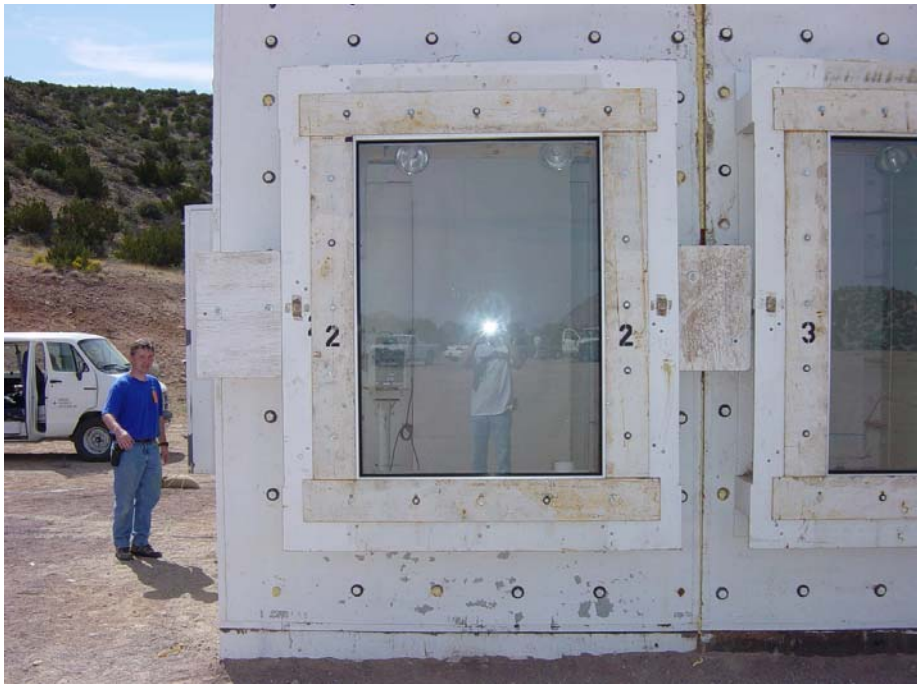


Figure 3-5 Exterior pre-test view of window 2. (DSC04001.jpg)

Figure 3-6 Exterior post-test view of window 2. (DSC04050.jpg)

Figure 3-7 Interior post-test view of window 2. (DSC04068.jpg)

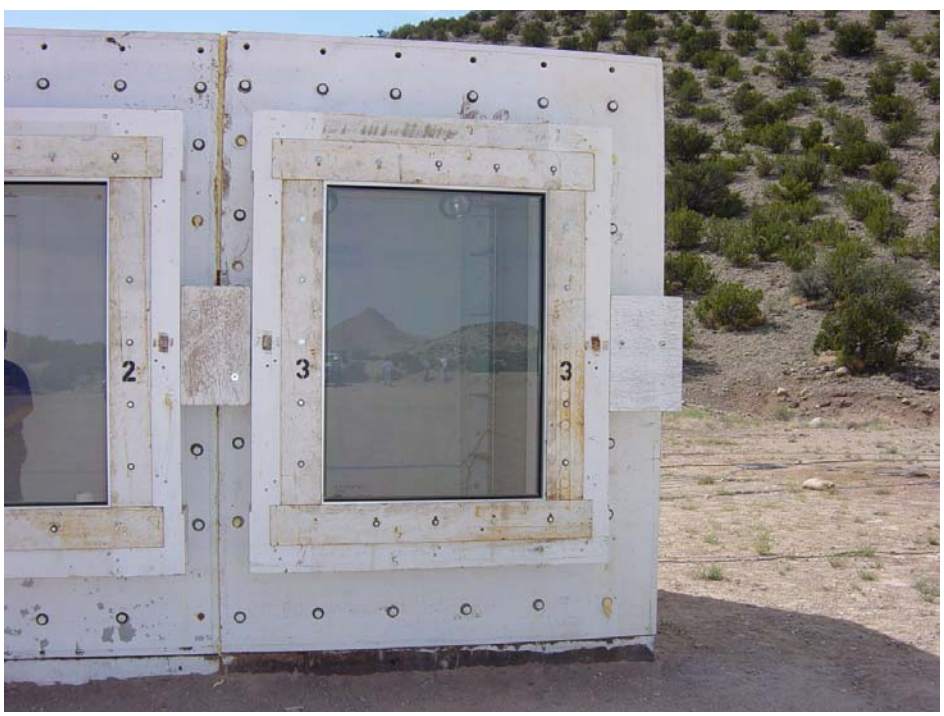


Figure 3-8 Exterior pre-test view of window 3. (DSC04003.jpg)


Figure 3-9 Exterior post-test view of window 3. (DSC04059.jpg)


Figure 3-10 Interior post-test view of window 3. (DSC04074.jpg)

Figure 3-11 Exterior pre-test view of window 4. (DSC04019.jpg)

Figure 3-12 Exterior post-test view of window 4. (DSC04084.jpg)

Figure 3-13 Interior post-test view of window 4. (DSC04092.jpg)

3.2 TEST 2 RESULTS

The explosive was detonated on September 24, 2003 at 3:47 pm. The charge was located at a standoff of 170 ft from the structures for a pre-test nominal target pressure of 4.7 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.

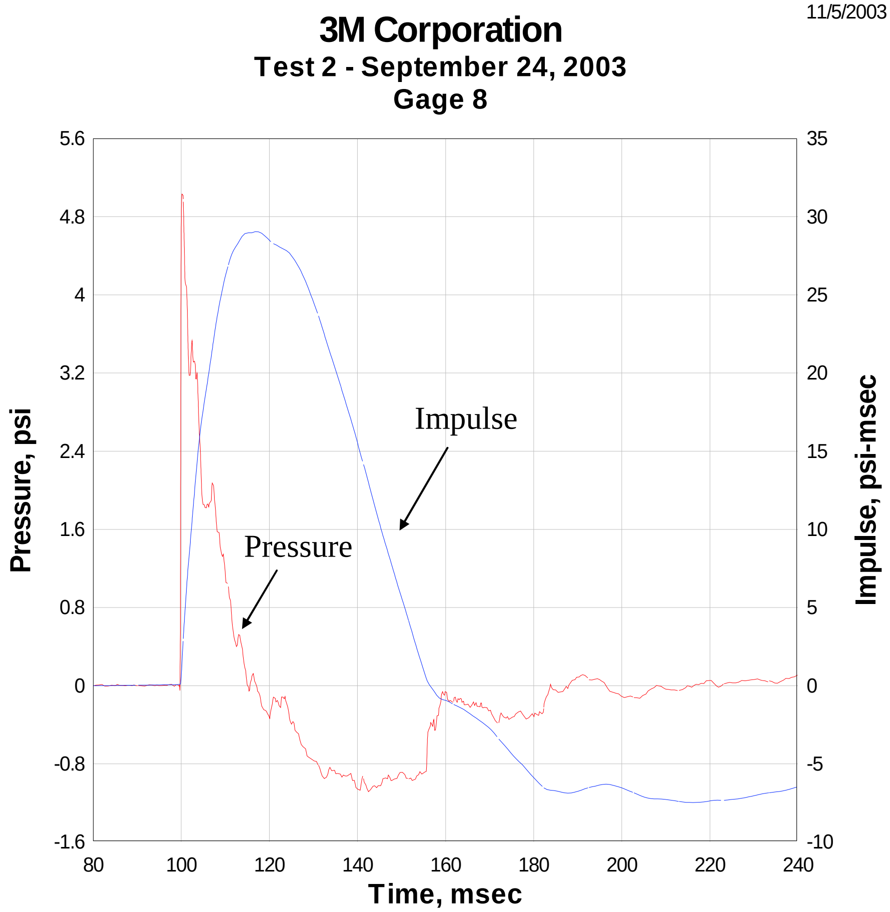


Figure 3-14 Typical airblast waveform from test 2.

Table 3.2 Average airblast values for test 2.

Structure	Avg. Peak Positive Pressure (psi)	Avg. Peak Positive Impulse (psi-msec)
1	4.18	28.97
2	4.17	28.87
3	4.00	29.91
Avg.	4.15	29.08

3.2.1 Window 1

Description: 1/4" monolithic AG, mechanically attached 8-mil security film (2-sided batten bar attachment)

Rating: GSA Condition 5

Glazing left frame and fell just outside of structure. Batten bar attachment screws failed along left side, and film tore along right side batten bar. Sides of frame deformed into window opening up to 1-3/4 inches. Glass fragments landed inside of structure. One glass fragment impacted the witness panel in Region 5. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo of window 1 is included in Figure 3-15. Figure 3-16 and Figure 3-17 contain post-test photos of the window.

3.2.2 Window 2

Description: 1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)

Rating: GSA Condition 4

Glazing left frame and landed 36 inches to the exterior of the structure. Film tore along both left and right batten bars. Sides of frame deformed into window opening up to 1-3/4 inches. Glass fragments landed inside of structure. Two glass fragments impacted the witness panel in Region 4. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo of window 2 is included in Figure 3-18. Figure 3-19 and Figure 3-20 contain post-test photos of the window.

3.2.3 Window 3

Description: 1/4" monolithic AG, mechanically attached 6-mil security film (2- sided batten bar attachment)

Rating: GSA Condition 4

Glazing remained in window opening due to mechanical attachment of film, although the film tore along a significant length of the batten bars. Sides of frame deformed into window opening up to 2 inches. Film remained attached to the frame in just two small areas along the batten bars, but glazing did not fall out of frame. Two glass fragments impacted the witness panel in Region 4.

A pre-test photo of window 3 is included in Figure 3-21. Figure 3-22 and Figure 3-23 contain post-test photos of the window.

3.2.4 Window 4

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 2

Outer pane failed with fragments landing outside of structure. Inner pane cracked but remained attached to frame. No fragments visible inside structure. Slight deformation at bottom of frame. No impacts evident on witness panel.

A pre-test photo of window 4 is included in Figure 3-24. Figure 3-25 and Figure 3-26 contain post-test photos of the window.

Figure 3-15 Exterior pre-test view of window 1. (DSC04110.jpg)

Figure 3-16 Exterior post-test view of window 1. (DSC04159.jpg)

Figure 3-17 Interior post-test view of window 1. (DSC04168.jpg)

Figure 3-18 Exterior pre-test view of window 2. (DSC04120.jpg)

Figure 3-19 Exterior post-test view of window 2. (DSC04178.jpg)

Figure 3-20 Interior post-test view of window 2. (DSC04189.jpg)

Figure 3-21 Exterior pre-test view of window 3. (DSC04124.jpg)

Figure 3-22 Exterior post-test view of window 3. (DSC04162.jpg)

Figure 3-23 Interior post-test view of window 3. (DSC04198.jpg)

Figure 3-24 Exterior pre-test view of window 4. (DSC04141.jpg)

Figure 3-25 Exterior post-test view of window 4. (DSC04214.jpg)

Figure 3-26 Interior post-test view of window 4. (DSC04217.jpg)

3.3 TEST 3 RESULTS

The explosive was detonated on September 25, 2003 at 10:38 am. The charge was located at a standoff of 170 ft from the structures for a pre-test nominal target pressure of 4.7 psi. A typical airblast waveform is shown in Figure 3-27, and the average airblast values from the exterior gages are given in Table 3.3. Statistical was performed on the test data and is included in Appendix B.

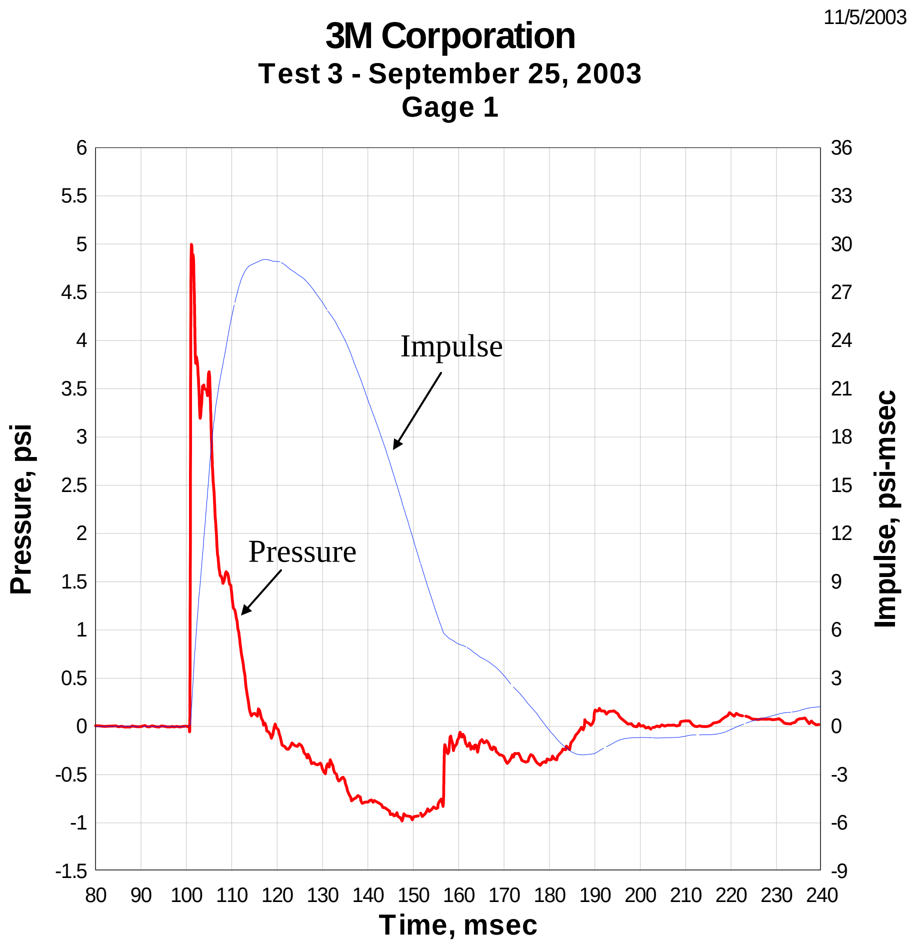


Figure 3-27 Typical airblast waveform from test 3.

Table 3.3 Average airblast values for test 3.

Structure	Avg. Peak Positive Pressure (psi)	Avg. Peak Positive Impulse (psi-msec)
1	4.17	28.43
2	4.30	30.21
3	4.13	30.66
Avg.	4.23	29.88

3.3.1 Window 1

Description: 1/4" monolithic AG, mechanically attached 8-mil security film (4-sided batten bar attachment)

Rating: GSA Condition 3b

Glazing remained in frame. Bottom of frame deformed into window opening approximately 3-1/4 inches. Sides of frame deformed into window opening approximately 1-1/4 inches. Film remained attached to the frame, but some of the glass was stripped from the film and landed to the exterior of the structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo of window 1 is included in Figure 3-28. Figure 3-29 and Figure 3-30 contain post-test photos of the window.

3.3.2 Window 2

Description: 1/4" monolithic TTG, daylight applied 8-mil security film

Rating: GSA Condition 3b

Glazing left frame and landed 96 inches to the exterior of the structure. Minor deformation at bottom of frame. No other visible frame deformation. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo of window 2 is included in Figure 3-31. Figure 3-32 and Figure 3-33 contain post-test photos of the window.

3.3.3 Window 3

Description: 1/4" monolithic AG, daylight applied 8-mil security film

Rating: GSA Condition 3b

Glazing left frame and fell just outside of structure. Slight deformation at bottom of frame. No other visible frame deformation. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo of window 3 is included in Figure 3-34. Figure 3-35 and Figure 3-36 contain post-test photos of the window.

3.3.4 Window 4

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 4-mil security film (4-sided batten bar attachment)

Rating: GSA Condition 2

Outer pane failed with fragments landing outside of structure. No visible frame deformation. Inner pane cracked but remained attached to frame. No fragments visible inside structure. No impacts evident on witness panel.

A pre-test photo of window 4 is included in Figure 3-37. Figure 3-38 and Figure 3-39 contain post-test photos of the window.

Figure 3-28 Exterior pre-test view of window 1. (DSC04237.jpg)

Figure 3-29 Exterior post-test view of window 1. (DSC4280.jpg)

Figure 3-30 Interior post-test view of window 1. (DSC04288.jpg)

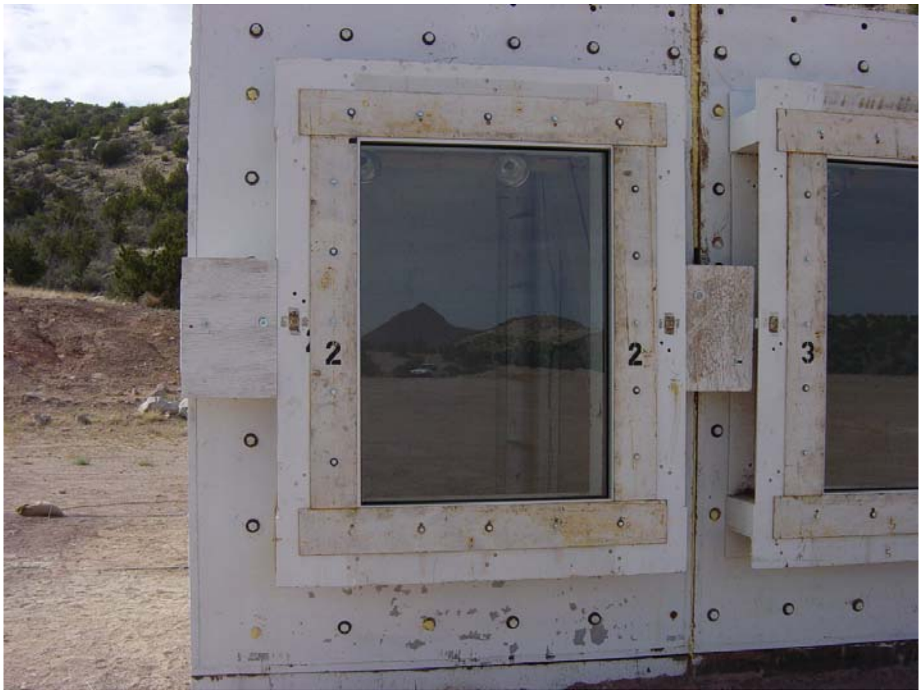


Figure 3-31 Exterior pre-test view of window 2. (DSC04248.jpg)

Figure 3-32 Exterior post-test view of window 2. (DSC04292.jpg)

Figure 3-33 Interior post-test view of window 2. (DSC04304.jpg)

Figure 3-34 Exterior pre-test view of window 3. (DSC04249.jpg)

Figure 3-35 Exterior post-test view of window 3. (DSC04297.jpg)

Figure 3-36 Interior post-test view of window 3. (DSC04318.jpg)

Figure 3-37 Exterior pre-test view of window 4. (DSC04251.jpg)

Figure 3-38 Exterior post-test view of window 4. (DSC04330.jpg)

Figure 3-39 Interior post-test view of window 4. (DSC04341.jpg)

3.4 TEST 4 RESULTS

The explosive was detonated on September 25, 2003 at 1:30 pm. The charge was located at a standoff of 170 ft from the structures for a pre-test nominal target pressure of 4.7 psi. A typical airblast waveform is shown in Figure 3-40, 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.

