Certified Test Report
BR606 Blast Resistant Glazing System

SHOCK TUBE TESTING OF WINDOWS FOR BLAST RESISTANCE CERTIFICATION

BakerRisk Project No. 01-00750-002-00

Prepared for:
United States Aluminum Corp.

Prepared by:
Michael J. Lowak

January 5, 2005

BAKERRISK
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1.0 TEST INFORMATION

Test Sponsor:	**United States Aluminum Corp.** **720 Cel-River Road** **Rock Hill, South Carolina, 29730**		
Manufacturer:	**United States Aluminum Corp.** **720 Cel-River Road** **Rock Hill, South Carolina, 29730**		
Testing Agency:	**Baker Engineering and Risk Consultants, Inc. (BakerRisk)** **3330 Oakwell Court, Suite 100** **San Antonio, TX 78218**		
Window Model:	**BR606 Blast Resistant Glazing System**		
Test Load:	**Peak Blast Pressure** **Positive Phase Impulse**	**=** **=**	**5.9 psi** **44 psi-msec**
Test Standard:	**ASTM F 1642 – 03** ***"Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings"***		

Baker Engineering & Risk Consultants, Inc. (BakerRisk) certifies that all information contained in this document is accurate to the best of our knowledge, and that every attempt was made during these tests to meet the requirements of the referenced test method

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2.0 SPECIMEN DESCRIPTION

The window units submitted for certification testing were 6800 Series Fixed Window units. The Series BR606 Blast Resistant System units submitted for testing had overall dimensions of 96 inches in width and 96 inches in height. The units represented an 8-foot wide window wall including four panes of glass as shown in Figure 1. Each lite was a 1 5/16-inch thick IGU consisting of a ¼-inch thick glass exterior lite, a ½-inch air space, and a ½-inch thick laminated annealed glass interior lite. The laminated lite included a 0.060-inch thick Butacite interlayer. Panes A and C included annealed glass exterior lites, but panes B and D included tempered glass exterior lites. The glass extended into the frame 0.562-inch on all sides, and a 1/4-inch wide by 7/16-inch deep Dow 995 silicone bead was provided on the interior face of the IGU.

The detailed drawings of the framing system are included in Appendix 2. The center vertical mullion was reinforced with a steel insert to improve the flexural strength of the member. Details of the insert are provided in Detail 8. All connections of horizontal members to vertical members included the use of a shear block as shown in the details. The perimeter frame members were attached to a steel test buck using 3/8-inch diameter, Grade 5 bolts at the spacings shown in the detail drawings. The vertical mullion insert was attached directly to the test buck with two ¾-inch diameter Grade 5 bolts at each end.

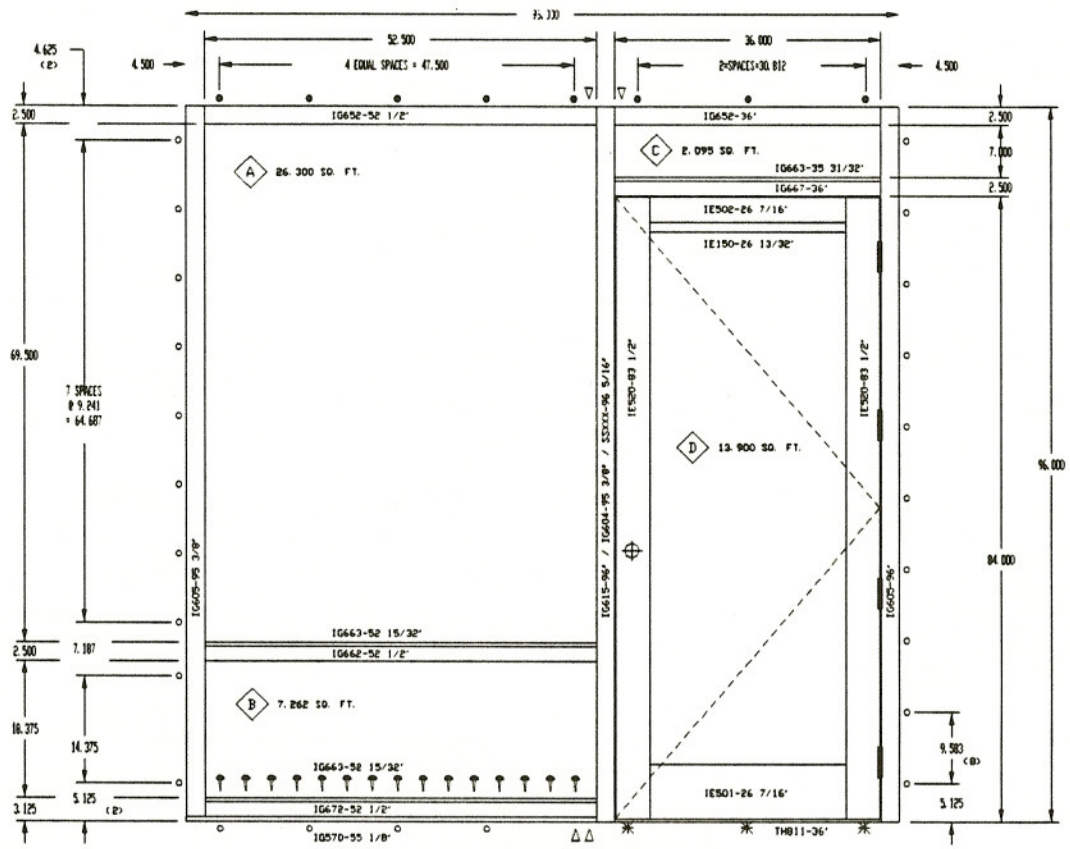


Figure 1. BR606 Test Specimen

3.0 DISCUSSION OF RESULTS

Three Series BR606 Blast Resistant System specimens were tested to certify the level of blast resistance based on the test method presented by ASTM F1642-03. All three tests (Tests UA1, UA2, and UA3) resulted in ASTM "Minimal Hazard" window responses. In all tests, some dusting debris was generated on the protected side of the window. No damage to the witness panel was observed in Tests UA1 and UA2, and only one perforation of the witness panel was observed in Test UA3. This level of debris hazard is allowable under the "Minimal Hazard" rating. The test results of Test UA1 and UA2 are also consistent with GSA Performance Condition 2, but the Test UA3 response is classified as a GSA Performance Condition 4 based on the single witness panel impact. All glass dusting debris originated from the two larger glass panes in the unit. The two smaller panes did not break under the applied loading.

Very limited damage to the framing was observed in Tests UA1, UA2, and UA3. The door was observed to rebound open in each test, but remained operable and typically, the closure no longer held the door seated in the doorframe. In Test UA1, additional damage was observed to the frame of the door panel, because in rebound the bottom of the door impacted part of the test apparatus after very limited swing. A slight adjustment was made in the mounting of the specimen for Test UA2 and UA3 to prevent the restriction on the door swing. Without the restriction on the amount of door swing, the door panel frame was not damaged in Tests UA2 and UA3. The vertical mullion was measured to have roughly 1/16-inch permanent deformation in each of these tests. Accelerometer data measured in the test indicates that the peak deflection of the vertical mullion was 1.2 inches in each of Test UA2 and UA3.

A summary of the test results is provided in Table 1. The test setup and equipment are described in Appendix 1. Detailed test information, pressure-time histories for the applied load, and a limited photographic record for each test are included in Appendix 2. Each test was documented using still photography, video, and high-speed video. All photographs, video footage, and high-speed video footage taken of the tests are included on an accompanying compact disc along with an electronic version of this report.

Table 1. Summary of Test Results

Test No.	Specimen Description	Pressure (psi)	Impulse (psi-msec)	Duration (msec)	Response
UA1	Series BR606 (96" x 96")	6.3	46	19	GSA - Condition 2 ASTM – Minimal Hazard
UA2	Series BR606 (96" x 96")	5.9	44	19	GSA - Condition 2 ASTM - Minimal Hazard
[1]UA3	Series BR606 (96" x 96")	6.1	45	19	GSA - Condition 4 ASTM - Minimal Hazard
[1]GSA Hazard Level 4 was due to a single glass sliver impact in the Level 4 area of the witness panel.					

APPENDIX 1
TEST APPROACH AND SETUP

Test Approach

The test program followed the general procedures and window performance criteria from the ASTM F 1642-03 *Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings*. Also referenced is the General Services Administration (GSA) *Standard Test Method for Glazing and Glazing Systems Subject to Airblast Loadings*. The two documents are very similar, but have slightly different methods of reporting window performance. The ASTM document provides descriptions of various Hazard Ratings, and the GSA document provides descriptions of various Performance Conditions. Although the terminology is different, the two systems are very comparable. A tabularized comparison of the two performance rating schemes is provided in Appendix 1 - Table 1. A copy of the ASTM document can be obtained from ASTM. The GSA document is available for public distribution and a copy of the document is provided in Appendix 3.

The referenced test standards require the testing of three like specimens to certify performance of a glazing or glazing system. This program was conducted as a combined certification and research program. The window system was tested to various blast loads to determine the best suited blast loading to use in the certification tests, and then additional repeat tests were conducted to satisfy the repeatability requirement of the referenced test standards.

