3M

Scotchshield™ Ultra Security Window Film Systems

Explosive Blast Tests per GSA Security Criteria

Test Site: Energetic Materials Research and Testing Center
Socorro, New Mexico

Conducted by Applied Research Associates, Inc.
September, 2003

Summary: Four high explosive open-air tests were performed to evaluate the hazard mitigation performance of **3M™ Scotchshield™ Ultra Security Window Film Systems** on commercial size windows. The results demonstrated that glass treated with 3M Scotchshield Ultra Security Film offer significant increased protection against the dangers of flying glass caused by explosive blast loads. **Several 3M Scotchshield window film systems met the GSA Security Criteria for Class C Level Buildings.**

3M CONFIDENTIAL

ARA-TR-03-16095.1

Explosive Tests for the Evaluation of 3M Company Window Systems

Prepared by:

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November 2003

Prepared for:

3M Company
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3M Center, 223-2S-24
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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 Company. Four 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 Company. The support and efforts of Mr. Jim Mannix (3M Company'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).

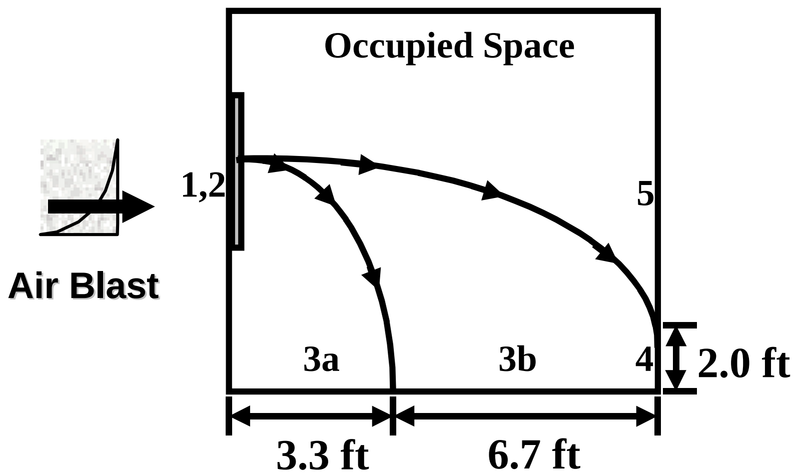
3M Company commissioned ARA to perform open-air high explosive tests from September 24 to September 25, 2003. Four high-explosive tests were conducted, with four window units evaluated in each test. The windows were mounted in enclosed concrete reaction structures.

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 Company, 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 on page 18 for reference.

TEST CONFIGURATION

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.

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.

The charge standoff to each structure for all four tests was 170 ft. The maximum reflected pressure levels for tests 1, 2, 3 and 4, were nominally 4.19 psi, 4.15 psi, 4.23 psi and 4.21 psi respectively. The placement of these structures for this test series is as shown Figure 1, page 10.

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.

INSTRUMENTATION

The reaction structures were instrumented with exterior pressure gages 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 to monitor the infill pressures. Infill pressures from all tests were very small and would not likely pose a hazard to occupants.

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.

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

TEST CHARGE

The explosive charge for all four 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.

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.

TEST MATRIX

A test matrix (Page 16) 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.

