Designation: E 1549 – 95 (Reapproved 2000)ε1

Standard Specification for ESD Controlled Garments Required in Cleanrooms and Controlled Environments for Spacecraft for Non-Hazardous and Hazardous Operations[1]

This standard is issued under the fixed designation E 1549; 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.

ε1 NOTE—To bring Subcommittee E21.05's existing standards into compliance with Part H of ASTM's Form and Style Manual, the M designation has been editorially removed in July 2000.

1. Scope

1.1 This document specifies special items of clothing (cleanroom garments) designed to protect aerospace products from electrostatic discharge and from contaminants released by personnel and garments. Special clothing includes low linting coveralls, footwear, and head covers.

1.2 The function of cleanroom garments is to contain the contaminants generated by people and to minimize contaminants from the garments.

1.3 Two types of fabrics can be selected for the garments. Both types are inherently static-dissipative materials to prevent electrical discharges that can damage sensitive hardware or initiate explosions in the presence of flammable vapors. The material specified for "hazardous environments" is flame resistant and provides additional protection to the wearer. Selection of garment design and fabric should be based on the user's needs with respect to functional and environmental requirements.

1.4 Additional, background information can be found in SD-TR-91-26 and IES-RP-CC003.2.

1.5 *This standard is intended to be in compliance with the ASTM policy on Fire Standards.* [2] *Flammability tests specified in this standard should be used to measure and describe the properties of fabrics in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fabrics under actual fire conditions. However, results of the tests may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of operations in controlled environment areas.*

1.6 *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 and health practices and determine the applicability of regulatory limitations prior to use.*

1.7 The values stated in SI units are to be regarded as the standard. The values in parentheses are for information purposes only but are hard conversions.

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[3]

D 204 Test Methods for Sewing Threads[3]

D 1683 Test Method for Failure in Sewn Seams of Woven Fabrics[4]

D 1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting[5]

E 96 Test Methods for Water Vapor Transmission of Materials[6]

E 176 Terminology of Fire Standards[7]

E 535 Practice for Preparation of Fire-Test-Response Standards[7]

E 1560 Test Method for Gravimetric Determination of Nonvolatile Residue from Cleanroom Wipers[8]

F 51 Test Method for Sizing and Counting Particulate Contaminant In and On Clean Room Garments[8]

F 739 Test Method for Resistance of Protective Clothing Materials to Permeation By Liquids or Gases Under Condition of Continuous Contact[9]

2.2 *U.S. Federal Standards:*

FED-SPEC-191 Textile Test Method[10]

FED STD A-A 50195 Thread Aramid

FED-STD-209E Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones[10]

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[1] This specification is under the jurisdiction of ASTM Committee E-21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.05 on Contamination.

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[2] ASTM Fire Test Standards, 4th Edition, Dec. 1993, available on request from ASTM Headquarters, 100 Barr Harbor Dr., PO Box C700, West Conshohocken, PA 19428–2959.

[3] *Annual Book of ASTM Standards*, Vol 07.01.

[4] Withdrawn. See 1998 *Annual Book of ASTM Standards*, Vol 07.01.

[5] *Annual Book of ASTM Standards*, Vol 08.01.

[6] *Annual Book of ASTM Standards*, Vol 04.06.

[7] *Annual Book of ASTM Standards*, Vol 04.07.

[8] *Annual Book of ASTM Standards*, Vol 15.03.

[9] *Annual Book of ASTM Standards*, Vol 11.03.

[10] Available from U.S. General Services Administration, Washington, DC.

