Screening Tests for Prototype Wildland Fire Shelters for External Inquiries

12/2011

Introduction

The current fire shelter (M-2002) used by wildland firefighters was developed by the Forest Service's Missoula Technology and Development Center (MTDC). The new shelter design was put into service in 2003 and transition to the new shelter from the earlier model was complete for all agencies January 2010. The Forest Service does not anticipate any significant evaluation of new materials or designs until at least 2015. When the Forest Service determines that a new shelter design is needed, a notice will be placed in www.Fedbizopps.gov with detailed instructions for submission of products for consideration. This document has been developed to assist those interested in testing fire shelter materials or designs in the interim.

This document is provided as a service and should not be considered a performance standard. Completion of these tests does not imply approval.

When performing these tests, it is recommended that the current fire shelter be tested alongside new materials, composites, and designs as a control to allow for comparison. This document is intended to avoid restriction of design wherever possible.

At a minimum, any new fire shelter design should have at least the same level of radiant and convective protective performance provided by the current shelter. The new shelter should be as strong as the current shelter. If thread is used, it should be able to have high tensile breaking strength and high temperature tolerance. Bulk size and weight are considerations, because firefighters must carry the shelter on their persons whenever they are on the fireline. The weight of the large size current shelter is 5.5 lbs. It is critical that firefighters be able to deploy their shelters quickly. With practice, the current shelter can be deployed in about 20 seconds.

Test Apparatus and Test Methods

The tests described are standard and non-standard methods. The standardized tests are widely available and can be performed at many laboratories. Most of the non-standard testing apparatus is located at the Protective Clothing and Equipment Research Facility (PCERF) at the University of Alberta, Edmonton, Canada. All of the tests described in this document except the Mullen Burst and Peel Strength tests can be performed at that location. MTDC has had the Mullen Burst and Peel Strength tests performed at Custom Laminating Corporation, Mt. Bethel, PA. The tests in this document were designed during development work on the current fire shelter. The current test methods and apparatus may require modifications to test other materials or designs.

The performance tests are divided into three tiers to guide the order of testing in a way that should reveal weaknesses early in the process. However, there is no requirement to perform the tests in the order provided. Evaluating new materials for use in emergency fire shelters requires considerable testing and evaluation.

Some tests, especially strength tests, can produce variable test data. It is recommended to use the M-2002 fire shelter as a control to evaluate data results of any new materials being tested.

Testing of material for smoke evolution, combustion, toxicity, and strength (Tier I and II) will help the designer determine if the material(s) are suitable to move into full scale fire shelter design tests (Tier III).

The three tiers are:

- Tier I: Small scale thermal and radiant exposure tests
- Tier II: Material toxicity screening and strength tests
- Tier III: Full scale shelter tests: convective and radiant exposure, durability, seam strength, elevated seam strength, and peel strength

The individual tests in each tier are:

Tier I) Small scale thermal and radiant exposure tests

1) Cone Flammability (see I.1)
2) Cup Furnace (see I.2)
3) Thermal Protective Performance (TPP) (see I.3)
4) Radiant Protective Performance (RPP) (see I.4)

Tier 2) Material toxicity screening and strength tests

1) Material toxicity screening (see II.1)

Strength tests:

2) Tensile (see II.2)
3) Tear Strength (see II.3)
4) Creased Breaking Strength (see II.4)
5) Elevated Temperature Tensile Strength (see II.5)
6) Puncture Resistance (see II.6)
7) Mullen Burst (see II.7)

Tier 3) Full scale convective and radiant exposure, durability, seam strength, elevated seam strength, peel strength, and thread melt

1) Convective Exposure (see III.1)
2) Radiant Exposure (see III.2)
3) Durability (see III.3)

4) Seam Strength (see III.4)
5) Elevated Seam Strength (see III.5)
6) Peel Strength (see III.6)

Test Procedures:

1. Sample Preparation

1.1 Application

Specific sample preparation procedure or procedures referenced in the sample preparation section of each test method shall be applied to that test method.

1.2 Sample Preparation

Material specimens shall be conditioned at a temperature of 21°C, ±3°C (70°F, ±5°F) and a relative humidity of 65%, ±5% until equilibrium is reached, as determined in accordance with ASTM 1776D-08A *Standard Practice for Conditioning and Testing Textiles* (Appendix C), or for at least 24 hours, whichever is shorter.

1.3 Specimens

Specimens for bench scale tests shall be tested within 5 minutes after removal from conditioning.

1.4 Procedure

All tests and calibrations that require heating or burning of the specimen shall be performed in a hood or ventilated area to carry away combustion products, smoke, or fumes.

Tier I Tests:

I.1 Cone Flammability Test

I.1.1 Application

This test shall apply to both woven and non-woven materials in the intended configuration of the shelter design.

I.1.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

I.1.3 Specimens

Specimens shall be 150 mm (6 in.) in diameter.

Multilayer material systems, separable or not, shall be tested in the intended composite construction.

A minimum of five specimens shall be tested.

I.1.4 Procedure

Specimens shall be tested using the burner assembly specified in CAN/CGSB-4.2 No.27.10-2000, *Flame Resistance – Vertically Oriented Textile Fabric or Fabric Assembly Test.*

Samples shall be cut and formed into a right circular cone. The overlap of material must be fastened using metal staples, so as to produce a seal capable of retaining gases evolved as the specimen is heated.