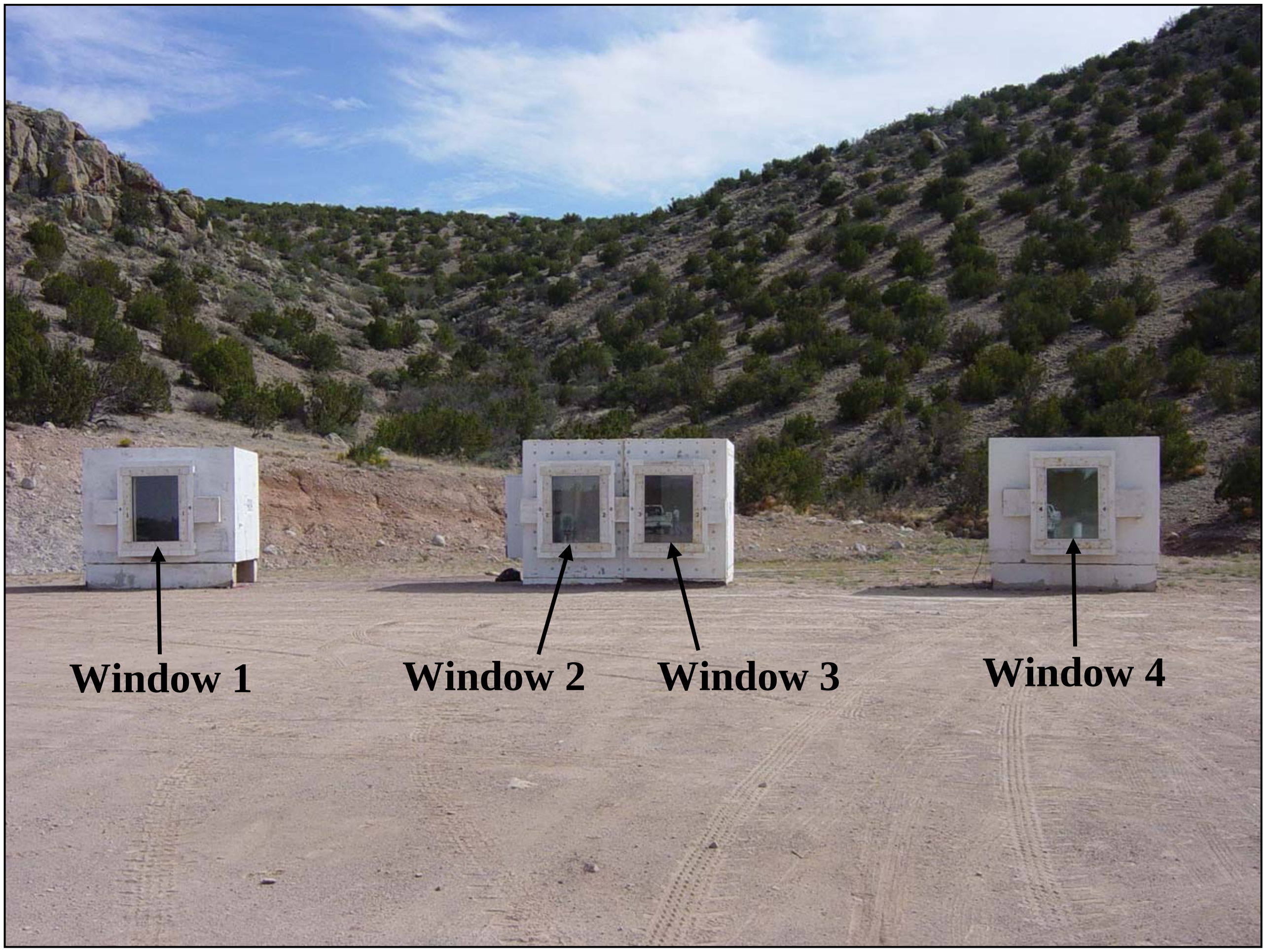


Figure 1 Structure orientation and window nomenclature.

