Notice

Since the production of this document, Solar Gard has been purchased by Saint-Gobain Performance Plastics Corporation. Solar Gard is now a subsidiary of Saint-Gobain. All references within this document to Bekaert, Bekaert Specialty Films or Bekaert Specialty Films LLC, including but not limited to legal notes, copy and or copyrights are null and void. All rights and responsibilities expressed or written within this document have been transferred from Bekaert Specialty Films, LLC to Saint-Gobain.

The company name in the following report could not be retroactivly changed from Bekaert to Solar Gard. The integrity of the product represented in the test has not changed and the results for this product are still valid. As the test is update the new report will reflect the Solar Gard name.

Saint-Gobain Performance Plastics
4540 Viewridge Avenue
San Diego, CA 92123 USA
Tel: 877 345 3478
E-mail: info@solargard.com
www.solargard.com

Solar Gard®
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Toll Free: 800-282-9031
Fax: 727-540-0132
www.armorcoatfilms.com

Armorcoat® Safety And Security Films

Explosive Blast Tests
Per GSA Security Criteria

Test Site: Chestnut Test Site, Kirtland Air Force Base, New Mexico
Owned and Operated by Defense Threat Reduction Agency

Conducted By: Applied Research Associates, Inc.
Security Engineering Group
February 2000

Summary: A number of high explosive tests were conducted in an open air environment to determine the hazard mitigation value of **Bekaert Specialty Films, LLC's Armorcoat® safety and security window films** installed to commercially available windows with annealed glass. These films were tested with and without "anchoring" systems. The results demonstrated that glass filmed with **Armorcoat** provided significant hazard reduction with regard to flying glass due to explosive blast loads. **These Armorcoat films as manufactured by Bekaert Specialty Films, LLC, met the GSA Security Criteria for Level C buildings for the tested configuration. Certain tested films met the overpressure requirements of the Level D Buildings, but due to range restrictions were only tested to 60% of the impulse requirement.**

APPLIED RESEARCH ASSOCIATES, INC.

Engineering and Applied Science

November 3, 2001

Bekaert Specialty Films, LLC
Attn: Mr. Steve Hojnowski
4540 Viewridge Ave.
San Diego, CA 92123

Reference: Bekaert Letter Dated 10-12-2001

Subject: Name Change of Company

Dear Sir:

I have reviewed your letter dated October 12, 2001 related to the change in name of Material Sciences Corporation to Bekaert Specialty Films, LLC. As I understand your letter, Bekaert Specialty Films, LLC purchased the Specialty Films, Inc. division of Material Sciences Corporation. Applied Research Associates performed explosive tests on MSC film products in the Feb-March 2000 timeframe. The test report was produced under the company's name MSC Specialty Films at that time. The test results and conclusions in the test report should directly apply under your new name providing that the material production process and materials used remain the same as that tested.

We look forward to assisting you in the future under your new name.

Sincerely,

Joseph L. Smith
Vice President
Director, Security Consulting Services

112 MONUMENT PLACE ■ VICKSBURG, MS 39180
(601) 638-5401 ■ FAX (601) 634-06-31

Engineering and Applied Science

ARA-TR-00-0041.1-3

Explosive Tests For the Evaluation of the Glass Fragment Mitigation Characteristic of MSC Specialty Films Inc. Security Window Films

Prepared by:

Joseph L. Smith, Director of Security Engineering
James T. Brokaw, Senior Blast/Security Engineer

Applied Research Associates, Inc.
Security Engineering Group
112 Monument Place
Vicksburg, MS 39180

August 2000

Prepared for:

MSC Specialty Films Inc.
4540 Viewridge Avenue
San Diego, CA 92123

PREFACE

Applied Research Associates, Inc. (ARA) conducted high-explosive tests on February 15-March 3, 2000, in order to evaluate the response of security window film to blast loads. Five high explosive tests were conducted and four windows were evaluated in each test for a total of 20 window samples. This report documents the findings of these tests.