The sample shall be installed in a restraint device so that the seam formed is opposite the point of application of the burner flame.

The location of the burner shall be such that the tip of the flame contacts the sample at a point 30 mm $\pm$5 mm below the peak of the cone formed with the sample.

The flame shall be applied to the specimen for a period of 30 seconds.

I.1.5 Report

The report shall include observations about the behavior of the material during the exposure. This shall include the presence of smoke, gases, open flame within the cone sample, as well as a description of the condition of the sample, both inside and outside, at the end of the exposure period.

I.2 Cup Furnace

I.2.1 Application

The test apparatus and procedures are specified in (see II.1 Material Toxicity Screening Test) with the following modifications.

This test shall apply to both woven and non-woven materials in the intended configuration of the shelter design.

I.2.2 Specimens

The specimen shall be 150 mm x 150 mm (6 in. x 6 in.). The specimen should be cut in half 150 mm x 75 mm (6 in. x 3 in.) before being introduced into the preheated quartz crucible.

Multilayer material systems, separable or not, shall be tested in the

intended composite construction.

I.2.3 Sample Preparation

All specimens to be tested shall be conditioned as specified in 1.2.

I.2.4 Apparatus

The test apparatus is specified in FS 5100-615 (see II.1 Material Toxicity Screening Test) except that a 200 mm x 200 mm (8 in. x 8 in.) blank cover replaces the Sample Holder.

I.2.5 Procedure

Testing shall be performed in accordance with FS 5100-615 except that the 1 liter quartz crucible is preheated to 600ºC prior to the sample being introduced. After a suitable time has elapsed the temperature of the bottom of the quartz crucible should be measured using a either a surface thermocouple probe or infrared thermometer and should read 600ºC±10ºC.

Each sample shall be weighed and recorded prior to exposure.

The 200 mm x 175 mm (6 in. x 3 in.) samples may be rolled into a loose cylinder to ease its introduction into the crucible. Place the specimens to be tested in the quartz beaker as quickly as possible.

The sample shall be weighed and recorded after exposure.

I.2.6 Report

The results for each test run should include the same report as required in FS 5100-615 with the addition of mass of specimen before and after exposure.

I.3 Thermal Protective Performance (TPP) - Convective Exposure

I.3.1 Application

This test shall apply to both woven and non-woven materials in the intended configuration of the shelter design.

I.3.2 Specimens

Specimens shall be 100 mm x 100 mm (4 in. x 4 in.).

Multilayer material systems, separable or not, shall be tested in the intended composite construction.

I.3.3 Sample Preparation

All specimens to be tested shall be conditioned as specified in 1.2.

I.3.4 Apparatus

The test apparatus specified in ISO 9151:1995 *Protective clothing against heat and flame -- Determination of heat transmission on exposure to flame* shall be used.

I.3.5 Procedure

Thermal protective performance testing shall be performed in accordance with ISO 9151:1995 *Protective clothing against heat and flame -- Determination of heat transmission on exposure to flame.*

Specimens shall be mounted by placing the surface of the material to be used as the outside of the shelter face down on the mounting plate. The subsequent layers, if any, shall be placed in the order they would be used in the construction of the fire shelter material.

At the completion of each exposure, each specimen shall be examined for evidence of melting, shrinkage, or breaking open.

I.3.6 Report

The time to second degree burn shall be determined to the nearest 0.1 second at the point when the sensor response and the tissue tolerance curve cross.

Performance shall be based on the time required to produce a second degree burn in human tissue as shown in Table 1.

The individual test TPP rating of each specimen shall be reported. The average TPP rating shall be calculated and reported. If the sensor response curves do not cross, then the TPP rating shall be reported as “>60".

I.3.7 Computer Processing of the Data.

The information provided in Table 1 shall be permitted to be used as the criteria of performance in the software of a computer program. In this case the sensor shall be compared with the thermal response, either pain sensation or second degree burn in human tissue to determine the thermal end point. The product of the time to a second degree burn and the exposure heat flux shall be the TPP rating.

The TPP rating shall be calculated as the product of exposure heat Flux and time to burn as follows:

TPP rating = F x t

where:

F = exposure heat flux (cal/cm^2-s)

t = time to burn (s).

Table 1. Human Tissue Tolerance to Second Degree Burn

Exposure Time	Heat Flux		Total Heat		Calorimeter* Equivalent		
sec	cal/cm^2-s	kW/m^2	cal/cm^2	$kW\text{-}s/m^2$	$\Delta T\ ^oF$	$\Delta T\ ^oC$	ΔmV
1	1.2	50	1.20	50	16.0	8.9	0.46
2	0.73	31	1.46	61	19.5	10.8	0.57
3	0.55	23	1.65	69	22.0	12.2	0.63
4	0.45	19	1.80	75	24.0	13.3	0.69
5	0.38	16	1.90	80	25.3	14.1	0.72
6	0.34	14	2.04	85	27.2	15.1	0.78
7	0.30	13	2.10	88	28.0	15.5	0.80
8	0.274	11.5	2.19	92	29.2	16.2	0.83
9	0.252	10.6	2.27	95	30.2	16.8	0.86
10	0.233	9.8	2.33	98	31.1	17.6	0.89
11	0.219	9.2	2.41	101	32.1	17.8	0.92
12	0.205	8.6	2.46	103	32.8	18.2	0.94
13	0.194	8.1	2.52	106	33.6	18.7	0.97
14	0.184	7.7	2.58	108	34.3	19.1	0.99
15	0.177	7.4	2.66	111	35.4	19.7	1.02
16	0.168	7.0	2.69	113	35.8	19.8	1.03
17	0.160	6.7	2.72	114	36.3	20.2	1.04
18	0.154	6.4	2.77	116	37.0	20.6	1.06
19	0.148	6.2	2.81	118	37.5	20.8	1.08
20	0.143	6.0	2.86	120	38.1	21.2	1.10
25	0.122	5.1	3.05	128	40.7	22.6	1.17
30	0.107	4.5	3.21	134	42.8	23.8	1.23

Stoll, A.M., and M.A. Chianta, "Method and Rating System for Evaluation of Thermal Protection," Aerospace Medicine, Vol. 40, 1968, pp. 1232-1238.