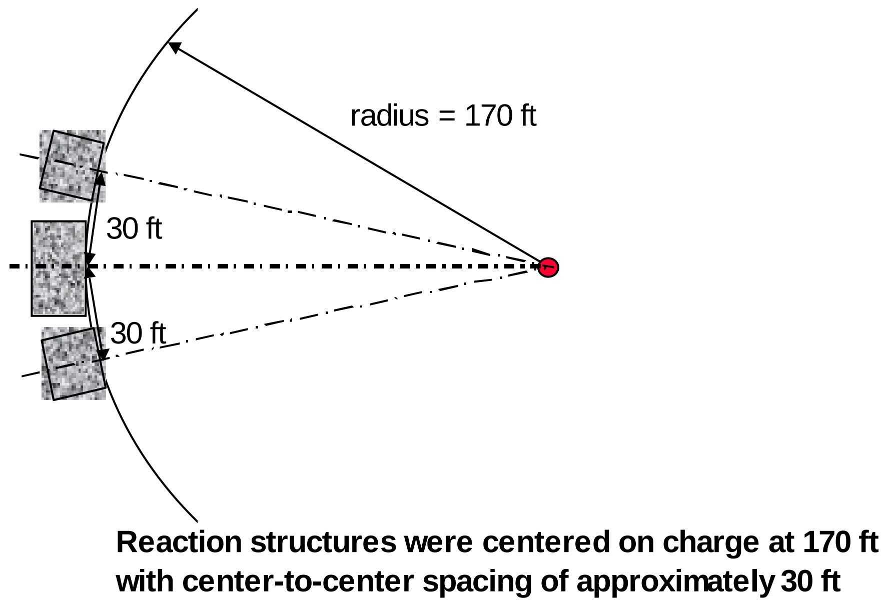


Figure 2 Radial orientation of structures (not drawn to scale).

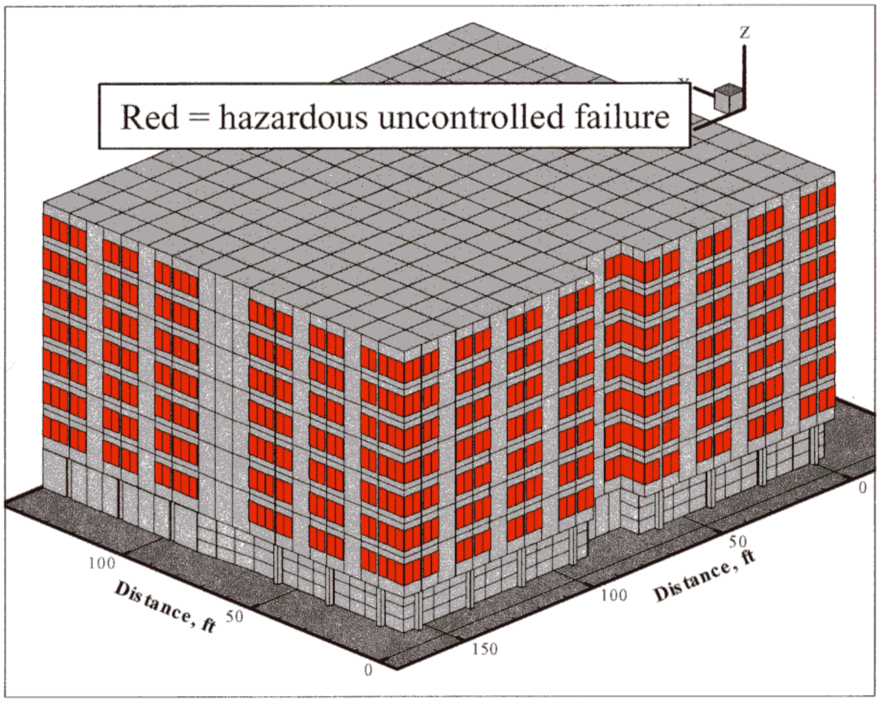
RESULTS SUMMARIES AND MAJOR FINDINGS

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 (see page 17).

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 4 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.