FED-STD-751a Stitches, Seams, and Stitchings[10]

2.3 *U.S. Department of Defense:*

MIL-C-43122E Cloth, Sateen, Cotton, Flame Retardant Treated[11]

MIL-C-43339D Coveralls, Industrial: Lint-Free, 7 Nov. 1988[11]

MIL-W-43685B Webbing and Tape, Textile, Aramid Fiber, 20 Sept. 1989[11]

SD-TR-89-63 Standard Methods for Measurement of Nonvolatile Residue on Surfaces, E. N. Borson, E. J. Watts, G. A. To; U.S. Air Force, Space Systems Division, 10 Aug. 1989[12]

SD-TR-91-26 Garment Selection for Cleanrooms and Controlled Environments for Spacecraft, E. J. Watts, U.S. Air Force, Space Systems Division, 1 April 1991[12]

AGMC/MAQC-335c "Personnel Garments, Electrostatic Discharge (ESD) Requirements for the Protection of ESD Sensitive Items[13]

2.4 *NASA:*

MMA-1985-79, Revision 2, Standard Test Method for Evaluating Triboelectric Charge Generation and Decay[14]

GP-1098 STS Safety, Reliability, and Quality Assurance Ground Safety Plan, Launch Complex 39, KSC Industrial Area[15]

NHB 8060.1 C, NASA Handbook, Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion, April 2, 1991, Upward Flame Propagation Test (Test 1)[16]

2.5 *Others:*

NFPA #702-1980 Standard for Classification of the Flammability of Wearing Apparel[17]

IES-RP-CC-003.2 Garments Required In Cleanrooms And Controlled Environment Areas[18]

3. Terminology

3.1 Terminology related to textiles is based on Terminology D 123. Terminology related to fire safety is based on Terminology E 176.

3.2 *General Definitions:*

3.2.1 *cleanroom*, *n*—an area in which the airborne particle concentrations, temperature, humidity, molecular species, pressure, activities, and other environmental parameters are controlled, as required, to produce acceptable products.

3.2.1.1 *Discussion*—The use of HEPA, or better, filters are usually required for the incoming air, and the maximum allowable airborne particle concentrations are specified in accordance with FED-STD-209.

3.2.2 *electrostatic discharge, ESD*, *n*—a high voltage electrical discharge that occurs when electrical charges accumulate on or in materials as a result of friction between materials.

3.2.3 *fiber*, *n*—a particle with a length to diameter ratio of ten or more. (See *textile fibers*.)

3.2.4 *gloss*, *n*—a shiny or lustrous appearance resulting from the tendency of a surface to reflect light at one angle more than at others.

3.2.5 *HEPA (high efficiency particulate air) filter*, *n*—a filter for air with a removal efficiency in excess of 99.97 % for 0.3-µm particles.

3.2.6 *NVR (nonvolatile residue)*, *n*—quantity of residual soluable, suspended, and particulate matter remaining after the controlled evaporation of a volatile liquid at a specified temperature.

3.2.6.1 *Discussion*—The liquid is usually filtered through a membrane filter, of a specified size, before evaporation. The process used to determine the NVR may affect the quantitative measurement. Process factors include filter size, solvent, and the evaporation temperature and atmosphere. For this reason, the process must be defined. The NVR of fabrics is determined by extracting a specified quantity of fabric using a specified solvent. The solvent is then evaporated to determine the NVR extracted from the fabric. See *extractable matter*, 3.3.7, which is frequently used to describe NVR in fabrics.

3.2.7 *particle*, *n*—a solid or liquid object generally between 0.001 and 1000 µm (1 mm) in size.

3.2.8 *U.S. Customary Units System, USCS*, *n*—The system of units in common use in the United States. This is frequently called the "inch-pound system."

3.3 *Fabric Definitions:*

3.3.1 *count*, *n*—in woven textiles, the number of warp yarns (ends) and filling yarns (picks) per unit distance as counted while the fabric is held under zero tension and is free of folds and wrinkles.

3.3.2 *Dacron®*, *n*—DuPont registered trademark for its polyester fiber.

3.3.3 *Delrin®*, *n*—DuPont trade name for a crystalline form of polymerized formaldehyde.

3.3.4 *denier*, *n*—a direct numbering system for expressing linear density, equal to the mass in grams per 9000 m of yarn, filament, fiber, or other textile strand.

3.3.5 *drycleaning*, *n*—cleaning fabrics in a substantially nonaqueous liquid medium.

3.3.5.1 *Discussion*—Perchloroethylene is typically used.

3.3.6 *end*, *n*—an individual warp yarn (single or ply) or cord.