*Iron-Constantan thermocouple

I.4 Radiant Protective Performance (RPP) - Radiant Exposure

I.4.1 Application

This test shall apply to both woven and non-woven materials in the intended configuration of the shelter design.

I.4.2 Specimens

Specimens shall be 100 mm x 200 mm (4 in. x 8 in.). A minimum of 5 specimens shall be tested.

Multilayer material systems, separable or not, shall be tested in the

intended composite construction.

I.4.3 Sample Preparation

All specimens to be tested shall be conditioned as specified in 1.2.

Laundering as specified in NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Fire Fighting, 2011*, shall be excluded.

I.4.4 Apparatus

The test apparatus specified in NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Fire Fighting, 2011 - Radiant Protective Performance Test*, shall be used.

I.4.5 Procedure

Thermal protective performance testing shall be performed in accordance with NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Fire Fighting, 2011 - Radiant Protective Performance Test.*

All testing and calibration shall be performed in a hood or ventilated area to carry away combustion product, smoke or fumes. Procedures for testing and calibration shall be performed using the same hood and ventilation conditions.

Specimens shall be mounted by placing the surface of the material to be used as the outside of the shelter face down on the mounting plate. The subsequent layers, if any, shall be placed in the order they would be used in the construction of the fire shelter material. Composite materials, if used, shall be assembled so the intended outer layer faces the radiant source.

A 6 mm (0.25 in.) spacer shall be used to maintain a space between the back face of the material tested and the front surface of the copper calorimeter. The spacer shall be installed between the back side of the material to be tested and the front face of the insulating block holding the copper calorimeter.

The calorimeter sensing surface should be smooth, clean, and painted with a quality high temperature flat black paint* of known emissivity with a value of greater than 0.90. It may take two or three light coats to completely and evenly cover the surface. If the coating on the calorimeter is damaged due to cleaning of residues it should be cleaned and repainted prior to continued testing.

*Krylon 1618 or Zynolyte Z635 have been found to be suitable.

Construction for the copper calorimeter shall be performed in accordance with ASTM F1939-08 *Standard Test Method for Radiant Heat Resistance of Flame Resistant Clothing Materials with Continuous Heating*, see 6.1.5 Sensor.

The total thermal heat flux shall be set at 84 kW/m^2 $\pm$ 4 kW/m^2 (2 cal/cm^2-s $\pm$0.1 cal/cm^2-s) using the copper calorimeter-based sensor assembly.

At the completion of each exposure each specimen shall be examined for evidence of melting, shrinkage, or breaking open.

I.4.6 Report

The individual test RPP rating of each specimen shall be reported. The average RPP rating shall be calculated and reported. If a RPP rating is greater than 60 then the RPP rating shall be reported as ">60". In calculating the average for the set of specimens a result of >60 shall be set as 60.

If an individual result from any test set varies more than $\pm$10% from the average result, the results from the test shall be discarded and another set of specimens shall be tested.

Performance shall be based on the time required to produce a second degree burn in human tissue as shown in Table 1.

The individual test RPP rating of each specimen shall be reported. The average RPP rating shall be calculated and reported. If a RPP rating is greater than 60 then the RPP rating shall be reported as ">60".

I.4.7 Computer Processing of the Data.

The information provided in Table 1 shall be permitted to be used as the criteria of performance in the software of a computer program. In this case, the sensor shall be compared with the thermal response, either pain sensation, or second degree burn in human tissue to determine the thermal end point. The product of the time to a second degree burn and the exposure heat flux shall be the RPP rating.

The time to second degree burn shall be determined to the nearest 0.1 second at the point when the sensor response and the tissue tolerance curve cross. If the sensor response curves do not cross, ">60", shall be recorded as the test result.

The RPP rating shall be calculated as the product of exposure heat flux and time to burn as follows:

RPP rating = F x t

where:

F = exposure heat flux (cal/cm^2-s)
t = time to burn (s)

Tier II Tests:

II.1 Material Toxicity Screening Test

Refer to U. S. Department of Agriculture Forest Service 5100-615- *Protocol for Evaluating Off-Gas Toxicity of Fire Shelter Material 2010* for test apparatus, test procedure, and report requirements.

Strength Tests:

Introduction: Strength test data on a sample set of material can produce a large standard of deviation. This may not dictate failure of the sample set. When new prototype materials produce a large standard of deviation it is suggested to use the New Generation Fire Shelter material as a baseline for comparison.

II.2 Tensile Strength

II.2.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.2.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.2.3 Specimens

Specimens shall be 100 mm x 150 mm (4 in. x 6 in.).