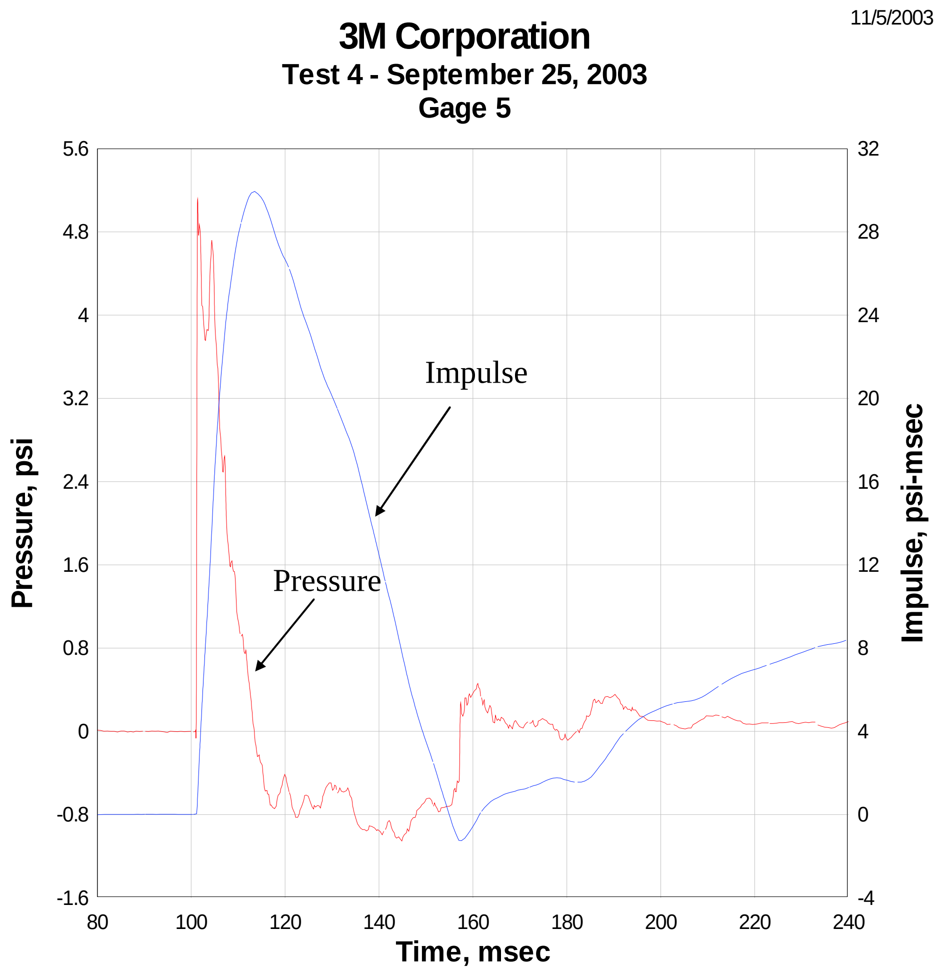


Figure 3-40 Typical airblast waveform from test 4.

Table 3.4 Average airblast values for test 4.

Structure	Avg. Peak Positive Pressure (psi)	Avg. Peak Positive Impulse (psi-msec)
1	4.33	29.50
2	4.29	30.01
3	3.94	29.34
Avg.	4.21	29.72

3.4.1 Window 1

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 2

Outer pane failed with fragments landing outside of structure. No visible frame deformation. Inner pane cracked but remained in frame. Light dusting of glass on sill. No impacts evident on witness panel.

A pre-test photo is included in Figure 3-41. Post-test photos are located in Figure 3-42 and Figure 3-43.

3.4.2 Window 2

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 6-mil security film

Rating: GSA Condition 3b

Outer pane failed with fragments landing outside of structure. Inner pane left the frame and fell just outside of structure. Minor deformation at bottom of frame. No other visible frame deformation. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo is included in Figure 3-44. Post-test photos are located in Figure 3-45 and Figure 3-46.

3.4.3 Window 3

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 8-mil security film

Rating: GSA Condition 5

Outer pane failed with fragments landing outside of structure. Top and bottom of inner pane pulled out of frame while the sides remained attached. Deformation occurred at bottom of frame. No other visible frame deformation. One glass fragment impacted the witness panel in Region 4. Two glass fragments impacted the witness panel in Region 5.

A pre-test photo is included in Figure 3-47. Post-test photos are located in Figure 3-48 and Figure 3-49.

3.4.4 Window 4

Description: 1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 8-mil security film (4-sided batten bar attachment)

Rating: GSA Condition 3a

Outer pane failed with fragments landing outside of structure. Inner pane did not leave frame, but small tears (approximately 8 to 11 inches in length) occurred in film at bottom corners. No visible frame deformation. Inner pane cracked but remained in frame. Fragments landed in 3a region inside of structure. No impacts evident on witness panel.

A pre-test photo is included in Figure 3-50. Post-test photos are located in Figure 3-51 and Figure 3-52.

Figure 3-41 Exterior pre-test view of window 1. (IMG_3604.jpg)

Figure 3-42 Exterior post-test view of window 1. (DSC04350.jpg)

Figure 3-43 Interior post-test view of window 1. (DSC04355.jpg)

Figure 3-44 Exterior pre-test view of window 2. (IMG_3612.jpg)

Figure 3-45 Exterior post-test view of window 2. (DSC04364.jpg)

Figure 3-46 Interior post-test view of window 2. (DSC04383.jpg)

Figure 3-47 Exterior pre-test view of window 3. (IMG_3613.jpg)

Figure 3-48 Exterior post-test view of window 3. (DSC04367.jpg)

Figure 3-49 Interior post-test view of window 3. (DSC04395.jpg)

Figure 3-50 Exterior pre-test view of window 4. (IMG_3625.jpg)

Figure 3-51 Exterior post-test view of window 4. (DSC04413.jpg)

Figure 3-52 Interior post-test view of window 4. (DSC04432.jpg)

3.5 TEST 5 RESULTS

The explosive was detonated on September 25, 2003 at 3:49 pm. The charge was located at a standoff of 170 ft from the structures for a pre-test nominal target pressure of 4.7 psi. A typical airblast waveform is shown in Figure 3-53, 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.

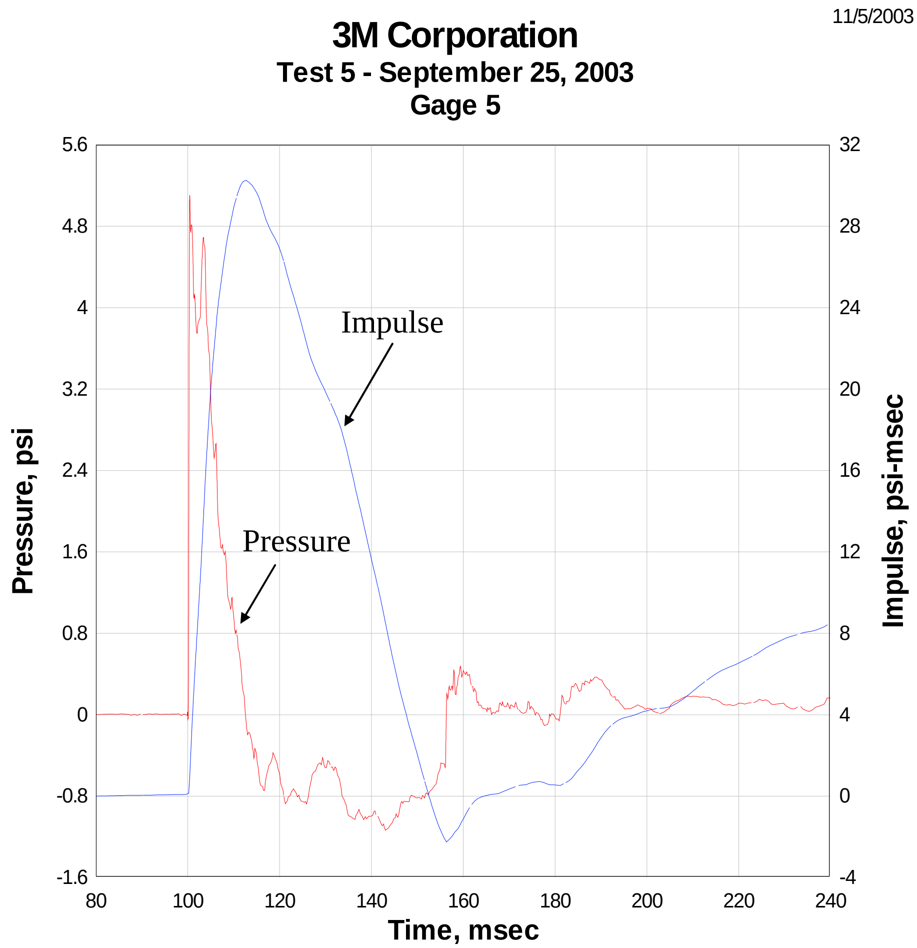


Figure 3-53 Typical airblast waveform from test 5.

Table 3.5 Average airblast values for test 5.

Structure	Avg. Peak Positive Pressure (psi)	Avg. Peak Positive Impulse (psi-msec)
1	4.38	29.71
2	4.19	29.83
3	4.09	30.92
Avg.	4.21	30.07

3.5.1 Window 1

Description: 1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)

Rating: GSA Condition 3b

Film tore along entire left edge and glazing folded inward in window opening, attached to frame only at the right edge. Sides of frame deformed into window opening up to 1-1/2 inches. Fragments landed in 3b region inside of structure. No impacts evident on witness panel. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo of window 1 is included in Figure 3-54. Figure 3-55 and Figure 3-56 contain post-test photos of the window.

3.5.2 Window 2

Description: 1/4" monolithic TTG, mechanically attached 4-mil security film (4-sided batten bar attachment)

Rating: GSA Condition 3b

Film tore throughout large center region of glazing with torn area falling to the exterior of the structure. Sides of frame deformed into window opening up to 1-1/2 inches. Center area of glazing hung outside of structure. Fragments landed in 3b region inside of structure. No impacts evident on witness panel.

A pre-test photo of window 2 is included in Figure 3-57. Figure 3-58 and Figure 3-59 contain post-test photos of the window.

3.5.3 Window 3

Description: 1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 5

Top, bottom, and right edge of glazing pulled out of frame. Glazing remained attached to the frame only at along the left jamb. No visible frame deformation. One glass fragment impacted the witness panel in Region 5. Window edges (left and right) are based on a person standing to the exterior of the window looking inward.

A pre-test photo of window 3 is included in Figure 3-60. Figure 3-61 and Figure 3-62 contain post-test photos of the window.

3.5.4 Window 4

Description: 1/4" monolithic AG, wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)

Rating: GSA Condition 4

Glazing left frame and landed approximately 48 inches to the exterior of the structure. Sides of frame deformed into window opening up to 1 inches. One glass fragment impacted the witness panel in Region 4.

A pre-test photo of window 4 is included in Figure 3-63. Figure 3-64 and Figure 3-26 contain post-test photos of the window.

Figure 3-54 Exterior pre-test view of window 1. (DSC04446.jpg)

Figure 3-55 Exterior post-test view of window 1. (DSC04508.jpg)

Figure 3-56 Interior post-test view of window 1. (DSC04517.jpg)

Figure 3-57 Exterior pre-test view of window 2. (DSC04456.jpg)

Figure 3-58 Exterior post-test view of window 2. (DSC04497.jpg)

Figure 3-59 Interior post-test view of window 2. (DSC04533.jpg)

Figure 3-60 Exterior pre-test view of window 3. (DSC04460.jpg)

Figure 3-61 Exterior post-test view of window 3. (DSC04493.jpg)

Figure 3-62 Interior post-test view of window 3. (DSC04546.jpg)

Figure 3-63 Exterior pre-test view of window 4. (DSC04478.jpg)

Figure 3-64 Exterior post-test view of window 4. (DSC04558.jpg)

Figure 3-65 Interior post-test view of window 4. (DSC04567.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.

Government agencies outside of the GSA may require reporting of fragment weight distribution within the test structure. The post-test weight distribution of glass fragments inside of the test structure for each window tested is included in Appendix D.

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 nominal average impulses generated during tests 1 through 5 ranged from 29.0 to 30.1 psi-msec with average peak pressures of approximately 4.2 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.

	Summary			
Test Article	**Window 1**	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4" monolithic AG, wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, mechanically attached 4-mil security film (4-sided batten bar attachment)	1/4" AG (outer), 1/2" air gap, 1/4" AG (inner), wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)
Pressure	4.15	4.23	4.06	4.34
Impulse	27.48	28.55	29.09	32.63
GSA Performance Condition	3b	3b	4	2

Table 4.2 Summary of results for Test 2.

	Summary			
Test Article	**Window 1**	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4" monolithic AG, mechanically attached 8-mil security film (2-sided batten bar attachment)	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)	1/4" monolithic AG, mechanically attached 6-mil security film (2-sided batten bar attachment)	1/4" AG (outer), 1/2" air gap, 1/4" AG (inner), wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
Pressure	4.18	4.21	4.09	4.00
Impulse	28.97	28.77	29.06	29.91
GSA Performance Condition	5	4	4	2

Table 4.3 Summary of results for Test 3.

	Summary			
Test Article	**Window 1**	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4" monolithic AG, mechanically attached 8-mil security film (4-sided batten bar attachment)	1/4" monolithic TTG, daylight applied 8-mil security film	1/4" monolithic AG, daylight applied 8-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 4-mil security film (4-sided batten bar attachment)
Pressure	4.17	4.46	4.15	4.13
Impulse	28.43	29.86	30.56	30.66
GSA Performance Condition	3b	3b	3b	2

Table 4.4 Summary of results for Test 4.

	Summary			
Test Article	**Window 1**	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), wet-glazed 8-mil security film (4-sided attachment – 3M Ultraflex)	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 6-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), daylight applied 8-mil security film	1/4” AG (outer), 1/2” air gap, 1/4" AG (inner), mechanically attached 8-mil security film (4-sided batten bar attachment)
Pressure	4.33	4.42	4.16	3.94
Impulse	29.50	29.55	30.48	29.34
GSA Performance Condition	2	3b	5	3a

Table 4.5 Summary of results for Test 5.

	Summary			
Test Article	**Window 1**	**Window 2**	**Window 3**	**Window 4**
Specimen Description	1/4" monolithic AG, mechanically attached 4-mil security film (2-sided batten bar attachment)	1/4" monolithic TTG, mechanically attached 4-mil security film (4-sided batten bar attachment)	1/4" monolithic AG, wet-glazed 4-mil security film (4-sided attachment – 3M Ultraflex)	1/4" monolithic AG, wet-glazed 6-mil security film (4-sided attachment – 3M Ultraflex)
Pressure	4.38	4.41	3.97	4.09
Impulse	29.71	30.12	29.54	30.92
GSA Performance Condition	3b	3b	5	4

APPENDIX A

GSA TEST METHOD

US General Services Administration Standard Test Method for Glazing and Window Systems Subject to Dynamic Overpressure Loadings

1. Introduction

This test standard is intended to ensure an adequate measure of standardization and quality assurance in the testing of window systems including but not limited to glazing, sealants, seats and seals, frames, anchorages and all attachments and/or secondary catcher or restraint mechanisms designed to mitigate the hazards from flying glass and debris. This standard is the sole test protocol by which blast resistant windows and related hazard mitigation technology and products shall be evaluated for facilities under the control and responsibility of the US General Services Administration (GSA).[1]

2. Standard Designation

GSA Test Protocol: GSA-TS01-2003
Issue Date: January 1, 2003
Distribution: There are no publication or distribution restrictions for this standard.

3. References

a. "GSA Security Criteria, Final Working Version", Building Technologies Division, Office of Property Development, Public Buildings Service, General Services Administration, October 8, 1997, For Official Use Only.

b. "ISC Security Design Criteria for New Federal Office Buildings and Major Renovation Projects", The Interagency Security Committee (ISC), May 28, 2001, For Official Use Only.

4. Terms and Definitions

The following terms and definitions are provided to facilitate the implementation of this test standard.

ANFO – A mixture of Ammonium Nitrate and Fuel Oil designed to produce explosive effects.

Annealed Glass (AG) – This is the most common glass type that is used in construction. It is also the weakest glass type and fails in large hazardous dagger-like fragments.

Bite – The depth of glass or glazing that is captured in the window frame.

Explosive – Any substance or device, which will produce upon release of its potential energy, a sudden outburst of energy thereby exerting high pressures on its surroundings.

Fully Thermally Tempered Glass (TTG) – This glass type has about four times the compressive strength of regular annealed glass. TTG is the same glass used by car manufacturers for side windows in automobiles. It is often called safety glass. The fully thermally tempered glass tends to dice into small cube like pieces upon failure.

GSA Building Security Technology Program – GSA's Office of the Chief Architect has conducted research and developed technology in order to produce the tools and methodologies required to implement blast hazard mitigation in open, public facilities. The technology transfer web site www.oca.gsa.gov presents the major products and findings of this program.

[1] Tests performed prior to January 1, 2003 that used the previous GSA test protocol, "US General Services Administration (GSA) Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings," shall be accepted as having fully complied with all requirements of this standard.

Heat Strengthened Glass (HSG) – This glass type is partially tempered. It has approximately twice the compressive strength of typical annealed glass. Like AG, HSG fails in large, dangerous shards.