The tests were performed at the Chestnut Test Site on Kirtland Air Force Base in New Mexico. This test site is owned and operated by the Defense Threat Reduction Agency (DTRA), which is the US Government's lead agency for force protection. A special thanks is extended to DTRA for allowing ARA use of the test site. This work was sponsored by MSC Specialty Films Inc. The support and efforts of MSC Specialty Films Inc. are acknowledged and greatly appreciated

NAME	**TITLE**	**PROJECT ASSIGNMENT**
James T. Brokaw	Senior Engineer	Principal investigator, field test engineer
Joseph L. Smith	Director, Security Engineering Group	Program oversight, technical review
Robert E. Walker	Principal Engineer	Technical review
Larry M. Bryant	Senior Engineer	Analysis
Charles Ellison	Staff Engineer	Analysis
Paul Gay	Engineering Aide	Analysis
Donald Cole	Principal Engineer	Test site oversight
Sue Babcock	Principal Engineer	Test conductor
Rob Cilke	Senior Engineer	Video analysis support
Manny Davilla	Technician	Photography
Jeff Gentry	Technician	Test bed setup
Lonnie Bamert	Technician	Explosives

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. In cooperation with the Defense Threat Reduction Agency, Applied Research Associates conducted tests to assess the capability of security window film to reduce the hazards of flying glass shards during an explosion. Propelled by the forces of a terrorist bomb, glass fragments cause large numbers of serious injuries.

The US General Services Administration (GSA) developed criteria for evaluation of acceptable levels of protection from the glass fragment hazards in a terrorist bombing. These criteria are part of the comprehensive security criteria (GSA Security Criteria, Final Working Version, January 1997) developed by the GSA, which includes physical security, electronic security, and many other criteria for blast considerations. 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. The current GSA Test Procedure is included in Appendix A.

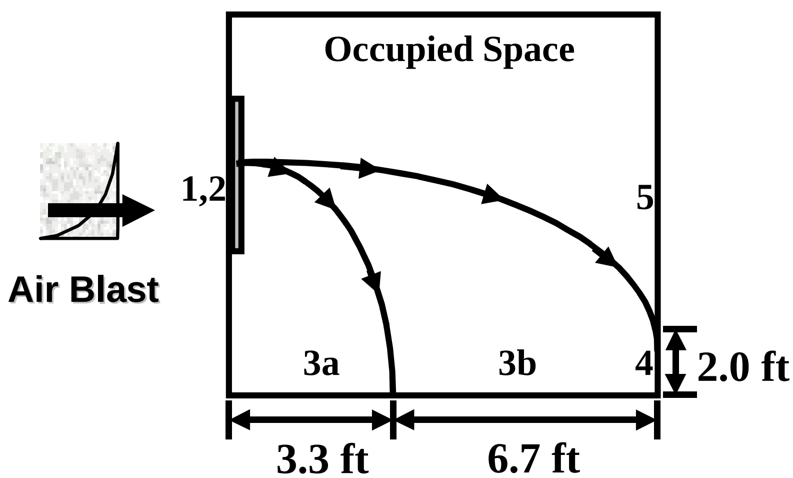
MSC Specialty Films Inc. commissioned ARA to perform a series of five open-air high explosive tests in order to evaluate the performance of security window film products. The tests were conducted from February 15 to March 3, 2000. Four windows were evaluated in each test for a total of 20 windows. The test data collected in this effort will provide useful information for many other government and civilian entities, both domestic and foreign, that are responsible for security planning of building facilities.

The test used the GSA protocol in Appendix A. The windows were mounted in enclosed concrete reaction structures. The response of each window was captured with high-speed film and still photography. An exterior high-speed camera and an exterior normal-speed video camera were used to capture the views of the structures and the explosive detonation for each test. The reaction structures were instrumented with pressure gages to measure the exterior reflected pressure on the specimens and the internal pressure in the structures.