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

A minimum of five specimens in each of the warp and fill direction shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

II.2.4 Procedure

Specimens shall be tested as specified in ASTM D5034-09 *Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test).*

II.2.5 Report

The tensile strength of an individual specimen shall be the average of the five highest peak loads registered. The tensile strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The average tensile strength and standard deviation for warp direction and fill direction shall be reported.

II.3 Tear Strength Test

II.3.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.3.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.3.3 Specimens

Specimens shall be 100 mm x 150 mm (4 in. x 6 in.).

A minimum of five specimens in each of the warp direction and the fill direction shall be tested.

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

II.3.4 Procedure

Specimens shall be tested as specified in ASTM D5587-07ae1 *Standard Test Method for Tearing Strength of Fabrics by Trapezoid Procedure.*

II.3.5 Report

The tear strength of an individual specimen shall be the average of

the five highest peak loads registered. The tear strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

Report average tear strength and standard deviation for warp direction and fill direction.

II.4 Creased Breaking Strength Test

II.4.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.4.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.4.3 Specimens

Specimens shall be 100 mm x 150 mm (4 in. x 6 in.).

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

A minimum of five specimens in each of the warp direction and fill direction shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

II.4.4 Procedure

Specimens shall be tested as specified in ASTM D5034-09 *Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test).* Prior to testing samples shall be folded in half, forming 100 mm x 75 mm (4 in. x 3 in.) rectangle and creased. The spacing between the rollers used for creasing shall be determined using a standard thickness gauge and shall be set to twice the material thickness as determined using ASTM D1777-96 (2002) *Standard Test Method for Thickness of Textile Materials.*

II.4.5 Report

The creased breaking strength of an individual specimen shall be

the average of the five highest peak loads registered. The creased breaking strength for each specimen shall be reported to the nearest 1 N (0.2 lbf).

Report average creased breaking strength and standard deviation for the warp direction and fill direction.

II.5 Elevated Temperature Tensile Strength

II.5.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.5.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.5.3 Specimens

Specimens shall be 100 mm x 150 mm (4 in. x 6 in.).

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

A minimum of five specimens in each of the warp direction and the fill direction shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

II.5.4 Apparatus

The standard tensile strength test fixture shall be modified to elevate the central 75 mm (3 in.) of the specimen under test to a uniform temperature of 260^{o}C (500^{o}F). The test fixture shall consist of an aluminum enclosure, heated air source, and temperature controller. The heated air source used shall have sufficient capacity to raise the specimen temperature to 260^{o}C within two minutes.

II.5.5 Procedure

Specimens shall be tested as specified in ASTM D5034-09 *Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test).*

Prior to load application the specimen shall be allowed to come to thermal equilibrium at 260°C (500°F), approximately two minutes.

II.5.6 Report

The tensile strength of an individual specimen shall be the average of the five highest peak loads registered. The tensile strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The average tensile strength and standard deviation for the warp direction and fill direction shall be reported.

II.6 Puncture Resistance Test

II.6.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.6.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.6.3 Specimens

Specimens shall be 100 mm (4 in.) diameter.

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

A minimum of five specimens shall be tested.

II.6.4 Apparatus

Testing machine as described in ASTMD6797 – 07 *Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst Test.*, except that a ball burst apparatus shall replace the clamp assembly.

The polished steel ball specified in Method 5120 shall be replaced with the modified blunt end probe. The blunt end probe shall have a diameter of 9.5 mm (0.375 in) and shall be chamfered at 45° to remove the sharp corner.

II.6.5 Procedure

Specimens shall be tested as specified in ASTMD6797 – 07 *Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst Test.*

II.6.6 Report

The puncture resistance of an individual specimen shall be the average of the five highest peak loads registered. The burst strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The average puncture strength and standard deviation shall be reported.

II.7 Mullen Burst Strength

II.7.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

II.7.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

II.7.3 Specimens

Specimens shall be 65 mm (2.5 in.) diameter.

For multilayered shelter designs, each layer needs to be tested separately. For laminated shelter designs, each laminate layer needs to be tested separately. Additionally, the composite of all layers of the fire shelter shall be tested.

A minimum of five specimens shall be tested.

II.7.4 Apparatus

A Mullen Burst Tester shall be used. A motor drive Model A Mullen Burst Tester shall be used. The Burst Tester shall be driven by a motor speed of 1750 rpm and use a Model 305-B Mullen® Tester Diaphragm supplied by Mullen® Testers.

Material with a foil laminate shall be tested with the foil against the diaphragm.

II.7.5 Procedure

The Burst Test shall be tested as specified in ASTMD6797 – 07 *Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst Test.*

II.7.6 Report

An average of 3 tests across the material width shall be reported. The burst strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The lowest value of 3 tests across the material width and standard deviation shall be reported.

Tier III tests:

Introduction: Tier III tests are designed to test a full scale fire shelter and the components of the design.

III.1 Convective Exposure

III.1.1 Application

This test shall apply to full sized prototype fire shelters.

III.1.2 Sample Preparation

Samples for conditioning shall be removed from any packing material prior to conditioning.

All specimens to be tested shall be conditioned as specified in 1.2.

III.1.3 Specimens

A minimum of three shelters shall be tested.

III.1.4 Apparatus

The apparatus used to test full sized shelters shall be capable of producing flame contact over 90% of the shelter surface for at least 30 seconds (see drawing III.1).

The apparatus shall use propane as a fuel and shall have appropriate safety features to prevent the accidental release of fuel.