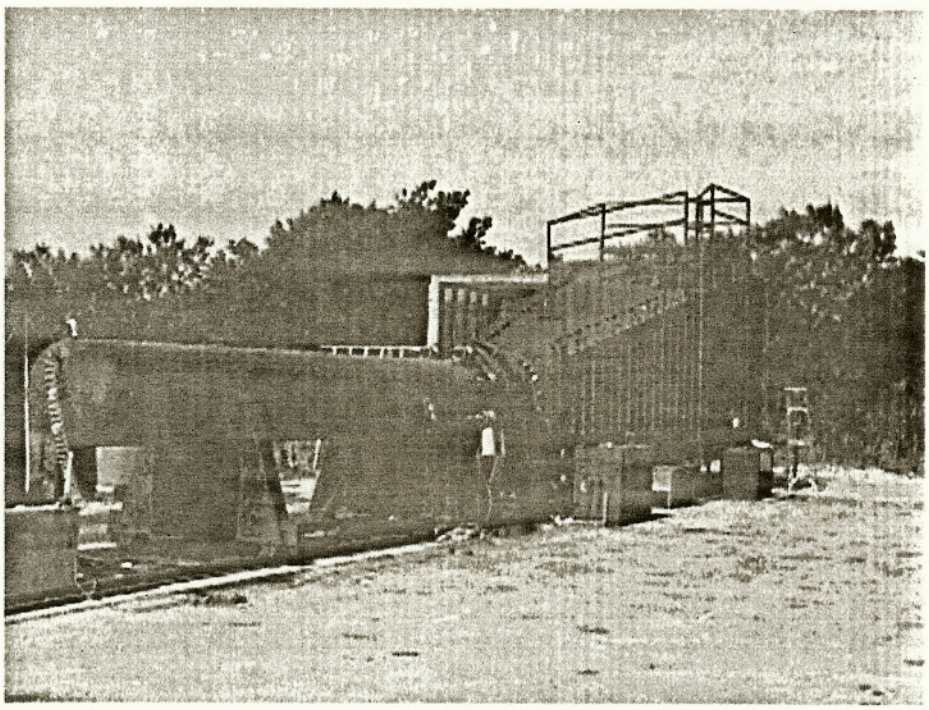
Appendix 1 - Table 1. ASTM Hazard Ratings and GSA Performance Conditions

ASTM Hazard Rating	ASTM Description	Similar GSA Performance Condition	GSA Description
No Break	The glazing is observed not to fracture and there is no visible damage to the glazing system.	1	Glazing does not break. No visible damage to glazing or frame.
No Hazard	The glazing is observed to fracture but is fully retained in the facility test frame or glazing system frame, and the rear surface (the surface opposite the airblast loaded side of the specimen) is intact.	2	Glazing cracks but is retained by the frame. Dusting or very small fragments near sill or on floor acceptable.
Minimal Hazard	The glazing is observed to fracture and the total length of tears in the glazing plus the total length of pullout from the edge of the frame is less than 20% of the glazing sight perimeter. Also there are less than 3 pinhole perforations and no fragment indents anywhere in a vertical witness panel located 3 m (120 in.) from the interior face of the specimen, and there are fragments with a sum total united dimension of 25 cm (10 in.) or less on the floor between 1 m (40 in.) and 3 m (120 in.) from the interior face of the specimen. Glazing dust and slivers are not accounted for in the rating.	3A	Glazing cracks. Fragments enter space and land on floor no further than 3.3 ft. from the window.
Very Low Hazard	The glazing is observed to fracture and is located within 1 m (40 in.) of the original location. Also, there are three or less pinhole perforations and no fragment indents anywhere in a vertical witness panel located 3 m (120 in.) from the interior face of the specimen and there are fragments with a sum total united dimension of 25 cm (10 in.) or less on the floor between 1 m (40 in.) and 3 m (120 in.) from the interior face of the specimen. Glazing dust and slivers are not accounted for in the rating.	3B	Glazing cracks. Fragments enter space and land on floor no further than 10 ft. from the window.
Low Hazard	The glazing is observed to fracture, but glazing fragments generally fall between 1 m (40 in.) of the interior face of the specimen and 0.5 m (20 in.) or less above the floor of a vertical witness panel located 3 m (120 in.) from the interior face of the specimen. Also, there are ten or fewer perforations in the area of a vertical witness panel located 3 m (120 in.) from the interior face of the specimen and higher than 0.5 m (20 in.) and none of the perforations penetrate through the first layer of the witness panel.	4	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.
High Hazard	Glazing is observed to fracture and there are more than ten perforations in the area of a vertical witness panel located 3 m (120 in.) from the interior face of the specimen and higher than 0.5 m (20 in.) above the floor or there are one or more perforations in the same witness panel area with a fragment penetration into the second layer of the witness panel.	5	Glazing cracks and window sys-tem fails catastrophically. Frag-ments enter space impacting a vertical witness panel at a dis-tance of no more than 10ft. from the window at a height greater than 2 ft. above the floor.

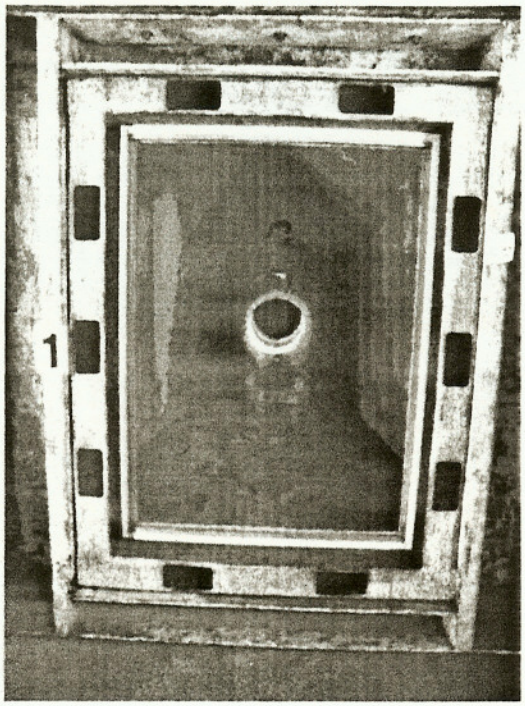
Test Apparatus

The dynamic tests of the windows were conducted in BakerRisk's large shock tube. BakerRisk's shock tube is a test apparatus that consists of two major sections, a driver section and an expansion section. Blast pressures are generated when a rupture diaphragm placed between the two sections fails due to pressure in the driver section. A shock wave then travels down the expansion section and loads the test specimen at the end of the expansion section. In this particular test series, the driver was baffled to reduce the effects of reloading by reflections that exist in the shock tube. A photograph of the shock tube is shown in Appendix 1 - Figure 1.

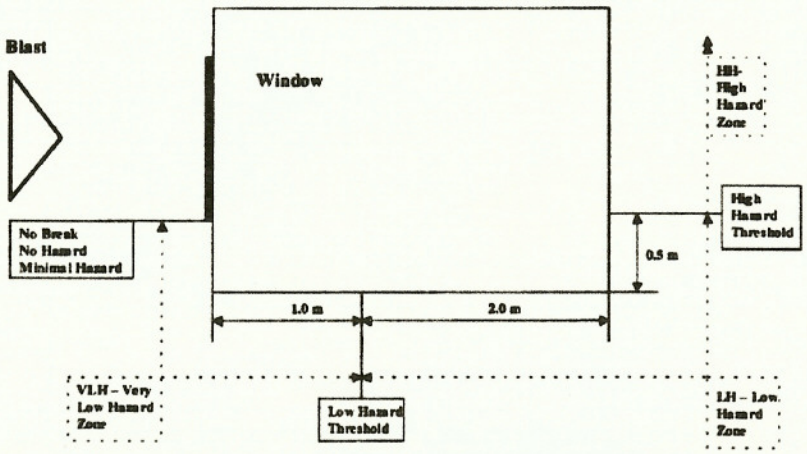
The shock tube has an 8-foot square target area. The test specimens were 66.5 inches wide and 92.5 inches tall and were mounted such that the specimen was centered in the target area of the shock tube. An 8-foot wide by 10-foot deep room was placed behind the window specimens with a witness panel mounted to the back wall of the room. A photograph illustrating the typical mounting of a window specimen is shown in Appendix 1 - Figure 2. The witness room behind the window was used to allow determination of the ASTM Hazard Ratings and GSA Performance Conditions for each test. Appendix 1 - Figure 3 graphically depicts the ASTM Hazard Rating System. Appendix 1 - Figure 4 graphically depicts the GSA Performance Condition rating system.