The test charge was 600 lb of Ammonium Nitrate and Fuel Oil (ANFO), which is equivalent to 500 lb of TNT. The standoff distance to the structures was varied to affect specific peak pressures on the test specimens.

A thorough test matrix was developed to explore the effect of film thickness and attachment method on window response. The nominal window size for the tests was 4 ft by 5-1/2 ft. One-fourth inch thick annealed glass was used during testing. The windows were tested in commercially available aluminum storefront window frames. The glass type and film attachment method for each window is given in the summary and test description for each test.

The GSA glass fragment hazard rating scheme is presented graphically and is described in the table which follows. The 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. MSC Specialty Films Inc. safety/security films provided significant reductions in glass fragment hazards versus unprotected windows. The films performed well at mitigating hazard in monolithic, ¼ inch annealed glass window systems. Different film attachment methods performed to specified criteria for GSA Level C buildings up to a 4 psi (28 psi-msec) peak blast pressure. Thicker film with attachment system performed to a GSA performance condition 3 at 10 psi and 48 psi-msec.

RESULT SUMMARIES AND CONCLUSIONS

The GSA Security Criteria requires that windows meet a certain level of performance for a particular blast 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 blast performance criteria though the use of certain window types in Level A and B buildings is prohibited. Level E 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 worst-case threat scenario location given the 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 ½ psi or higher due to the design threat at the site perimeter must be designed up 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 blast load for windows is a triangular blast load that instantaneously rises to 4 psi and decays linearly to zero over a duration of 14 milliseconds (msec). The performance required for GSA Level C buildings is a Condition 4 or lower. The associated impulse requirement is 28 psi-msec. Thus, window specimens that performed to a Condition 4 or lower at 4 psi/28 psi-msec from this test series can be considered for use in GSA Level C Buildings. This is generally true for windows that are the size of those tested or smaller. Framing and anchorage conditions specific to a particular project must be addressed separately.

For GSA Level D buildings, the maximum required design load for windows is a triangular blast load that instantaneously rises to 10 psi and decays linearly to zero over a duration of about 17.9 msec (i.e., 89 psi-msec impulse). All windows that performed to a Condition 3 or better can be considered for use on Level D buildings up to the maximum pressure and impulse level at which they were tested. 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.

Interagency Security Committee (ISC) Security Criteria are similar with minor modifications.

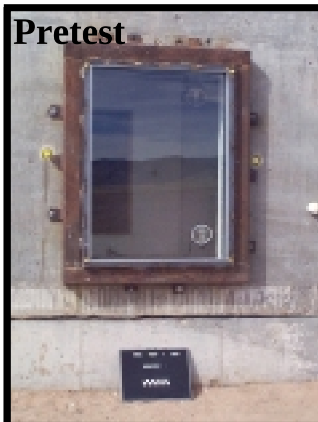
Result Summaries

Test windows were constructed with standard commercial aluminum frames and ¼ inch annealed glass. The windows were tested under conditions consistent with the "US General Services Administration (GSA) Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loading" (Appendix A). Twelve test articles were tested at GSA Performance Criteria for Level C buildings 4 psi (28 psi-msec). Eight test articles were tested at a higher pressure loading of 10 psi. The results for the test articles at 4 psi (28 psi-msec) are summarized in Table 4.1 through Table 4.3. The articles tested at 10 psi (48 psi-msec) are summarized in Table 4.4.

Table 4.1 presents results of test articles using daylight application of film when subject to airblast loading of 4 psi (28 psi-msec). Film was installed in a daylight application with a 1/16 inch or smaller gap between the edge of the window film and the window frame. Each of the following test articles with daylight application surpassed the GSA Performance Criteria requirements for Level C buildings (performance conditions 1 through 4 are acceptable).