Burners shall be capable of generating a diffusion flame and shall be arranged to provide a uniform exposure over the surface of the shelter under test.

Equipment suitable for the measurement of the following parameters shall be installed within the shelter under test and recorded during the exposure and for 1 minute following the exposure.

Temperatures shall be measured at a location no more than 150 mm (6 in.) from the intended head end of the shelter at heights of 50 mm (2 in.) and 250 mm (10 in.) above the floor of the shelter using either Type K or Type J thermocouples.

Heat flux to the surface of a half cylinder fiberglass form, which represents a human form, diameter 300 mm (12 in.), length 1800 mm (71 in.) laid on the floor of the test chamber, under the fire shelter, shall be measured at a minimum of six locations. The instrumentation used to measure heat flux shall respond to total flux (radiant plus convective) and shall have an accuracy of $\pm$10%.

The composition of the atmosphere within the shelter shall be measured using a real time analyzer suitable for the measurement of oxygen, carbon dioxide, carbon monoxide and hydrocarbons. Samples of atmosphere shall be drawn during the exposure at a level of 50 mm (2 in.) above the floor at the intended head end of the shelter. The equipment used shall have the following resolution: Oxygen 0.1%, Carbon Dioxide 0.1%, Carbon Monoxide 10 ppm, Hydrocarbons 10 ppm.

For one replication the concentration of hydrogen chloride and hydrogen cyanide shall be measured by drawing a 10 liter sample at 1 L/min of the atmosphere from within the shelter through a 0.1 M solution of sodium hydroxide immediately following the exposure to flames. This procedure is described in Appendix A.

One replication sample of atmosphere shall be obtained for use in screening for volatile compounds. The procedure is outlined in Appendix B.

Visual conditions within the shelter shall be recorded during the exposure using a suitable video camera installed in a protective enclosure.

III.1.5 Procedure

The shelter to be tested shall be weighed and the starting mass recorded to the nearest 1 g (0.002 lb).

The shelter to be tested shall be installed on a suitable internal frame capable of maintaining the shape during the exposure.

The shelter should be exposed to flame until the temperature at breathing level (50 mm above the floor) reaches 150^{o}C, while visual observations from inside are recorded with a video camera in a protected enclosure.

Immediately following the exposure, samples from the internal atmosphere shall be obtained for HCL and HCN using the procedure outlined in Appendix A and volatile gases using the procedure in Appendix B.

After exposure and cool down, external observations of the condition of the shelter shall be made and recorded.

Prior to removal of the shelter from the internal frame, the shelter and frame shall be vigorously shaken at least four times and any additional damage recorded.

The mass of the shelter shall be determined after exposure and shaking.

III.1.6 Report

The report shall include visual observations of the external condition of the shelter after exposure and shall include references to delamination of composite materials, discoloration, smoke evolved, and structural integrity.

The temperature at the head end from the 50 mm (2 in.) level and the 250 mm (10 in.) level at a minimum of every 1 second shall be reported.

The time when the temperature reaches 150ºC at the 50 mm (2 in.) level shall be reported.

At the time reported when the 50 mm (2 in.) level reaches 150ºC, the temperature at the 250 mm (10 in.) level shall be reported.

The heat flux on the surface of the fiberglass half cylinder form from the six locations, or more if used, at 1 second intervals from the start of the test shall be reported.

The peak concentration of CO, CO_2, HC, and the time of occurrence shall be reported.

The minimum oxygen level and the time of occurrence shall be reported.

Visual observations from the video camera recording of conditions within the shelter during the exposure shall be reported and shall include references to smoke and internal flaming whether present or not.

The physical condition of the shelter after shaking shall be reported and shall include references to no damage, minimal damage, substantial damage or destroyed.

The mass of the shelter shall be determined after exposure and shaking. The change in total mass shall be reported.

A toxicologist shall review the data upon completion of the GC/MS analysis for volatile gases.

Findings of any compounds or combination of gases that could pose a risk to human health shall be reported.

III.2 Radiant Exposure

III.2.1 Application

This test shall apply to full sized prototype fire shelters.

III.2.2 Sample Preparation

Samples for conditioning shall be removed from any packing material prior to conditioning.

All specimens to be tested shall be conditioned as specified in 1.2.

III.2.3 Specimens

A minimum of three shelters shall be tested.

III.2.4 Apparatus

The apparatus used to test full sized shelters shall be capable of irradiating a minimum of 50% of the shelter surface for a period of 15 minutes (see drawing III.2).

If the apparatus uses a gaseous fuel it shall have appropriate safety features to prevent the accidental release of fuel.

Burners or electric heaters shall be capable of generating a radiant flux and shall be arranged to provide a uniform exposure over the surface of the shelter.

Radiant heat flux to the surface of the shelter shall be 40 kW/m^2 $\pm$ $10kW/m^2$and shall be verified using either copper calorimeters, guardon gauges or other such measurement device that is applicable. For the purpose of complying with this standard, measurements shall be made in a minimum of 10 locations evenly spaced over the irradiated portion of the fire shelter under test.

Equipment suitable for the measurement of the following parameters shall be installed within the shelter under test and recorded during the exposure.

Temperatures shall be measured at a location no more than 150 mm (6 in.) from the intended head end of the shelter at heights of 50 mm (2 in.) and 250 mm (10 in.) above the floor of the shelter using either Type K or Type J thermocouples. The placement of the head end of the shelter and thermocouples shall be located such that this portion is positioned under the radiant heaters for full radiant flux measurements.