Incident Pressure – The overpressure (i.e., pressure above ambient) produced by an explosion in the absence of a structure or other object. Units are typically psi.

Impulse – The area under a pressure-time waveform. Units are typically psi-msec.

Interlayer – Any material used to bond two lites of glass and/or other glazing material together to form a laminate. For annealed glass the interlayer is normally a 0.030 in. thick polyvinyl butyral (PVB). For thermally tempered glass the interlayer is normally a 0.060 in. thick PVB. Some applications use a thicker interlayer (0.090 in. and 0.120 in. are sometimes used in special applications).

Laminated Glass – Two or more plies of glass bonded together by interlayer(s). When broken, the interlayer tends to retain the glass fragments.

Lexan – Lexan® is GE's product name for polycarbonate.

Lite – Another term for a pane of glass.

mil – Unit of measure commonly used for reporting laminate interlayer or security window film thickness. 1 mil = 1/1000th of 1 inch.

Monolithic Glass – A single sheet of glass without any laminations.

Plastic Explosive – Any of a series of plastic demolition explosives with great shattering power. These normally typically contain a high percentage of a high explosive such as RDX combined with a mixture of various oils, waxes, and plasticizers. Upon manipulation these materials consolidate into a rubbery fully plasticized mass that may be kneaded and pressed into any shape. Plastic explosives have excellent mechanical and adhesive properties, and may be stretched into long strands without breakage.

Polycarbonate – Any of a family of thermoplastics marked by a high softening temperature and high impact strength. Polycarbonate is extensively used in ballistic resistant window applications.

Primary Fragments – Fragments produced directly from the contents or casing of an explosive device.

Quasi-static Pressure – The late-time pressure produced in an internal detonation. It consists of slowly decaying shocks as well as gas pressures. The duration of the quasi-static pressure depends upon the vented area relative to the volume of the space affected. Units are typically psi.

Reflected Pressure – Pressure pulse generated when a shock front impinges onto an unyielding surface. Units are typically psi.

SDOF – Single-degree-of-freedom (SDOF) systems are commonly used for the analysis of windows under blast-induced loads. Using this approach for dynamic analysis, a given structure or window component is reduced to an "equivalent" SDOF system and its dynamic deflections can be determined. Deflections determined from the SDOF system will be equivalent to the deflection of a specified point in the real structure or structural element. With the deflections known, basic structural analysis principles can then be used to proceed with the analysis and/or design. More sophisticated methods such as multi-degree-of-freedom (MDOF) or finite element methods may be required or preferred in some cases.

Setback – The distance between where a bomb is allowed and the target.

Secondary Fragments – Fragments produced by an explosive device that are made up of the target materials or other materials other than those directly resulting from the device itself.

Security Window Film – A thin material, usually a polyester composite, that is applied to a glass surface for the purpose of controlling failure. Security window film, in the context of mitigating hazards from blast, is normally 7-mil (7/1000 in.) thick or thicker. Some manufacturers have special multi-layered products in the 4-mil thickness range that possess properties approaching that of normal 7-mil products. These films are normally applied to the interior surface of the glass. Security window film may be optically clear, tinted, or reflective. They may be daylight, edge-to-edge, wet glazed or mechanically attached to the window frame. Mechanical attachment normally provides the higher levels of protection.

Shock Front – A shock wave is a wave formed of a zone of extremely high pressure within a fluid, especially one such as the atmosphere that propagates through the fluid at supersonic speed, i.e., faster than the speed of sound. Shock waves are caused by the sudden, violent disturbance of a fluid, such as that created by a powerful explosion or by the supersonic flow of a fluid over a solid object. The rapid expansion of hot gases resulting from detonation of an explosive charge will form a shock wave. The leading edge of the shock wave is commonly referred to as the shock front.

Standoff – Standoff is synonymous with setback and may be used interchangeably with the term setback.

Thermally Tempered Glass – See Fully Thermally Tempered Glass.

TNT – Trinitrotoluene (TNT), a pale yellow, solid organic nitrogen compound used chiefly as an explosive, prepared by stepwise nitration of toluene. Because TNT melts at 82º C (178º F) and does not explode below 240º C (464º F), it can be melted in steam-heated vessels and poured into casings. It is relatively insensitive to shock and cannot be exploded without a detonator. For these reasons, it is one of the most favored chemical explosives and is extensively used in munitions and for demolitions.

WINGARD – WINdow Glazing Analysis Response and Design is a computer program available from the US General Services Administration (www.oca.gsa.gov). This program is the GSA and ISC standard for the analysis and design of windows subjected to blast loads.

WINLAC – WINdow Lite Analysis Code is a computer program available from the US Department of State. Versions 4.0 and later are derivative versions of the GSA code ***WINGARD*** adapted to meet the unique requirements of the US Department of State.

5. Performance Criteria

This test method uses the ISC Security Design Criteria (Reference 3.b.) to rate the performance of window systems subjected to airblast loads. Protection and related hazard levels are categorized as a performance condition as indicated in Table 1 and Figure 1. These conditions are determined based upon the post-test location of fragments and debris relative to the original (pre-test) location of the window. Predictions of glazing response should be conducted with the computer program ***WINGARD***. The computer program ***WINLAC*** may be used for projects or tests supporting the US Department of State.

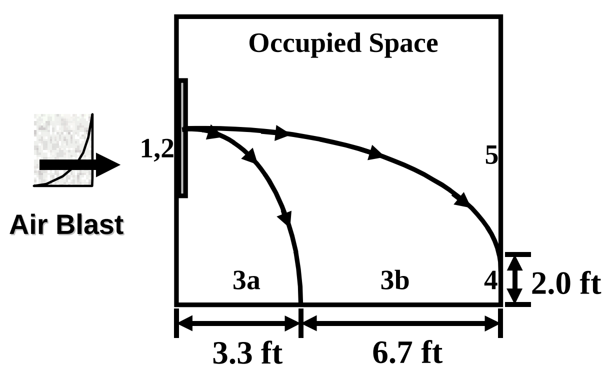


Figure 1. GSA/ISC performance conditions for window system response.

Table 1. GSA/ISC Performance Conditions for Window System Response.

Performance Condition	Protection Level	Hazard Level	Description of Window Glazing Response
1	Safe	None	Glazing does not break. No visible damage to glazing or frame.
2	Very High	None	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
3a	High	Very Low	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
3b	High	Low	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
4	Medium	Medium	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.
5	Low	High	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.

6. Requirements

6.1 Test Conductor
The test conductor shall be responsible for executing the test(s). The test conductor shall be an agency/organization that is qualified to perform such services and should be independent of the test specimen manufacturer or vendor.

6.2 Methods
Tests performed using this standard may be performed as open-air high explosives events or may use shock tubes to generate the required blast pressure loadings.

6.3 Blast Loads
In order to meet GSA requirements, tests meeting this standard shall produce a blast pressure pulse that rises instantaneously to a peak overpressure, P, and decays with time to produce a positive phase impulse, I. The actual measured values of P and I shall meet or exceed those required by relevant GSA project or test specifications in accordance with applicable security design criteria. The pressure-time waveform shall have one primary positive phase peak followed by a decay in pressure. Significant secondary pressure pulses should be avoided and under no circumstances shall significant secondary pressure pulses exceed a value of P/4, unless specifically required by the project specification or design criteria. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4 Test Site, Test Apparatus and Test Instrumentation
Tests performed under this standard may use explosive charges or shock tube. The test environment must produce the desired pressure and impulse as well as the desired pressure-time waveform characteristics. In general, explosive charges in open-air tests are preferred since they generally produce complete pressure waveforms that replicate the environments of interest.

6.4.1 Test Reaction Structures and Witness Panels and Test Framing
The test reaction structures shall be enclosed structures that prevent the rapid blast pressure engulfment of the test specimens. For tests that use open-air explosive charges, the test reaction structures shall be placed at appropriate distances and angles of incidence to produce the desired pressure-time loading conditions. The test reaction structures shall be non-responding relative to the test specimen(s) unless the response of the supporting reaction structure is important to demonstrating the performance of the tested specimen. If a responding support structure is required to demonstrate the performance of the specimen(s), then an appropriate responding structure should be provided. For tests using shock tubes, an enclosed reaction structure shall be provided at the end of the shock tube in a

manner similar to that used for open-air explosive tests. This enclosed structure shall be designed to allow a failed window system to enter the enclosed space and land on the floor and/or impact the witness panel in order to allow determination of the performance condition as shown in Figure 1. An enclosed structure is also required so that infill pressures may be measured in the enclosed space after window failure.

A witness panel designed to record fragment and debris impacts shall be located within the enclosed reaction structure a distance not to exceed 10 ft from the interior face of the window glazing. The witness panel shall consist of a foam board with a thin aluminum sheet or paper to record penetrations and/or perforations.

Test specimens shall be mounted in frames that replicate the desired in-place conditions. For example, if the test is designed to demonstrate a system in a truly non-reacting frame then a frame shall be provided that offers sufficient resistance to load. Likewise, if a test is designed to demonstrate an energy absorbing system, then a suitable frame shall be provided.

6.4.2 Explosive Charges and Source

For tests using explosive charges, a high explosive source shall be used to generate the desired peak pressure and the positive phase impulse on the test specimen. Any type of explosive may be used as long as the desired waveform characteristics are produced and the tests are reproducible within acceptable ranges of P and I. 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. If required to reduce the potential for ejecta debris from the crater, a blast mat, concrete pad or sand pit may be used at the discretion of the test conductor.

For tests using shock tubes, explosives or compressed gas with a rupture diaphragm may be used to generate the desired peak pressure and positive phase impulse on the test specimen. The test source must be designed so as not to overload the specimen with excess impulse. A negative pressure phase is desired in order to replicate actual explosive loading conditions.

6.4.3 Photographic Measurements

Photographic equipment shall be available to document the test. High-speed photography (500 to 1,000 frames per second), normal speed video, and still photography are recommended. As minimum, there should be at least one high-speed camera to record the response of each test specimen from an interior view. In addition, pre- and post-test still photography is required to document the condition of the tested specimens. Still photography shall be provided for both interior and exterior views.

6.4.4 Active Instrumentation and Data Acquisition

A minimum of two airblast pressure transducers shall be used on each test reaction structure to measure the pressure-time waveform acting on the exterior surface of tested specimens. 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-time history within the linear range of the transducer. The transducers shall have a rise/response time and resolution sufficient to capture the complete event.

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.

6.5 Specimens

The test sponsor shall provide the test specimens. The test sponsor shall provide extra specimens in case of accidental breakage or damage during shipping. Each specimen shall be marked with the manufacturer’s name, model and serial numbers (if applicable), and date of manufacture. In addition, each specimen shall be marked to indicate the proper orientation (i.e., interior/exterior) to ensure proper mounting in the test reaction structures. The specimens shall be mounted and anchored in the reaction structures in accordance with the manufacturer’s instructions. The test conductor shall ensure that the test specimens are handled and stored in compliance with manufacturer’s instructions.

Unless intended to replicate a specific condition or designed to meet specific project requirements, the standard test window size shall be nominally 48 inches wide by 66 inches tall. The window should be mounted in the test reaction structure such that the windowsill height replicates the desired in-place conditions for a particular project, or if performed as a generic test, should be approximately 24 inches off the reaction structure floor. Actual tested conditions shall be recorded and reported.

6.6 Test Measurements

6.6.1 Prior to the Test

Prior to the test, the test conductor shall:

- Record the ambient temperature within 30 minutes of test time.
- Measure and record test specimen dimensions. Measure and report actual glazing thickness.
- Photographically record the pre-test condition of the test specimens, the test frame, and the test site/apparatus configuration. This photographic record shall consist of still photographs and may include motion pictures or video.
- For tests using explosives, measure and record the test charge construction and the standoff distance from the center of the charge to the exterior face of the test specimen(s).
- For shock tube tests, measure and record the blast source construction (compressed gas and/or explosives).

6.6.2 After the Test

After the test, the test conductor shall:

- Photographically record the post-test condition of the test specimen(s), the location of any fragments/debris in the reaction structure, the test frame(s), and the test site/apparatus. This photographic record shall consist of still photographs and may include motion pictures or video.
- Record and photograph any perforations and/or penetrations of the witness panel.
- Determine and record the performance condition in accordance with the criteria shown in Table 1 and Figure 1. Minor dents or scratches on the witness panel paper or aluminum sheet that do not penetrate or perforate shall be noted but not counted as fragment/debris impacts for the purpose of determining the performance condition.

6.6.3 Units of Measure

The preferred units of measure for these tests are as follows:

- <u>Length, width, thickness, depth, displacement</u>: feet, inches, mil
- <u>Time</u>: sec, msec
- <u>Weight, force</u>: lb
- <u>Pressure</u>: lb/in^2 (psi)
- <u>Impulse</u>: psi-msec
- <u>Temperature</u>: deg F

6.7 Reports

Upon completion of a test, the test conductor shall report the results of the test. The following mandatory information shall be reported. Additional information may be reported as appropriate.

- Test site location, test date and time.
- Description of the test site or apparatus setup. This should include a description of the explosive charge and/or other explosive shock wave source used in the test.
- Pre- and post-test description of the test specimen(s), including pertinent dimensions, construction, materials and condition.
- Pre- and post-test description of the test framing and anchorage.
- Ambient temperature for each test.
- Peak positive pressure, P, and positive phase impulse, I, recorded by each pressure transducer. Average measured pressure and impulse. Descriptions of any anomalous measurements.
- The recorded airblast pressure-time history from each pressure transducer.
- The location of any debris and/or fragments to include any perforations and/or penetrations of the witness panel.
- The performance condition for each tested specimen in accordance with Table 1 and Figure 1.
- The test report shall contain a photographic record of the test setup. In addition, the test report shall contain detailed photographs of each test specimen prior to and following the test.

The test conductor shall keep an original of the test report on file for at least three years from submittal of the test report to the test sponsor. The test conductor shall provide a minimum of one copy of the test report plus applicable video and photographic records to the test sponsor.

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.

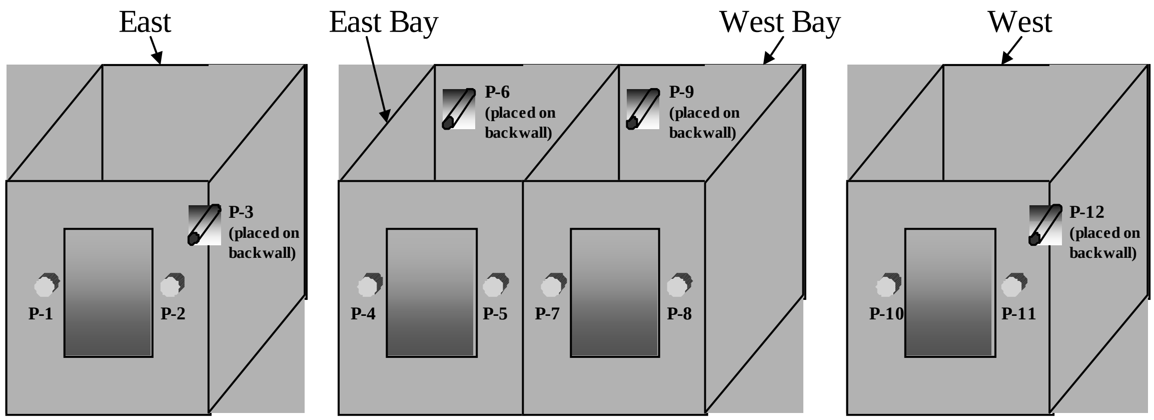


Figure B.1. Illustration of pressure gauge locations.

The table below (Table B.1) summarizes the peak pressures and impulses. Waveforms for each of the gauges (for each test) follow Table B.1. 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: Gages with no values listed were not functioning correctly, and therefore, their output was not included in the results.