Peak Pressure (PSI)	Test Article	Film	Application Method	GSA Performance Condition
4.3	MSC-1-1	No film	---	5
4.3	MSC-1-3	4-mil	daylight	3b
4.3	MSC-1-2	7-mil	daylight	3b
4.3	MSC-1-4	8-mil, 2 ply	daylight	3b

Table 4.1 Summary of results for daylight installed film at 4-psi (28 psi-msec) pressure on ¼ inch annealed glass (46 × 64 inch window panes).


Pretest


Post-Test


Post-Test


Post-Test

Test 1, Window 1,
4.3 psi, 28.7 psi-msec

- 1/4" AG, no film
- Glazing failed and entered the structure at high velocity
- 99% of glass entered structure, impacted witness panel both above and below 2 ft


Pretest

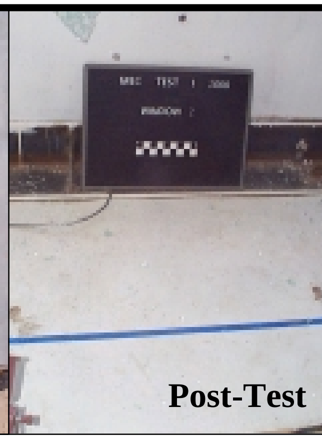

Post-Test


Post-Test

Test 1, Window 3,
4.3 psi, 28.7 psi-msec

- 1/4" AG, 4-mil daylight film
- Glazing cracked and film tore but was partially retained in frame
- Glazing resting on sill, few fragments entered the structure, no impacts on witness panel

Pretest

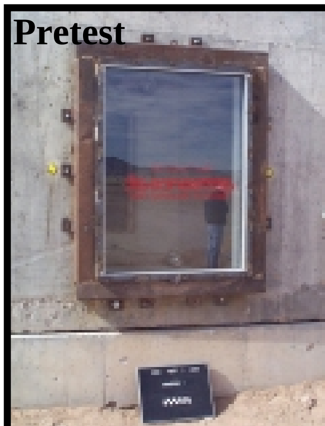


Post-Test

Post-Test

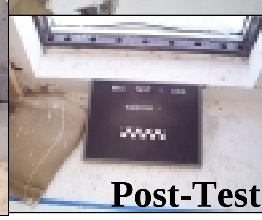
Test 1, Window 2,
4.3 psi, 28.7 psi-msec

- 1/4" AG, 7-mil daylight film
- Glazing cracked and film tore
- Glazing landed approximately 2 ft in front of structure, few fragments entered the structure, no impacts on witness panel



Pretest

Post-Test



Post-Test

Post-Test

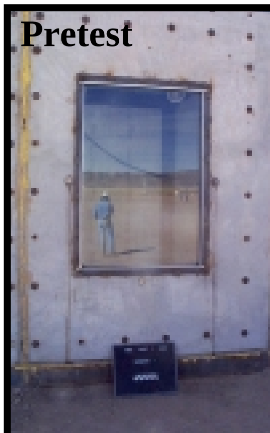
Test 1, Window 4,
4.3 psi, 28.7 psi-msec

- 1/4" AG, 8-mil daylight film
- Glazing cracked and film tore but was partially retained in frame
- Glazing was drawn out of the structure, 20" farthest extent of glazing

Table 4.2 presents results of test articles using two-sided mechanical attachment of film when subject to airblast loading of 4 psi (28 psi-msec). Film was installed with the right and left side of the film anchored by a mechanical attachment. The film extended under the attachment and was secured to the frame by a metal batten and self tapping screws. Each of the following test articles passed the GSA Performance Criteria for Level C buildings (performance conditions 1 through 4 are acceptable).

Peak Pressure (PSI)	Test Article	Film	Attachment Method	GSA Performance Condition
4.2	MSC-2-2	4-mil	2-sided mechanical	3b
4.2	MSC-2-3	7-mil	2-sided mechanical	3b
4.2	MSC-2-1	8-mil, 2 ply	2-sided mechanical	3b
4.2	MSC-2-4	14-mil, 3 ply	2-sided mechanical	3b

Table 4.2 Summary results for film with 2-sided mechanical attachment at 4 psi, 28 psi-msec pressure on ¼ inch annealed glass (46 × 64 inch window panes).



