This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: F2588 – 12 (Reapproved 2020)

Standard Test Method for Man-In-Simulant Test (MIST) for Protective Ensembles[1]

This standard is issued under the fixed designation F2588; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method specifies the test equipment and procedures for conducting tests to estimate the entry of chemical agent vapor simulant through protective ensembles while worn by test subjects.

1.2 This test method permits the evaluation of protective ensembles consisting of protective garments or suits, gloves, footwear, respirators, and interface devices.

1.3 The results of this test method yield local physiological protective dosage factors at individual locations of the human body as well as a systemic physiological protective dosage factor for the entire ensemble.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E171/E171M Practice for Conditioning and Testing Flexible Barrier Packaging

F1052 Test Method for Pressure Testing Vapor Protective Suits

F1154 Practices for Evaluating the Comfort, Fit, Function, and Durability of Protective Ensembles, Ensemble Elements, and Other Components

F1359/F1359M Test Method for Liquid Penetration Resistance of Protective Clothing or Protective Ensembles Under a Shower Spray While on a Manikin

F1494 Terminology Relating to Protective Clothing

F1731 Practice for Body Measurements and Sizing of Fire and Rescue Services Uniforms and Other Thermal Hazard Protective Clothing

2.2 *National Fire Protection Association (NFPA) Standards:*[3]

NFPA 1971 Standard on Protective Ensembles for Structural and Proximity Fire Fighting

NFPA 1994 Standard on Protective Ensembles for CBRN Terrorism Incidents

2.3 *U.S. Military Publication:*[4]

Test Operations Procedure (TOP 10-2-022) Man-In-Simulant Test (MIST)—Chemical Vapor Testing of Chemical/Biological Protective Suits, September 2001

3. Terminology

3.1 *Definitions:*

3.1.1 *chemical agent vapor simulant, n*—a substance used to replicate vapor characteristics of a chemical agent which is a more toxic substance.

3.1.1.1 *Discussion*—In this test method, methyl salicylate is used as a chemical agent vapor simulant for the blister agent, distilled mustard.

3.1.2 *chemical terrorism agent, n*—a liquid, solid, gaseous, or vapor chemical warfare agent or a toxic industrial chemical used to inflict lethal or incapacitating casualties, generally on a civilian population as a result of a terrorist attack.

3.1.3 *interface area, n*—a location on the body where two or more protective clothing items (for example, suits, garments, hoods, gloves, footwear, respirators, or other items) come into contact.

3.1.3.1 *Discussion*—Interfaces are potential breaches that could allow entry of chemicals into the interior of the protective ensemble.

[1] This test method is under the jurisdiction of ASTM Committee F23 on Personal Protective Clothing and Equipment and is the direct responsibility of Subcommittee F23.30 on Chemicals.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, http://www.nfpa.org.

[4] U.S. Army Developmental Test Command (DTC), ATTN: CSTE-DTC-TT-S, Aberdeen Proving Ground, MD 21005-5055.

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3.1.4 *interface device, n*—an item of the ensemble that is intended to provide protection to the interface area.

3.1.5 *local physiological protective dosage factor ($PPDF_l$), n*—a physiological protective dosage factor at a specific location on the body.

3.1.5.1 *Discussion*—In this test method, local physiological protective dosage factors are measured at 30 different locations on the body.

3.1.6 *onset of symptoms exposure dosage (OSED), n*—the dosage that causes threshold effects to the average human.

3.1.7 *passive adsorbent dosimeters (PADs), n*—two-sided packets with one side made from a permeable film and the second side made from a chemically impermeable film, which are filled with absorbent material, and are placed on the skin at specific locations of the body to collect any chemical vapor challenge that has infiltrated the protective ensemble.

3.1.8 *physiological protective dosage factor (PPDF), n*—the factor by which protection is improved against effects from vapor exposure for the protected individual compared with whole-body exposure of the unprotected individual.

3.1.9 *protective ensemble, n*—the combination of protective clothing with respiratory protective equipment, hoods, helmets, gloves, boots, communication systems, cooling devices, and other accessories intended to protect the wearer from a potential hazard when worn together.

3.1.9.1 *Discussion*—For evaluating the vapor penetration and permeation resistance of protective ensembles against chemical agent vapor simulant, the protective ensemble includes all those clothing items or accessories, which are necessary to provide resistance to inward leakage by chemical vapors.

3.1.10 *systemic physiological protective dosage factor ($PPDF_{sys}$), n*—a physiological protective dosage factor determined for the entire ensemble.

3.2 For definitions of other terms related to protective clothing used in this test method, refer to Terminology F1494.

4. Summary of Test Method

4.1 This test method establishes procedures for testing complete protective ensembles worn by test subjects when exposed to chemical agent vapor simulant. Methyl salicylate (MeS) is used to simulate chemical agent vapor penetration through ensemble interfaces and openings.

4.2 This test method tests the vapor penetration and permeation resistance of a protective ensemble by the placement of passive adsorbent dosimeters (PADs) containing sorbent material onto the test subjects at specific locations on the body.

4.3 After test subjects wearing the ensemble to be evaluated finish a series of activities inside the test chamber, these PADs are removed from the test subject and analyzed for MeS.

4.4 Data obtained from the individual PADs are used to assess the vapor penetration and permeation resistance of the ensemble at each body location and for the overall ensemble.

5. Significance and Use

5.1 This test method is intended to evaluate the penetration and permeation resistance for complete ensembles to vapors from chemical warfare agents and other chemical substances.

5.1.1 This test method differs from Test Method F1052 by providing an evaluation of ensembles worn on human test subjects and measuring the inward leakage of a chemical agent vapor simulant as it would be absorbed by the wearer's skin. Test Method F1052 is not applicable to the range of protective ensembles that are evaluated by this test method.

5.1.2 This test method differs from Test Method F1359/F1359M by using a chemical agent vapor simulant as compared to a liquid challenge and in the use of human test subjects. This test method further provides a quantitative assessment of inward leakage for the chemical agent vapor simulant.

5.1.3 The use of this test method to determine the inward leakage of other chemical vapor threats must be evaluated on a case-by-case basis.

5.2 This test method is applied to complete ensembles consisting of a suit or garment in combination with gloves, footwear, respirators, and interface devices.

5.2.1 This test method permits any combination or configuration of ensemble elements and components, including ensembles where the respirator covers the face or head.