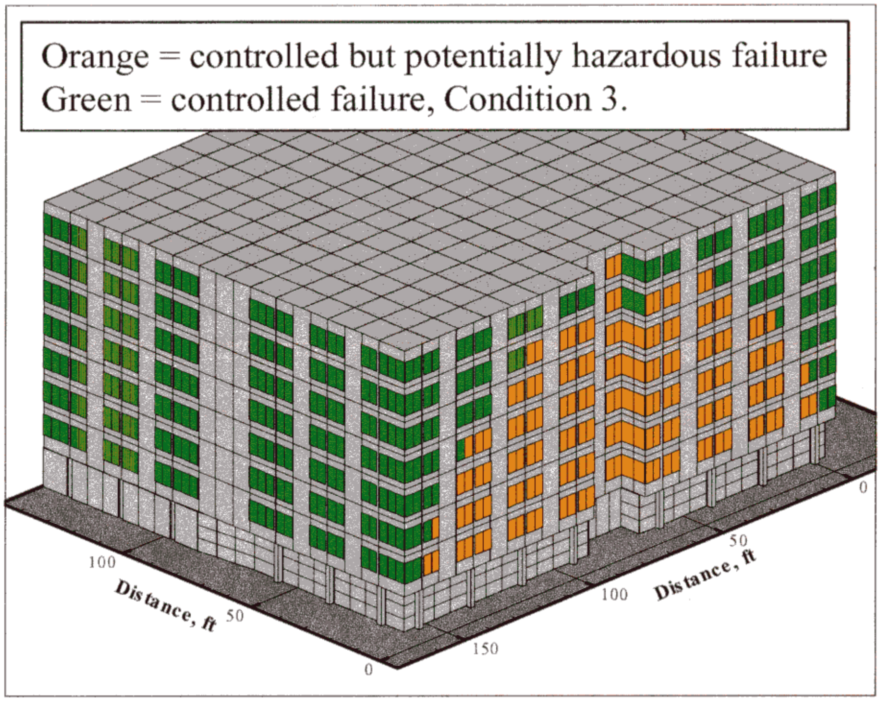


Figure 3. Damage comparison calculations: top calculation = no film; bottom calculation = film retrofits.

CONSOLIDATED RESULTS

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

Table 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 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 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 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

Explosive tests performance results per GSA security criteria
With 3Mtm Scotshieldtm Safety and Security Window films

Test # Standoff distance Peak Pressure	Unit #	Test Articles	Performance level achieved (GSA rating)
Test 1 Standoff = 170 ft Peak Pressure = 4.19 psi	1 2 3 4	¼" AG monolithic, SH8CLARL, 4 side Ultraflex (wet glaze) ¼" AG monolithic, SCLARL400, 4 side Ultraflex (wet glaze) ¼" AG monolithic, SCLARL400, 4 side batten ¼" AG insulated, SCLARL400, 4 side Ultraflex (wet glaze)	3b 3b 4 2
Test 2 Standoff = 170 ft Peak Pressure = 4.15 psi	1 2 3 4	¼" AG monolithic, SH8CLARL, 2 side batten ¼" AG monolithic, SCLARL400, 2 side batten ¼" AG monolithic, Ultra600, 2 side batten ¼" AG insulated, Ultra600, 4 side Ultraflex (wet glaze)	5 4 4 2
Test 3 Standoff = 170 ft Peak Pressure = 4.23 psi	1 2 3 4	¼" AG monolithic, SH8CLARL, 4 side batten ¼" TG monolithic, SH8CLARL, daylight application ¼" AG monolithic, SH8CLARL, daylight application ¼" AG insulated, SCLARL400, 4 side batten	3b 3b 3b 2
Test 4 Standoff = 170 ft Peak Pressure = 4.21 psi	1 2 3 4	¼" AG insulated SH8CLARL, 4 side Ultraflex (wet glaze) ¼" AG insulated Ultra600, daylight application ¼" AG insulated SH8CLARL, daylight application ¼" AG insulated, SH8CLARL, 4 side batten	2 3b 5 3a

Test Notes:
1) All window units had a ½ inch minimum bite
2) All windows were mounted in commercial aluminum frames: clear opening = 46 inches x 64 inches.
3) AG = annealed glass, TG = tempered glass
4) Witness panels were located 120 inched behind window
5) The test bed is situated at an altitude of 6,200 feet 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 ½ inch (glazing edge) x ¾ 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 ½ 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 frames.

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

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

ADDENDUM

EXPLOSIVE BLAST TEST PERFORMANCE RESULTS

KIRTLAND AFB, 1998

3M

Scotchshield™ Ultra Security Window Film Systems

Explosive Blast Tests
per GSA Security Criteria

Test Site: Defense Special Weapons Agency's
Chestnut Test Site, Kirtland AFB, New Mexico

Conducted by Applied Research Associates, Inc.
January 1998

Summary: Six high explosive open-air tests were performed to evaluate the hazard mitigation performance of **3M™ Scotchshield™ Ultra Security Window Film Systems** on commercial size windows. The results demonstrated that glass treated with 3M Scotchshield Ultra Security Film offer significant increased protection against the dangers of flying glass caused by explosive blast loads. **Several 3M Scotchshield window film systems met the GSA Security Criteria for Class C and Class D Level Buildings.**

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St. Paul, MN 55144-1000
1-800-480-1704
www.3m.com/windofilm

APPLIED RESEARCH ASSOCIATES, INC.