Pretest

Post-

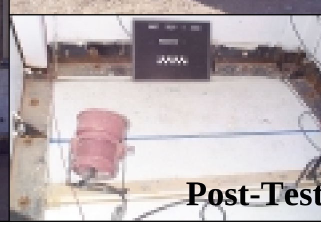
Post-Test

Test 2, Window 2,
4.2 psi, 29.0 psi-msec

- 1/4" AG 4-mil 2-sided film
- Glazing failed and film tore
- Few fragments inside structure, no impacts on witness panel, 3 large pieces of glazing in front of structure (maximum extent 20 ft)

Pretest

Post-Test

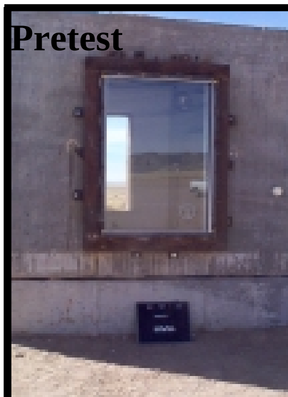


Post-Test

Post-Test

Test 2, Window 3,
4.2 psi, 29.0 psi-msec

- 1/4" AG, 7-mil 2-sided film
- Glazing failed and film tore
- Few fragments inside structure, no impacts on witness panel, window on ground outside structure (maximum extent 4 ft)



Test 2, Window 1,
4.2 psi, 29.0 psi-msec

- 1/4" AG, 8-mil 2-sided film
- Glazing failed and film tore but was partially retained in frame
- Few fragments inside structure, no impacts on witness panel

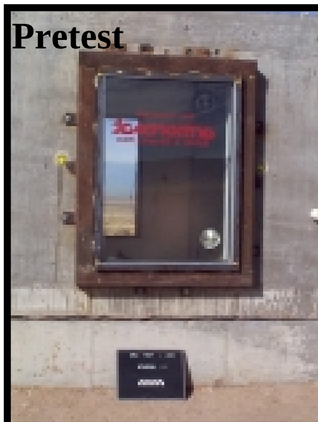
Test 2, Window 4,
4.2 psi, 29.0 psi-msec

- 1/4" AG, 14-mil 2-sided film
- Glazing failed and film tore but was partially retained in frame
- Few fragments inside structure, no impacts on witness panel

Table 4.3 presents results of test articles using four-sided mechanical attachment of film or a four-sided wet glaze attachment when subject to airblast loading of 4 psi. In the four-sided attachment, film was installed with the film anchored by a mechanical attachment on each side of the window frame. The film extended under the attachment and was secured to the frame by a metal batten and self tapping screws. In the wet-glazed installation, the film was installed as a daylight application and then ½ inch of the film surface was secured to ½ inch of the frame (excluding the glazing bead) using a bead of Dow-Corning 995 structural silicone adhesive in a chamfered application. Each of the following test articles passed the GSA Performance Criteria for Level C buildings (conditions 1 through 4 are acceptable).

Peak Pressure (PSI)	Test Article	Film	Attachment Method	GSA Performance Condition
4.4	MSC-3-1	8-mil, 2-ply	4-sided mechanical	3a
4.4	MSC-3-4	8-mil, 2-ply	Wet Glazed	3a

Table 4.3 Summary of results for film with four-sided mechanical attachment or four-sided wet glaze at 4 psi (28 psi-msec) on ¼ inch annealed glass (46×64 inch window panes).