3.3.7 *extractable matter*, *n*—nonfibrous material in or on a textile, not including water, which is removable by a specified solvent or solvents, as directed in a specified procedure. See *NVR*, 3.2.6.

3.3.8 *textile fiber*, *n*—(*1*) general—a generic term for the various types of matter that form the basic elements of textile fabrics and other textile structures.

(*2*) specific—a unit of matter that is characterized by having a length at least 100 times its diameter or width and which can

[11] Available from U.S. Natick Research Development and Engineering Center, Natick, MA 07160-5014.

[12] Reprints available from The Aerospace Corporation Library, P.O. Box 92957, El Segundo, CA 90009.

[13] Aerospace Guidance and Metrology Center, U.S. Air Force, Neward AFS, Ohio, 22 Feb. 1989.

[14] NASA Kennedy Space Center, Materials Testing Branch, 15 July 1988.

[15] NASA Kennedy Space Center.

[16] Office of Safety and Mission Quality (Code QR), NASA Headquarters, Washington, DC 20546.

[17] Available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.

[18] Available from the Institute of Environmental Sciences, 940 E. Northwest Highway, Mount Prospect, IL 60056.

be spun into a yarn or made into a fabric by interlacing in a variety of methods, including knitting, braiding, felting, and twisting.

3.3.9 *filament*, *n*—a variety of fiber having extreme length, not readily measured.

3.3.9.1 *Discussion*—Synthetic fibers formed from man-made and natural polymers are in this class.

3.3.10 *filling*, *n*—yarn running from selvage to selvage at right angles to the warp in a woven fabric.

3.3.11 *float*, *n*—the portion of a warp or filling yarn that extends unbound over two or more filling or warp yarns.

3.3.12 *laundering*, *n*—a process used to refurbish a textile product by (*1*) cleaning it in water containing a detergent or surfactant and (*2*) drying it.

3.3.12.1 *Discussion*—Laundering for cleanroom garments requires the use of water, cleaning agents, environmental control, and packaging so that the garments are compatible with the final product cleanliness requirements.

3.3.13 *lint*, *n*—fiber fragments abraded from textile materials; also loose short fibers or fluff.

3.3.14 -*Nomex*®, *n*—a synthetic aramid fiber manufactured by DuPont that meets the requirements of NASA Handbook, NHB 8060.1C, Test 1 for flame retardancy.

3.3.15 *nylon*, *n*—a manufactured fiber in which the fiber-forming substance is a long chain synthetic polyamide in which less than 85 % of the amide linkages,

$$-\underset{\underset{\displaystyle O}{\|}}{C}-NH- \qquad (1)$$

are attached directly to two aromatic rings.

3.3.16 *polyester*, *n*—a manufactured fiber in which the fiber-forming substance is any long chain synthetic polymer composed of at least 85 % by weight of an ester of a substituted aromatic carboxylic acid, including but not restricted to substituted terephthalate units,

$$p\,(-R-O-\underset{\underset{\displaystyle O}{\|}}{C}-C_6H_4-\underset{\underset{\displaystyle O}{\|}}{C}-O-) \qquad (2)$$

and para substituted hydroxy-benzoate units,

$$p\,(-R-O-C_6H_4-\underset{\underset{\displaystyle O}{\|}}{C}-O-) \qquad (3)$$

3.3.17 *porosity*, *n*—the ratio of the volume of air or void contained within the boundaries of a material to the total volume (solid matter plus air or void) expressed as a percentage.

3.3.18 *selvage*, *n*—the woven edge portion of a fabric parallel to the warp.

3.3.19 *sewn seam*, *n*—a juncture of which two or more planar structures such as textile fabrics, are joined by sewing, usually near the edge.

3.3.20 *static dissipative fabric*, *n*—an inherently static control fabric with surface resistivity between 10^5 ohms per square and not more than 10^9 ohms per square.

3.3.21 *stitch*, *n*—*in sewn seams*, the repeated unit formed by the sewing thread(s) in the production of seams.

3.3.22 *Teflon*®, *n*—DuPont trade name for tetrafluoroethylene polymer fiber. It is chemically resistant and does not absorb moisture.