5.2.2 This test method accommodates protective ensembles or protective clothing having any combination of the following characteristics:

(1) The protective ensemble or clothing is constructed of air-permeable, semipermeable, or impermeable fabrics,

(2) The protective ensemble or clothing is of a single or multi-layered design, or

(3) The protective ensemble or clothing is constructed of inert or sorptive fabrics.

5.3 MeS has been used as a simulant for chemical warfare agents. MeS is primarily a simulant for distilled mustard (HD) with a similar vapor pressure, density, and water solubility. The use of MeS in vapor form does not simulate all agents or hazardous substances to which ensemble wearers are potentially exposed.

5.4 The principal results of this test are physiological protective dosage factors that indicate the relative effectiveness of the ensemble in preventing the inward leakage of the chemical agent vapor simulant and its consequent dosage to the wearer's skin as determined by the use and placement of personal adsorbent devices (PAD) on human test subjects.

5.4.1 Specific information on inward leakage of chemical agent vapor simulant is provided by local physiological protective dosage factors for individual PAD locations to assist in determining possible points of entry of the chemical agent vapor simulant into the ensemble.

5.4.2 The determination of the local physiological protective dosage factors is based on ratio of the outside exposure dosage to the inside exposure dosage on the wearer's skin at specific locations of the body and accounts for the specific susceptibility of the average human's skin at those locations to the effects of blister agent, distilled mustard using the onset of

symptoms exposure dosages (OSED) at different points on the body. The specific OSED values used in this test method are based on the exposure concentration of distilled mustard that causes threshold effects to the average individual human in the form of reversible skin ulceration and blistering (1).[5]

5.4.3 The body locations chosen for the placement of PADs were chosen to represent the range of body areas on the human body, with preference to those body areas generally near interfaces found in common two-piece ensembles with separate respirator, gloves, and footwear. Additional locations are permitted to be used for the placement of PAD where there are specific areas of interest for evaluating the inward leakage of the chemical agent vapor simulant.

NOTE 1—Common interface areas for protective ensemble include the hood to respirator facemask, clothing or suit closure, upper torso garment to lower torso garment, garment sleeve to glove, and garment pant cuff to footwear.

5.4.4 An assessment of the vapor penetration and permeation resistance for the entire ensemble is provided by the determination of a systemic physiological protective dosage factor. The same PAD data are used in a body region hazard analysis to determine the overall physiological protective dosage factor accounting for the areas of the body represented by the location, and the relative effects of the nerve agent, VX. A systemic analysis assists in the evaluation for those chemical agents, such as nerve agents, affecting the human body through a cumulative dose absorbed by the skin (2).

5.4.5 Examples of analyses applying PAD data for the assessment of ensemble inward leakage resistance are provided in NFPA 1971, Standard on Protective Ensemble for Structural and Proximity Fire Fighting, and NFPA 1994, Standard on Protective Ensemble for CBRN Terrorism Incidents.

5.4.6 The general procedures in this test method are based on Test Operations Procedure (TOP 10-2-022), Man-In-Simulant Test (MIST)—Chemical Vapor Testing of Chemical/Biological Protective Suits.

5.5 The human subject activities simulate possible causes of changes in ensemble vapor barrier during expected activities. These activities are primarily based on stationary activities provided in Part A of Practices F1154 and are intended to create movements that are likely to affect the integrity of the ensemble and its interface areas. Additional activities (such as dragging a dummy and climbing a ladder) have been added to simulate activities that might be used by first responders during emergency events such as rescuing victims from a terrorism incident involving chemical agents. The test method permits the modification of the activity protocol to simulate the specific needs of the protective ensemble application.

5.6 The length of the human subject exposure to the chemical agent vapor simulant is set at 30 min in the test chamber with a 5-min decontamination period. This test duration is intended to replicate a possible exposure of a first responder during a terrorism incident involving chemical agents. If a self-contained breathing apparatus is used, a 60-min rated respirator must be used or provisions made for supplemental umbilical air (through a supplied air system). The test method permits the adjustment of the exposure period to simulate the specific needs of the protective ensemble application.

5.7 Test results generated by this test method are specific to the ensemble being evaluated. Changing any part of the ensemble necessitates a new set of testing for the modified ensemble.

5.8 Additional information on man-in-simulant testing is provided in (3).

6. Facilities and Apparatus

6.1 *Test Chamber*—A sealed chamber having the following characteristics:

6.1.1 Provides a minimum volume of sufficient dimensions to permit free movement of the test subject(s) when fully dressed in the ensemble.

6.1.2 Maintains a temperature of 27 ± 5 °C (80 ± 10 °F) and relative humidity of 65 ± 20 %.

6.1.3 Provides a nominal range of wind speed of 0.9 to 2.2 m/s (2 to 5 mph).

6.2 *Other Test Facilities*—Areas for the test operator(s), dressing, decontamination, first stage undressing, and second stage undressing.

6.2.1 A test operator area shall be located immediately adjacent to the test chamber and shall include the monitoring equipment for the test chamber MeS concentration, temperature, humidity, and air speed. The test operator area shall include a means for test operators to directly observe test subject(s) in the chamber.

6.2.2 The dressing area shall be located away from the test chamber to ensure that this area is free from contamination by the test agent.

6.2.3 The area for decontamination shall be well ventilated, physically isolated from the test chamber, and one that permits ready drainage of wash water.

6.2.4 The first stage undressing area shall be adjacent to the decontamination area, but well away from the test chamber.

6.2.5 The second stage undressing area shall be adjacent and accessible to the first stage undressing area.

6.3 *MeS Generator,* a vapor generator that must be capable of operation by remote control from the test operator area and shall be able to dispense MeS at the controlled rate required to maintain vapor concentration at a level that is ±15 mg/m^3 of the target concentration. (Also see 12.1.2.)

6.4 *MeS Detector,* a detector capable of providing a real-time analysis of the MeS concentration in the test chamber.

6.5 *Refrigerator*—Capable of maintaining a temperature of 4.0 ± 3 °C (38.6 ± 5 °F).

6.6 *Analytical Equipment and Supplies,* used for extracting MeS from the adsorbent used in the PADs and providing an analysis of the extracted MeS concentration. The sensitivity of the analytical technique shall provide for a detection limit of 3 mg.min/m^3 (approximately 30 ng MS per PAD). The analytical technique shall be linear up to at least a dose of

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

1000 mg.min/m^3, with a coefficient of variation on replicate spiked dosimeter samples of less than 15 %.