Heat flux to the surface of a half cylinder fiberglass form, representing a human form, diameter 300 mm (12 in.), length 1800 mm (71 in.) laid on the floor of the test chamber, under the fire shelter, shall be measured at a minimum of ten locations. The instrumentation used to measure heat flux shall respond to total flux (radiant plus convective) and shall have an accuracy of $\pm$10%.

The composition of the atmosphere within the shelter shall be measured using a real time analyzer suitable for the measurement of oxygen, carbon dioxide, carbon monoxide, and hydrocarbons. Samples of atmosphere shall be drawn during the exposure at a level of 50 mm (2 in.) above the floor at the intended head end of the shelter. The equipment used shall have the following resolution: Oxygen 0.1%, Carbon Dioxide 0.1%, Carbon Monoxide 10 ppm, Hydrocarbons 10 ppm.

For one replication the concentration of hydrogen chloride and hydrogen cyanide shall be measured by drawing a 10 liter sample at 1 L/min of the atmosphere from within the shelter through a 0.1 M solution of sodium hydroxide immediately following the exposure from the radiant source. This procedure is described in Appendix A.

For one replication a sample of atmosphere shall be obtained for use in screening for volatile compounds. This procedure is described in Appendix B.

Visual conditions within the shelter shall be recorded during the Exposure using a suitable video camera installed in a protective enclosure.

III.2.5 Procedure

The shelter to be tested shall be weighed and the starting mass recorded to the nearest 1 g (0.002 lb).

The shelter to be tested shall be installed on a suitable internal frame capable of maintaining the shape during the exposure.

The shelter shall be exposed for a period of 15 minutes while recording visual observations from inside the shelter.

HCl and HCN concentration shall be determined for one of the three shelters.

After exposure and cool down, external observations of the condition of the shelter shall be made and recorded.

Prior to removal of the shelter from the internal frame the shelter and frame shall be vigorously shaken at least four times and any additional damage recorded.

The mass of the shelter shall be determined after exposure and shaking.

III.2.6 Report

The report shall include visual observations of the external condition of the shelter after exposure and shall include references to delamination of composite materials, discoloration, smoke evolved and structural integrity.

The temperature at the head end from the 50 mm (2 in.) level and the 250 mm (10 in.) level shall be reported at a minimum of every 1 second.

The time the temperature reaches 150ºC at the 50 mm (2 in.) level shall be reported.

At the time reported when the 50 mm (2 in.) level reaches 150ºC, the temperature at the 250 mm (10 in.) level shall be reported.

The heat flux on the surface of the fiberglass half cylinder form from the six locations, or more if used, at 1 second intervals from the start of the test shall be reported.

The peak concentration of CO, CO_2, HC, and the time of occurrence shall be reported.

The minimum oxygen level and the time of occurrence shall be reported.

Visual observations from the video camera recording of conditions within the shelter during the exposure shall be reported and shall include references to smoke and internal flaming whether present or not.

The physical condition of the shelter after shaking shall be reported and shall include references to no damage, minimal damage, substantial damage or destroyed.

The mass of the shelter shall be determined after exposure and shaking. The change in total mass shall be reported.

A toxicologist shall review the data upon completion of the GC/MS analysis for volatile gases.

Findings of any compounds or combination of gases that could pose a risk to human health shall be reported.

III.3 Durability

III.3.1 Application

This test shall apply to full sized fire shelters.

III.3.2 Sample Preparation

Samples shall be left intact within its protective containment bag, if any.

III.3.3 Specimens

A minimum of three shelters shall be tested.

III.3.4 Apparatus

The apparatus used to evaluate the durability shall be capable of repeated compressive loading of a full sized fire shelter to a maximum load of 1115 N (250 lbf) and shall be capable of recording the number of complete cycles.

A set of plattens shall be firmly affixed to the testing machine and shall apply a uniform load over the surface of the shelter under test.

The testing machine used shall be capable of load control and shall have the capability of both maximum and minimum compressive limits.

Load shall be measured with an accuracy of 10N.

III.3.5 Procedure

The shelter under test shall be placed between the testing machine plattens and load limits set to minimum compression - 100 N, maximum compression - 1115 N.

Cross head speed shall be set to a minimum of 100 inches per minute.

The test shall be complete after the shelter has been subjected to 4000 compressive cycles.

After reaching 4000 cycle the material layers making up the shelter, if any, shall be separated and viewed in front of a light source to accentuate any holes or tears.

III.3.6 Report

The report shall include a description of the shelter before and after testing.

The condition of the shelter after 4000 cycles shall be reported.

The description shall include, but not be limited to, condition of seams and folds, fraying, fiber and thread breakage, cracking or separation of bonded layers or any other condition that reduces the ability of the shelter to provide a barrier to heat and gases.

III.4 Seam Strength Test

III.4.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

III.4.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

III.4.3 Specimens

Specimens shall be 100 mm x 150 mm (4 in. x 6 in.).

All major seams that connect material layers together, shall be tested. This shall include any attachments (handles, straps, etc.) that are used in the construction of the shelter.

A minimum of five specimens for each major seam shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

III.4.4 Procedure

Specimens shall be tested as specified in CAN/CGSB-4.2, No.32.2-M89 *Breaking Strength of Seams in Woven Fabrics.*

III.4.5 Report

The breaking strength of an individual specimen shall be the average of the five highest peak loads registered. The breaking strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The average breaking strength and standard deviation for each major seam and attachment shall be reported.