Engineering and Applied Science

April 2, 1998

Attn: Mr. James E. Mannix
Market Development Supervisor
Specified Construction Markets Department
3M Center, Building 225-4S-08
St. Paul, MN 55144-1000

Subject: Large Scale Explosive Test Results

Dear Mr. Mannix:

The attached report summarizes the test results for our independent evaluation of your Ultra 400 and 600 film products. The tests were performed by Applied Research Associates, Inc. (ARA) in January 1998 at one of the Defense Special Weapons Agency's test sites on Kirtland AFB in Albuquerque, NM. We performed these tests in compliance with the GSA's test standard protocols "Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings." The GSA method is an adaptation of the ASTM method F1642-96.

Tests were performed using 600 lb. ANFO charges, which are equivalent to a 500-lb. TNT detonation. The tested pressure and impulse levels indicate that 3M™ film products are an appropriate and viable technology for consideration in meeting GSA's glazing protection requirements.

The products that we evaluated clearly provide a significant mitigation of glass fragment hazards under the tested condition. It has been a pleasure assisting you with the evaluation of these important products. If we may be of additional help, please contact me at any time.

Sincerely,

Joseph L. Smith
Director, Security Engineering

112 MONUMENT PLACE ■ VICKSBURG, MS 39180
(601) 638-5401 ■ Fax (601) 634-0631

RESULTS SUMMARIES AND MAJOR FINDINGS

IMPLICATION OF RESULTS AND GSA SECURITY REQUIREMENTS

The 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 security classifications of Levels C and D. Level A and Level B buildings, which are lower in security classification than C and D buildings, require no specific performance criteria though use of certain window types in Level A and B buildings is prohibited. Level E GSA buildings are very high security buildings and the generalized criteria do not give guidance for these buildings.

The airblast loading that is used in the window design for GSA Level C and Level D buildings is based on a particular threat size at the worse case threat scenario location based on available perimeter standoff. Realistic limits are placed on the maximum design loads with the assumption that some damage and potential injury are acceptable. For Level C buildings, any portion of the building that is predicted to experience blast pressures of _ psi or higher due to the design threat at the site perimeter must be designed to the maximum predicted load. For Level D buildings the design is to correspond to the actual predicted blast environment.

For GSA Level C Buildings the maximum required design load is a triangular blast load that instantaneously rises to 4 psi and decays linearly to zero over a duration of 13.9 milliseconds (msec). The performance required for GSA Level C buildings is a Condition 4 or lower. The impulse that this blast load generates is 27.8 psi-msec. The impulse generated during testing at 4 psi was nominally 28-30 psi-msec. Thus, window specimens that performed to a Condition 4 or better at 4 psi from this test series can be considered for use in GSA Level C Buildings. This is true for windows that are the size of those tested or smaller. Framing conditions specific to a particular project must be addressed separately.

For GSA Level D buildings the maximum required design load is a triangular blast load that instantaneously rises to 10 psi and decays linearly to zero over a duration of about 17.9 msec. All windows that performed to a Condition 3 or better can be considered for use on Level D buildings <u>up to the maximum pressure and impulse level at which then were tested</u>. This is true for windows that are the size of those tested or smaller. Framing conditions specific to a particular project must be addressed separately. The SHR extension (significant-hazard-reduction) is used to distinguish performances within the same given GSA hazard condition, i.e. a 3-SHR is a better performance rating in that the tested sample provided significantly more hazard mitigation compared to that of a standard 3.

CONSOLIDATED RESULTS

The results of the tests were consolidated into several tables. Each table shows results for a particular glass type and thickness for the various configurations tested.

Table 1 shows results for 1/4-inch thick annealed glass specimens. The test article designation gives the test

number then the window number. For example “3M-1-4”indicates 3 M Test 1 Window 4. Six of the seven 1/4-inch thick monolithic annealed glass windows tested with security window films achieved a GSA Condition 3 at 4 psi.

Table 1 Summary of results for 1/4-inch thick monolithic annealed glass windows.