NOTE 2—Examples of suitable analytical techniques include gas chromatography with thermal desorption of the adsorbent in the PAD, and high-performance liquid chromatography with methanol extraction of the adsorbent in the PAD.

7. Supplies

7.1 *Passive Adsorbent Dosimeter (PAD)*—An item placed on the skin of a human test subject for adsorbing chemical challenge vapor that penetrates the ensemble, which can be later analyzed to determine the dose received at a specific body location. PADs are adhesive-backed foil packets measuring 25 mm by 35 mm by 0.02 mm, which contain an adsorbent material covered by a high-density polyethylene barrier film. The active surface sampling area of a PAD is 4.3 ± 0.6 cm^2 and its uptake rate is 10 ± 2 cm^3/min. Specifications for preparation of PADs are provided in Appendix X1.[6,7]

NOTE 3—The barrier film has a penetration rate similar to human skin when exposed to MeS and acts as a pseudo-skin barrier.

7.2 *Test Activity Aids:*

7.2.1 A 70-kg, non-rigid human dummy outfitted with a circular rope looped under the arms with sufficient length to permit dragging the dummy from the head side by a test subject.

7.2.2 A 2-m extension ladder, that is secured alongside one of the test chamber walls.

7.2.3 A stool without a back, approximately 600 mm (24 in.) high.

7.3 *Decontamination Materials:*

7.3.1 *Decontamination Equipment*—For spraying ensemble exterior during decontamination process.

7.3.2 *Liquid Soap*—Mild household detergent that does not contain bleach and is free of fragrances.

7.4 *Analysis Materials:*

7.4.1 Glass vials with a non-adsorbent lid liner of sufficient size to accommodate removed PADs.

7.4.2 Aluminum foil.

8. Reagent

8.1 *Test Simulant*—Methyl salicylate (MeS - $C_8H_8O_3$) CAS # 119-36-8 with a minimum purity of 95 %.

9. Hazards and Safety Precautions

9.1 Review the use of MeS as chemical agent vapor simulant with respect to exposure to human test subjects. An analysis of possible percutaneous toxicity for MeS is presented in Appendix X2.

NOTE 4—MeS is more commonly known as oil of wintergreen and has a relatively low percutaneous toxicity. It is used as a denaturant and flavoring agent and medicinally is used as a topical anti-inflammatory and dermal keratolytic agent.

9.2 Use human test subjects that are medically and physically suitable to perform these tests without danger to themselves.

9.2.1 Ensure that a medical certificate for each test subject has been issued within twelve months prior to testing.

9.2.2 Select test subjects that are familiar with the use of protective ensembles and with the selected respirator.

9.2.3 Conduct qualitative or quantitative respirator fit test for each test subject before a MIST evaluation.

9.2.4 Each test subject must use a protective ensemble and a professionally fitted respirator at all times during MIST evaluations.

9.3 If necessary for the test facility, have the specific evaluation protocol reviewed and approved by a human subjects review board or similar panel to ensure the safety and health of the selected test subjects.

10. Sampling and Test Specimens

10.1 Test specimens shall consist of a complete ensemble with protective clothing, gloves, and footwear and shall include the respirator where applicable.

10.1.1 Where the ensemble utilizes the respirator facepiece as the ensemble visor, the ensemble shall be tested with each type or model of the respirator specified by the manufacturer.

10.1.2 Where the respirator is completely encapsulated by the ensemble, the ensemble shall be tested with a respirator specified by the manufacturer.

10.2 A minimum of four specimens shall be tested. Specimens representing a minimum of two different ensemble sizes shall be tested.

10.3 Where the ensemble has multiple types of external fittings, each type of external fitting shall be present on each specimen at the time of testing.

10.4 The ensembles shall be selected to fit or be adjustable to fit the selected test subjects in accordance with the manufacturer's sizing provisions that are specific to each ensemble item.

NOTE 5—Additional information on sizing can be found in Practice F1731.

10.5 Ensembles or components of the ensemble that have been previously subjected to this test method shall not be subjected to additional tests unless it can be demonstrated that the ensemble or components are free of contamination.

NOTE 6—SCBA and some styles of footwear are likely to be acceptably decontaminated after washing and then air drying three weeks in a ventilated space. Some items such as gloves and garments may not be easily decontaminated.

10.5.1 Underclothing and socks shall be permitted to be reused provided they have been laundered with a detergent that has been demonstrated not to cause interference with the analytical method.

11. Conditioning

11.1 Specimens for conditioning shall be complete ensembles and shall include the respirator where the ensemble utilizes the respirator facepiece as the ensemble visor.

[6] The sole source of supply of PADs known to the committee at this time is Syon, ITW Devcon, Danvers, MA 01923 ("Natick Sampler," Part Number 037-002101-113).

[7] If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

11.2 Each specimen shall be conditioned for a minimum of 4 h by exposure to a temperature of 27 ± 5 °C (80 ± 10 °F) and relative humidity of 65 ± 20 % as described in Practice E171/E171M using a controlled temperature and humidity chamber or space.

11.3 Other conditioning shall be applied to the protective ensemble or ensemble components to simulate wear or use of the ensemble, as appropriate to the protective ensemble application.

NOTE 7—If protective ensembles are intended to be laundered and reused prior to chemical agent exposure, consider testing protective ensembles after suitable care procedures have been applied.

12. Procedure

12.1 *Pretest Chamber and Facility Preparation:*

12.1.1 Locate three PADs for a total of nine, in each of the following three areas: the dressing area, the Stage 1 undress area, and the Stage 2 undress area to conduct background sampling and for quality control during the trial.

12.1.2 Establish the concentration of MeS in the test chamber at 100 ± 15 mg/m^3, as measured by a MeS detector of the chamber air.

12.1.2.1 Steps shall be taken to avoid generation of liquid aerosol.

12.1.3 Measure the concentration of MeS every 60 s using the real-time MeS detector to verify compliance with the concentration requirement, and take an air sample at least every 10 min to separately validate the real-time MeS detector measurements.

12.1.4 Establish the environmental conditions inside the test chamber at a temperature of 27 ± 5 °C (80 ± 10 °F) and a relative humidity of 65 ± 20 %.

12.1.5 Establish an average wind speed of 1.6 m/s (3.5 mph) with the nominal range of wind speed of 0.9 to 2.2 m/s (2 to 5 mph) in the areas of the chamber where the test subjects will be performing their stationary activities.