III.5 Elevated Temperature Seam Strength Test

III.5.1 Application

This test shall apply to both woven and non-woven materials used in fire shelters.

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III.5.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

III.5.3 Specimens

Specimens shall be 100 mm x 200 mm (4 in. x 8 in.).

All major seams that connect material layers together, shall be tested. This shall include any attachments (handles, straps, etc.) that are used in the construction of the shelter.

A minimum of five specimens in each major seam shall be tested.

Where the material is isotropic, then ten specimens shall be tested.

III.5.4 Apparatus

The standard tensile strength test fixture shall be modified to elevate the central 75 mm (3 in.) of the specimen under test to a uniform temperature of 260^{o}C (500^{o}F). The test fixture shall consist of an aluminum enclosure, heated air source, and temperature controller. The heated air source used shall have sufficient capacity to raise the specimen temperature to 260^{o}C within two minutes.

III.5.5 Procedure

Specimens shall be tested as specified in CAN/CGSB-4.2, No. 32.2-M89 *Breaking Strength of Seams in Woven Fabrics.*

Prior to load application the specimen shall be allowed to come to thermal equilibrium at 260°C (500°F), approximately two minutes.

III.5.6 Report

The breaking strength of an individual specimen shall be the average of the five highest peak loads registered. The breaking strength for each specimen shall be reported to the nearest 1 N (0.2 lbf) of force.

The average breaking strength and standard deviation for each major seam and attachment shall be reported.

III.6 Peel Strength

III.6.1 Application

This test shall apply to any materials that are bonded to each other by glue or other adhesives.

III.6.2 Sample Preparation

Samples for conditioning shall be at least 1 m (1 yd) square of material.

All specimens to be tested shall be conditioned as specified in 1.2.

III.6.3 Specimens

Woven and non-woven material samples shall be selected so that different warp and fill threads are tested with each sample.

A minimum of ten specimens in each the warp direction and fill direction shall be tested.

III.6.4 Apparatus

Test for peel strength shall be in accordance with ASTM D1876 – *Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)* except the applied separation rate shall be 3 inches per minute.

III.6.5 Procedure

The creep test shall be performed using a 50-gram weight in a dead weight, 180-degree angle peel test at a temperature of 425 ±5°F and uncontrolled humidity. The sample shall be hung by the cloth component and the 50-gram weight shall be attached to the aluminum foil. The test chamber shall be configured such that no

movement is induced into the sample due to airflow. The test strips shall be 2 inches wide and the same length as required for the peel strength test. The test strips may be cut with the warp or weave (machine or X-machine) direction.

If a material is laminated to foil, the foil may tear before the laminate separates. Failure (tearing) of the foil prior to failure of the bond is an acceptable result.

III.6.6 Report

Report each individual peel strength and the average peel strength for each material tested. Acceptable peel strength must be greater than 1.75 lb/inch.

Appendix A. Determining Concentration of HCN and HCL - Full scale convective exposure

A.1 Application

This procedure shall apply to convective tests of prototype full scale shelters.

A.2 Specimens

A 10 liter sample of atmosphere from inside a fire shelter shall be obtained.

A.3 Apparatus

The sample system shall be capable of drawing a 10 liter sample of atmosphere, through a standard 30 mL midget impinger*, containing 20 mL of 0.1 M NaOH solution at a rate of 1 L/min.

A.4 Procedure

Prior to drawing a sample the atmosphere inside the shelter under test shall be mixed for 10 seconds with a small mixing fan to ensure uniform interior conditions.

A solution of 0.1 M Sodium Hydroxide (NaOH) in water shall be prepared by dissolving 4g of NaOH in 1.0 L of distilled water. The solution may be stored for a maximum period of 1 month prior to use.

The impinger used shall be rinsed prior to use with distilled water to ensure no contamination from previous samples.

20 ml±1.0ml of 0.1 molar NaOH shall be added to the impinger.

The impinger shall be mounted on a stand intended to keep it upright and prevent the spillage of NaOH solution during the exposure.

A 10 ± 0.1 liter sample of atmosphere shall be drawn through the NaOH solution at a rate of 1 L/min. The flow rate shall be adjusted to ensure that none of the NaOH solution enters the line connecting the impinger to the sample system/flow meter.

At the end of the sample period (approximately 10 minutes) the flow should be stopped by "breaking the vacuum" with a suitable valve, prior to turning off the sample system.

After removal of the shelter under test, the impinger stem shall be removed from the base and a small amount of distilled water used to rinse any residual solution into the base of the impinger. Additional distilled water should be added to the base of the impinger to make the total solution volume 25 mL. This should be done very carefully as this is the volume that will be used in the calculation of species concentration.

The impinger solution shall be transferred to a clean glass vial, labeled and sent to a suitable laboratory for analysis.

* A midget impinger such as Fisher Scientific part number LG-6890-102(top), LG-6890-122 (base) has been found to be suitable.

Appendix B. Gas Chromatograph / Mass Spectrometer (GC/MS) Screening for Volatile Organics

B.1 Application

This procedure shall apply to tests of full sized prototype fire shelters.

B.2 Specimens

A 1 liter sample of atmosphere from inside a fire shelter shall be obtained.

