APPENDIX A.1 – TEST PROTOCOLS

The National Wind Institute, Debris Impact Test Facility (NWI - DIF) at Texas Tech University (TTU) performs debris impact tests on storms shelters, shelter components, and building materials to evaluate their ability to resist various types of projectiles propelled at different speeds in accordance to accepted and proposed test protocols as follows:

A.1.1 - PROTOCOLS FOR DEBRIS IMPACT TESTING

Protocol 1	Hurricane envelope impact by a 9 lb. wood 2"x4" propelled at 34 mph, in accordance with the Florida Building Code, the International Code Council, and the Texas Dept. of Insurance windstorm Resistant Construction Guide.
Protocol 2	Hurricane shelter speed impact by a 9 lb. wood 2"x4" propelled at 0.40 x the design wind speed (mph) for horizontal impacts and 0.10 x the design wind speed (mph) for vertical impacts, in accordance to ICC 500 – ICC/NSSA (2008).[1] Standard for the Design and Construction of Storm Shelters
Protocol 3	Hurricane shelter speed impact by a 9 lb. wood 2"x4" propelled at 0.50 x (0.40 ICC-500 Edition 2008) the design wind speed (mph) for horizontal impacts and 0.33 x (0.10 ICC-500 Edition 2008) the design wind speed (mph) for vertical impacts, in accordance with FEMA 320, "Taking Shelter from the Storm," 2014 Edition and FEMA 361, "Design and Construction Guidance for Community Safe Rooms," 2015 Edition.
Protocol 4	Tornado shelter speed impact by a 15 lb. wood 2"x4" propelled at 100 mph for horizontal impacts and 67 mph for vertical impacts, in accordance with FEMA 320, "Taking Shelter from the Storm," 2014 Edition, FEMA 361, "Design and Construction Guidance for Community Safe Rooms," 2015 Edition, and the ICC-500 Standard for "The Design and Construction of Storm Shelters," 2014 Edition.1
Protocol 5	Department of Energy (DOE) Impact Standards

[1]The ICC 500 – ICC/NSSA Standard for the Design and Construction of Storm Shelters is a referenced standard in the International Residential Code (since 2009) and the International Business Code (since 2009). This is a Life Safety Standard for protection from tornadoes and hurricanes. For hurricanes the Standard uses an Extreme Wind Map with wind speeds starting at 225 mph and with contours along the Atlantic and Gulf Coast stepping inland in 10 mph increments to 160 mph. Doors are required by ICC-500 to withstand design pressures + a design safety factor of 1.2. Doors for hurricanes without glazing can be static pressure tested to withstand design pressures + a design safety factor of 1.5.

A.1.2 - INTRODUCTION

All testing is conducted by a registered professional engineer (Engineer of Record). The primary objective in debris impact testing of storm shelters and shelter components is to assure compliance with a high standard of performance in protecting shelter occupants from wind-borne debris. Performance criteria include preventing perforation of the shelter or component by the design missile and preventing deformations which could cause injuries to the occupants.

A.1.3 - TEST CRITERIA

The testing described is for simulated windborne debris. The primary simulations are impacts of a 2x4-in. wood board traveling along the board's longitudinal axis, striking the test subject perpendicular to the test subject face. Standards that use this type of simulated debris include ASTM E 1886 & ASTM E 1996 "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protection Systems Impacted by Missiles and Exposed to Cyclic Pressure Differentials," SSTD 12-99 "SBCII Test Standard for Determining Impact Resistance From Windborne Debris;" ANSI A250.13, "Testing and Rating of Severe Windstorm Resistant Components for Swing Door Assemblies;" FM 4473, "specification Test Standard for Impact Resistance Testing of Rigid Roofing Materials by Impacting with Freezer Ice Balls, July 2005; ICC 500 – "ICC/NSSA Standard for the Design and Construction of Storm Shelters;" and Texas Tech University, Wind Science and Engineering's Tornado Test Criterion adopted by the Federal Emergency Management Agency in publication FEMA 320, "Taking Shelter from the Storm," and FEMA 361, " Design and Construction Guidance for Community Shelters." The hurricane test criterion is addressed in Article A.1.1, Protocols 1-3 and uses a 9-lb. 2x4-in. wood board, called a missile. The missile speed therein described is a function of the guideline selected and the hurricane wind speed chosen from the guideline. The tornado test criterion found in Article A.1.1, Protocol 4, uses a 15-lb. 2x4-in. wood board traveling horizontally at 100-mph, which corresponds to a 250-mph wind, and is the criterion used in designing vertical surfaces for occupant protection. The criterion for falling debris from a 250 mph tornado is a 15-lb. 2x4-in. board traveling at 67-mph (two-thirds the horizontal speed), striking perpendicular to the surface. The one-third criterion is used for surfaces horizontal to the ground and inclined less than 30-degrees. Lesser tornado missile impact speeds for decreased tornado wind speeds are included in the test regimen and are addressed in FEMA 361. Additional factors of safety are inherent in the criterion, since there is a very small probability that a missile will be traveling along its axis and will strike perpendicular to the surface.