12.2 *Pretest Test Subject Preparation:*

12.2.1 Ensure that test subjects and test operators, which have contact with the test subjects, have followed pre-trial procedures, including proper hydration and the avoidance of personal hygiene products that contain MeS.

NOTE 8—Examples of products that may contain MeS are toothpaste, soap, and deodorant.

12.2.2 Place PADs on test subjects at the body region locations shown in Fig. 1.

12.2.2.1 Apply all PADs to the test subjects in the dressing area, which is free from contaminated items.

12.2.2.2 Locate cheek PADs entirely within the respirator facepiece. Locate any other face PADs entirely outside the seal of the respirator facepiece.

12.2.3 The test subject shall wear clothing under the protective ensemble as specified by the manufacturer. If no undergarments are specified or required by the manufacturer as part of the protective ensemble, the test subject shall wear a short-sleeve cotton shirt and shorts or underwear.

12.2.4 Have the test subject don the protective ensemble and respirator in the dressing room in accordance with the manufacturer's instructions.

12.2.4.1 If taping is used to secure any part of the ensemble, note the specific type of tape, the placement of the tape, and the length of time required to complete the taping.

12.3 *Exposure Testing:*

12.3.1 Set the test concentration of MeS in the test chamber at 100 ± 15 mg/m^3 before proceeding with the test.

12.3.2 During the test, place a minimum of four PADs inside the test chamber at different positions representative of the locations where the test subjects conduct their physical activities. PADs from the same lot as the PADs worn by the test subject(s) shall be used. The test chamber PADs shall be used to calibrate the PAD lot used in the analysis (12.5.2).

12.3.2.1 Expose the test chamber PADs in the test chamber for 30 min, +5 min/−0 min and then remove from the test chamber.

12.3.3 After sealing the protective ensemble, have the test subject enter the test chamber and seal the test chamber.

12.3.4 The test subject shall enter the test chamber within 60 min after removal of the protective ensemble from the conditioning environment.

12.3.4.1 More than one test subject shall be permitted in the chamber at the same time, provided that all test subjects can complete all tasks completely in the appropriate time period and that each test subject has an unobstructed direct path to the wind stream.

12.3.5 Test subject(s) shall perform the following physical activity protocol. An alternative physical activity protocol and length of test shall be permitted to better simulate the respective activities anticipated for the use of the specific protective ensemble. The test chamber MeS concentration shall remain within acceptable limits during the activity protocol.

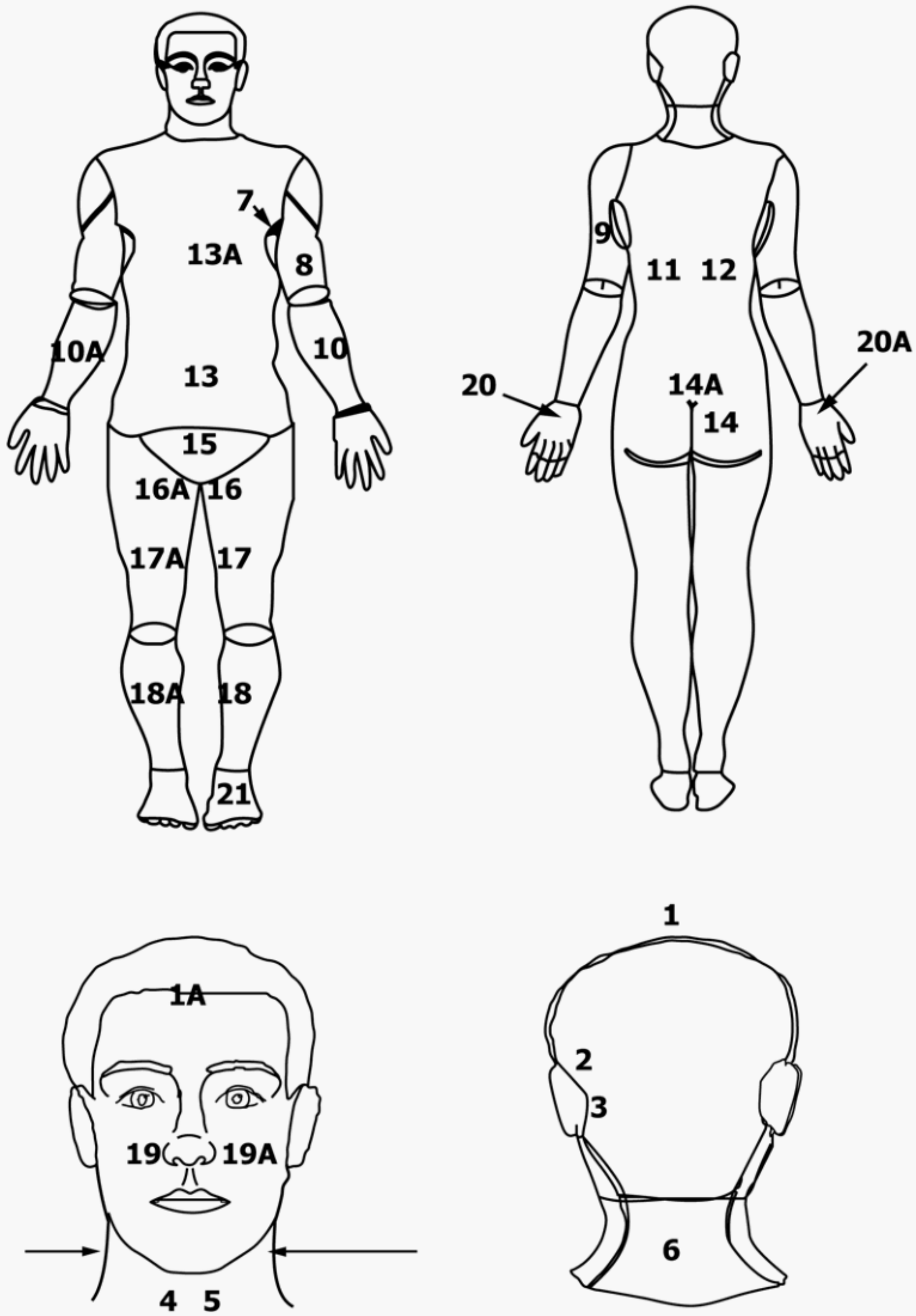
12.3.5.1 *Activity 1*—Drag a 70-kg human dummy using a rope looped underneath the arms of the dummy using both hands for a distance of 10 m over a 15-s period. Stop and rest for 15 s. Perform activity twice. Based on the interior dimensions of the chamber, it shall be permitted to have the test subject drag the dummy in a back and forth or circular manner within the chamber.