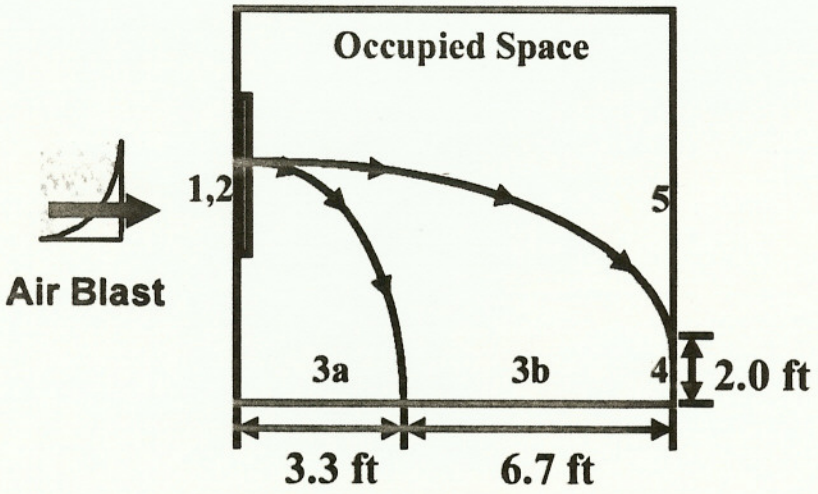
Appendix 1 - Figure 1. Photograph of BakerRisk Large Shock Tube



Appendix 1 - Figure 2. Mounted Specimen in Shock Tube



Appendix 1 - Figure 3. Illustration of ASTM Hazard Rating System



Side view schematic of criteria

Appendix 1 - Figure 4. Illustration of GSA Performance Conditions

Active Instrumentation

The applied test load was measured in the test using three dynamic pressure transducers. The transducers were located on the sidewalls and floor of the shock tube very near the target face in order to record the applied pressure data. Baseline tests have been performed with a rigid plate mounted over the shock tube target area and an additional pressure transducer mounted at the center of the plate. These baseline tests were performed to determine the shock tube configuration required to deliver specific loads for various threats and to serve as proof that the side and floor-mounted transducers record loads similar to that recorded by the center mounted transducer. The typical variation between transducer readings is approximately 5%. Another dynamic pressure transducer was fielded in the sidewall of the witness room, five feet behind the window specimen, to measure any blast pressure entering the protected space.

The data from the pressure transducers were recorded using a LeCroy - 6810, 16-channel 12-bit waveform digitizer that is capable of sampling rates up to 5 Mhz; however, a 1 Mhz sample rate was used for these tests. The voltage signals from the transducers were conditioned using a PCB-483B07 multipurpose 12-channel amplifying power unit. Recorded data was saved to computer disk for data plotting and interpretation. High-speed video, normal video, and digital still photography were also used to document the tests. Video and photographic data accompanies this report on CD. Several views were recorded using high-speed video cameras at different times during the tests. In all cases, an overall view of the window was recorded with normal and high-speed video. Other high-speed video views included a close-up view of the intermediate horizontal members to document movement of the member or of the member connections.

APPENDIX 2
DETAILED TEST DATA

APPENDIX 2
DETAILED TEST DATA

Test UA1

United States Aluminum Window Testing

Test Name UA1 **Test Date** 6/23/2004
Driver Length 57 **Driver Pressure** 25 psi
RWE 24"

Temperature Information (°F)
Ambient 81
Witness Room Interior 84
At Glass Surface 86

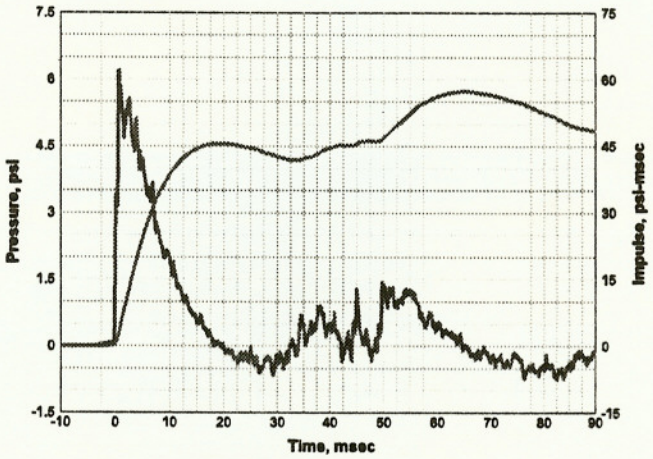
Gauge Number	Gauge Type	Serial Number	Sensitivity	Full Scale Voltage (volts)	Negative Offset Voltage (volts)	Conditioner Gain	Peak Pressure	Maximum Impulse	Duration
1	102M196	18619	100.1	4	-1	1	6.2	45.6	20.1
2	102M196	18620	94.31	4	-1	1	6.3	46.1	17.7
3	102M196	21227	99.82	4	-1	1	6.4	45.8	20.1
4	102M196	21225	103	4	-1	1	0.2	1.5	22.0
5									
6									
7									
8						Average Airblast Data	6.3	45.8	19.3
9									
10						Video Time Offset	0	msec	
11									
12									
13									
14									
15									
16									

Window Description

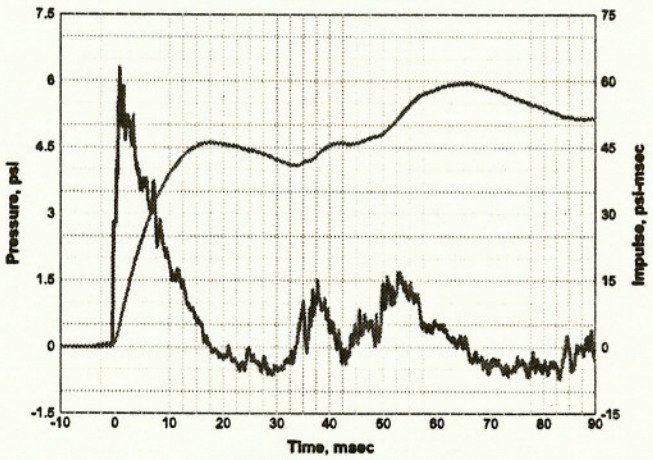
United States Aluminum Series BR606 Blast Resistant Glazing System in an 8-foot by 8-foot window wall configuration with door as shown in drawings labeled USA-2775, Sheets 1 through 15.

Response Description

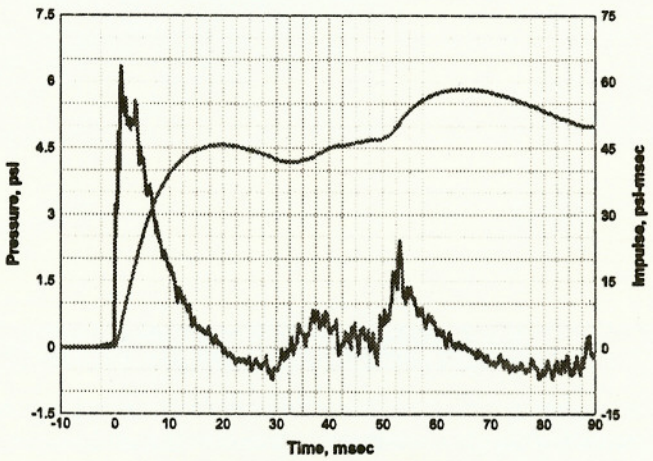
The two larger panes of glass shattered and glass dusting debris was generated on the protected side of the window. Dusting debris was observed on the floor of the witness panel up to 10 feet from the test specimen, but no impacts or punctures in the witness panel were observed. The framing members were observed to be only slightly damaged. The door frame was observed to be damaged slightly due to impact of the bottom of the door with a part of the shock tube as it rebounded open after a very limited amount of swing. The damage should be considered as non-typical response due to the restriction of the door swing. The remaining frame members were observed to have no apparent damage. The vertical mullion was measured to have a permanent deformation of 1/16 of and inch. All connections were found to have no significant movement or damage.