Test 3, Window 1,
4.4 psi, 28.0 psi-msec

- 1/4" AG, 8-mil 4-sided film
- Glazing cracked but film was retained in frame
- Few fragments entered structure, fragments to 23 ft in front of structure

Test 3, Window 4,
4.4 psi, 28.0 psi-msec

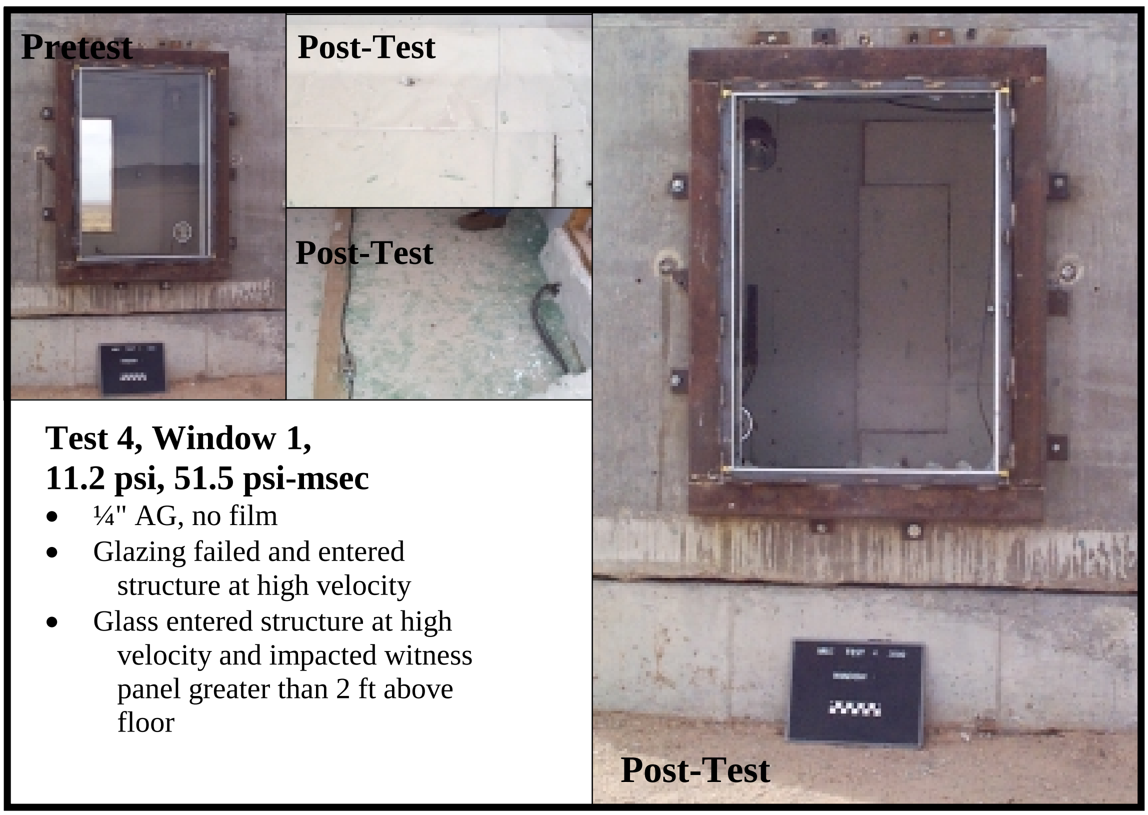
- 1/4" AG, 8-mil wet glazed film
- Glazing cracked
- Few fragments entered structure, fragments to 19 ft in front of structure

Table 4.4 presents the results of test articles when subjected to airblast loading of 10 psi and 48.3 psi-msec when using four-sided mechanical attachment.

Note: Although reflected pressure is per GSA Level D criteria, nominally, the measured impulse was 48.3 psi-msec not the full 89 psi-msec listed in the criteria.