1/4 inch AG Specimens	**Summary**							
Test Article	3M-1-4	3M-1-1	3M-1-2	3M-1-3	3M 2-3	3M 2-4	3M-4-1	3M-4-3
Security Film	No film	Ultra 400	Ultra 400	3M 7 mil	Ultra 400	Ultra 400	Ultra 600	Ultra 400
Attachment	N/A	day-lite batten	4-sided batten	4-sided batten	4-sided batten	2-sided batten	4-sided glazed	wet
Window Frame	steel	steel	steel	steel	aluminum	steel	steel	aluminum
Nom. Peak pressure, psi	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Condition	5	3-SHR	3-SHR	3-SHR	5-SHR	3-SHR	3	3-SHR

Table 2 gives results for the 1/4-inch thick monolithic HSG windows that were tested. Both window systems performed quite well and provided significant glass fragment hazard mitigation at the respective blast pressure levels at which they were tested.

Table 3 gives results for the 1/4-inch thick monolithic TTG windows that were tested. The protected TTG windows performed very well in providing glass fragment mitigation up to blast pressures as high as 5 psi.

Table 4 gives results for 3/8-inch thick monolithic TTG windows and Table 5 gives results for 1/2-inch thick monolithic TTG windows. Three of these four windows performed very well at providing protection to building occupants from glass fragmentation at significantly high blast environments. Similarly, Table 6 shows significant fragment mitigation performance for filmed windows versus unprotected for the 1-inch insulated TTG units.

Table 2 Summary of results for 1/4-inch thick monolithic heat strengthened glass windows.

1/4 inch HSG Specimens	**Summary**	
Test Article	3M-2-1	3M-3-3
Security Film	Ultra 400	Ultra 600
Attachment	4-sided batten	4-sided batten
Window Frame	steel	steel
Nom. Peak pressure, psi	4.0	5.0
Condition	3-SHR	3-SHR

Table 3 Summary of results for 1/4-inch thick monolithic thermally tempered glass windows.

1/4 inch TTG Specimens	**Summary**						
Test Article	3M-2-2	3M-4-2	3M-4-4	3M 3-1	3M 3-2	3M-3-4	3M-6-1
Security Film	Ultra 400	Ultra 400	Ultra 400	Ultra 400	Ultra 600	Ultra 400	Ultra 400
Attachment	4-sided batten	wet glazed	4-sided batten	4-sided batten	4-sided batten	day-lite	day-lite
Window Frame	aluminum	aluminum	steel	steel	steel	steel	steel
Nom. Peak pressure, psi	4.0	4.0	4.0	5.0	5.0	5.0	9.0
Condition	3-SHR	2	3-SHR	3-SHR	2	3	5

Table 4 Summary of results for 3/8-inch thick monolithic thermally tempered glass windows.

3/8 inch TTG Specimens	**Summary**	
Test Article	3M-5-1	3M-5-4
Security Film	Ultra 400	Ultra 400
Attachment	4-sided batten	day-lite
Window Frame	steel	steel
Nom. Peak pressure, psi	9.0	9.0
Condition	3	3-SHR

Table 5 Summary of results for 1/2-inch thick monolithic thermally tempered glass windows.

1/2 inch TTG Specimens	**Summary**	
Test Article	3M-5-2	3M-5-3
Security Film	Ultra 600	Ultra 600
Attachment	4-sided batten	4-sided batten
Window Frame	steel	steel
Nom. Peak pressure, psi	9.0	9.0
Condition	2	5-SHR

Table 6 Summary of results for 1 inch insulated thermally tempered glass windows.

1inch Insulated TTG, 1/4" inch TTG + 1/2" airgap + 1/4" TTG	**Summary**		
Test Article	3M-6-4	3M-6-2	3M-6-3
Security Film	No film	Ultra 400	Ultra 600
Attachment	N/A	4-sided batten	4-sided batten
Window Frame	steel	steel	steel
Nom. Peak pressure, psi	9.0	9.0	9.0
Condition	5	3-SHR	2

MAJOR FINDINGS

This test series showed that the 3M Ultra series of security window films provide significant benefit in mitigating window glass fragment environments in blast. Per the GSA criteria the 4-mil Ultra 400 and 6-mil Ultra 600 3M films performed to required levels for many of the configurations tested. Both products performed well up to blast pressures as high as 9 psi. Many configurations tested performed to the required level of protection for GSA Level C buildings at the maximum design load. Several others performed to the required level of protection for Level D buildings up to 9 psi and for an impulse of about 50 psi-msec. Another major finding of this test series is that the mechanical batten system and the wet glazed systems provide an adequate attachment to aluminum frames for the conditions evaluated. It is likely that the connection of the aluminum frame into the exterior wall would be the weakest part of a typical aluminum framed window system. This must be handled carefully so that a balanced window system is developed.