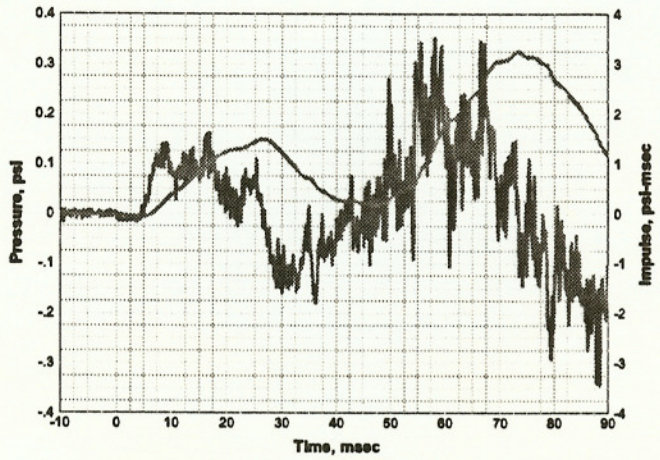
Applied Load, Gauge 1



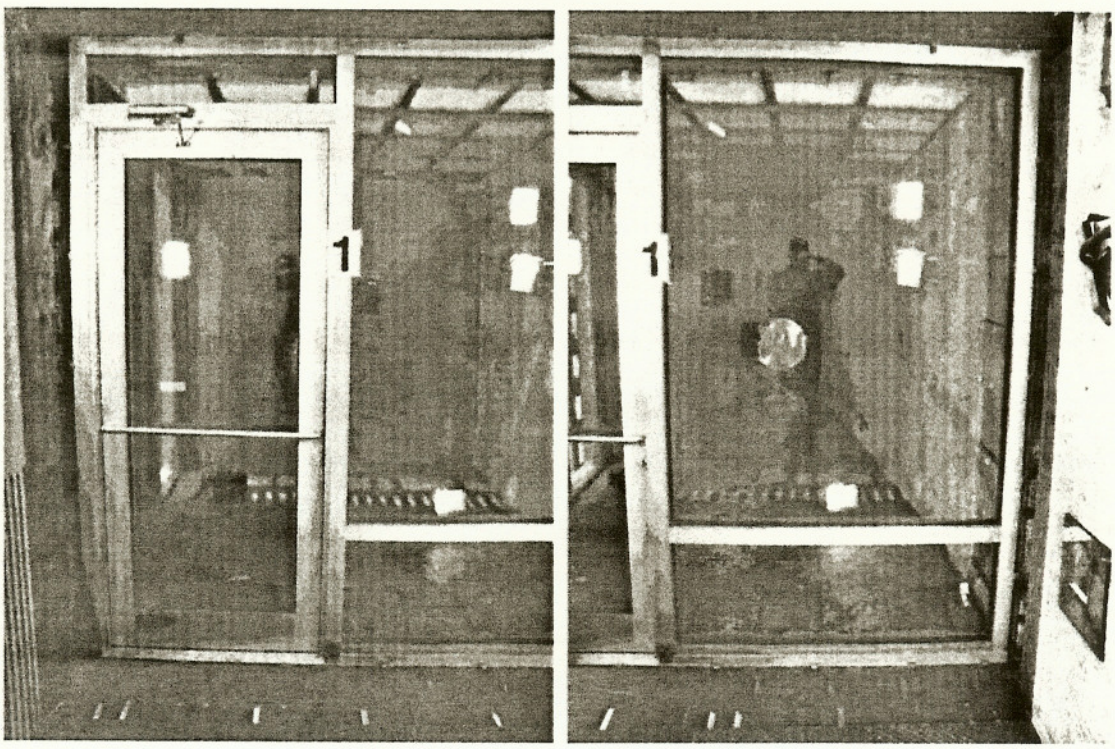
Applied Load, Gauge 2



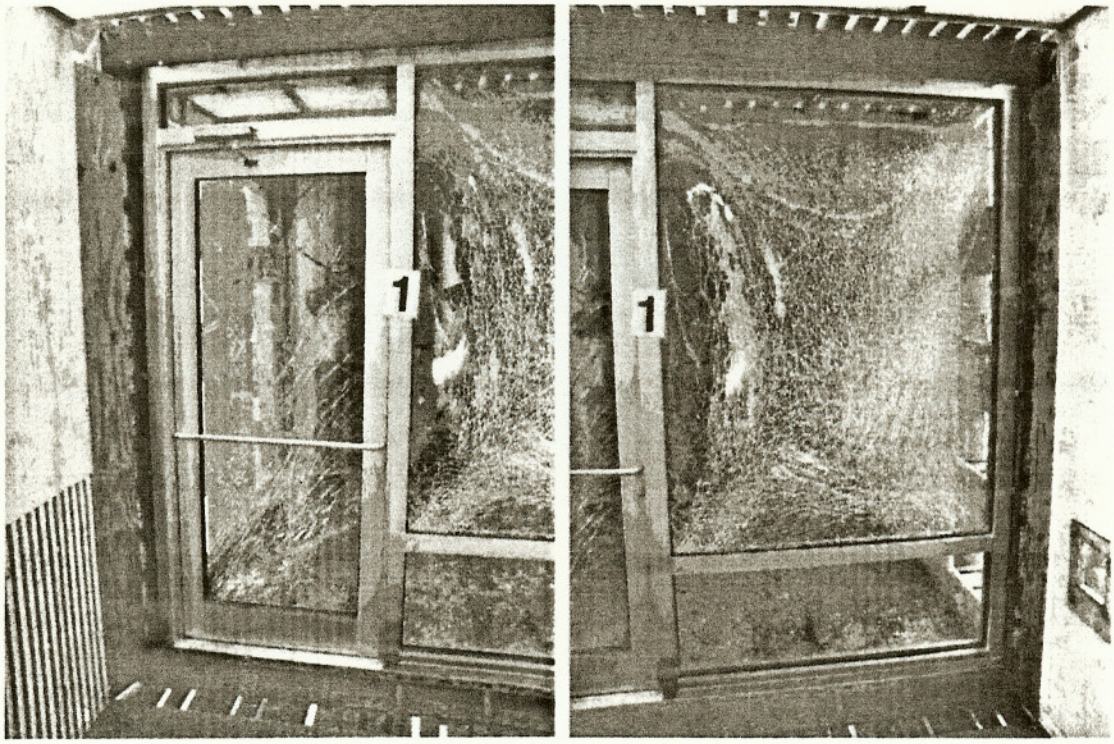
Applied Load, Gauge 3



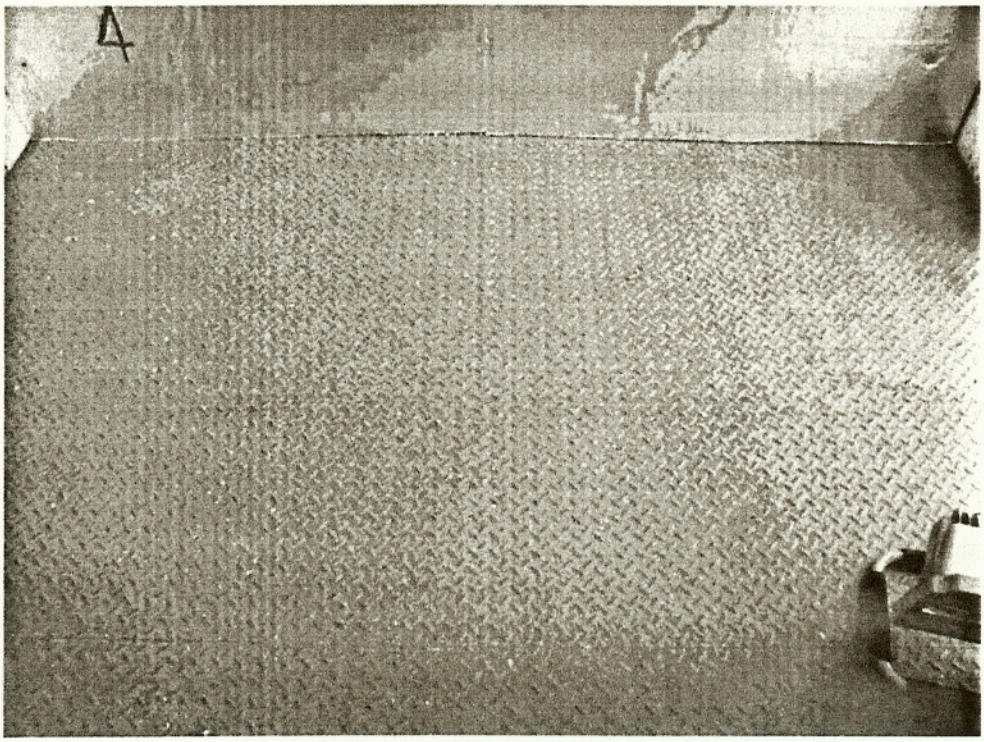
Pressure in Protected Space, Gauge 4



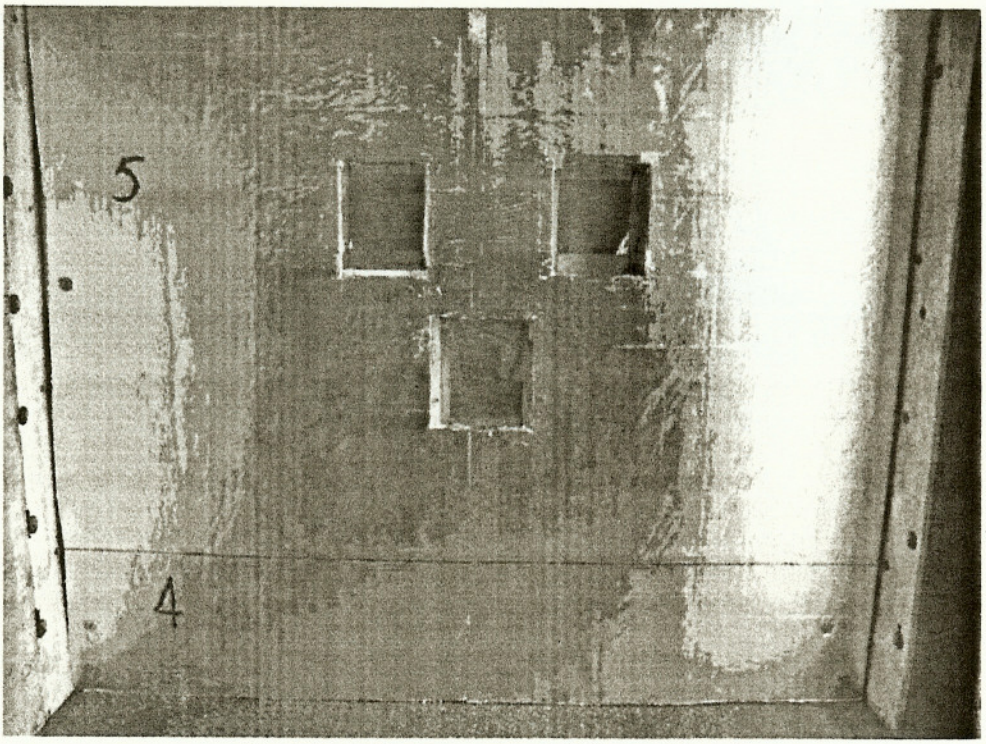
Pre-test Photographs of Test Specimen



Post-test Photographs of Test Specimen



Glass Debris on Floor of Witness Room



Post-test Photograph of Witness Panel

Test UA2

United States Aluminum Window Testing

Test Name UA2 **Test Date** 6/23/2004
Driver Length 57 **Driver Pressure** 25 psi
RWE 24"

Temperature Information (°F)