B.3 Apparatus

The sample system shall be capable of drawing a 1 liter sample of atmosphere into a tedlar sample bag* without contamination. All materials that contact the sample shall be constructed of stainless steel, tedlar or teflon.

B.4 Procedure

A new tedlar sample bag shall be evacuated and attached to the sample system prior to exposing the fire shelter.

After exposing the shelter, the internal atmosphere shall be mixed using a small fan. After mixing, a sample of atmosphere shall be drawn from inside the shelter.

The valve on the sample bag should be closed prior to detachment from the sample system.

The bag shall be suitably labeled and sent to a laboratory capable of screening the contents for volatile gases.

*Suitable sample bags have been obtained from Safety Instruments

Appendix C. Referenced Publications

The following documents or portions thereof are referenced within this document. The edition indicated here for each reference is the current edition as of January 2011.

ASTM Publications. American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA, 19428-2959.

ASTM D1776-08A *Standard Practice for Conditioning and Testing Textiles*

ASTM D1777-96 (2007) *Standard Test Method for Thickness of Textile Materials*

ASTM D1876-08 *Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)*

ASTM D5034-09 *Standard Test Method for Breaking Strength and Elongation of Textile Fabrics (Grab Test)*

ASTM D5587-08 *Standard Test Method for Tearing Strength of Fabrics by Trapezoid Procedure*

ASTM D6797-07 *Standard Test Method for Bursting Strength of Fabrics Constant-Rate-of-Extension (CRE) Ball Burst Test*

CAN/CGSB Publications. Canadian General Standards Board, Place du Portage III, 6B1,11 Laurier Street, Gatineau, Quebec, K1A 1G6, Canada

CAN/CGSB-4.2, No.32.2-M89 *Breaking Strength of Seams in Woven Fabrics*

CAN/CGSB-4.2 No.27.10-2000, *Flame Resistance: Vertically Oriented Textile*

Fabric or Fabric Assembly Test

ISO Publications. International Organization for Standarization, 1, rue de Varembe´, Case postale 56, CH 1211 Geneve 20, Switzerland

ISO 9151:1995 *Protective clothing against heat and flame -- Determination of heat transmission on exposure to flame*

NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA, 02269-9101

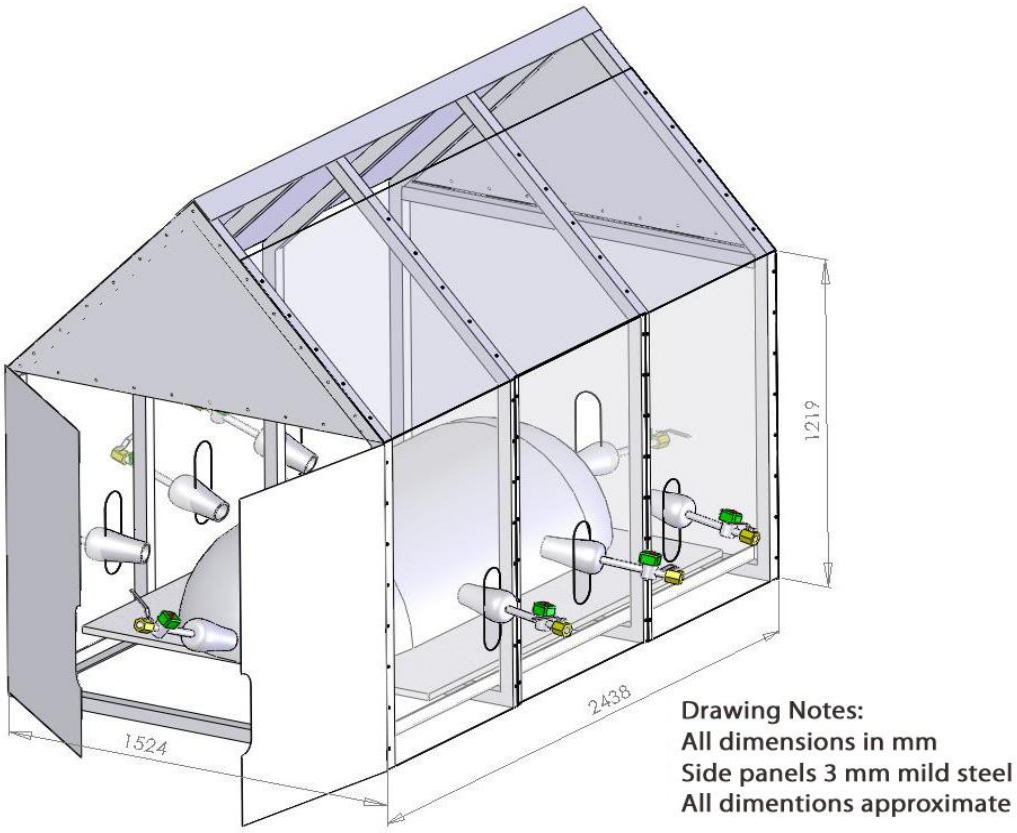
NFPA 1977 *Standard on Protective Clothing and Equipment for Wildland Fire Fighting*, 2011

USDA Forest Service. Missoula Technology and Development Center, 5785 Hwy 10 West, Missoula, MT 59808.

U.S. Department of Agriculture Forest Service 5100-615A – *Protocol for Evaluating Off Gas Toxicity of Fire Shelter Material (2010)*

Drawings:

III.1 – Full Scale Convective Test Apparatus



III.2 – Full Scale Radiant Exposure Test Apparatus