Test Number	Gauge Number*/ Average/ Standard Deviation	Peak Positive Pressure (psi)	Peak Positive Impulse (psi-msec)
1	1	4.01	26.86
	2	4.28	28.11
	3	0.21	1.20
	4	4.04	27.48
	5	4.43	29.62
	6	0.30	3.97
	7	----	----
	8	4.06	29.09
	9	0.35	5.63
	10	----	----
	11	4.34	32.63
	12	----	----
	Average External Gauge	4.19	28.96
	Standard Deviation External Gauge	0.18	2.06
2	1	4.08	29.29
	2	4.28	28.66
	3	0.20	1.20
	4	3.98	27.42
	5	4.44	30.12
	6	0.26	3.09
	7	----	----
	8	4.09	29.06
	9	0.33	5.59
	10	----	----
	11	4.00	29.91
	12	----	----
	Average External Gauge	4.15	29.08
	Standard Deviation External Gauge	0.18	0.97

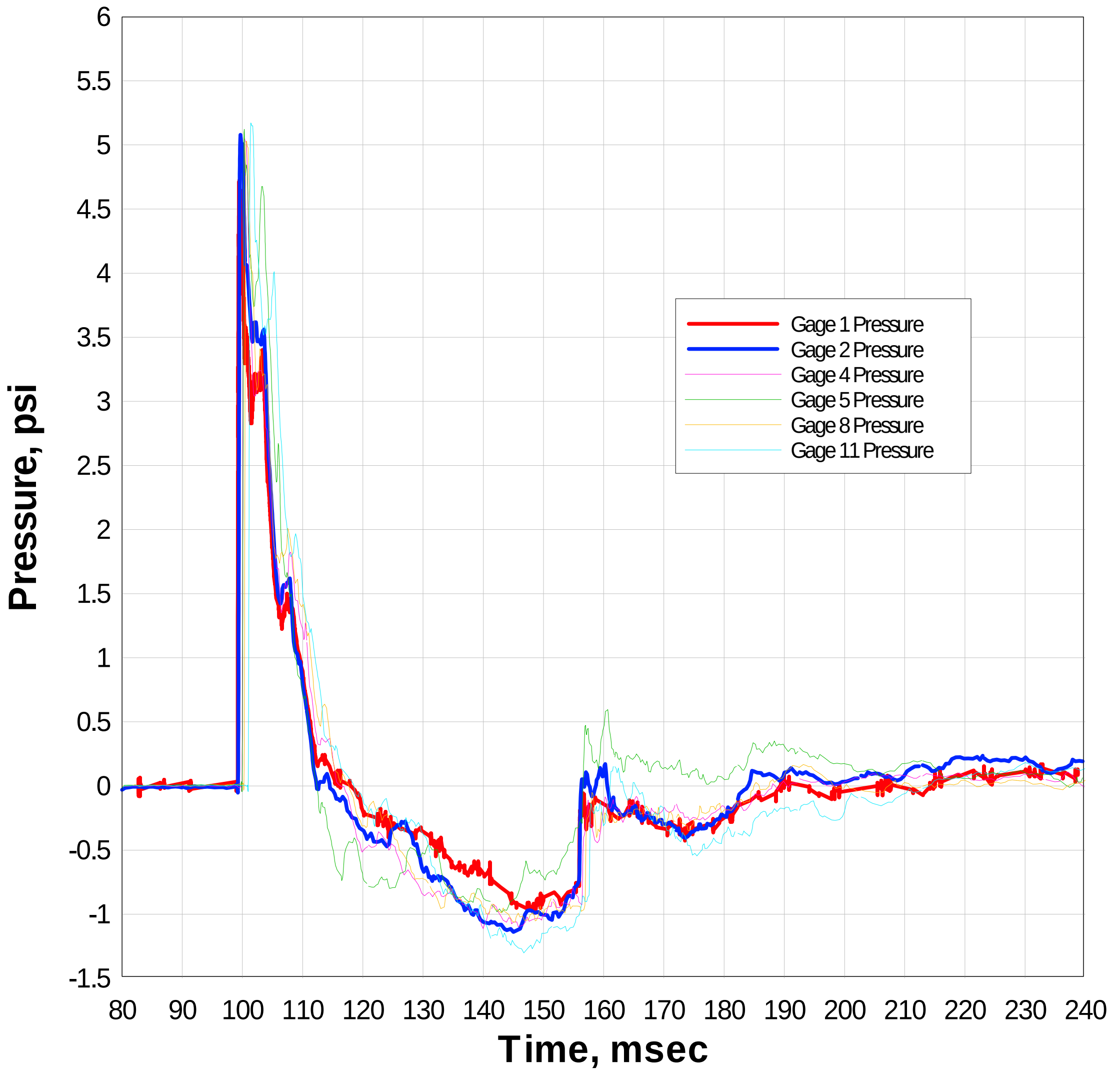
Test Number	Gauge Number*/ Average/ Standard Deviation	Peak Positive Pressure (psi)	Peak Positive Impulse (psi-msec)
3	1	4.10	29.04
	2	4.24	27.81
	3	0.21	1.71
	4	4.85	32.38
	5	4.06	27.34
	6	0.27	5.04
	7	4.22	32.92
	8	4.08	28.21
	9	0.33	7.55
	10	3.71	28.46
	11	4.56	32.85
	12	0.14	0.99
	Average External Gauge	4.23	29.88
	Standard Deviation External Gauge	0.35	2.41
4	1	4.39	31.07
	2	4.27	27.93
	3	0.21	1.71
	4	4.41	29.15
	5	4.43	29.95
	6	0.27	5.04
	7	3.87	30.17
	8	4.44	30.78
	9	0.34	7.55
	10	3.89	29.96
	11	4.00	28.73
	12	0.14	0.96
	Average External Gauge	4.21	29.72
	Standard Deviation External Gauge	0.25	1.05

Test Number	Gauge Number*/ Average/ Standard Deviation	Peak Positive Pressure (psi)	Peak Positive Impulse (psi-msec)
5	1	4.06	28.92
	2	4.70	30.50
	3	0.24	1.96
	4	4.40	29.96
	5	4.43	30.27
	6	0.25	2.81
	7	3.85	30.45
	8	4.08	28.62
	9	0.32	6.40
	10	4.23	33.20
	11	3.96	28.65
	12	0.21	2.78
	Average External Gauge	4.21	30.07
	Standard Deviation External Gauge	0.28	1.49

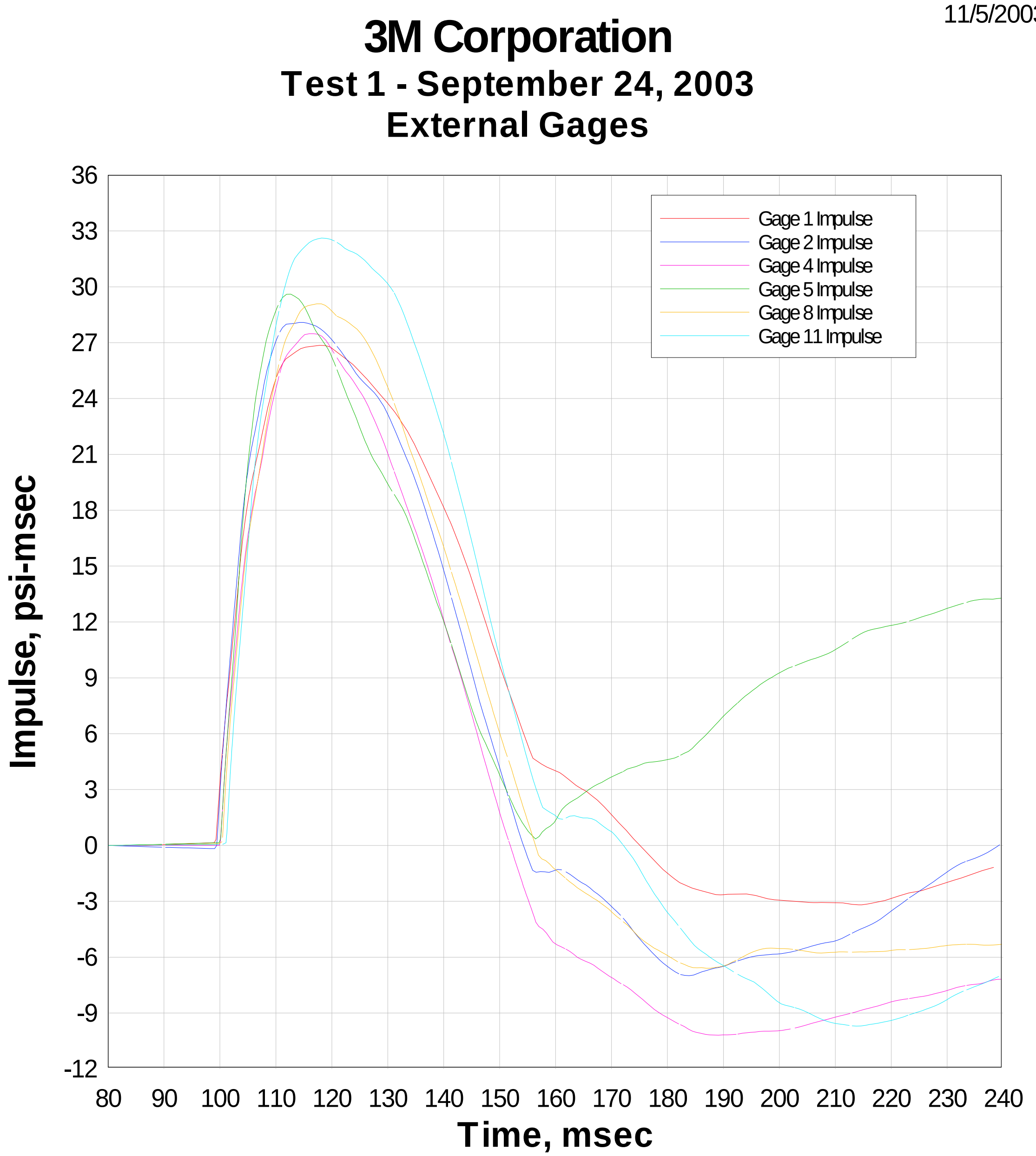
*Pressure Gauges 1,2,4,5,7,8,10, and 11 are located on the on the exterior of the structures. Pressure gauges 3, 6, 9, and 12 are located on the interior of the structures. For reference see Figure B.1.

11/5/2003

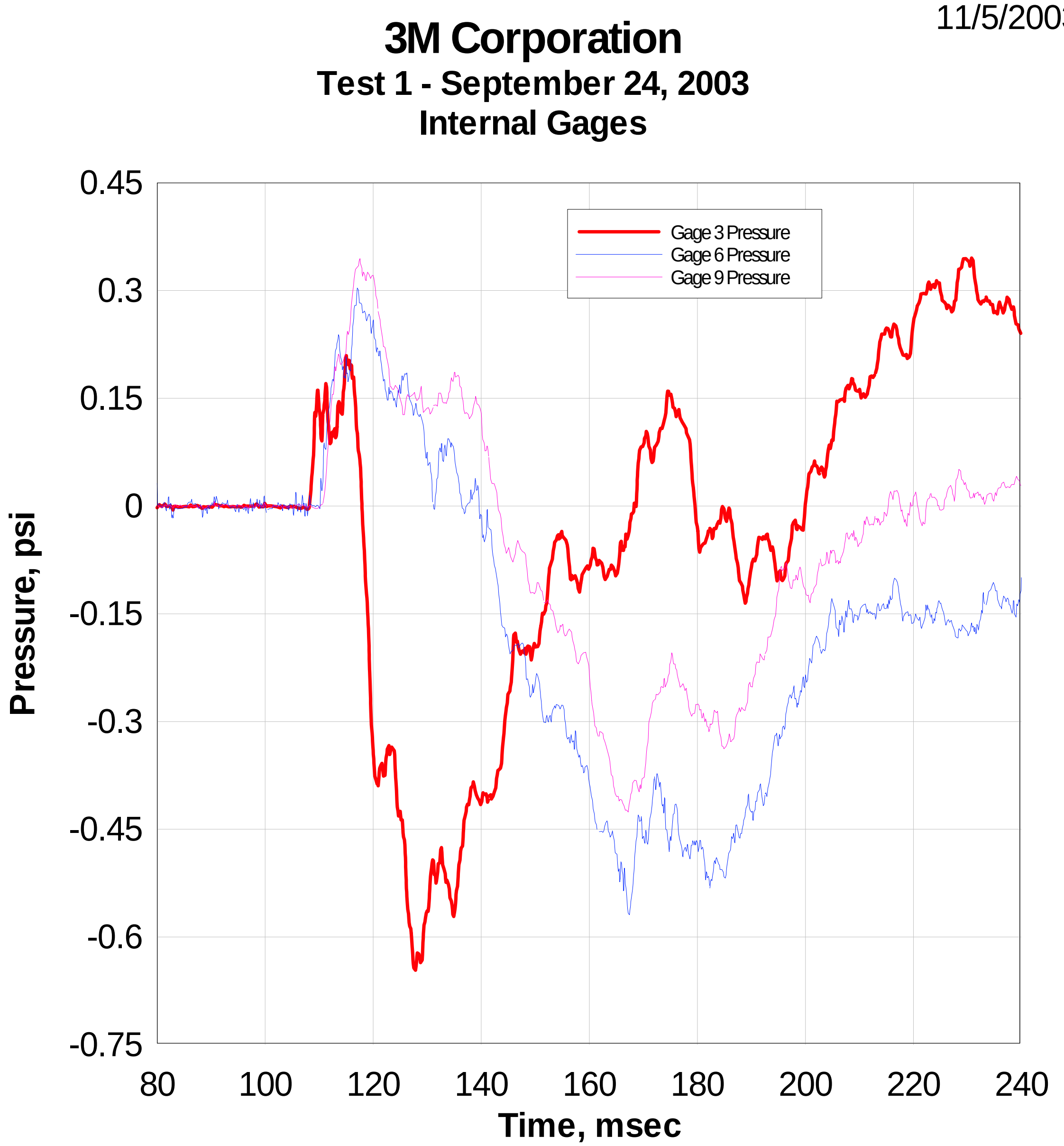
3M Corporation
Test 1 - September 24, 2003
External Gages



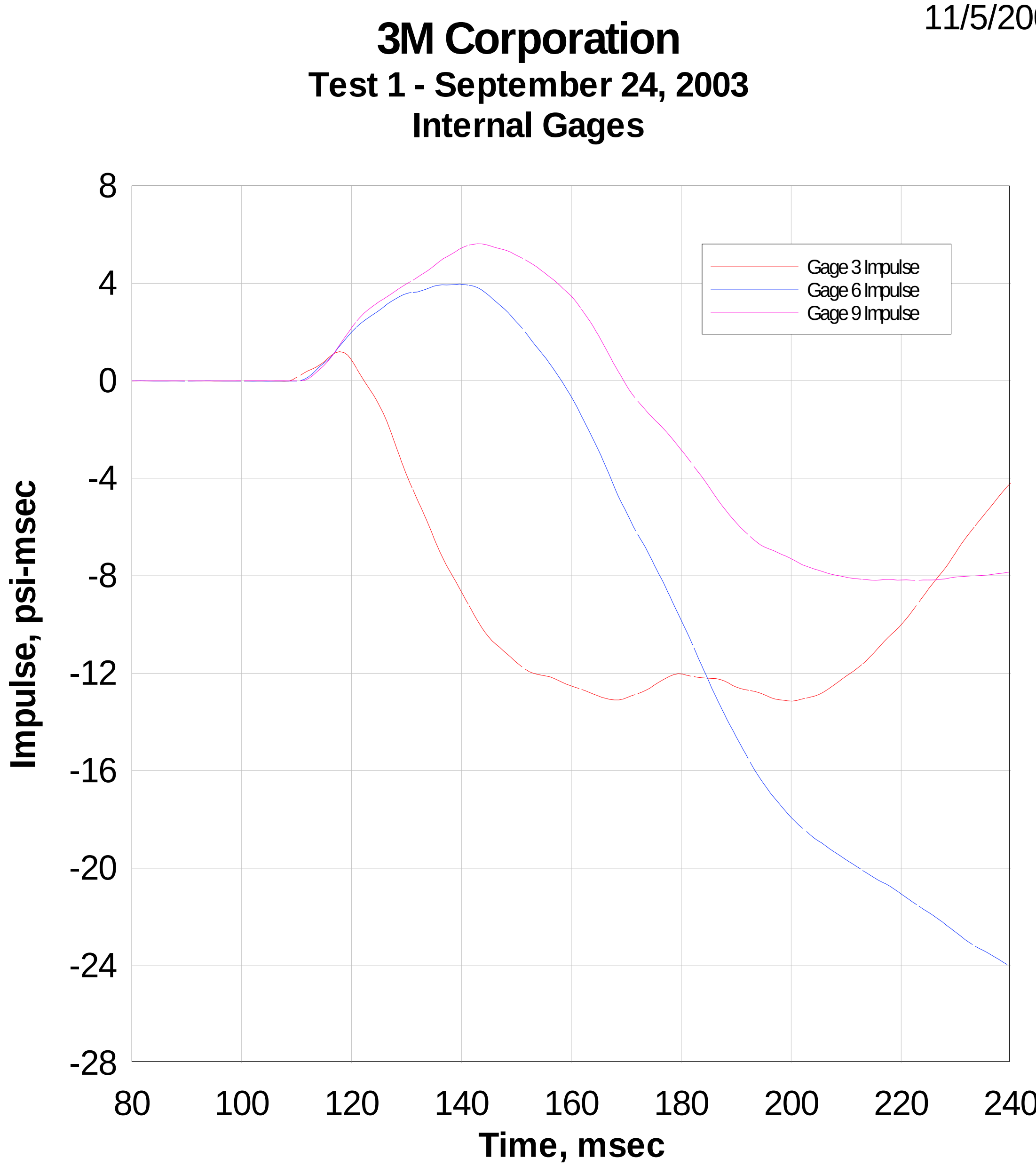
11/5/2003


3M Corporation
Test 1 - September 24, 2003
External Gages
Gage 1 Impulse
Gage 2 Impulse
Gage 4 Impulse
Gage 5 Impulse
Gage 8 Impulse
Gage 11 Impulse
Impulse, psi-msec
36
33
30
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
-12
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Time, msec

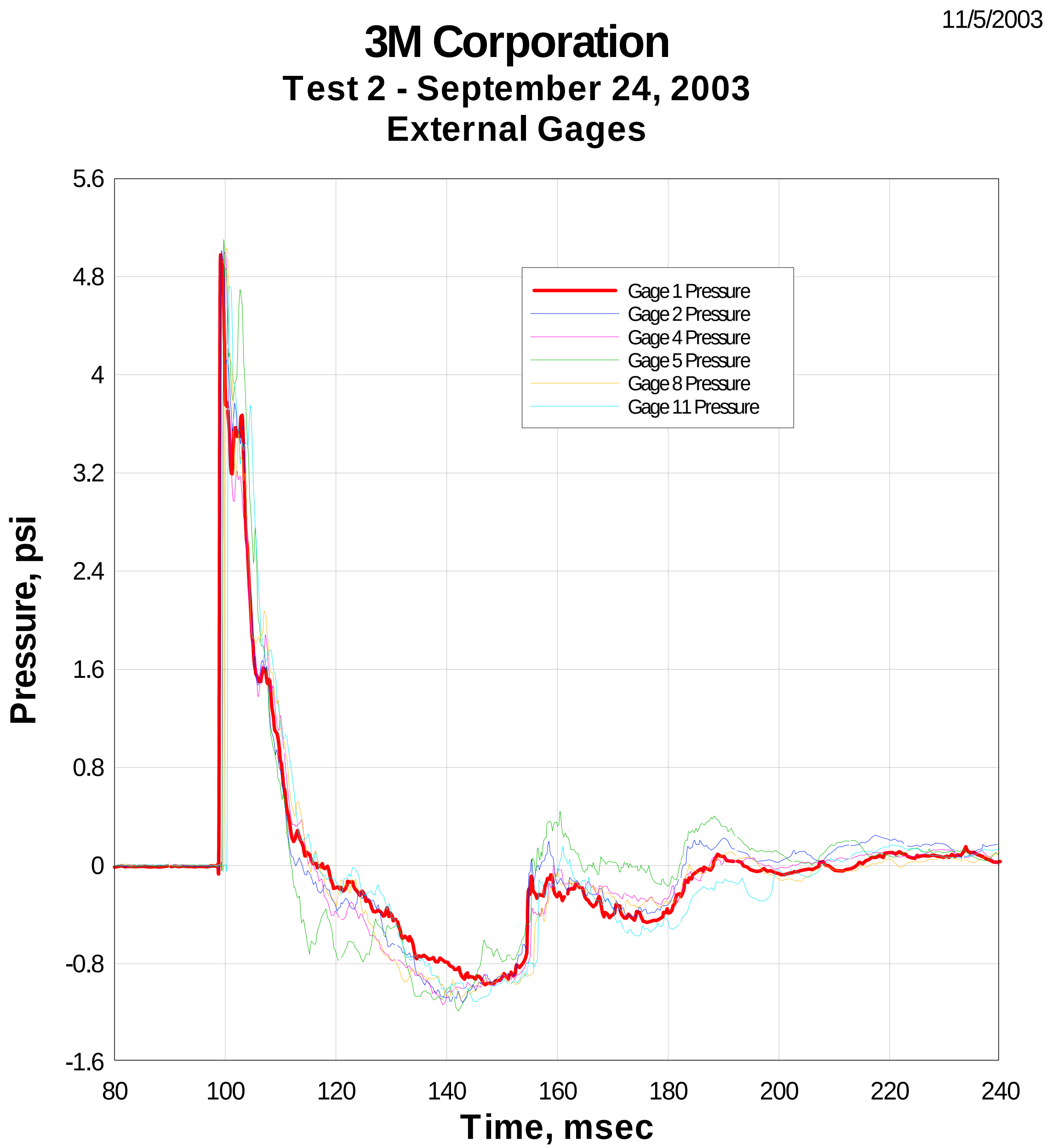
11/5/2003


3M Corporation
Test 1 - September 24, 2003
Internal Gages
Gage 3 Pressure
Gage 6 Pressure
Gage 9 Pressure
Pressure, psi
0.45
0.3
0.15
0
-0.15
-0.3
-0.45
-0.6
-0.75
80
100
120
140
160
180
200
220
240
Time, msec