3.3.23 *twill weave*, *n*—a weave characterized by diagonal lines produced by a series of floats staggered in the warp direction. Floats are normally formed by the filling (a filling-faced twill).

3.3.24 *warp*, *n*—(*1*) the yarn running lengthwise in a woven fabric. (*2*) a group of yarns in long lengths and approximately parallel, put on beams or warp reels for further textile processing including weaving, knitting, twisting, dyeing, and so forth.

3.3.25 *woven fabric*, *n*—a structure produced when at least two sets of strands are interlaced, usually at right angles to each other, according to a predetermined pattern of interlacing, and such that at least one set is parallel to the axis along the lengthwise direction of the fabric.

3.3.26 *yarn*, *n*—a generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric.

3.3.27 *yarn number*, *n*—a measure of the fineness or size of a yarn expressed either as mass per unit length (direct system) or as length per unit mass (indirect system).

3.3.27.1 *Discussion*—The kg/m (denier) system is a direct one, and denotes the linear density of the yarn.

3.4 *Fire Safety Definitions:*

3.4.1 *flame*, *n*—a hot, usually luminous, zone of gas that is undergoing combustion.

3.4.1.1 *Discussion*—The luminosity of a flame is frequently caused by the presence of glowing particulate matter suspended in the hot gases.

3.4.2 *flame resistance*, *n*—the ability to withstand flame impingement or give protection from it.

3.4.2.1 *Discussion*—Textiles are tested in accordance with the National Fire Protection Association Standard #702-1980, under the classification of wearing apparel.

3.4.3 *hazardous*, *adj*—of or involving danger of injury or loss of life resulting from exposure to a potentially dangerous environment.

3.4.3.1 *Discussion*—The primary hazard of concern in this specification is the protection of personnel from flame.

4. Garment Requirements

4.1 *General*:

4.1.1 Apparel worn in environmentally controlled facilities shall be functional and job oriented.

4.1.2 Uniforms shall form barriers between the human contaminator and their work.

4.1.3 *Health*:

4.1.3.1 Garments shall not irritate, react with, or be abrasive to the skin, and must not emit objectionable odor when wet or dry.

4.1.3.2 Pore size of the fabric and the permeability of air and moisture affect comfort.

NOTE 1—There is no standard test method for measuring the moisture vapor transmission rate of woven and non-woven cleanroom fabrics. The most commonly referred to document is Test Methods E 96 which gives test procedures applicable to sheet materials used in the construction industry as vapor barriers. The Water Vapor Permeability Cup test and the Method B (upright) test have been selected from Test Methods E 96 as

acceptable by fabric manufacturers.

4.1.4 All apparel shall be designed with a minimum of seams, raw edges, or dust collection features.

4.1.5 *Entrapment Areas*—Pockets (except for the zippered, optional badge pocket in 4.2.10), belts, pleats, fold-over collars, and folded or trough cuffs are prohibited. Pen-tabs are not recommended.

4.1.6 *Seams and Edges*:

4.1.6.1 *Sewing Thread*—Sewing thread shall be either multifilament, polyester, or multifilament Nomex aramid as specified in 5.3.1 and 6.3.1 to be compatible with the respective types of fabrics.

4.1.6.2 *Seams*—All seams shall be finished completely. Major garment seams shall be double-needle flat felled following FED-STD-751a, Seam Type LSC-2 and Stitch Type 401, 6.5-mm (¼-in.) gage. Seams shall pass the standard test methods for failure given in Test Method D 1683.

4.1.6.3 *Edges*:

(1) Raw edges at neck, wrist, and ankle hems shall either be serged (overcast) with Stitch Type 504, or bound with fabric before joining to any other part or being hemmed.

(2) The use of edge lock or other sealants on fabric edges to prevent fraying during manufacturing is not recommended. If such a material is used, it shall be completed removed prior to completion of the garment.

4.1.7 *Closures*:

4.1.7.1 *Zipper Closures*—Zipper tapes shall be woven from continuous filament polyester yarns. Zipper teeth shall be fabricated of a synthetic polymer such as Teflon filled Delrin (or equivalent).