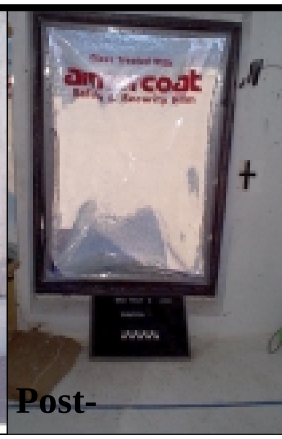
Peak Pressure	Test Article	Film	Attachment Method	GSA Performance Condition
11.2	MSC-4-1	No Film	---	5
9.2	MSC-5-4	14-mil, 3-ply	4-sided mechanical	3a
11.2	MSC-4-4	14-mil, 3-ply	4-sided mechanical	3b

Table 4.4 Summary of results for film with four-sided mechanical attachment or four-sided wet glaze at 10 psi pressure on ¼ inch annealed glass (46 × 64 inch window panes).



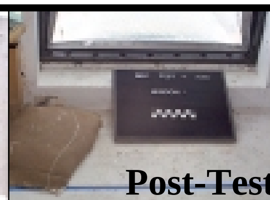
Test 4, Window 1,
11.2 psi, 51.5 psi-msec

- ¼" AG, no film
- Glazing failed and entered structure at high velocity
- Glass entered structure at high velocity and impacted witness panel greater than 2 ft above floor



Test 5, Window 4,
9.2 psi, 48.3 psi-msec

- 1/4" AG, 14-mil 4-sided film
- Glazing cracked and film was retained in frame
- Few fragments entered structure, no impacts on witness panel, fragments to 55 ft in front of structure



Test 4, Window 4,
11.2 psi, 51.5 psi-msec

- ¼" AG, 14-mil 4-sided film
- Glazing cracked but film was retained in frame
- Few fragments entered structure, no impacts on witness panel, fragments to 69 ft in front of structure

Conclusions

Of the window frame, film and attachment systems tested, several different systems met the GSA Performance Criteria for Level C Buildings. Testing included in this report indicates that even the 4-mil window films when properly installed can meet the GSA Level C criteria in a daylight application for the tested conditions. For higher loads, it is clear that heavier film and 4-sided attachment is required.

It is important to note the testing performed utilized standard ¼ inch annealed glass. In alternative glazing configurations (insulating glass, thicker glass, heat strengthened glass, thermally tempered glass, etc.), the results would differ. In fact, equivalent filmed systems may perform better. Any comparison with other testing should be done on comparable glazing configurations.

APPENDIX B

History and Need for GSA Testing

History and Need for GSA Testing

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 street pedestrians. 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. Similarly, over 5000 people were injured during the bombing of the US Embassy in Kenya in 1998.

To reduce the window glass fragment hazard generated by blast, several technologies have emerged, including security window films, laminated glass, blast curtains, blast louvers, etc. Security films, which are applied to the inner surface of the glazing, hold the glass together and use the plastic membrane response of the film to control the failure of the glazing. Blast testing has been performed on security window films, and they have been shown to be effective at reducing hazards associated with failed glazing.

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, Final Working Version, January 17, 1997 and subsequent revisions), which specifically addresses blast protection issues for both new and existing GSA facilities. 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 GSA Level C and D facilities.

MSC Specialty Films Inc. commissioned ARA to perform a series of five high-explosive blast tests in order to evaluate the performance of security window film products. The test data collected in this effort will provide useful information for many other government and civilian entities, both domestic and foreign, that are responsible for security planning of building facilities.

The explosive tests were conducted at the Defense Threat Reduction Agency's Chestnut Test Site on Kirtland Air Force Base in New Mexico during the period of February 15-March 3, 2000. The test procedure was designed in accordance with the procedure adopted by the GSA. The GSA test procedure is included in Appendix A. Each test used 600 lb of ANFO (500 lb of TNT). The window sizes were nominally 4 ft by 5-1/2 ft. The windows were mounted in enclosed concrete reaction structures for testing. The standoff distance to the charge was varied to affect particular blast pressure levels on the windows.

APPENDIX C

Conversion Factors

(Non-SI to SI Units of Measurement)

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	kilogram (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)