11/5/2003

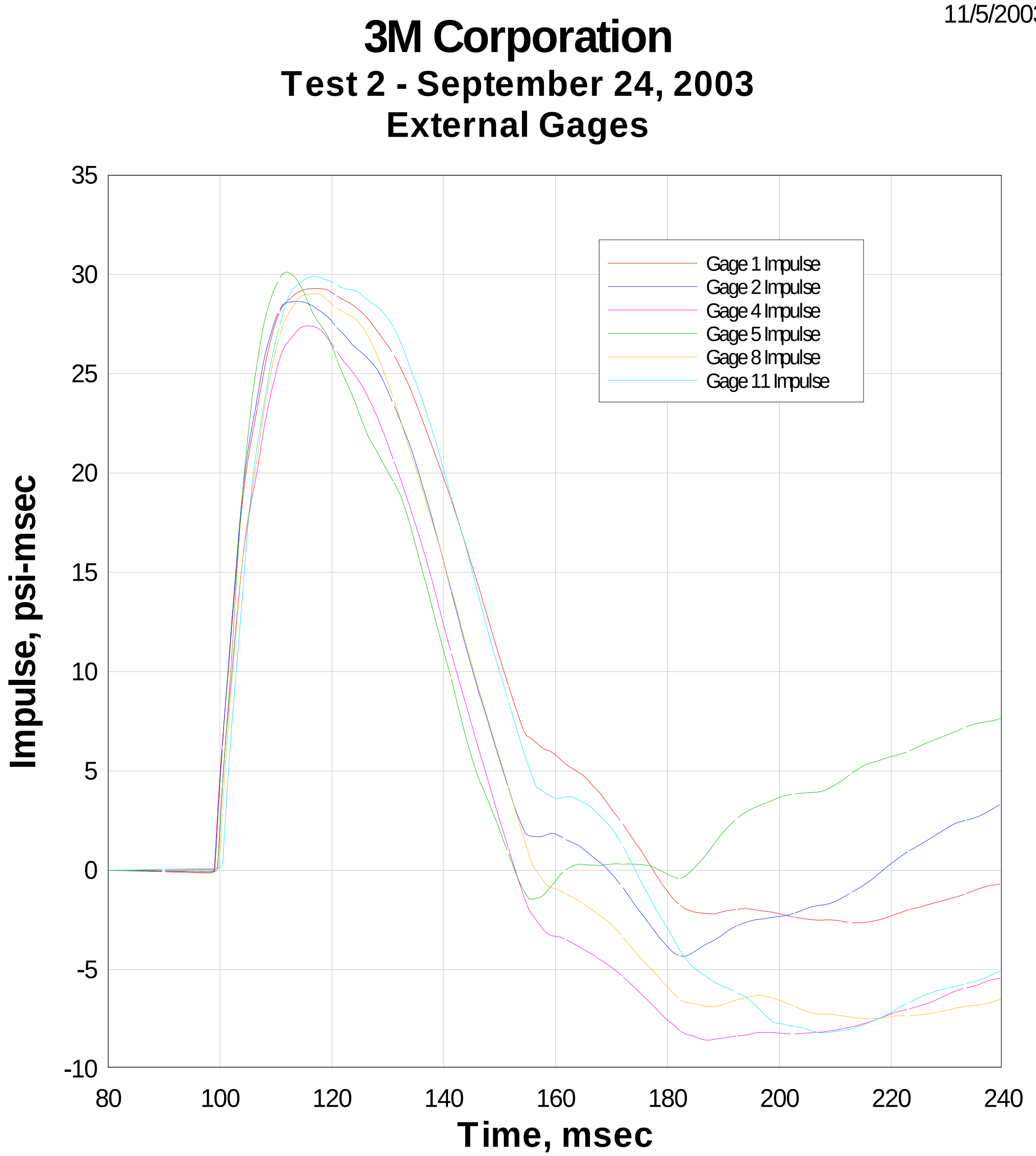


3M Corporation
Test 1 - September 24, 2003
Internal Gages
Impulse, psi-msec
Time, msec
Gage 3 Impulse
Gage 6 Impulse
Gage 9 Impulse
8
4
0
-4
-8
-12
-16
-20
-24
-28
80
100
120
140
160
180
200
220
240

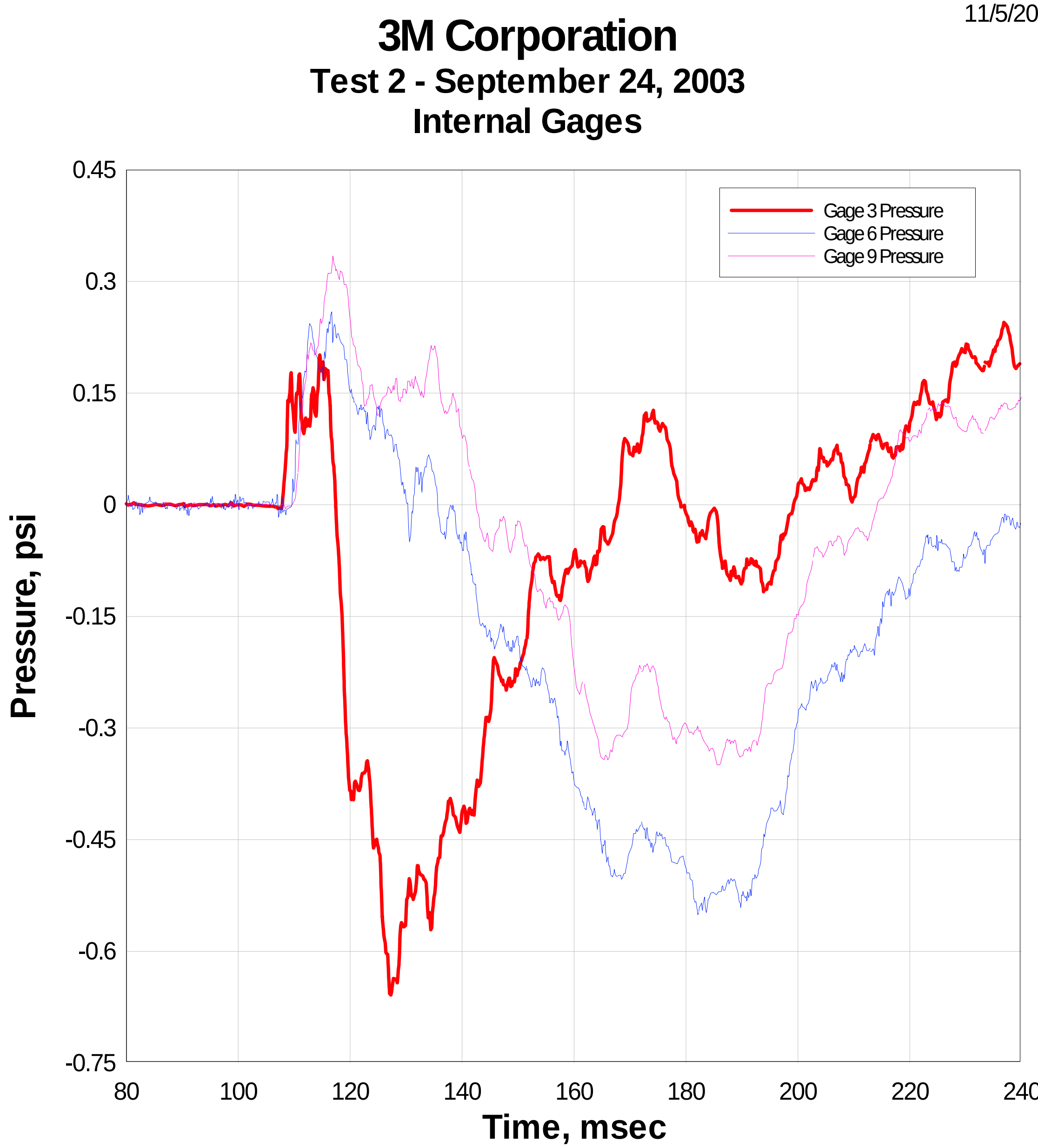


11/5/2003
3M Corporation
Test 2 - September 24, 2003
External Gages
Pressure, psi
Time, msec
Gage 1 Pressure
Gage 2 Pressure
Gage 4 Pressure
Gage 5 Pressure
Gage 8 Pressure
Gage 11 Pressure
5.6
4.8
4
3.2
2.4
1.6
0.8
0
-0.8
-1.6
80
100
120
140
160
180
200
220
240

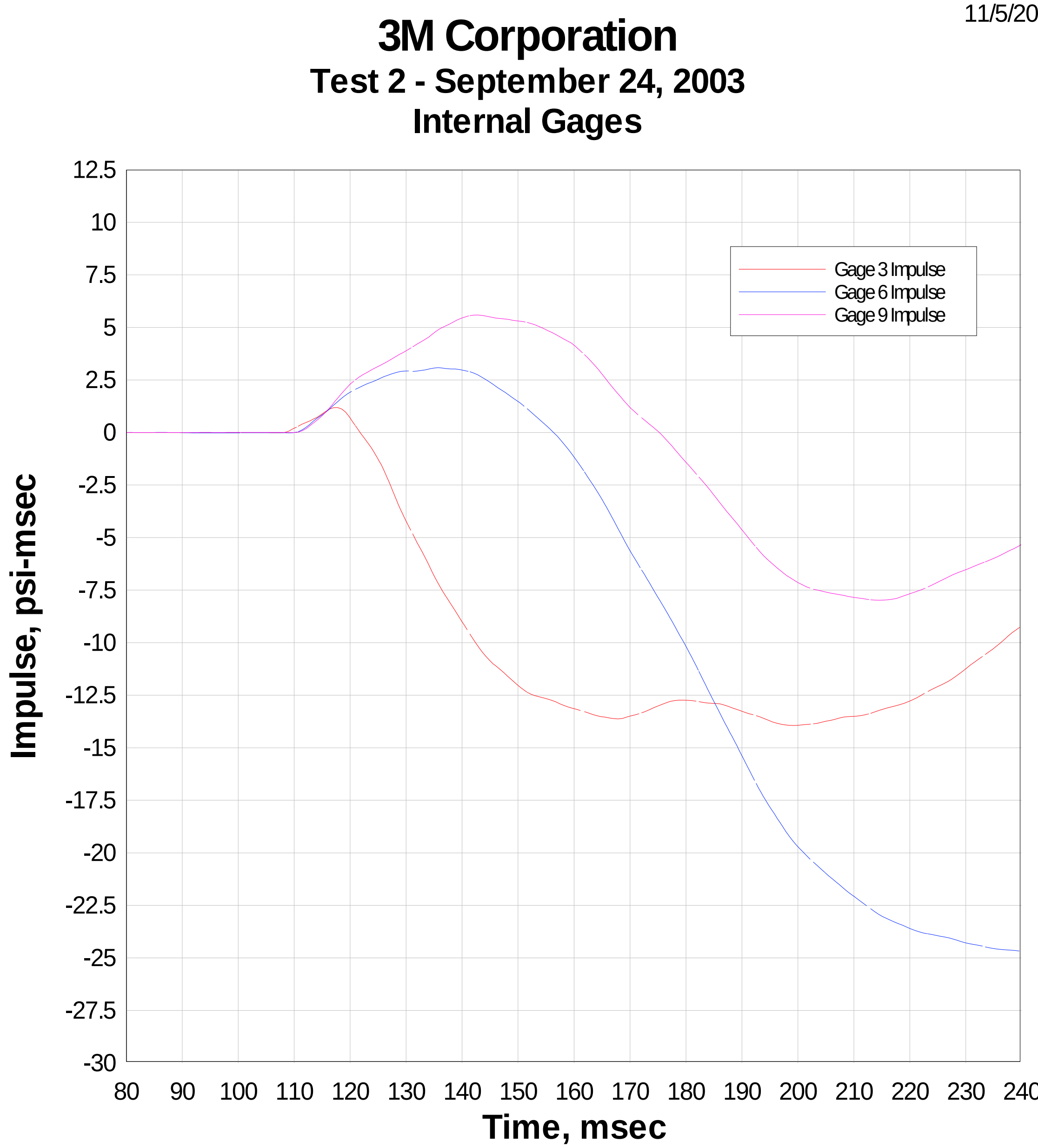
11/5/2003



3M Corporation
Test 2 - September 24, 2003
External Gages
Impulse, psi-msec
Time, msec
35
30
25
20
15
10
5
0
-5
-10
80
100
120
140
160
180
200
220
240
Gage 1 Impulse
Gage 2 Impulse
Gage 4 Impulse
Gage 5 Impulse
Gage 8 Impulse
Gage 11 Impulse

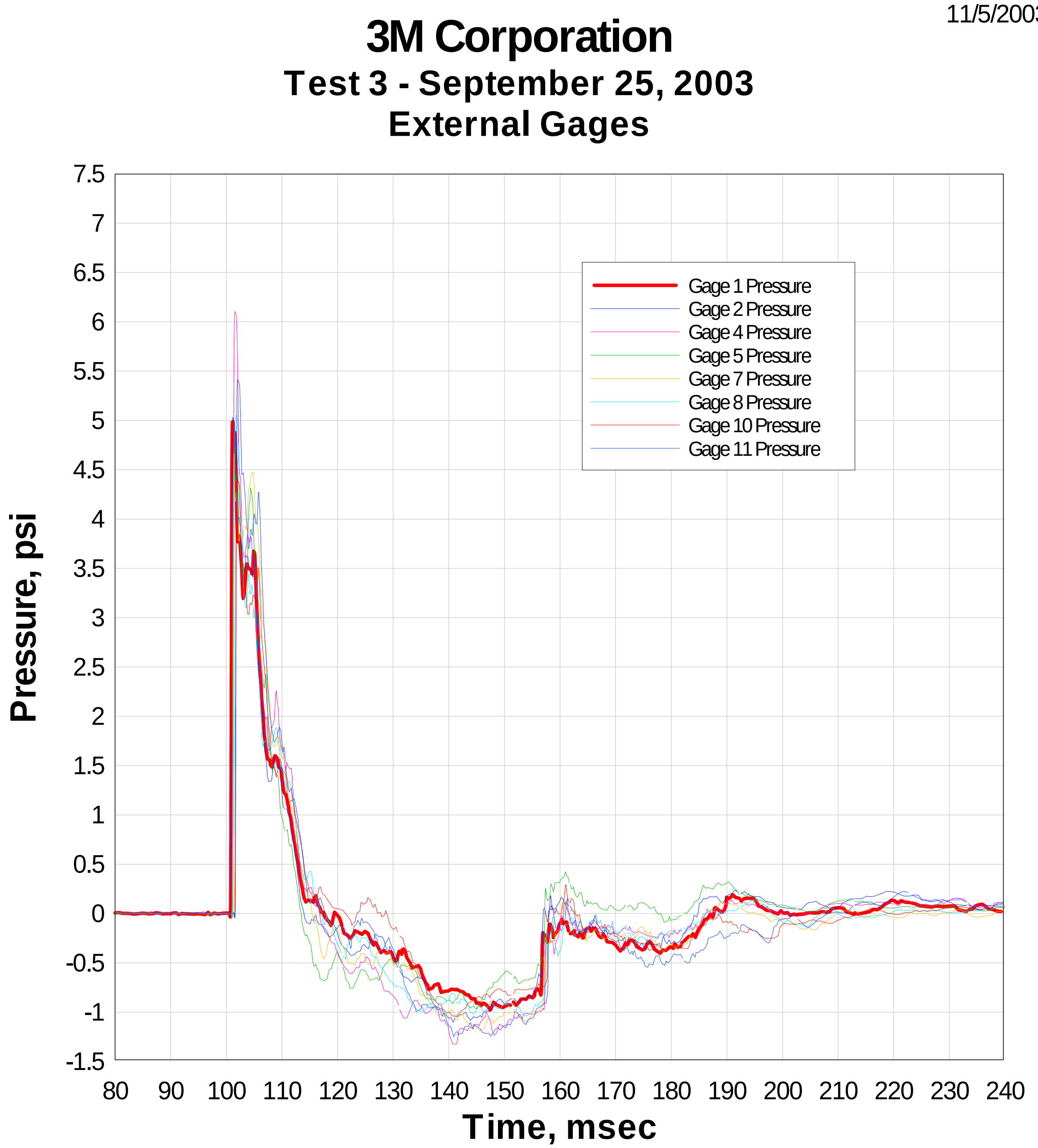

3M Corporation
Test 2 - September 24, 2003
Internal Gages
Gage 3 Pressure
Gage 6 Pressure
Gage 9 Pressure
0.45
0.3
0.15
0
-0.15
-0.3
-0.45
-0.6
-0.75
Pressure, psi
80
100
120
140
160
180
200
220
240
Time, msec