4.1.7.2 *Snaps, Grippers, and Buttons*:

(1) Snaps, grippers, and buttons shall not be used to close garments because they do not provide a seal and allow particles to escape from inside the garment.

(2) In addition, snaps, grippers, and buttons are not recommended for other uses on cleanroom protective clothing because of the possibility of the fasteners falling off.

(3) Stainless steel snaps may be selected only for closures which are covered by another part of the garment. Users may take exception to this if they deem the risk to be acceptable.

4.1.7.3 *Hook and Loop Fasteners*[19]—Hook and loop fasteners are not recommended because of the possibility of contaminating critical parts from the shedding of particles when the mating sections are opened and closed and leakage of particles from personnel through the closure.

4.1.8 *Initial Cleaning*—All garments shall be water-washed a minimum of two times before initial use to remove manufacturing residues.

4.2 *Coveralls*:

4.2.1 The recommended cleanroom coverall ensemble design is shown in Fig. 1.

4.2.2 *Collar*—The collar shall be military style (mandarin) as shown in Fig. 2.

4.2.3 *Sleeves*—The sleeves shall be inset to maximize matching of the carbon filaments for antistatic purposes. Raglan sleeve design is permissible provided that careful attention is given to matching the carbon filaments between sleeve and body.

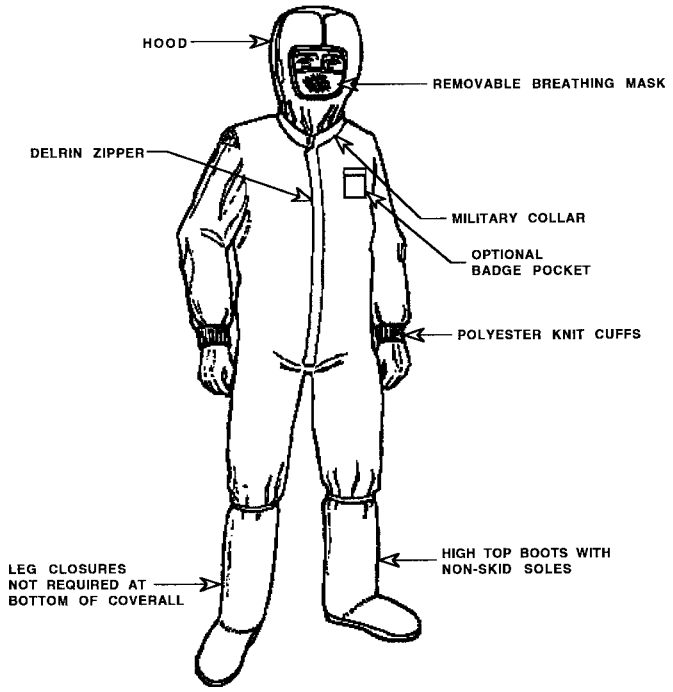
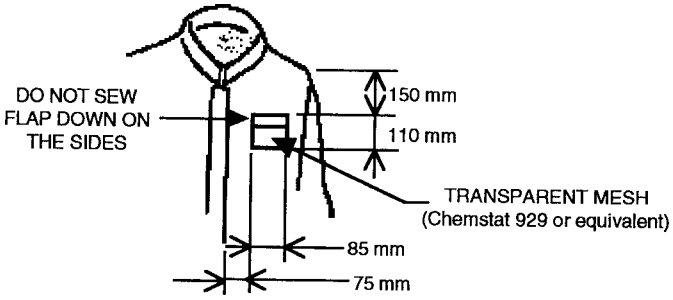


FIG. 1 Clean Room Garment Ensemble



NOTE 1—These dimensions are typical. Actual dimensions shall be selected to fit the badges to be used.

FIG. 2 Optional Badge Pocket Detail

4.2.4 *Cuffs*:

4.2.4.1 The recommended construction is knit, polyester cuffs. However, snaps may be used consistent with the recommendations in 4.1.7.2(3).

4.2.4.2 *Material*—Multifilament 100 % polyester knit cuffs shall be sewn at the wrist to provide a positive closure.