Ambient	88
Witness Room Interior	91
At Glass Surface	93

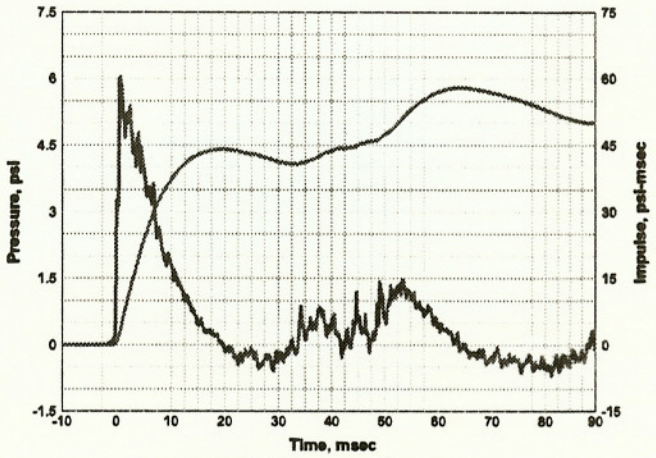
Gauge Number	Gauge Type	Serial Number	Sensitivity	Full Scale Voltage (volts)	Negative Offset Voltage (volts)	Conditioner Gain	Peak Pressure	Maximum Impulse	Duration
1	102M196	18619	100.1	4	-1	1	6.0	44.1	19.8
2	102M196	18620	94.31	4	-1	1	5.9	44.2	17.5
3	102M196	21227	99.82	4	-1	1	5.9	44.5	19.8
4	102M196	21225	103	4	-1	1	0.2	1.7	19.9
5	353B18	60248	10.53	10	-2	0.5	1.19		16.7
6									
7									
8						Average Airblast Data	5.9	44.3	19.0
9									
10						Video Time Offset	0	msec	
11									
12									
13									
14									
15									
16									

Window Description

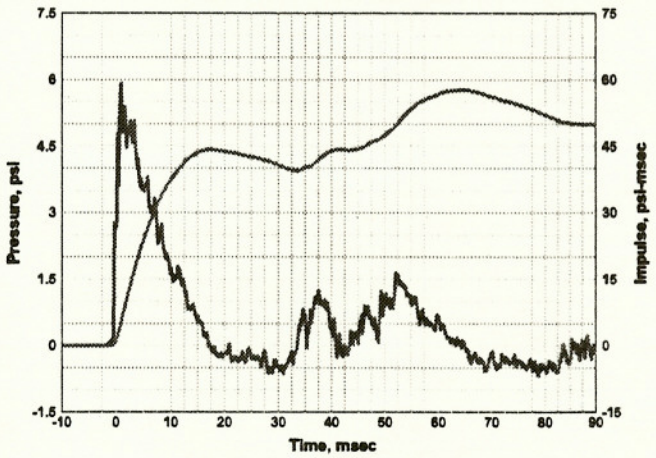
United States Aluminum Series BR606 Blast Resistant Glazing System in an 8-foot by 8-foot window wall configuration with door as shown in drawings labeled USA-2775, Sheets 1 through 15.

Response Description

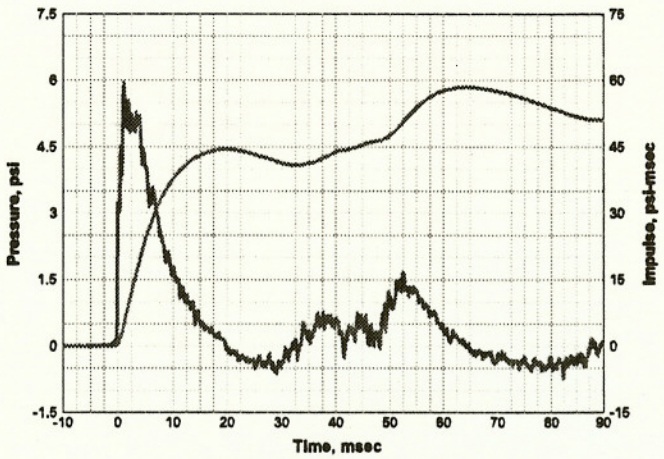
The two larger panes of glass shattered and glass dusting debris was generated on the protected side of the window. Dusting debris was observed on the floor of the witness panel up to 10 feet from the test specimen, but no impacts or punctures in the witness panel were observed. The frame members were observed to have no apparent damage. The vertical mullion was measured to have a permanent deformation of 1/16 of and inch. All connections were found to have no significant movement or damage.