Different types and sizes of projectiles are tested in accordance to the Protocols, see A.1.1, Test Protocols. Impact speeds are as specified in these protocols, and in A.1.3, Test Criteria.

A.1.4 - TEST PROCEDURE

Shelter impacts are conducted in accordance to the Guidelines. Shelter appurtenances, vents, louvers, windows, or installed electrical equipment, shelving seats, etc., are impacted by a single missile if they are perceived by the Test Engineer of Record as vulnerable with regard to Life Safety.

Laboratory pressure tests are not conducted on shelters and shelter panels. Numerical analysis of wind pressures is outlined in the above listed standards in the A.1.3 - Test Criteria. Pressure tests are required for swinging door assemblies in accordance to FEMA 320, FEMA 361, and ICC-500. Pressure testing is conducted in accordance to the NWI DIF Air Bladder Standard 1.1.2016, "Standard Test Method for Structural Performance of Exterior Doors, Windows, Curtain Walls, and Skylights by Uniform Static Air Pressure Difference using Air Bladders." Referenced ASTM Standards in the NWI DIF Standard 1.1.2016 include the following: E72, "Standard Test Methods of conducting Strength Tests of Panels for Building Construction," E330, "Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Differences," E575, "Standard Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies," E1886, "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials," E1996, "Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Windborne Debris in Hurricanes," F2247, "Standard Test Method for Metal Doors Used in Blast Resistant Applications (Equivalent Static Load Method)."

Test pressures are dependent upon the storm wind speed selected and the location of the door or component in the building envelope, per ASCE 7-10. A 1.20 safety factor must be included in the design pressures doors and components of shelters to meet the requirements of ICC-500. Pressure tests may be conducted to other pressures as directed by the manufacturer using the same NWI DIF Standard 1.1.2016

A.1.5 - PASS/FAIL CRITERIA

A.1.5.1 The criterion, Protocols 1-4, for the shelter/shell/panel test pass/fail is as follows:

A.1.5.1.1 The test subject must be impacted by a minimum of three missiles in the areas as described in Articles A.1.3 and A.14;

A.1.5.1.2 The missile may penetrate that test subject, but may not perforate the safe side (back face) of the subject;

A.1.5.1.3 The test subject's permanent deflection after impact must be less than 3-in.

A.1.5.1.4 Segments, spallings, or otherwise de-laminated portions of the test subject, though still attached to the subject, may not extend into the safe compartment 3-in. or more; and

A.1.5.1.5 Segments of the test subject or appurtenances attached to the test subject must not be ejected or otherwise released into the safe compartment by the impact force.

A.1.5.1.6 Door assemblies manufactured to SDI and DHI standards must hold the required test pressures,

A.1.5.1.7 Maintain locked and firmly attached two door points of locking and hinging. FEMA 320/361 recognizes that one test missile can destroy or otherwise disengage one locking point or one hinge. The guideline therefore requires that at least two locking points remained engaged and doors with only two points of locking must have both locks remain engaged and locked at the conclusion of the impact tests. Door does not have to be operable at the conclusion of the impact or pressure tests.

A.1.5.1.8 Pass/fail rating of the door relates to the full door assembly, including door, locking hardware, hinge, hinge screws, and door frame. Tested frame attachment

connectors must be equal to or less than shear strength that is commonly specified and used for the intended installation.

A.1.5.2 The pass/fail criterion for Protocol 5 is in strict accordance to the DOE Standards.

A.1.5.3 The pass/fail criterion for Protocol 6 is in strict accordance to ANSI/FM 4473, *Test Stand for Impact Resistance Testing of Rigid Roofing Materials by Impact with Freezer Ice Balls.*

A.1.6 - TEST EQUIPMENT

A.1.6.1 Debris Impact Air Cannon:

A.1.6.2 Air Tank – 30 gallon, Manchester Model Number 301853.