11/5/2003



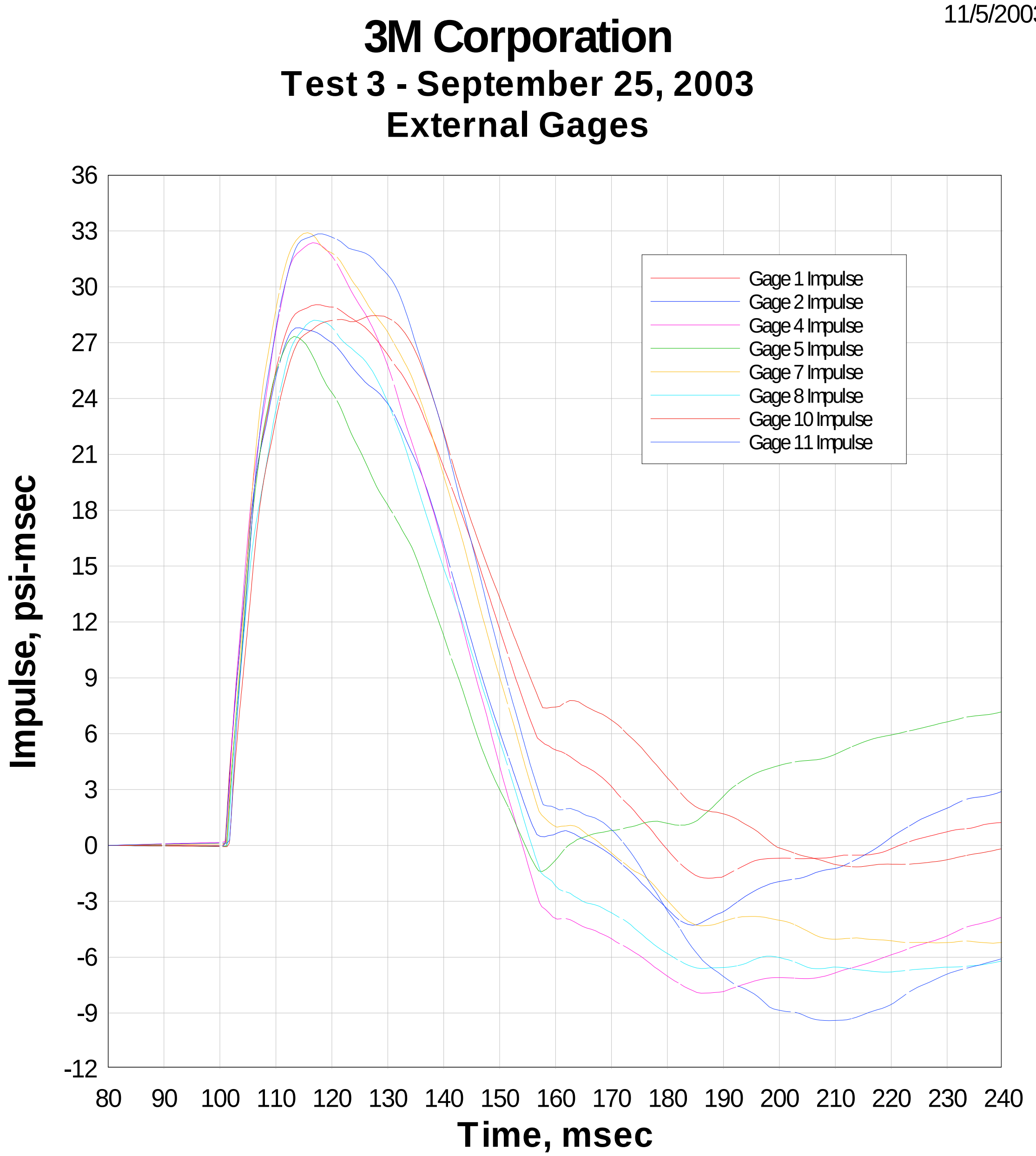
3M Corporation
Test 2 - September 24, 2003
Internal Gages
Gage 3 Impulse
Gage 6 Impulse
Gage 9 Impulse
12.5
10
7.5
5
2.5
0
-2.5
-5
-7.5
-10
-12.5
-15
-17.5
-20
-22.5
-25
-27.5
-30
Impulse, psi-msec
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Time, msec

11/5/2003

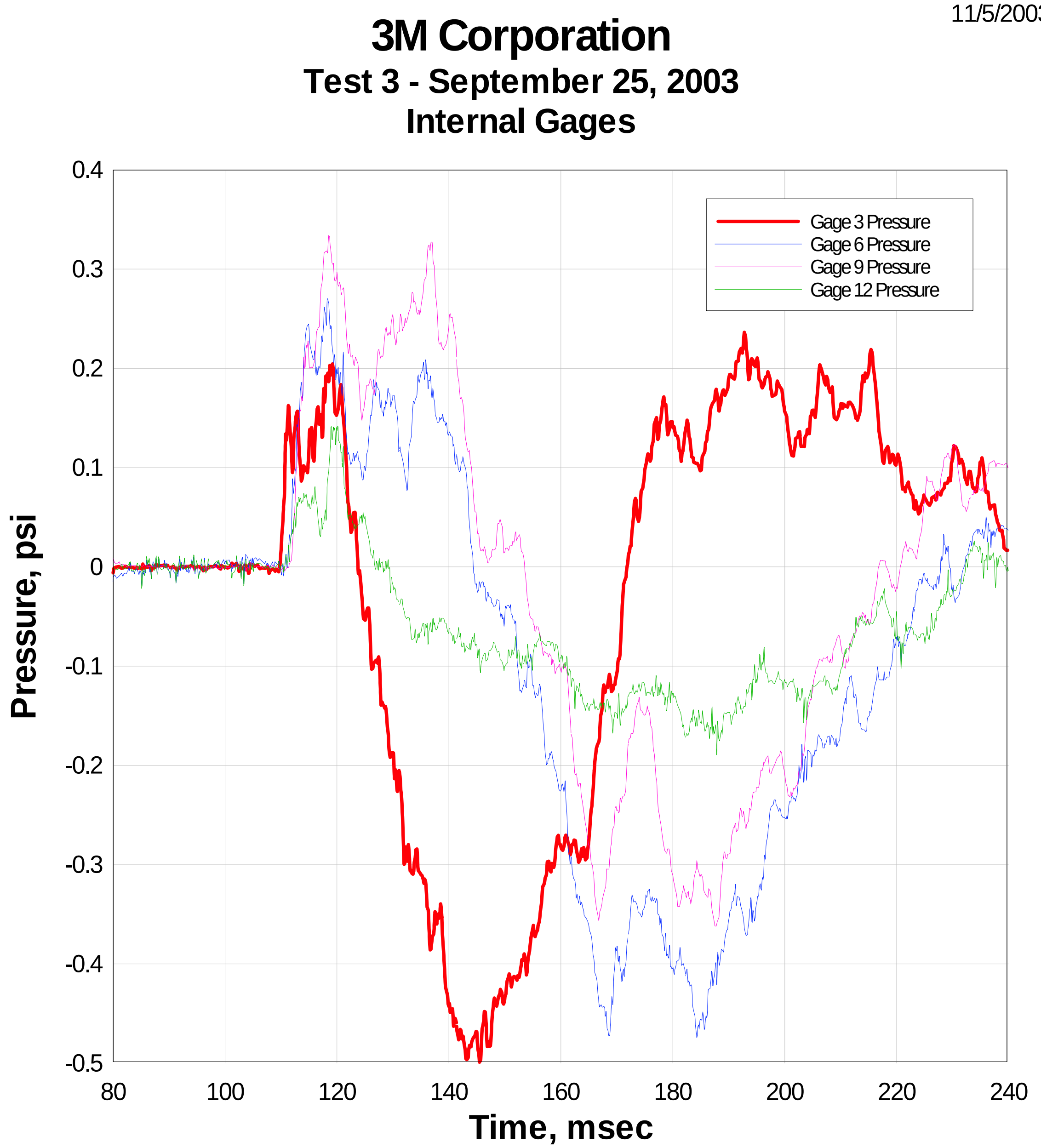


3M Corporation
Test 3 - September 25, 2003
External Gages
Pressure, psi
Time, msec
7.5
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Gage 1 Pressure
Gage 2 Pressure
Gage 4 Pressure
Gage 5 Pressure
Gage 7 Pressure
Gage 8 Pressure
Gage 10 Pressure
Gage 11 Pressure

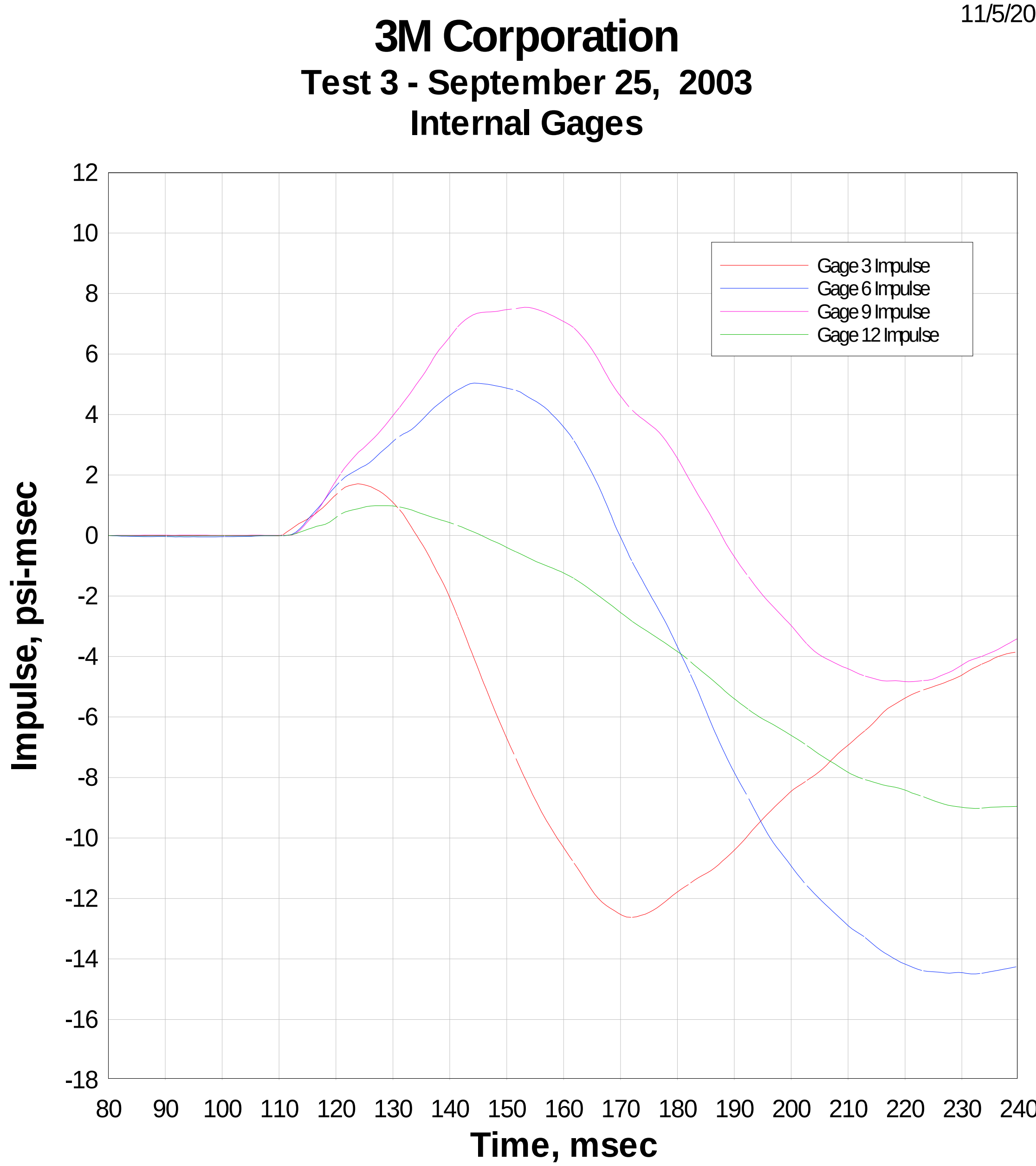
11/5/2003



3M Corporation
Test 3 - September 25, 2003
External Gages
Impulse, psi-msec
Time, msec
36
33
30
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
-12
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
Gage 1 Impulse
Gage 2 Impulse
Gage 4 Impulse
Gage 5 Impulse
Gage 7 Impulse
Gage 8 Impulse
Gage 10 Impulse
Gage 11 Impulse

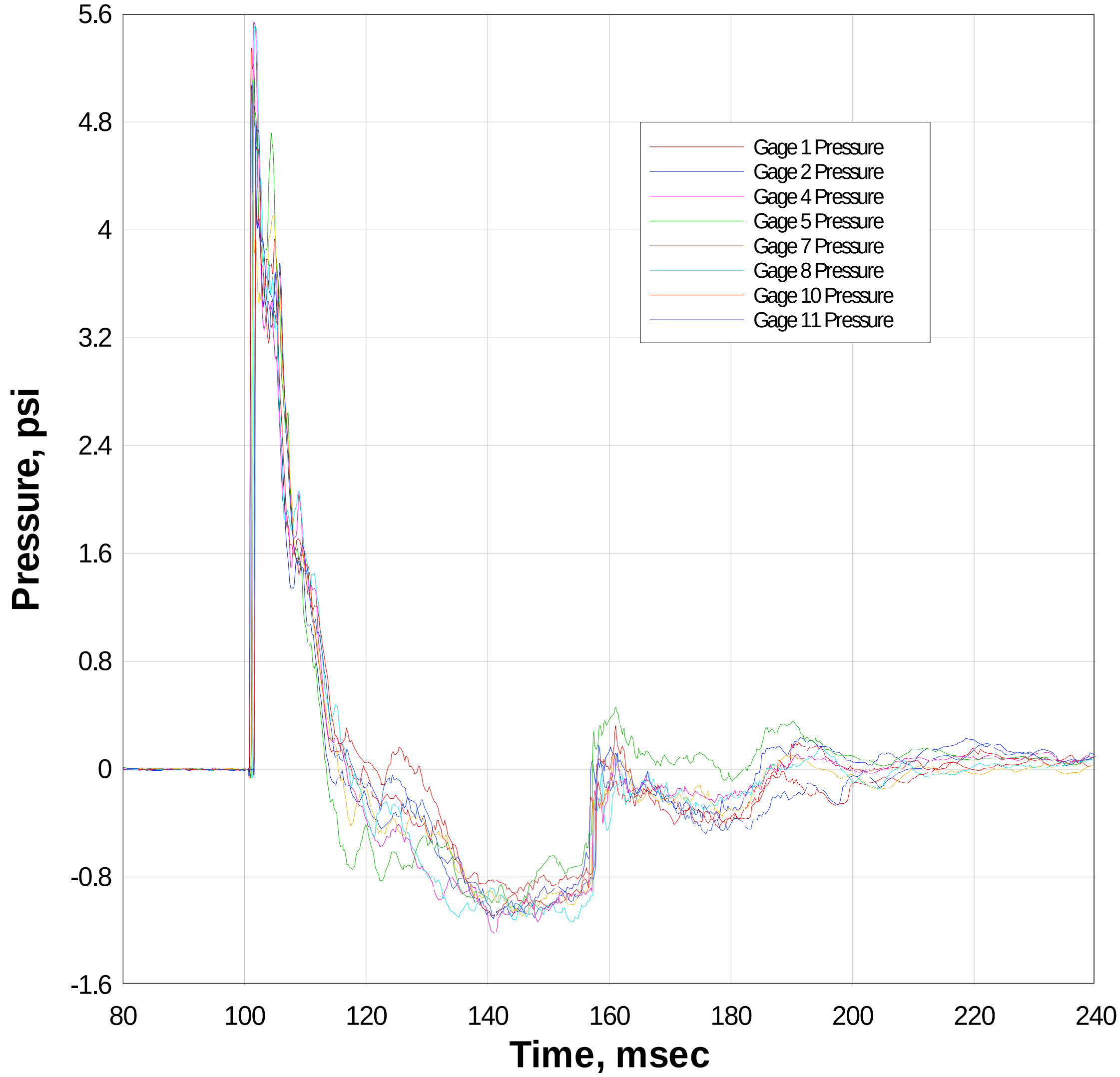

3M Corporation
Test 3 - September 25, 2003
Internal Gages
Gage 3 Pressure
Gage 6 Pressure
Gage 9 Pressure
Gage 12 Pressure
Pressure, psi
Time, msec
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
80
100
120
140
160
180
200
220
240