12.3.5.2 *Activity 2*—Duck squat, pivot right, pivot left, stand. Rotate orientation 90° to wind stream. Perform activity eight times, for a total of two complete revolutions, 90° at a time, for a total of 1 min.

12.3.5.3 *Activity 3*—Stand erect. With arms at sides, bend body to left and return, bend body forward and return, bend body to right and return. Rotate orientation 90° to wind stream. Perform activity eight times, for a total of two complete revolutions, 90° at a time, for a total of 1 min.

12.3.5.4 *Activity 4*—Stand erect. Extend arms overhead in the lateral direction, then bend elbows. Lower arms to sides. Extend arms overhead in the frontal direction, then bend elbows. Lower arms to sides. Rotate orientation 90° to wind stream. Perform activity eight times, for a total of two complete revolutions, 90° at a time, for a total of 1 min.

12.3.5.5 *Activity 5*—Stand erect. Extend arms perpendicular to the sides of torso. Twist torso left and return, twist torso right



PAD LOCATIONS

1 – scalp (SCA)	10 – l. forearm (LFA)	16A – crotch (RCR)
1A – forehead (F)	10A – r. forearm (RFA)	17 – l. inner thigh (LIT)
2 – behind l. ear (LE)	11 – mid. back (MB)	17A – r. inner thigh (RIT)
3 – behind l. ear up. (LED)	12 – mid. back. dup. (MBD)	18 – l. inner shin (LIS)
4 – neck left (NE)	13 – abdomen (AB)	18A – r. inner shin (RIS)
5 – neck right.(NED)	13A – chest (C)	19 – cheek (RM)
6 – nape (NA)	14 – r. butt (RB)	19A – cheek (LM)
7 – l. armpit (LA)	14A – low. back (LB)	20 – left hand (G)
8 – l. inner up. arm (LIU)	15 – groin (GR)	20A – right hand (GD)
9 – l. out. up. arm. (LOU)	16 – crotch (LCR)	21 – foot (B)

FIG. 1 Locations of Passive Adsorption Dosimeters (PADs) on Test Subjects

and return. Lower arms to sides. Rotate orientation 90° to wind stream. Perform activity eight times, for a total of two complete revolutions, 90° at a time, for a total of 1 min.

12.3.5.6 *Activity 6*—Stand erect. Reach arms across chest completely to opposite sides. Lower arms to sides. Rotate orientation 90° to wind stream. Perform activity eight times, for a total of two complete revolutions, 90° at a time, for a total of 1 min.

12.3.5.7 *Activity 7*—Climb two steps of the ladder and touch the ceiling with one hand (use alternative hands each time). Climb down, squat, and touch the floor with both hands. Repeat activity three times within 1 min.

12.3.5.8 *Activity 8*—Crawl in place, by simulating crawling action, for 1 min. Rotate orientation 90° to wind stream every 15 s.

12.3.5.9 *Rest 1*—Sit on stool (facing wind) for 1 min.

12.3.5.10 *Rest 2*—Sit on stool (back to wind) for 1 min.

NOTE 9—Each physical activity and rest cycle is 10 min in duration. Each activity cycle consists of eight 1-min activities followed by a 2-min rest (sitting) period.

12.3.6 The test subject(s) shall perform the physical activities and rest periods in a test chamber location that provides an unobstructed exposure of the protective ensemble to the required wind stream.

12.3.6.1 The test subject shall perform all physical activities with a full range of motion and at a moderate speed.

NOTE 10—It is recommended that test subjects be provided instruction for each of the activities and be allowed to practice the activities prior to conducting tests. It is useful to have placards showing the specific activity to be conducted. A videotape of the activities shown to the test subjects in the test chamber can further control the pace of the activities.

12.3.7 The test subject shall perform the cycle of activity and rest a total of three times, for a total chamber exposure of 30 min.

12.4 *Test Completion and Decontamination:*

12.4.1 After completion of the 30-min exposure, the test subjects shall move to a decontamination area, where they shall remain for at least 5 min.

12.4.2 All exposed ensemble surfaces shall be washed, including items such as the respirator, boots, gloves, and helmets with a liquid soap solution (see 7.3.2). If the garment or suit is designed for wet decontamination, the garment or suit shall also be washed with the soap solution. Alternative decontamination methods, such as an air wash, shall be permitted if the selected decontamination method can be demonstrated to remove MeS to levels that do not result in contamination of the test subject during doffing of the protective ensemble.

12.4.3 The decontaminated test subject shall move to the first-stage undressing room. The test subject shall doff the respirator, helmet, and all items of clothing, except for underclothes. The first stage of undressing shall not exceed 5 min.

12.4.4 The test subject shall proceed to the second stage undressing room, where all PADs shall be removed.

12.4.5 As the PADs are removed, each PAD shall be backed with aluminum foil and placed in an individually labeled, sealed glass vial.

TABLE 1 Site-Specific Onset of Symptoms Exposure Dosage (OSED) by PAD Location

Body region	PAD locations	OSED (mg.min/m^3)
head/neck	1, 1A, 2, 3, 4, 5, 6, 19, 19A	100
torso/buttocks (excluding perineum)	11, 12, 13, 13A, 14, 14A, 15	100
arm/hand	7, 8, 9, 10, 10A, 20, 20A	50
leg/foot	17, 17A, 18, 18A, 21	100
perineum	16, 16A	25

12.4.6 The sealed glass vials with PADs shall be stored in a refrigerator (4 °C). The sealed glass vials with PADs shall not be removed from the refrigerator for more than a total of 15 min before processing.

12.5 *Analysis of PADs:*

12.5.1 The processing of the PAD samples shall be performed within 14 days of exposure in the test chamber.

12.5.2 Perform PAD lot acceptance testing to determine that the lot of PADs are suitable for use in testing.

12.5.2.1 The linear range of the analytical technique shall be sufficient to measure the dosage concentration from the four test chamber PADs.