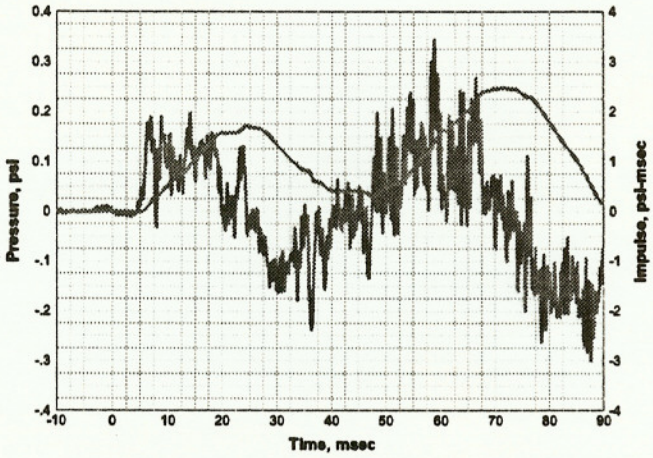
Applied Load, Gauge 1



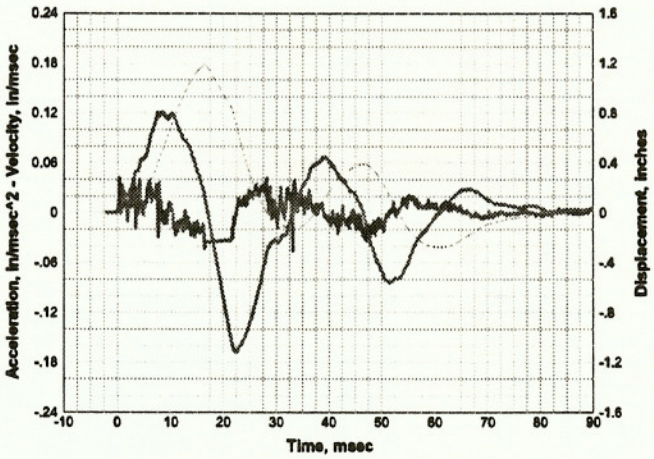
Applied Load, Gauge 2



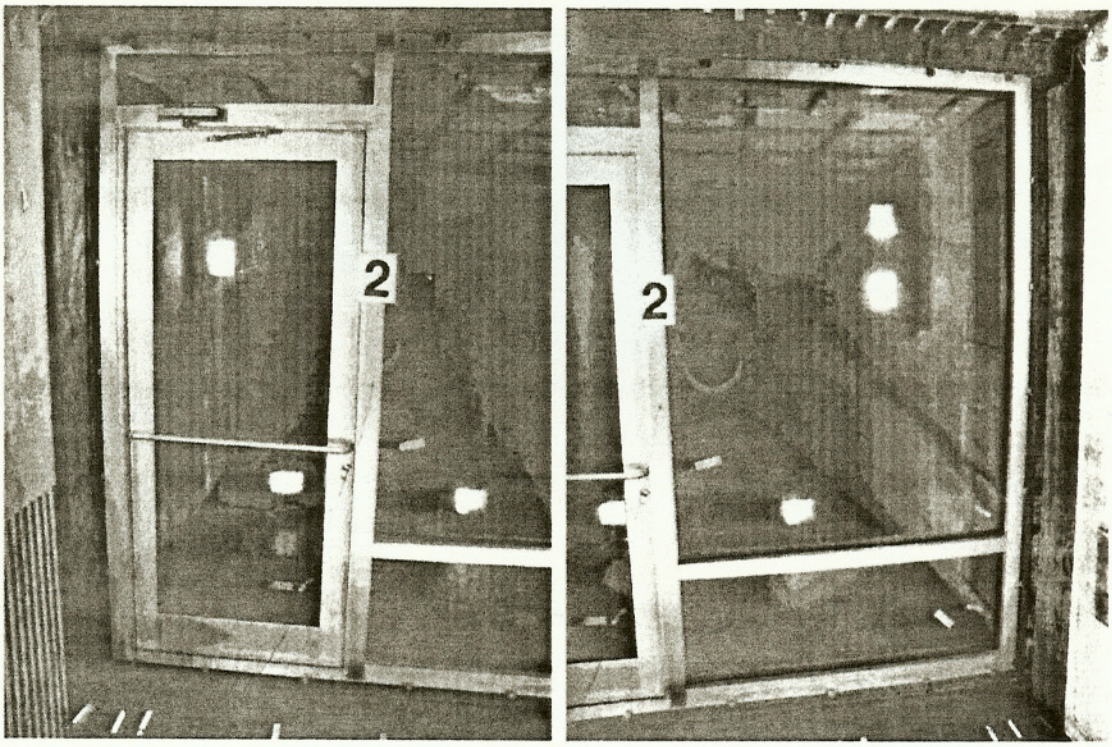
Applied Load, Gauge 3



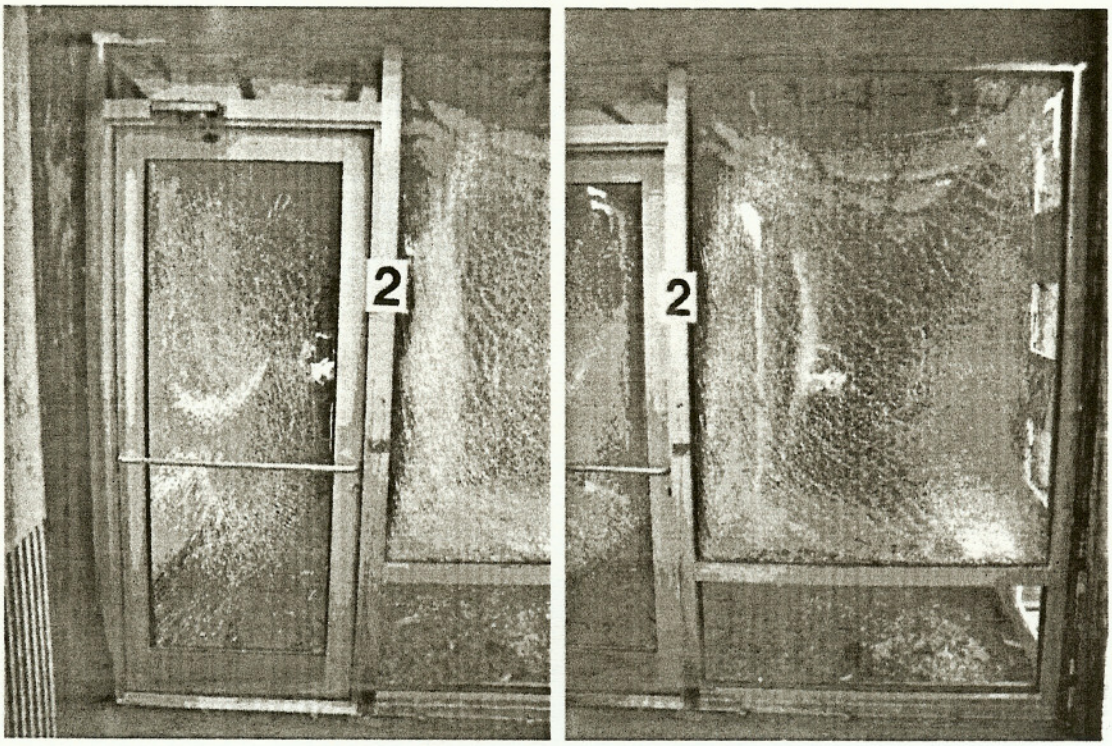
Pressure in Protected Space, Gauge 4



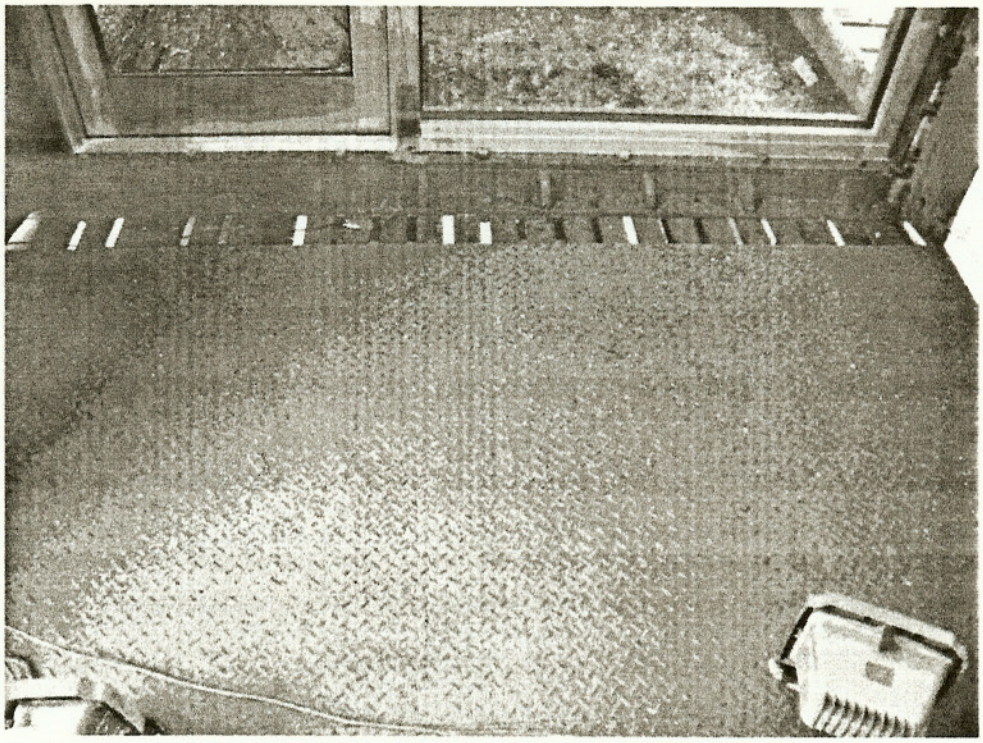
Accelerometer Data, Gauge 5



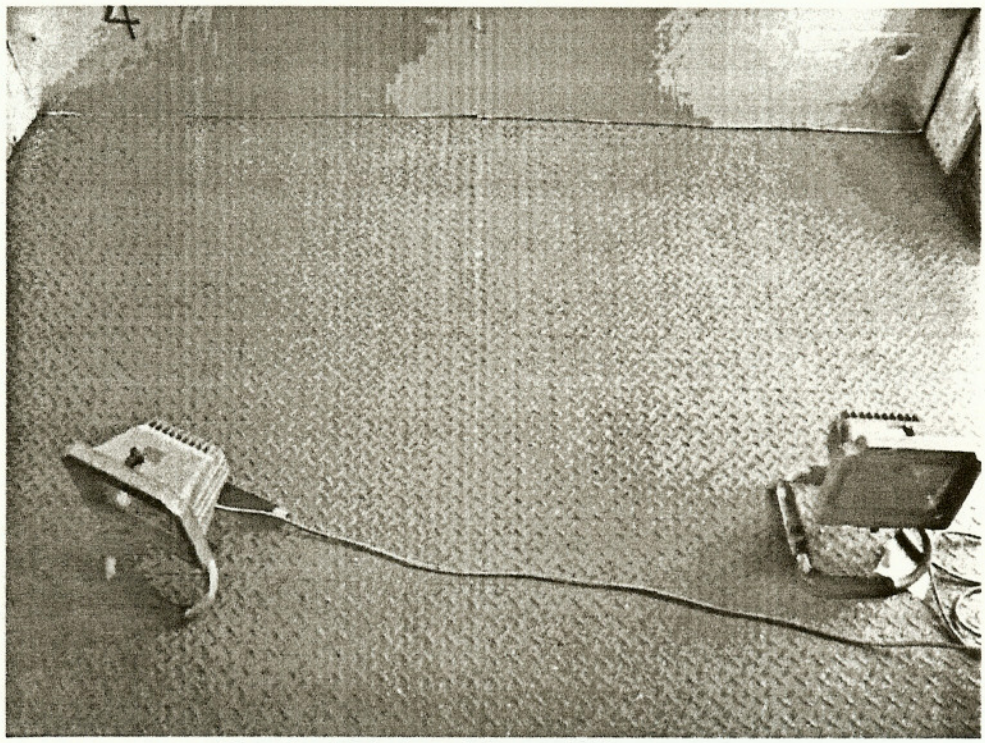
Pre-test Photographs of Test Specimen



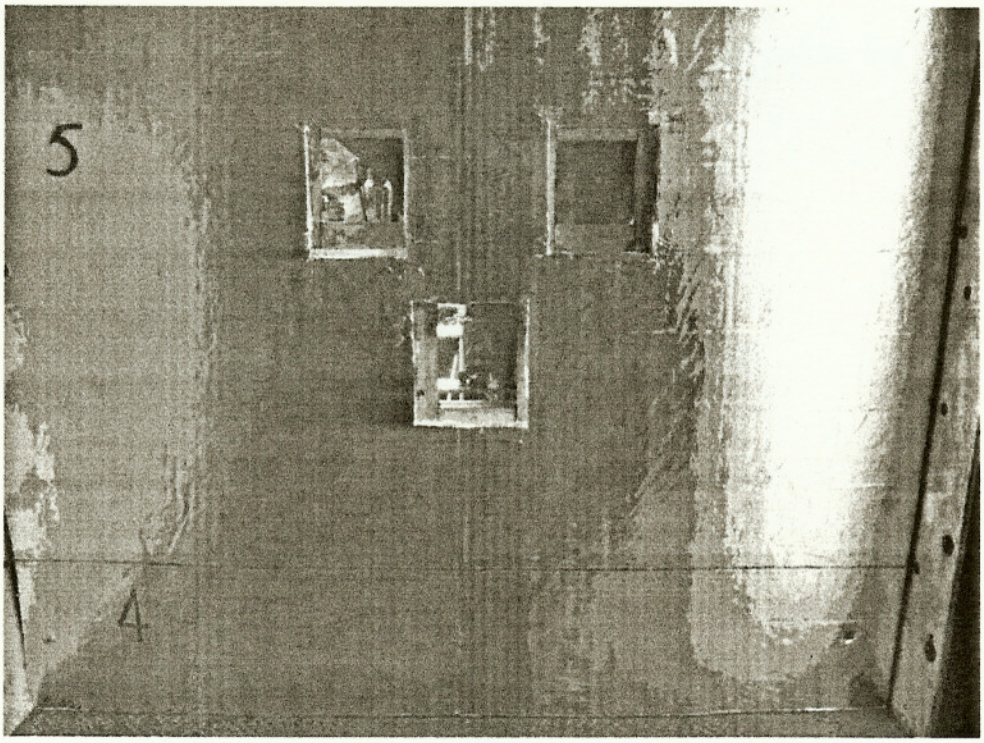
Post-test Photographs of Test Specimen



Dusting Debris on Immediately Behind Window



Dusting Debris on Floor of Witness Room



Post-test Photograph of Witness Panel

Test UA3

United States Aluminum Window Testing

Test Name UA3 **Test Date** 6/23/2004
Driver Length 57 **Driver Pressure** 25 psi
RWE 24"