11/5/2003

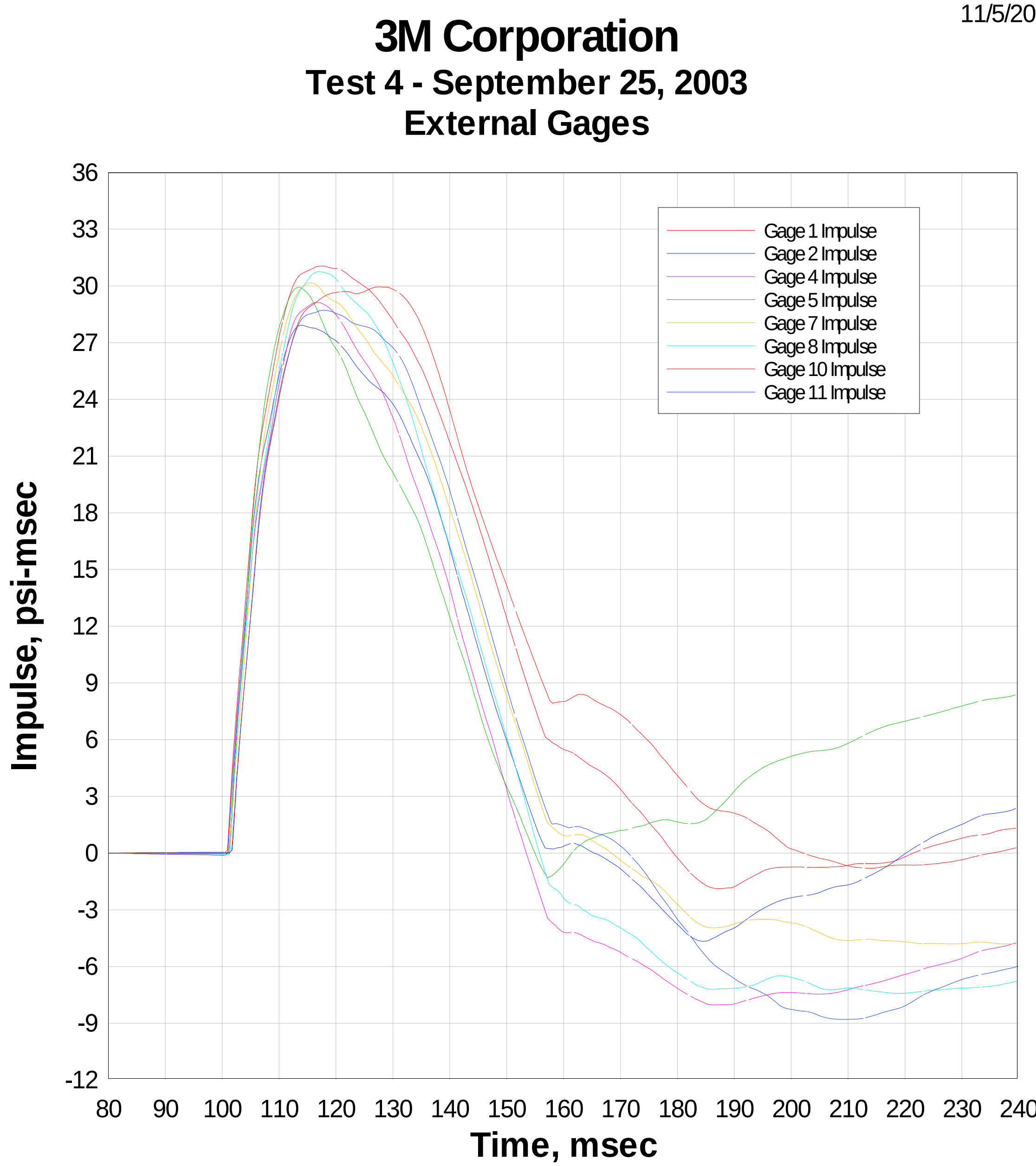

3M Corporation
Test 3 - September 25, 2003
Internal Gages
Gage 3 Impulse
Gage 6 Impulse
Gage 9 Impulse
Gage 12 Impulse
Impulse, psi-msec
Time, msec
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240

11/5/2003

3M Corporation
Test 4 - September 25, 2003
External Gages

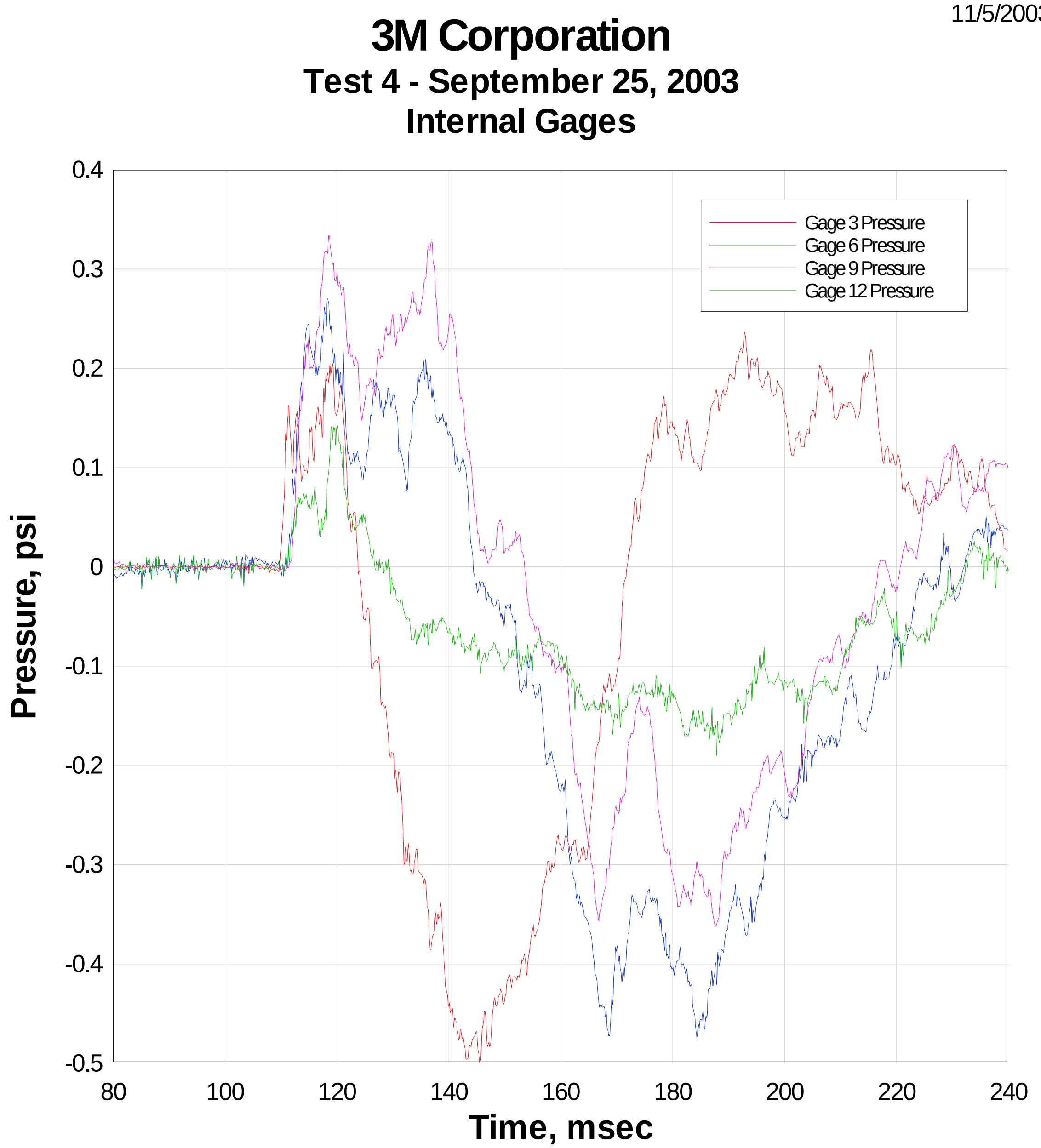


11/5/2003

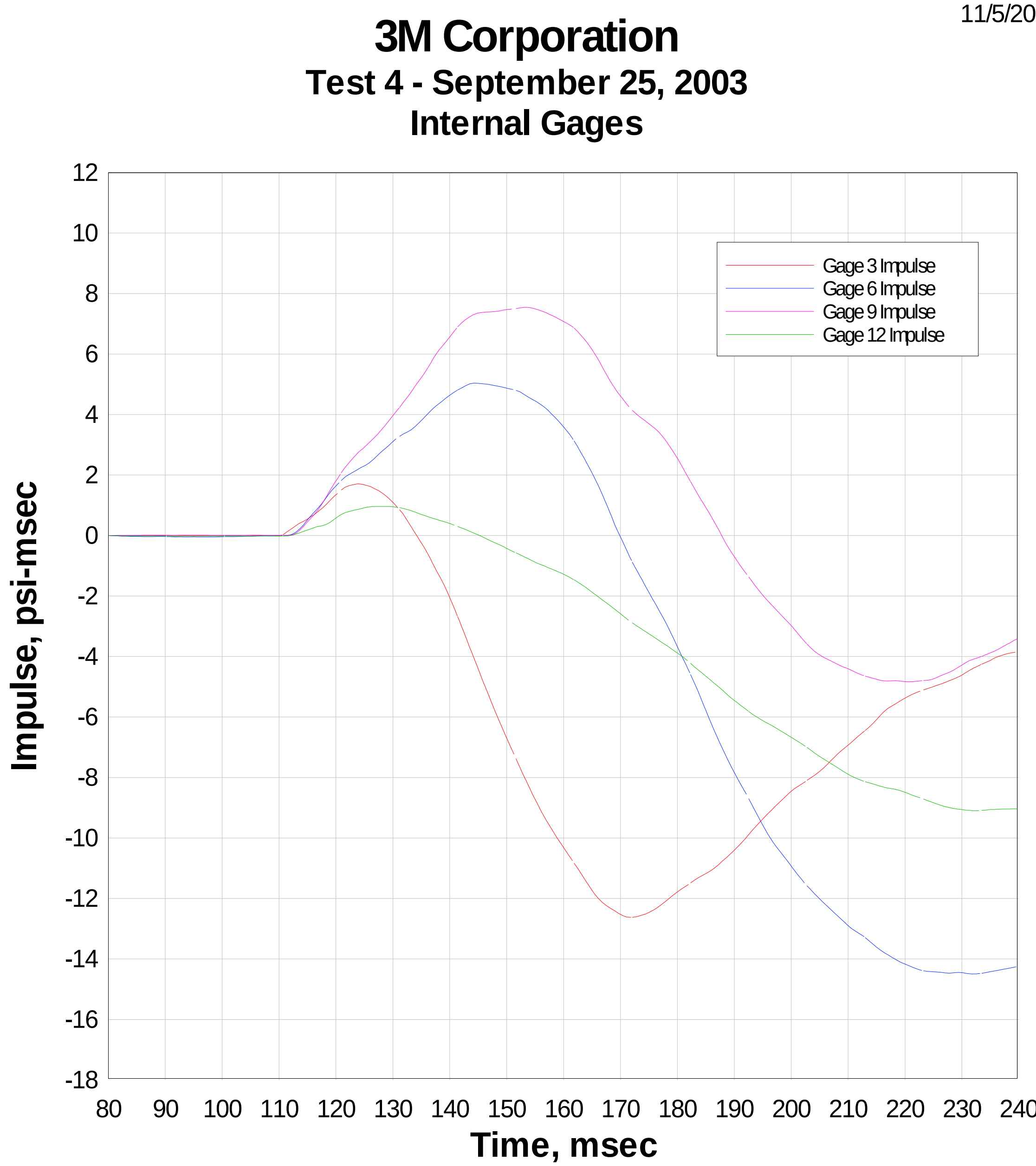


3M Corporation
Test 4 - September 25, 2003
External Gages
Gage 1 Impulse
Gage 2 Impulse
Gage 4 Impulse
Gage 5 Impulse
Gage 7 Impulse
Gage 8 Impulse
Gage 10 Impulse
Gage 11 Impulse
Impulse, psi-msec
Time, msec
36
33
30
27
24
21
18
15
12
9
6
3
0
-3
-6
-9
-12
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240

11/5/2003

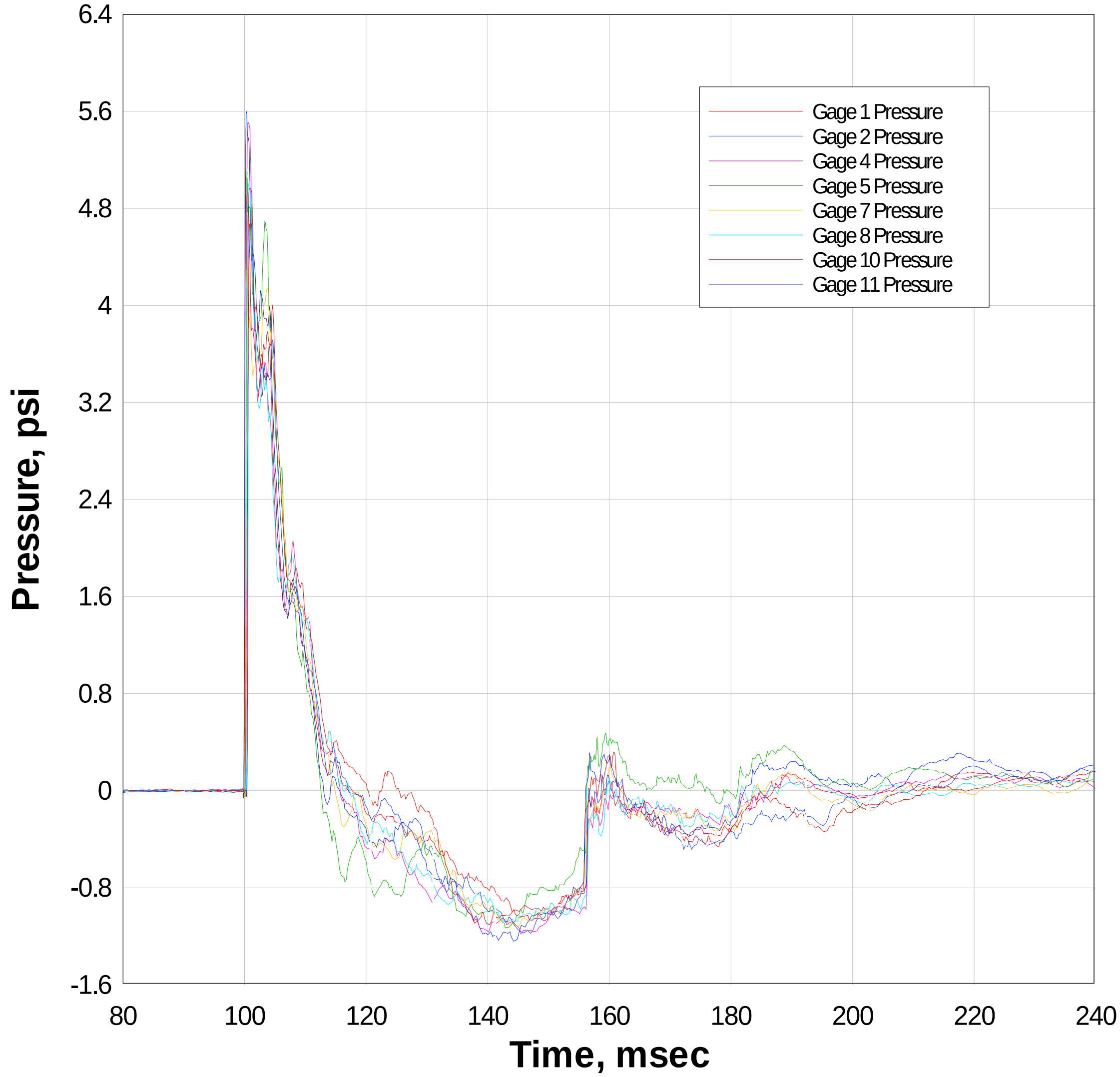

3M Corporation
Test 4 - September 25, 2003
Internal Gages
Gage 3 Pressure
Gage 6 Pressure
Gage 9 Pressure
Gage 12 Pressure
Pressure, psi
Time, msec
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
80
100
120
140
160
180
200
220
240

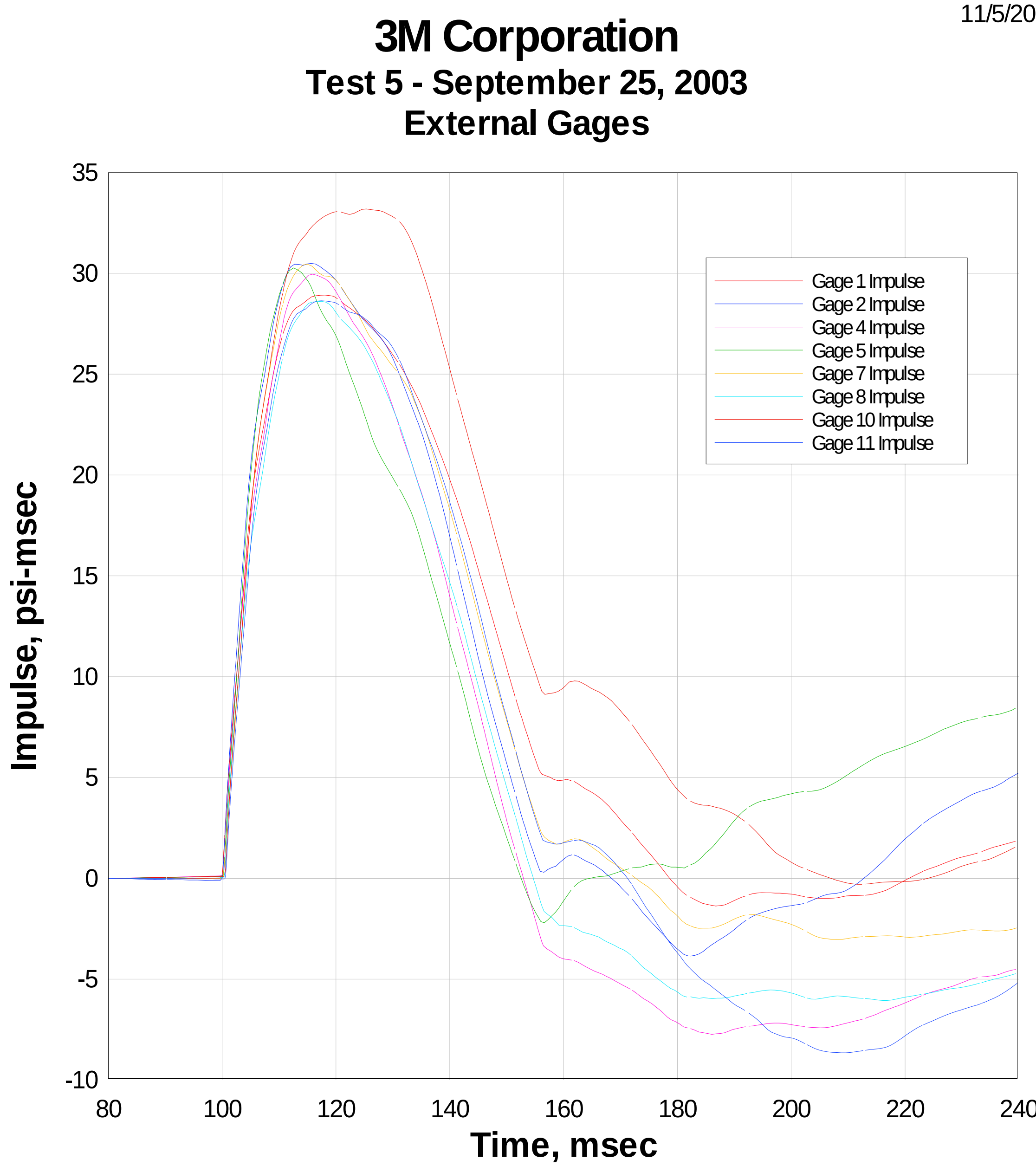
11/5/2003



3M Corporation
Test 4 - September 25, 2003
Internal Gages
Impulse, psi-msec
Time, msec
Gage 3 Impulse
Gage 6 Impulse
Gage 9 Impulse
Gage 12 Impulse
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240