Explosive Tests Performance Results per GSA Security Criteria
With 3M™ Scotchshield™ Ultra Security Window Films

Test # / Standoff / Peak pressure*	Unit #	Test Articles	Performance Level Achieved (GSA Rating)
Test 1	1	1/4-in. mono. AG, Ultra 400 w/day-life application	3-SHR
Standoff = 190 ft	2	1/4-in. mono. AG, Ultra 400 w/4-sided batten	3-SHR
Peak pressure = 4.0 psi	3	1/4-in. mono. AG, 7-mil film w/4-sided batten	3-SHR
	4	1/4-in. mono. AG (no film)	5
Test 2	1	1/4-in. mono. HSG, Ultra 400 w/4-sided batten	3-SHR
Standoff = 190 ft	2	1/4-in. mono. TTG, AI frame, Ultra 400 w/4-sided batten	3-SHR
Peak pressure = 4.0 psi	3	1/4-in. mono. AG, Al frame, Ultra 400 w/4-sided batten	5-SHR
	4	1/4-in. mono. AG, Ultra 400 w/2-sided batten	3-SHR
Test 3	1	1/4-in. mono. TTG, Ultra 400 w/4-sided batten	3-SHR
Standoff = 165 ft	2	1/4-in. mono. TTG, Ultra 600 w/4-sided batten	2
Peak pressure = 5.0 psi	3	1/4-in. mono. HSG, Ultra 600 w/4-sided batten	3-SHR
	4	1/4-in. mono. TTG, Ultra 400 w/day-lite application	3
Test 4	1	1/4-in. mono. AG, Ultra 600 w/4-sided batten	3
standoff = 190 ft	2	1/4-in. mono. TTG, Al frame, Ultra 400 w/4-sided wet glaze	2
peak pressure = 4.0 psi	3	1/4-in. mono. AG, A1 frame, Ultra 400 w/4-sided wet glaze	3-SHR
	4	1/4-in. mono. TTG, Ultra 400 w/4-sided batten	3-SHR
Test 5	1	3/8-in. mono. TTG, Ultra 400 w/4-sided batten	3
Standoff = 121 ft	2	1/2-in. mono. TTG, Ultra 600 w/4-sided batten	2
Peak pressure = 9.0 psi	3	1/2-in. mono. TTG, Ultra 400 w/4-sided batten	5-SHR
	4	3/8-in. mono. TTG, Ultra 400 w/day-life application	3-SHR
Test 6	1	1/4-in. mono. TTG, Ultra 400 w/day life application	5
Standoff=121 ft	2	1-in. insulated TTG, Ultra 400 w/4-sided batten	3-SHR
Peak pressure = 9.0 psi	3	1 in. insulated TTG, Ultra 600 w/4-sided batten	2
	4	1 in. insulated TTG (no film)	5

* Standoff distance and peak pressure have been adjusted for altitudes of 5200 ft.

Notes:

A. AG = annealed glass, HSG = heat strengthened glass, TTG = thermally tempered glass
B. Windows were mounted in heavy steel frames unless otherwise noted.
C. Window sizes for all steel frames were: 48 x 66 inches; clear opening 46 x 64 inches.
D. Window sizes for aluminum frames were: 461/8 x 64 1/8 inches; clear opening = 45 1/2 x 63 1/2 inches.
E. Witness panels were located 116 inches behind window.
F. The SHR stands for significant-hazard-reduction. This designation is used to distinguish performances within the same given GSA hazard condition; i.e. a 3-SHR is a better performance rating in that the tested sample provided significantly more hazard mitigation compared to that of a standard 3. The SHR designation can be given for GSA conditions 3-5.
G. Tested at the Defense Special Weapons Agency Chestnut Site, Kirtland AFB, New Mexico.