12.5.2.2 The average of the chamber vapor concentration and the actual time of exposure shall be used to determine the uptake rate from the following equation:

$$u = \frac{m}{Ct} \tag{1}$$

where m is the total mass measured on the PAD in mg, u is the uptake rate in cm^3/min, and Ct is the chamber vapor dosage in mg.min/cm^3 as measured during the test.

12.5.2.3 For the test results to be considered valid for a given ensemble, no more than one PAD from each of the body region locations tested (that is, no more than one PAD out of the four replicates for any particular region) shall be permitted to be lost to analysis over the course of the four test subjects. Refer to Table 1 for body region location.

13. Calculations

13.1 *Determination of Local Physiological Protective Dosage Factor:*

13.1.1 The arithmetic mean for the calibrated uptake rate shall be used to calculate the dosage measured by each PAD ($Ct_{insidei}$) from the same equation based on the measured mass taken up by the PAD.

13.1.2 The protection factor at each PAD location i inside the ensemble shall be calculated using the following equation:

$$PF_i = \frac{Ct_{outside}}{Ct_{insidei}} \tag{2}$$

where the $Ct_{outside}$ shall be determined from the measured chamber vapor dosage of the individual trial over the entire exposure.

13.1.3 The value for $Ct_{outside}$ shall be the average of the test chamber MeS concentration readings taken during the course of the test subject exposure period.

13.1.4 The results for each PAD location shall be expressed in terms of the local physiological protective dosage factor (PPDF) value as calculated in accordance with the following equation:

$$local\ PPDF_i = \frac{OSED_i}{25} PF_i \quad (3)$$

13.1.4.1 The site-specific onset of symptoms exposure dosages (OSED) for each PAD shall be based on ECt_{10} values for mustard blistering/ulceration in accordance with Table 1.

NOTE 11—ECt_{10} is the exposure concentration that causes threshold mustard effects of blistering and ulceration in 10 % of the population (4).

13.1.4.2 The average local physiological protective dosage factor (PPDF) values at each PAD location shall be calculated for all specimens tested.

13.2 *Determination of Systemic Physiological Protective Dosage Factor:*

13.2.1 The systemic physiological protective dosage factor ($PPDF_{sys}$) shall be calculated from the PAD data.

13.2.2 The systemic protection analysis shall use the systemic weighting body region hazard analysis values from Defense Research Establishment Suffield Report and National Research Council Report (3) to calculate the systemic physiological protective dosage factor for each ensemble test ($PPDF_{sys}$).

13.2.3 Calculate the $PPDF_{sys}$ for each specimen as follows:

$$PPDF_{sys} = \frac{\sum_i \frac{dz_i}{ED_{50i}}}{\sum_i \frac{dz_i}{ED_{50i} PF_i}} \quad (4)$$

where each of the terms is calculated using the information in Table 2.

NOTE 12—Some of the PAD locations are used more than once in the calculation. (See Table 2.)

13.2.4 Calculate the average systemic physiological protective dosage factor for all specimens tested.

NOTE 13—The values in Table 1 are based on an analysis of the chamber data of Gorrill and Heinen presented in AEP-52 (2) broken down by body region and are based on the ECt (10) values for severe erythema/blistering/desquamation by distilled mustard. They include data for hot/humid exposures, where volunteers wore clothing covering almost everything but hands/neck, and clothing was not necessarily removed immediately after exposure. Clothing was assumed to provide a PF of 2.

14. Report

14.1 State that the test was conducted as directed in Test Method F2588.

14.2 Provide a description of the ensemble evaluated, including:

14.2.1 The identification and type of each ensemble element, including the manufacturer name, style, primary materials of construction.

14.2.2 The sizes of the ensemble elements evaluated and a description of the fit of the garment.

14.2.3 Any specific external fixtures or other accessories used with the ensemble, as applicable.

TABLE 2 ED_{50i} Values by PAD and Body Location

Body Region *i* for BRHA Model	PADs mapped to this region (average dosage from each PAD, and then calculate PF_i)	Area of Body Region (dz_i, cm^2)	ED_{50i} for severe effects (VX) for body region (mg/individual)
Scalp	1, 1A	350	0.76
Ears	2, 3	50	0.46
Face, cheeks & neck	4, 5, 19, 19A	300	0.48
Chin & neck	4, 5	200	0.36
Nape	6	100	1.72
Abdomen	13A	2858	2.23
Back	11, 12, 14A	2540	2.65
Axillae	7	200	2.07
Upper arm medial	8	488	2.8
Upper arm lateral	9	706	6.57
Elbow fold	8, 9, 10, 10A	50	2.09
Elbow	8, 9, 10, 10A	50	2.25
Forearm extensor	10, 10A	487	2.8
Forearm flexor	10, 10A	706	6.57
Hands dorsum	20, 20A	200	2.91
Hands palmar	20, 20A	200	9.24
Buttocks	14	953	4.26
Groin	13, 15	300	1.22
Scrotum	16, 16A	200	0.11
Thigh anterior	17, 17A	2845	6.57
Thigh posterior	17, 17A	1422	4.26
Knee	17, 17A, 18, 18A	200	7.14
Popliteal space (back of knees)	17, 17A, 18, 18A	100	2.09
Shins	18, 18A	1897	6.57
Calves	18, 18A	948	2.8
Feet dorsum	21	500	6.6
Feet plantar	21	300	7.14

14.2.4 The use of taping or other means to secure interface areas, including the specific type of tape, the placement of tape or other interface fixtures, and the time required for their use.

14.2.5 Any specific conditioning or pretreatments that the ensemble elements were subjected to prior to testing.

14.2.6 A description of the donning and doffing procedures used.

14.3 Describe any deviations from the test method, including:

14.3.1 The placement of additional PADs and their location.

14.3.2 Changes in the activity protocol.

14.3.3 A change in the length of the overall activity protocol.

14.4 Provide test results for the ensemble evaluated, including:

14.4.1 The individual and average local physiological protective dosage factor (PPDFi) values for each PAD location for each specimen tested.

14.4.2 The systemic physiological protective dosage factor ($PPDF_{sys}$) value for each specimen tested and the average systemic physiological protective dosage factor ($PPDF_{sys}$) value for all specimens tested.

14.4.3 Any specific observations of ensemble failure based on loose or malfunctioning components.

15. Precision and Bias

15.1 *Precision*—It is not practical to specify the precision of the procedures in this test method because the test involves the

evaluation of different ensembles using test subjects. Factors related to the fit and functioning of the ensemble will affect test method precision.