3M Corporation
Test 5 - September 25, 2003
External Gages

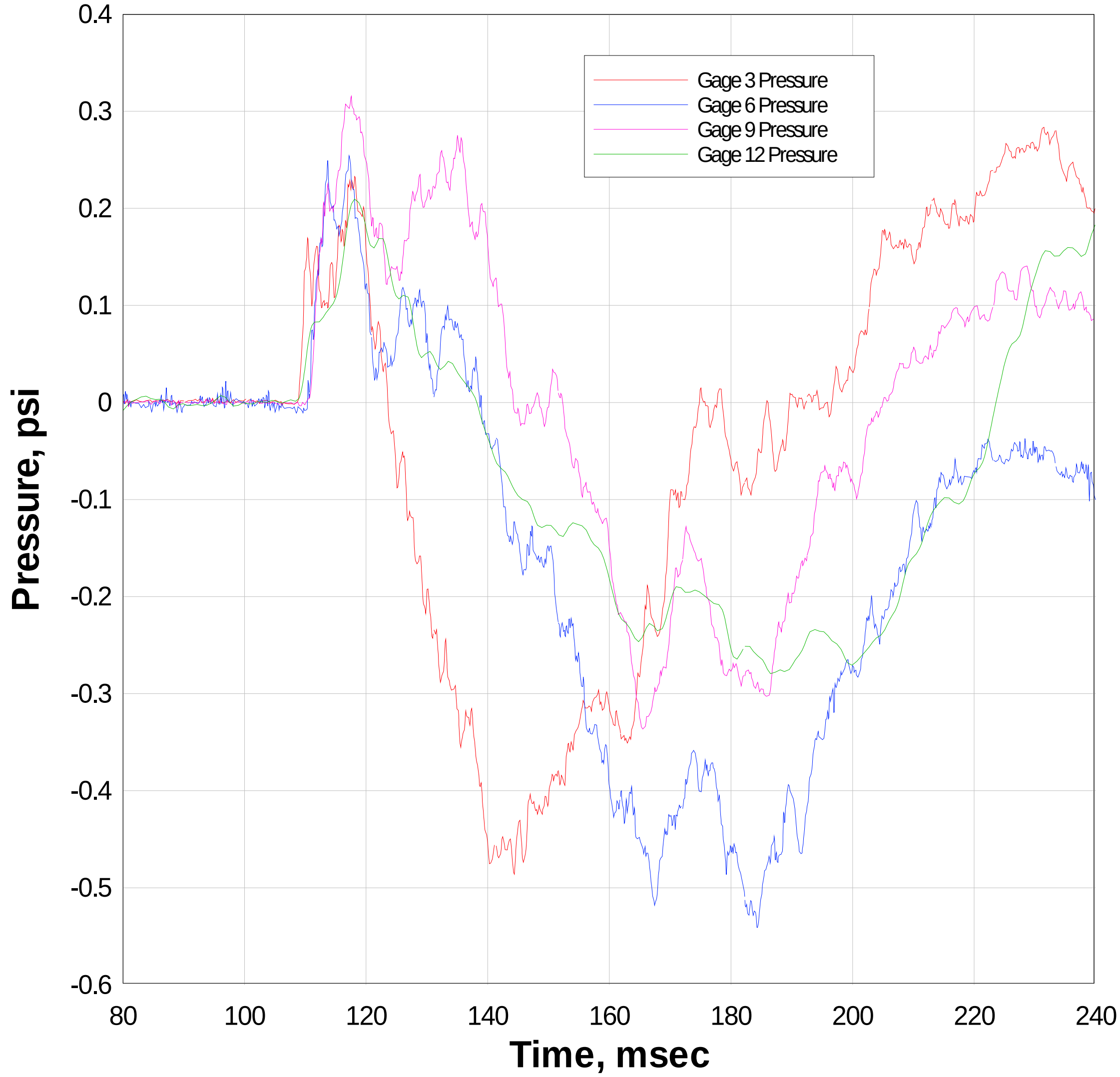


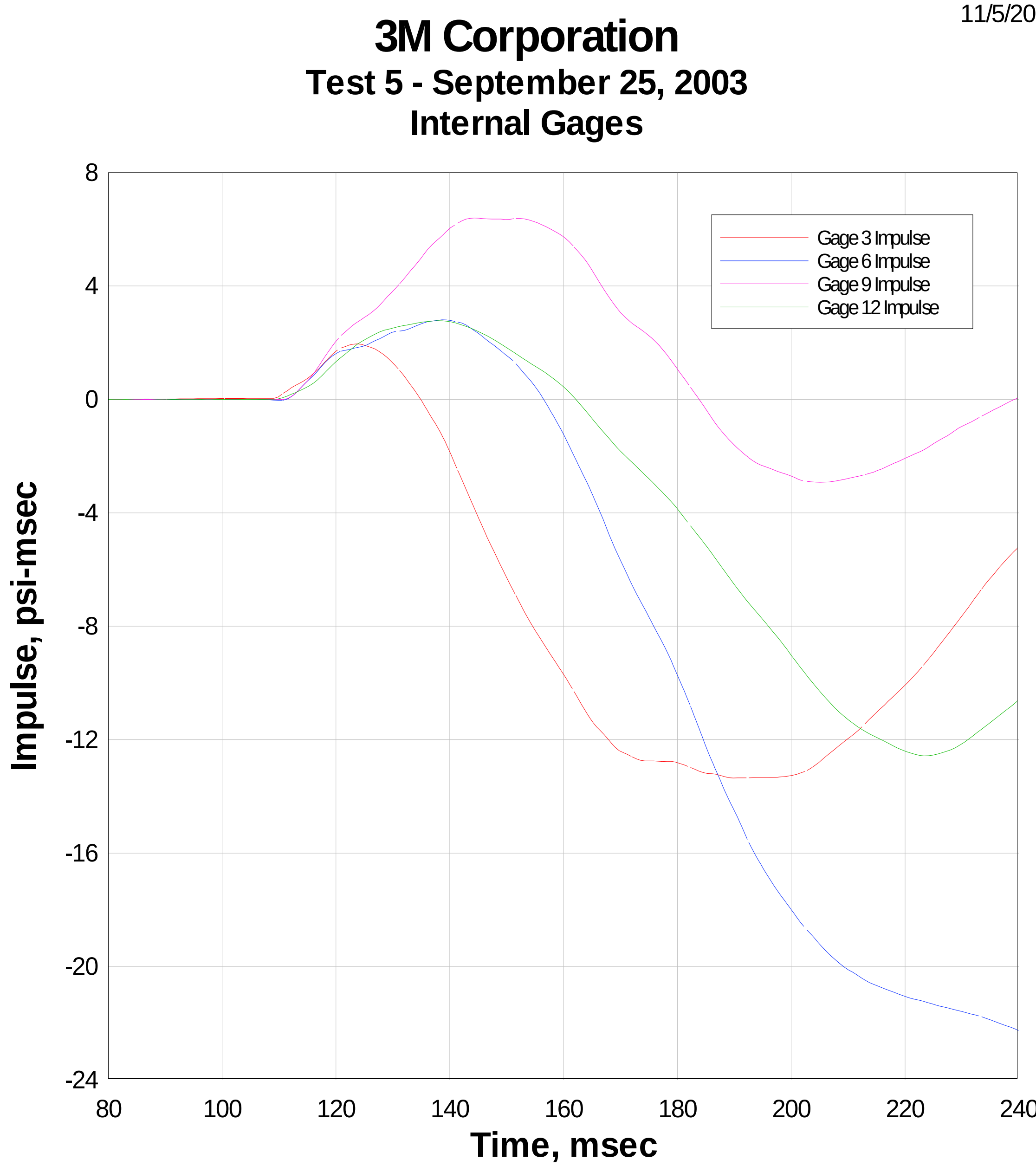


3M Corporation
Test 5 - September 25, 2003
External Gages
Impulse, psi-msec
Time, msec
35
30
25
20
15
10
5
0
-5
-10
80
100
120
140
160
180
200
220
240
Gage 1 Impulse
Gage 2 Impulse
Gage 4 Impulse
Gage 5 Impulse
Gage 7 Impulse
Gage 8 Impulse
Gage 10 Impulse
Gage 11 Impulse

11/5/2003

3M Corporation
Test 5 - September 25, 2003
Internal Gages

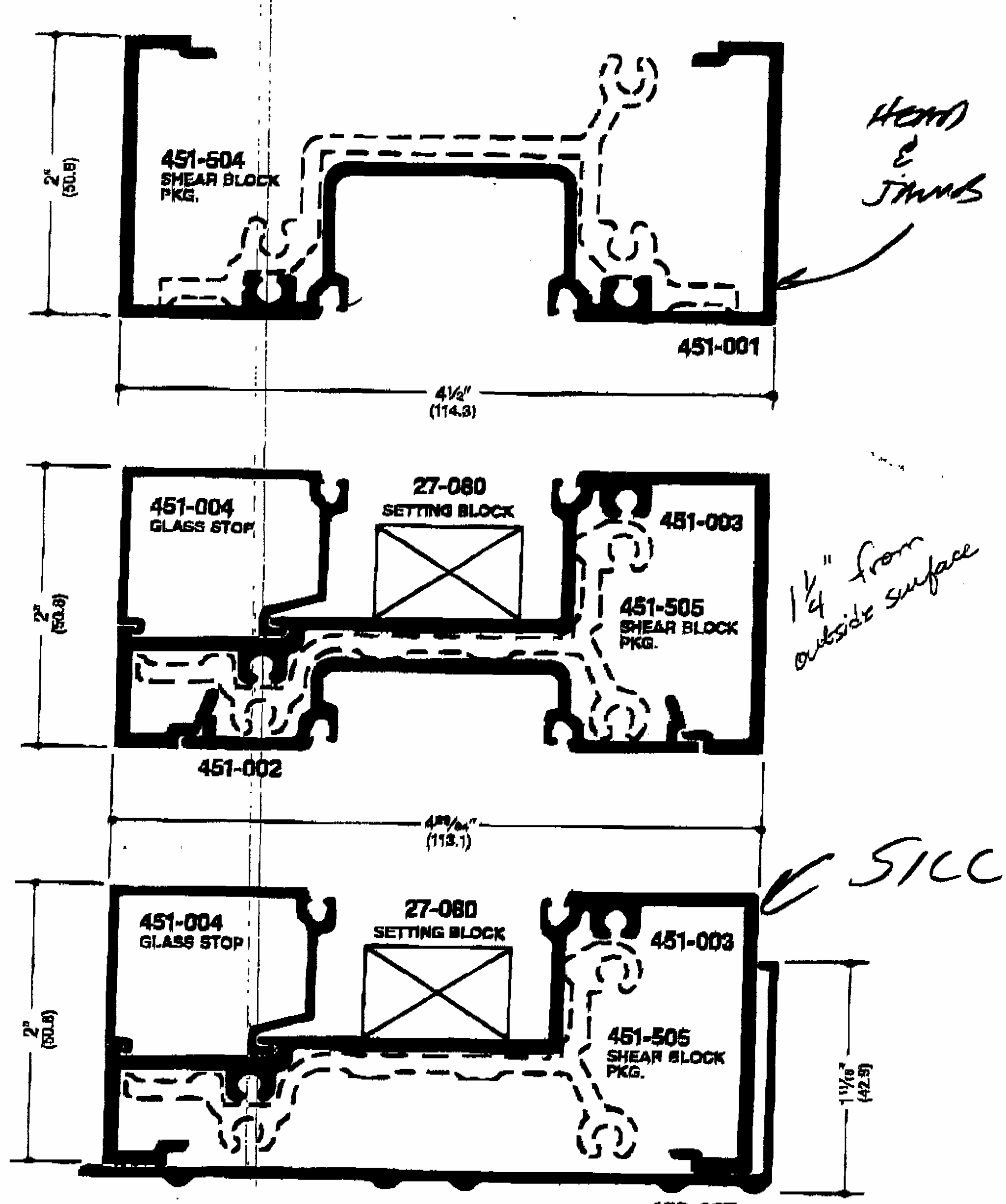



3M Corporation
Test 5 - September 25, 2003
Internal Gages
Impulse, psi-msec
8
4
0
-4
-8
-12
-16
-20
-24
80
100
120
140
160
180
200
220
240
Time, msec
Gage 3 Impulse
Gage 6 Impulse
Gage 9 Impulse
Gage 12 Impulse

APPENDIX C

FRAME AND GLAZING DETAILS

SCREW SPLINE SYSTEM 3



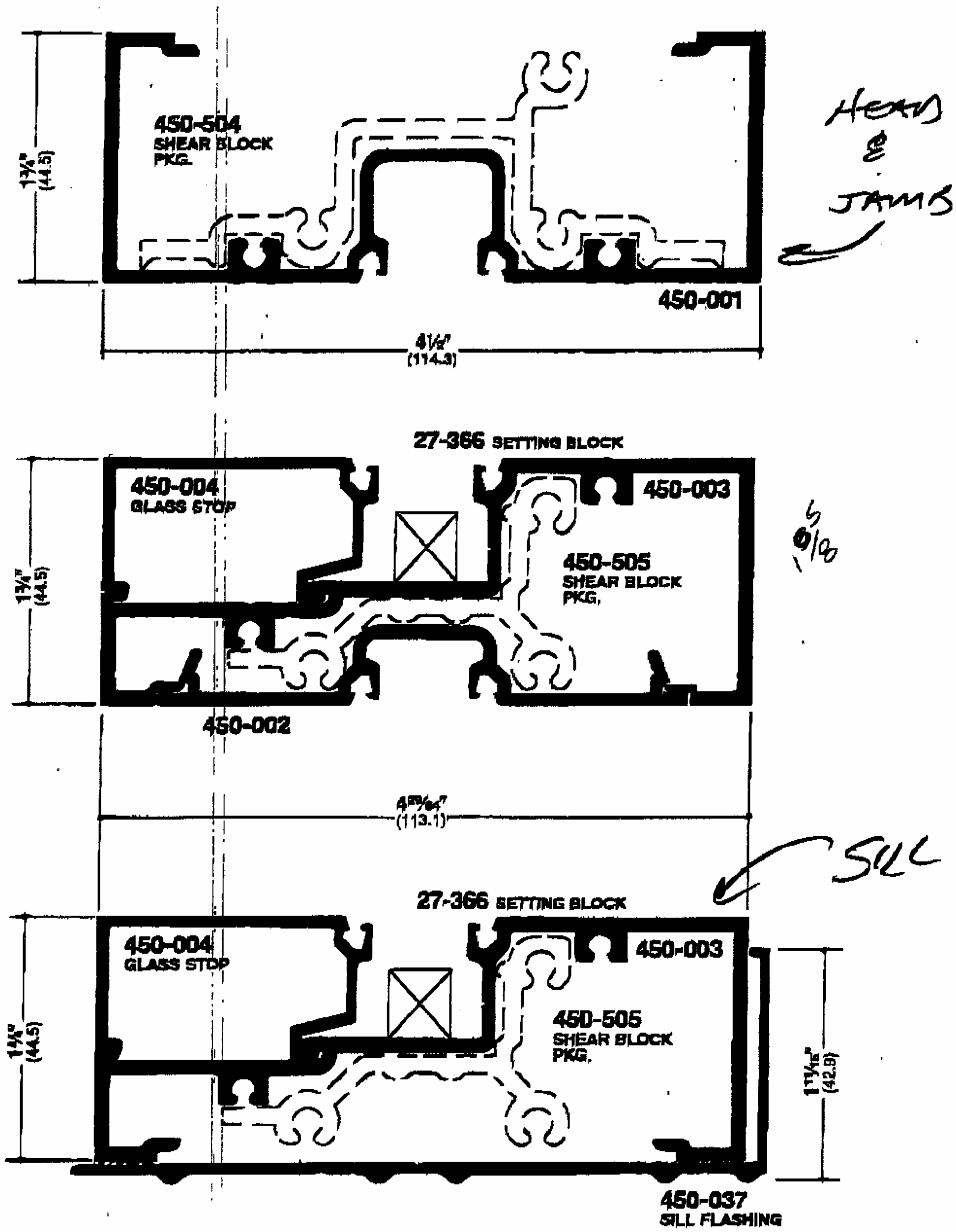
NOTE: SHEAR BLOCK PACKAGES SHOWN ARE FOR ATTACHMENT TO DOOR FRAMES.

TRIFAB® 451

Kawneer
KAWNEER COMPANY INC

LITHO IN U.S.A. JANUARY

SCREW SPLINE SYSTEM 3



NOTE: SHEAR BLOCK PACKAGES SHOWN ARE FOR ATTACHMENT TO DOOR FRAMES.

TRIFAB® 450 FULL SIZE Kawneer KAWNEER COMPANY, INC

APPENDIX D

GLASS FRAGMENT DISTRIBUTION

3M Tests
Conducted September 24 - 25, 2003
Post-Test Measurements
Weight of Glass Fragments in Various Regions
Page 1

Test #	Window #	Window Hazard Condition	Cubicle Region	Fragment Weight in Region (oz)
1	1	3b	3a	1.0
			3b	0.2
	2	3b	3a	2.2
			3b	2.7
	3	4	3a	0.7
			3b	0.6
	4	2	3a	Negligible
			3b	Negligible
2	1	5	3a	13.3
			3b	3.2
	2	4	3a	4.3
			3b	2.8
	3	4	3a	2.4
			3b	10.0
	4	2	3a	Negligible
			3b	Negligible
3	1	3b	3a	1.9
			3b	0.9
	2	3b	3a	3.6
			3b	3.5
	3	3b	3a	9.8
			3b	2.1
	4	2	3a	Negligible
			3b	Negligible
4	1	2	3a	Negligible
			3b	Negligible
	2	3b	3a	3.5
			3b	2.0
	3	5	3a	1.5
			3b	1.5
	4	3a	3a	0.1
			3b	Negligible
5	1	3b	3a	6.9
			3b	4.5
	2	3b	3a	2.2
			3b	4.6
	3	5	3a	1.3
			3b	0.9
	4	4	3a	0.5
			3b	0.6