4.2.4.3 *Construction*—The fabric shall be doubled over before stitching to the garment so there is no sewn seam at the terminus of the sleeve.

4.2.4.4 *Dimensions*—Finished cuffs shall be a minimum of 75 mm (3 in.) long. The diameter shall be sized so as to provide a snug fit around the wrist (See Table 1, Table 2, and Table 3.).

4.2.5 *Legs*—Leg closures are not recommended because the leg bottoms are enclosed within the high top boot. However, closures may be used provided the requirements of 4.1.7.2 and 4.1.7.3 are followed.

4.2.6 *Zipper Closures*—A full length self-locking zipper shall be used to close the main body of the coverall and a

[19] Such as Velcro.

TABLE 1 Size Specifications for Cleanroom Coveralls, Short Lengths Measurements in SI (USCS) [mm (in.)]

	XS	S	M	L	XL	XXL	XXXL	XXXXL	XXXXXL
SI SIZE (mm)	760–810	860–910	960–1020	1070–1120	1170–1220	1270–1320	1370–1420	1470–1520	1570–1630
USCS SIZE (in.)	(30–32)	(34–36)	(38–40)	(42–44)	(46–48)	(50–52)	(54–56)	(58–60)	(62–64)
Chest	1020 (40)	1070 (42)	1170 (46)	1270 (50)	1370 (54)	1470 (58)	1570 (62)	1680 (66)	1780 (70)
Waist	970 (38)	1020 (40)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)
Hip	1040 (41)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)	1830 (72)
Trunk	1550 (61)	1630 (64)	1680 (66)	1750 (69)	1800 (71)	1850 (73)	1910 (75)	1960 (77)	2010 (79)
Back yoke	440 (17¼)	470 (18½)	510 (20)	560 (22)	610 (24)	660 (26)	710 (28)	760 (30)	810 (32)
Leg inseam	700 (27½)	710 (28)	710 (28)	775 (30½)	775 (30½)	775 (30½)	775 (30½)	775 (30½)	775 (30½)
Sleeve inseam	430 (17)	430 (17)	480 (19)	480 (19)	480 (19)	480 (19)	480 (19)	480 (19)	480 (19)
Sleeve outseam	710 (28)	740 (29)	810 (32)	850 (33½)	880 (34½)	900 (35½)	930 (36½)	950 (37½)	980 (38½)
Wrist	280 (11)	290 (11½)	290 (11½)	290 (11½)	290 (11½)	300 (12)	300 (12)	300 (12)	300 (12)
Overall length	1520 (60)	1550 (61)	1570 (62)	1600 (63)	1630 (64)	1650 (65)	1680 (66)	1700 (67)	1730 (68)

POINTS OF MEASURE:
Chest: With coverall buttoned, distance around chest, 25 mm (1 in.) below underarm armhole seam.
Waist: With coverall buttoned, distance around center of waistband.
Hip: Distance around hips, measured at bottom of front fly.
Trunk: With front of waistband even with back waistband double the distance between the back collar seam and bottom of the crotch.
Yoke: Measured across shoulders between points where shoulder seams join the arm seams.
Inseam: (Leg): Distance from crotch seam to bottom of ankle.
Inseam: (Sleeve): Distance from armpit to wrist.
Tolerances: ±25 mm (1 in.) for all measurements except the wrist.
±12 mm (½ in.) for wrist measurements.

TABLE 2 Size Specifications for Cleanroom Coveralls, Long Lengths Measurements in SI (USCS) [mm (in.)]