15.2 *Bias*—No information can be presented on the bias for the procedure in this test method, for measuring the inward leakage of chemical agent vapor simulant of protective ensembles, because no protective ensemble having an accepted reference value is available at this time.

16. Keywords

16.1 chemical agent; man-in-simulant testing; physiological protective dosage factor; protective ensemble; terrorism incident; vapor simulant

APPENDIXES

(Nonmandatory Information)

X1. SPECIFICATIONS FOR PREPARATION OF PASSIVE ADSORBENT DEVICES (PADS)

TABLE X1.1 General PAD Specifications

Characteristic	Specification
Outer dimensions	25 mm by 35 mm (1 in. by 1 ⅜ in.)
Film sampling surface dimensions	18 mm by 25 mm (¾ in. by 1 in.)
Film sampling surface area	450 mm^2 (¾ in.^{2}) ± 2.5 %
Edge dimensions	0.68 mm (⅛ in.) sides; 0.19 mm (3⁄16 in.) ends
Corners	Trimmed 0.1 mm (3⁄32 in.) at 45 degree angle
Adsorbent	45 mg ±10 % Tenax TA

X1.1 *General Description*—Passive adsorbent dosimeters are small packets that are filled with an adsorbent, Tenax TA. The top layer of the packet is HDPE film that provides the sampling surface. The back of the packet is an impermeable, plastic-coated foil. Medical-grade, double-coated adhesive is affixed to the back of the packets enables the PADs to be attached to the skin of the test subject.

X1.2 *General PAD Specifications*—The general specifications for PADs are provided in Table X1.1.

PADs are assembled and packaged in an FDA-certified cleanroom. Adsorbent exposure is kept to a minimum. PADs are kept free of contamination from human contact or vapors in air that can be detected using analytical technique used to measure PAD adsorption of MeS. PADs are packaged as soon as feasible after assembly to minimize potential for contamination.

X1.3 Materials of Construction

X1.3.1 *Barrier Film*—The thickness of the barrier film is 0.025 mm (0.001 in.) ± 5 %, with the thickness measured every one metre. The color of the barrier film is natural. The barrier film is subject to a heat soak treatment at 95 °C for four days. The barrier film is high-density polyethylene (HDPE) meeting the specifications provided for the resin in Table X1.2 and film in Table X1.3.[7,8]

TABLE X1.2 Resin Properties of HDPE

Property	Typical Value	Test Method
Melt Flow Index, g/10 min		ASTM D1238
190 °C, 2.16 kg	0.07	
190 °C, 5kg	0.31	
130 °C, 21.6 kg (HLMI)	9.0	
Density, g/cm^3	0.950	ASTM D792
Melting Point, °F	260	ASTM D3417

TABLE X1.3 Properties of the Barrier Film

Property	Typical Value	Test Method
Dart Impact, g	350	ASTM D1709, Method A
Elmendorf Tear Resistance, g	24 Machine direction	ASTM D1922
	120 Transverse direction	
Tensile Strength at Yield, psi	5300 Machine direction	ASTM D882, 20 in./min
	5000 Transverse direction	
Tensile Strength at Break, psi	8900 Machine direction	ASTM D882, 20 in./min
	8500 Transverse direction	
Elongation at Break, %	300-500 Machine direction	ASTM D882, 20 in./min
	300-500 Transverse direction	
Secant Modulus of Elasticity, psi @ 2 % strain	122 000 Machine direction	ASTM D882, 20 in./min
	132 000 Transverse direction	
Water Vapor Transmission at 100 °F, g/24 h/100 in./mil	0.8	ASTM E96

X1.3.2 *Nylon/Foil Barrier Film*—The nylon/foil barrier film is a material meeting Mil-B-131H, "Barrier Materials, Water Vapor Proof, Greaseproof, Flexible, Heat-Sealable" for Type 1, Class 1. The film consists of four layers, from outside to inside, consisting of a 60 gauge Nylon, low-density polyethylene, 0.003-in. foil and 0.002-in. polyethylene layer. Specifications for the nylon/foil barrier film are provided in Table X1.4.[7,9]

[8] The sole source of supply of the Finathene HDPE 1285 known to the committee at this time is FINA Oil and Chemical Company, 8350 North Central Expressway, P.O. Box 2159, Dallas, TX 75221 USA, Ph: (214) 750-2400.

[9] The sole source of supply of the nylon/foil barrier film known to the committee at this time is Syon, ITW Devcon, Danvers, MA 01923 USA, Ph: (508) 881-8852 (6030 Nylon/Foil Barrier Bag material).

TABLE X1.4 Specifications for Nylon/Foil Barrier Film

Property	Typical Value	Test Method
Thickness, in.	0.005	ASTM D6988
Moisture vapor transmission rate, g/100 in.^{2}/24 h	<0.02	ASTM E96[AMS1]
Oxygen transmission rate, cm^3/m^2/24 h	<0.01	ASTM D3985[AMS2]
Tensile strength, at break, lb	22 Machine direction	TAPPI T404 TS66
	22 Transverse direction	
Breaking strength, grab, lb	62	Federal Standard 101
Bursting strength, psi	65	TAPPI T403 TS63
Puncture resistance, lb	17.5	Federal Standard 101
Heat seal conditions, single bar heat	400 °F/40 psi/2 s	

The nylon/foil barrier film is evaluated for oil resistance in testing in accordance with Federal Standard 101, Method 3014 and Mil-B-131H by pouring 5 mL of oil (TT-S-735, Type 6) into 3 in. by 3 in. pouches that are then sealed. The pouches are then placed in an oven set at 160 ± 2 °F for 24 h. Oil resistance is demonstrated when no leakage is observed.

The nylon/foil barrier film is evaluated for water resistance in testing in accordance with Federal Standard 101, Method 3028 and Mil-B-131H. Sample materials measuring not less than 6 in. by 6 in. are immersed in distilled water for 48 h. After the water exposures, the samples are then placed in an oven set at 160 ± 2 °F for 24 h. Water resistance is demonstrated when samples do not delaminate more than 1 in. in length along the edge and ½ in. in depth from the edge.