Temperature Information (°F)
Ambient 92
Witness Room Interior 94
At Glass Surface 96

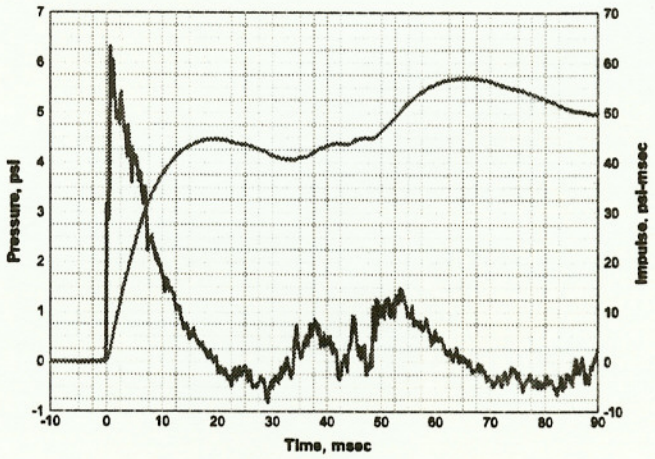
Gauge Number	Gauge Type	Serial Number	Sensitivity	Full Scale Voltage (volts)	Negative Offset Voltage (volts)	Conditioner Gain	Peak Pressure	Maximum Impulse	Duration
1	102M196	18619	100.1	4	-1	1	6.3	44.7	20.0
2	102M196	18620	94.31	4	-1	1	5.8	44.5	17.5
3	102M196	21227	99.82	4	-1	1	6.2	44.2	19.8
4	102M196	21225	103	4	-1	1	0.2	1.7	22.3
5	353B18	60248	10.53	10	-2	0.5	1.20		14.8
6									
7									
8						Average Airblast Data	6.1	44.5	19.1
9									
10						Video Time Offset	0	msec	
11									
12									
13									
14									
15									
16									

Window Description

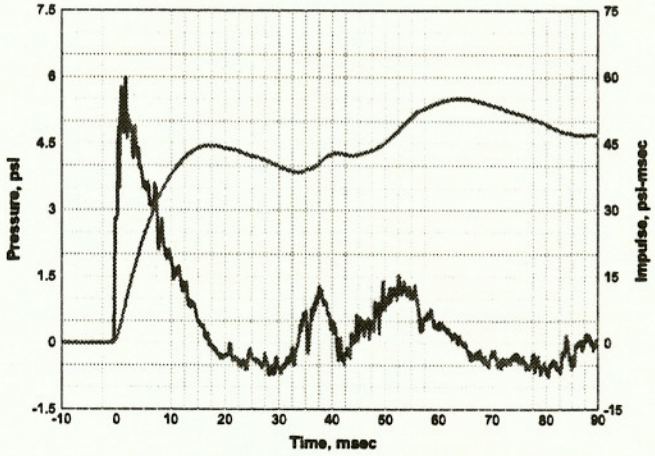
United States Aluminum Series BR606 Blast Resistant Glazing System in an 8-foot by 8-foot window wall configuration with door as shown in drawings labeled USA-2775, Sheets 1 through 15.

Response Description

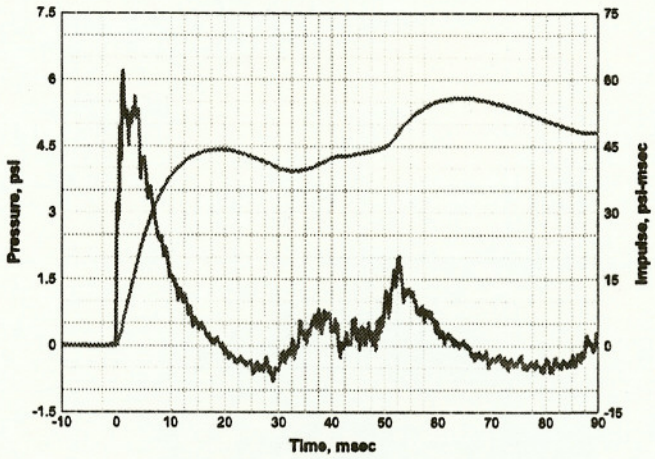
The two larger panes of glass shattered and glass dusting debris was generated on the protected side of the window. Dusting debris was observed on the floor of the witness panel up to 10 feet from the test specimen and a single puncture of the foil lined witness panel in the low hazard region was observed. The frame members were observed to have no apparent damage. The vertical mullion was measured to have a permanent deformation of 1/16 of and inch. All connections were found to have no significant movement or damage.