A.1.6.3 Air Valve – Valworx Model Number 564015 4-in. butterfly valve, double acting, EPDM with solenoid actuator.

A.1.6.4 4-in. aluminum quick coupler to connect barrel to valve.

A.1.6.5 4-in.or 6-in. x 20-ft. long Schedule 40 PVC barrel, depending upon test.

A.1.6.6 Pair Optical Timing Sensors – Keyence Model Number PZ251R and PZ125T 12/24 volt power supply. Through beam response time 3.28 f/s (1 m/s).

A.1.6.7 National Instruments (NI) Data Acquisition Card (DAC) with custom software installed on control panel computer.

A.1.6.7.1 NI cR10-922 – Real Time Controller

A.1.6.7.2 WY NI9205 Dac Card

A.1.6.7.3 WI NI9215 Dac Card

A.1.6.7.4 NI P515 Power Supply

A.1.6.7.5 Computer Name: Wind275668 ID V56L-VSV8-DH6K-QVWQ

A.1.6.7.6 NI Labview Signal Express – 2011 Full Version G11X49269

A.1.6.8 Control panel with laser sighting and a three stage firing system.

A.1.6.9 Horizontal articulating cannon carriage with DC motor drive and variable speed controller.

A.1.6.10 Cannon carriage mounted to a hydraulic scissor lift on wheels – Autoquip Model Number 84B16F20.

A.1.6.11 Steel reaction frame made of vertical and horizontal steel beams anchored to the floor to provide simple support at the top and bottom of the test specimen

TESTING EQUIPMENT CALIBRATION

A.1.6.12 Ohaus DS 10 Scale – Nicol Scales & Measurement Serial Number 75107

A.1.6.13 Ohaus SPX123 Scale - Nicol Scales & Measurement Serial Number B610180716

A.1.6.14 Starrett 6” Steel Rule - Transcat Serial C304SRE -16221270

A.1.6.15 Starrett 36” Steel Rule - Transcat Serial C604R-36 16221271

A.1.6.16 Starrett 3” Depth Micrometer – Transcat Serial 446AZ-3RL 16221274

A.1.6.17 Starrett 6” Digital Caliper – Transcat Serial EC799A-6/150

A.1.6.18 Control Company Stopwatch – Transcat Serial 1051 106470724

A.1.6.19 Crystal 500PSIXP2I Pressure Gauge – Transcat Serial 500PSIXP2i 686145

A.1.6.20 Crystal 500PSIXP2I Pressure Gauge – Transcat Serial 500PSIXP2i 687288

A.1.6.21 Starrett 1" Outside Digital Micrometer – Transcat Serial T444.1XRL-1 ST1414161

A.1.6.22 Projectile speed calibrated with Olympus iSpeed 3 HD 16 GB camera, 1280 x 1024 resolution @ 2,000 fps, maximum 150,000 fps

A.1.7 USE OF TESTING REPORT, TTU AND TTU NWI DIF LOGOS

The written report and supplemental photos and/or videos may be referenced or distributed by your company. But, Texas Tech University (TTU) cannot endorse products nor can the name of the University or any of its units or personnel be used in advertising without first securing written permission from the University. Any misuse or misrepresentation of the report and/or pictures will result in action being taken by the University against the responsible parties.

Storm shelter manufacturers or producers that have had products tested at Texas Tech University National Wind Institute Debris Impact Facility (TTU NWI DIF) can use the TTU NWI DIF logo provided they conform to the following:

A.1.7.1 The TTU NWI DIF logo may not be so prominent as to mislead the public or unduly play upon the TTU NWI DIF name.

A.1.7.2 Whenever the logo is used, one of the two alternative statements below is to be employed in the text.

A.1.7.2.1 Tested – complete shelter: The use of the TTU NWI DIF logo signifies that the complete shelter structure was tested and successfully passed debris impact resistance tests at TTU NWI DIF.

A.1.7.2.2 Tested shelter component or product component: The use of the TTU NWI DIF logo does not signify that the entire shelter structure or the entire product assembly was tested at Texas Tech, but rather only [shelter component or product component – name explicitly] was tested and successfully passed debris impact resistance tests at Texas Tech University.

A.1.7.3 All advertising and promotional texts containing the use of the TTU NWI DIF logo are to be presented to the TTU NWI DIF for review and approval before distribution.

Texas Tech University will challenge any use of the TTU NWI DIF logo that does not conform to the above standards.