X1.3.3 *Adhesive Backing*—The adhesive backing is a double-coated tape that consists of a 3-mil transparent polyethylene film, coated on both sides with a hypoallergenic, pressure-sensitive adhesive. The adhesive backing is of medical grade and provides adhesive to steel of 30 oz/in. (8.3 N/in.) minimum, a tape caliper without liner of 0.12 mm (4.9 mil), tensile strength of 4.5 lb/in. (20 N/25 mm) minimum, elongation of 200 %, minimum, and a liner removal of 50 g/in. (0.49 N/in.,) maximum.[7,10]

[10] The sole source of supply of the adhesive backing known to the committee at this time is 3M Medical Specialties, 3M Center, Building 275-5W-05, St. Paul, MN 55144-1000, Ph: (800) 228-3957 (3M Double Coated Medical Tape Cat. No. 1509).

TABLE X1.5 Test Parameters for Determining Cleanliness of Adsorbent

Analytical method	Thermal desorption, GC/FID
Tenax TA sample size	40 mg
Instrument sample desorption	250 °C, 6 min
Instrument trap desorption	274 °C, 4 min
Instrument column	0.53 mm id by 15 m by 1 µm df Stabilwax or equivalent
Oven temperature	120 °C, isothermal
FID temperature	250 °C

X1.3.4 *Adsorbent*—The sorbent is Tenax TA of 60 to 80 mesh size that is free of fines and interfering contaminants. A PAD amount of 40 mg ± 10 % is used. Chemical cleanliness of the Tenax TA has been found to be a major concern when analyzing PADs. Tenax TA must be washed to remove fines and preconditioned to remove materials that interfere with the gas chromatographic determination of MeS. Analytes collected by the samplers may be removed from the Tenax TA by either solvent extraction or thermal desorption prior to analysis.

X1.3.4.1 *Cleaning Procedure*—The following procedure is used for cleaning the Tenax TA adsorbent:

(1) Use HPLC grade methanol (MeOH).

(2) Transfer Tenax to Pyrex (or equivalent) container, cover with MeOH, place under vacuum (10 to 15 torr) until gas bubbles cease forming, maintain vacuum for 5 min, and increase pressure to ambient.

(3) Reduce pressure and increase pressure two more times.

(4) Wash with MeOH to remove fines.

(5) Heat in oven to 75 to 80 °C for 1 to 2 h or until dry.

X1.3.4.2 *Preconditioning Procedure*—Precondition the cleaned Tenax TA adsorbent by heating adsorbent to 340 °C under N_2 (six 9s purity, 20 mL/min) overnight.

X1.3.4.3 *Storage Procedure*—Store the preconditioned Tenax TA in an air-tight receptacle to minimize any exposure to the air.

X1.3.4.4 *Procedures for Determination of Cleanliness*—The adsorbent must be free of contaminants that interfere with the analytical detection of MeS. Tenax TA suppliers are required to provide chromatograms and supporting documentation to demonstrate cleanliness for each lot of adsorbent. The test parameters provided in Table X1.5 are used to determine cleanliness of the adsorbent.

The maximum interfering peak overlap or background level cannot be more than 5 ng at the MeS retention (elution) time.

X2. AN ANALYSIS OF POSSIBLE PERCUTANEOUS TOXICITY FOR MES

X2.1 MeS ($C_6H_4(OH)COOCH_3$, with a specific gravity 1.183 to 1.188, boiling point 220° to 224°), is the principal constituent of oil of wintergreen and oil of sweet birch. It is used as a denaturant and flavoring agent (0.0001 % to 0.6 %) and medicinally is used as a topical anti-inflammatory and dermal keratolytic agent.

X2.2 MeS is also safe to use based on the NFPA Rating System. The NFPA system provides information regarding the hazards of a material and the severity of these hazards. The numerical rating ranges from 0 to 4, with 0 posing no hazard. OSHA has not even established Permissible Exposure Limits for it. However, percutaneous absorption is dependent upon the concentration, vehicle used (for example, methyl > water), skin pH, and integrity of the skin barrier. The rat dermal LD50 is >2 gm/kg and serum concentrations >30 mg/dl are considered toxic in humans. Dermal research has demonstrated that only 1.5 % to 2.0 % and 12 % to 20 % of an applied dose is absorbed systemically after 30 min and 10 h, respectively. However, enhanced dermal absorption can occur with higher skin temperatures, occlusive dressings, dermal inflammatory disorders, and with skin disorders that result in disruption of dermal integrity (for example, psoriasis, burns, abrasions, etc.). Exercise can result in a greater than threefold increase in dermal absorption of MeS (due to increases in skin humidity, temperature, and blood flow). Acute toxicity from oral salicylates occurs with doses of 150 mg/kg (for example, 10.5 gm in a 70-kg individual). In this test method, the total MeS available dose within the chamber is approximately 69.5 g (139 m^3 × 500 mg/m^3). Utilizing a 2 % absorption rate, this would amount, under ideal conditions, to a maximal percutaneous absorption of 1.39 g (19.1 mg/kg in a 70-kg test subject). This dose would be almost eight orders of magnitude lower than the oral toxic dose of salicylates, but the actual absorbed dose would be much lower because subjects would not be tested nude. Some of the signs and symptoms of salicylate toxicity include tinnitus (ringing in the ears), nausea, vomiting, fever, hyperpnea (elevated breathing rate), hypoglycemia (low blood sugar) and altered mental states (for example, confusion, disorientation, seizures, etc.). The treatment of mild and moderate MeS toxicity is mainly supportive through the use of intravenous fluid supplementation, administration of bicarbonate to trap urinary salicylate ions, skin decontamination (dry wiping of the skin), and glucose administration, as needed. More severe toxicity (for example, seizures, severe acidosis, cardiopulmonary dysfunction, etc.) can be treated with hemodialysis. Therefore, the development of percutaneous salicylate toxicity at the levels of exposure during a man-in-simulant test is unlikely.

REFERENCES

(1) The Technical Cooperation Program, Chemical Biological Defence Technical Panel 11 on Low Burden, Integrated Protective Clothing, "Final Report: Development of a Standard Vapour Systems Test to Assess the Protection Capability of NBC Individual Protective Ensembles," Appendix G, Defence Research Establishment Suffield Report, April 1997, UNCLASSIFIED.

(2) NATO Document No. 1268015. AEP-52, "Assessment of the Effect Levels of Classical Chemical Warfare Agents Applied to the Skin to be Used in the Design of Protective Equipment."

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(4) Grotte, J. H. and Yang, L. I., "Report of the Workshop on Chemical Agent Toxicity for Acute Effects," IDA Document D-2176, Institute for Defense Analysis, Alexandria, VA, May 1998.

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