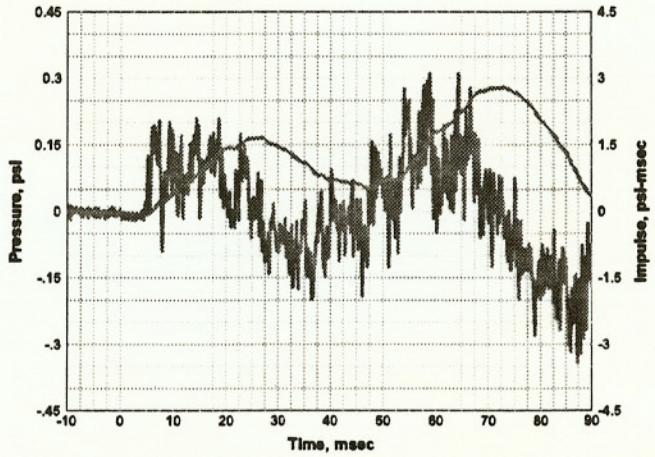
Applied Load, Gauge 1



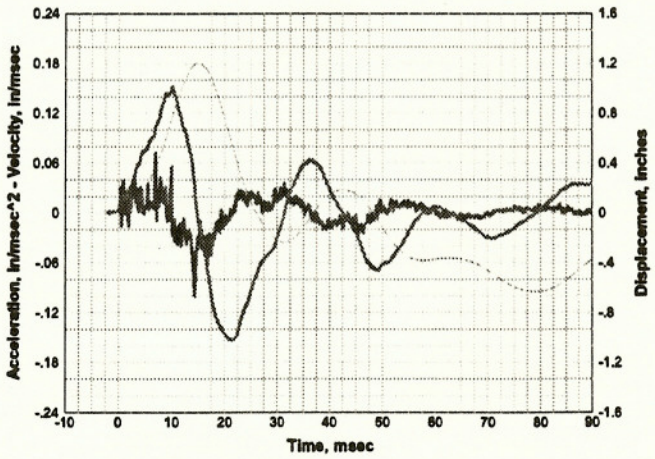
Applied Load, Gauge 2



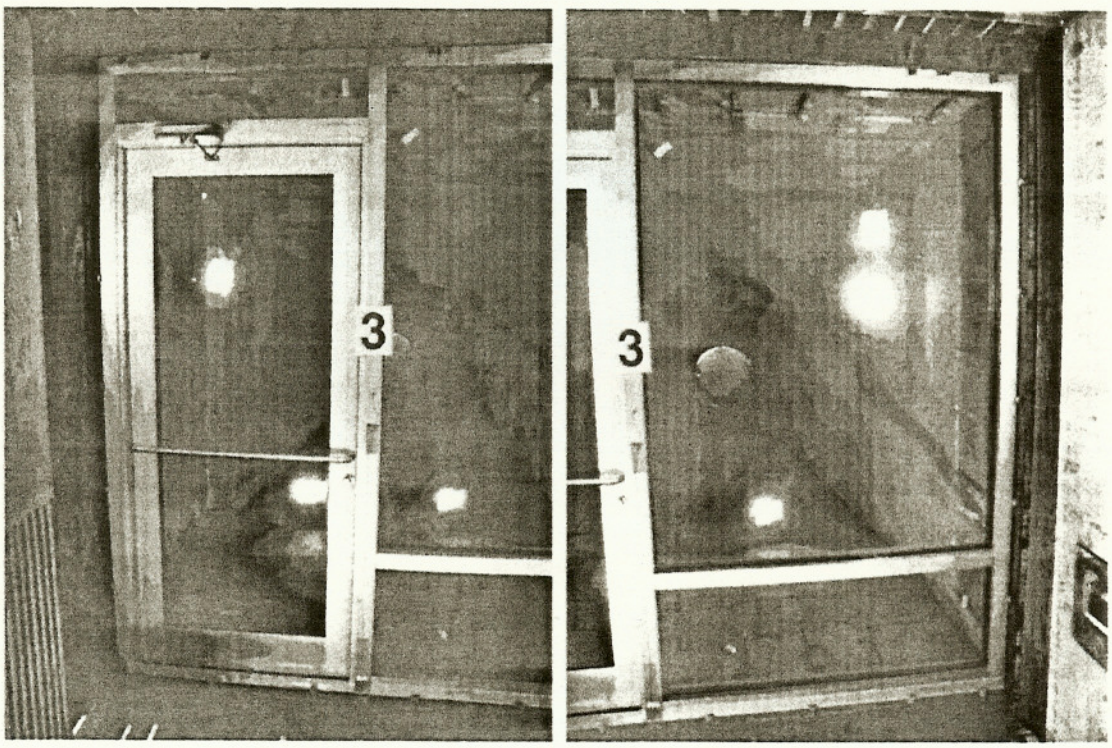
Applied Load, Gauge 3



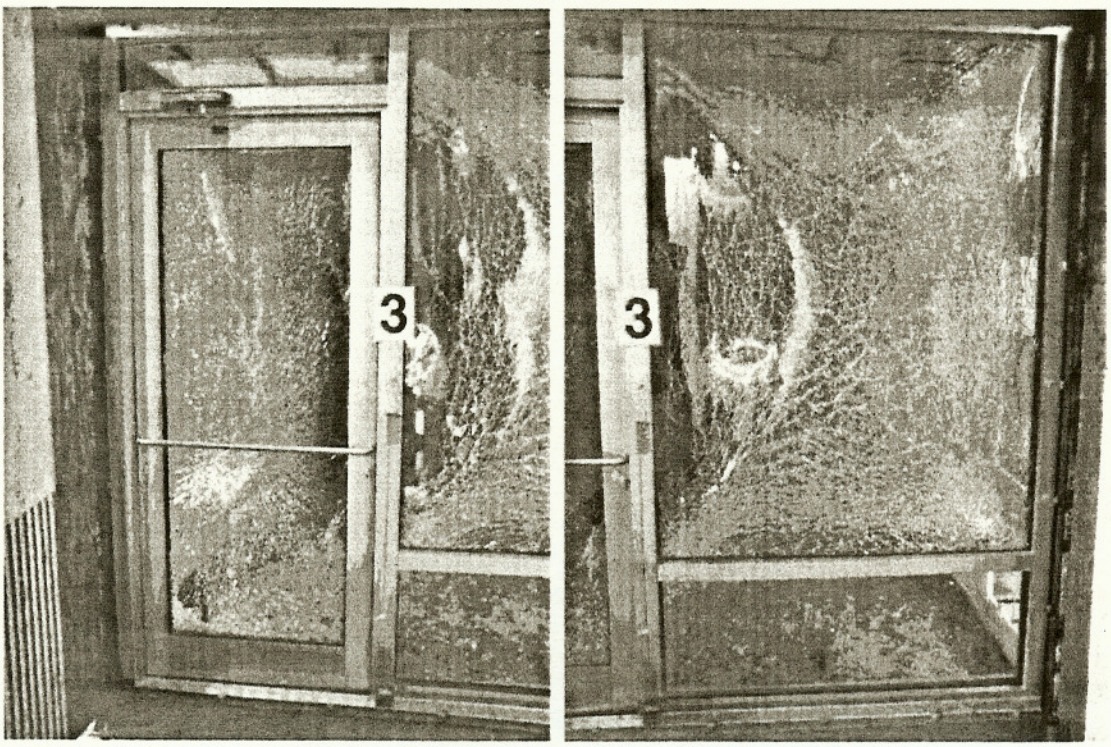
Pressure in Protected Space, Gauge 4



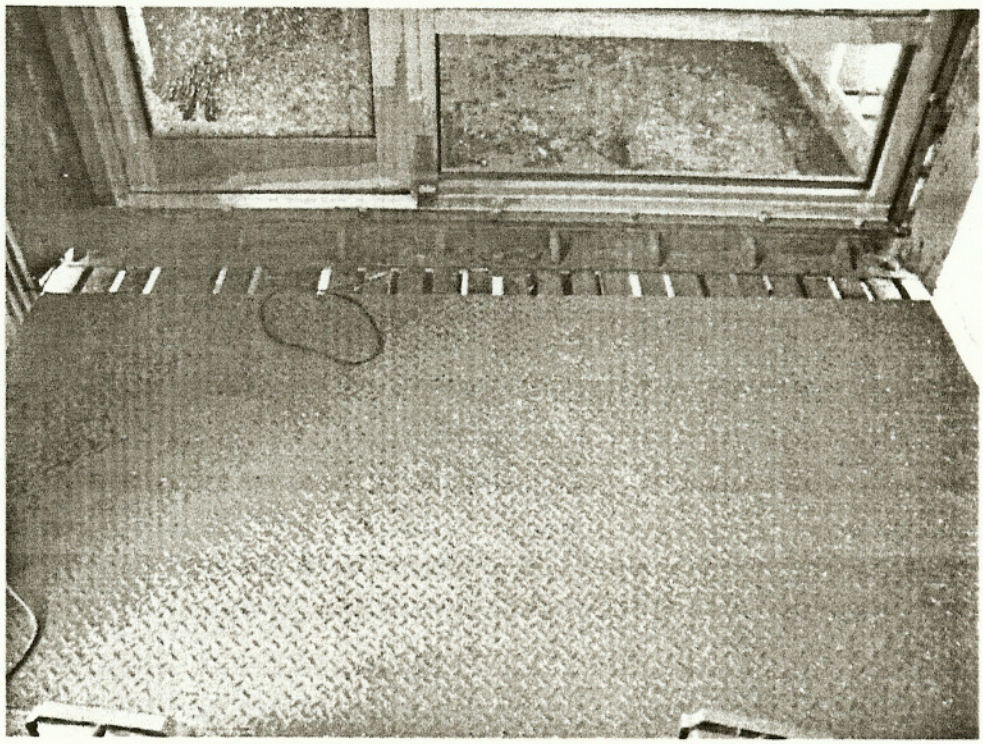
Accelerometer Data, Gauge 5



Pre-test Photographs of Test Specimen

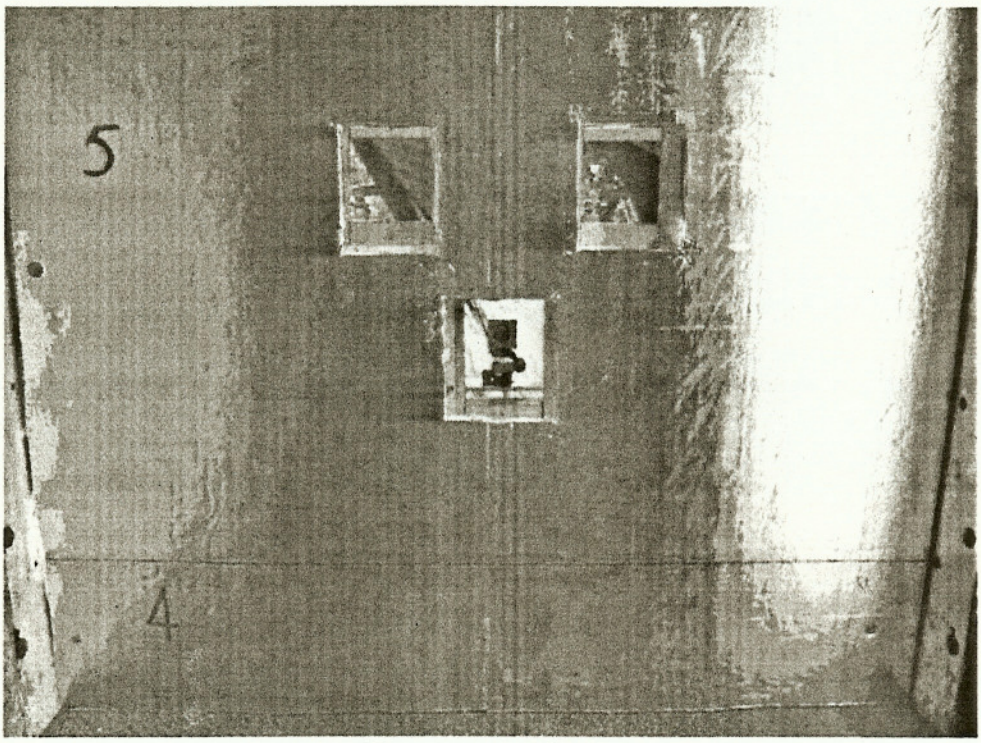


Post-test Photographs of Test Specimen

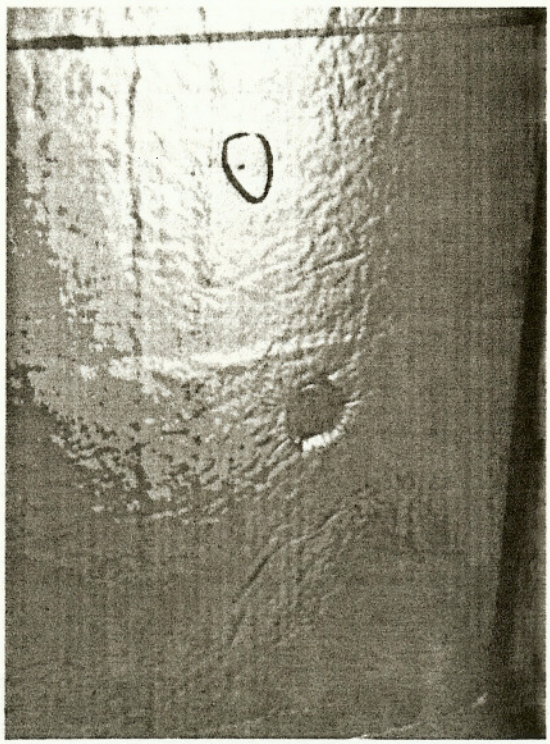


Dusting Debris on Sill of Window

Dusting Debris on Floor of Witness Room



Post-test Photograph of Witness Panel



Single Impact in Low Hazard Area of Witness Panel