	XS	S	M	L	XL	XXL	XXXL	XXXXL	XXXXXL
SI SIZE (mm)	760–810	860–910	960–1020	1070–1120	1170–1220	1270–1320	1370–1420	1470–1520	1570–1630
USCS SIZE (in.)	(30–32)	(34–36)	(38–40)	(42–44)	(46–48)	(50–52)	(54–56)	(58–60)	(62–64)
Chest	1020 (40)	1070 (42)	1170 (46)	1270 (50)	1370 (54)	1470 (58)	1570 (62)	1680 (66)	1780 (70)
Waist	970 (38)	1020 (40)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)
Hip	1040 (41)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)	1830 (72)
Trunk	1750 (69)	1830 (72)	1880 (74)	1960 (77)	2010 (79)	2060 (81)	2110 (83)	2160 (85)	2210 (87)
Back yoke	440 (17¼)	470 (18½)	510 (20)	560 (22)	610 (24)	660 (26)	710 (28)	760 (30)	810 (32)
Leg inseam	780 (31)	810 (32)	810 (32)	860 (34)	860 (34)	860 (34)	860 (34)	860 (34)	860 (34)
Sleeve inseam	530 (21)	530 (21)	580 (23)	580 (23)	580 (23)	580 (23)	580 (23)	580 (23)	580 (23)
Wrist	290 (11½)	290 (11½)	290 (11½)	290 (11½)	290 (11½)	290 (11½)	290 (11½)	290 (11½)	290 (11½)

POINTS OF MEASURE:
Chest: With coverall buttoned, distance around chest, 25 mm (1 in.) below underarm armhole seam.
Waist: With coverall buttoned, distance around center of waistband.
Hip: Distance around hips, measured at bottom of front fly.
Trunk: With front of waistband even with back waistband double the distance between the back collar seam and bottom of the crotch.
Yoke: Measured across shoulders between points where shoulder seams join the arm seams.
Inseam: (Leg): Distance from crotch seam to bottom of ankle.
Inseam: (Sleeve): Distance from armpit to wrist.
Tolerances: ±25 mm (1 in.) for all measurements except the wrist.
±12 mm (½ in.) for wrist measurements.

protective placket of fabric shall be sewn to the garment along the length of the zipper. Zipper closures shall meet the requirements of 4.1.7.1.

4.2.7 *Cutting the Fabric*—The directional line of cutting the fabric for the coverall shall be in the warp direction as specified in MIL-C-43339D.

4.2.8 *Sizes*—The choice of sizes shall be made from measurements listed in Table 1, Table 2 and Table 3 of this specification. The sizes are shown in both SI (metric) and USCS units.

4.2.9 *Labels*:

4.2.9.1 Each garment shall have a label sewn inside the garment at the neck, denoting size, date of manufacture, manufacturer's name, and fiber type. Printed bar codes may be used so that automated systems can be used to control garments.

4.2.9.2 The material shall not fray or deteriorate over the lifetime of the garment.

4.2.9.3 The printing shall be durable and compatible with wet- and dry-cleaning processes.

4.2.9.4 Logos and other labels may be applied using a gas sublimation transfer technique that dyes the yarn without producing particulate matter.

4.2.10 *Personnel Identification Pocket (Optional)*:

4.2.10.1 Badge pocket detail is shown in Fig. 2.

4.2.10.2 A badge pocket made of a double layer of transparent polyester mesh[20] may be sewn on the front of the coverall.

4.2.10.3 If used, the recommended location is 150 mm (6 in.) below the shoulder seam and 75 mm (3 in.) to the left of the zipper placket. User shall select appropriate size for badge pocket.

4.2.10.4 A self-locking Teflon-filled Delrin (or equivalent) zipper on polyester tape shall be used to close the top of the pocket and a double-layered polyester flap shall cover the zipper.

[20] Chemstat 929 (Stern & Stern Textiles), polyester mesh fabric has been found to be satisfactory. Other fabrics may be available.

TABLE 3 Size Specifications for Cleanroom Coveralls, Short Lengths Measurements in SI (USCS) [mm (in.)]

	XS	S	M	L	XL	XXL	XXXL	XXXXL	XXXXXL
SI SIZE (mm)	760–810	860–910	960–1020	1070–1120	1170–1220	1270–1320	1370–1420	1470–1520	1570–1630
USCS SIZE (in.)	(30–32)	(34–36)	(38–40)	(42–44)	(46–48)	(50–52)	(54–56)	(58–60)	(62–64)
Chest	1020 (40)	1070 (42)	1170 (46)	1270 (50)	1370 (54)	1470 (58)	1570 (62)	1680 (66)	1780 (70)
Waist	970 (38)	1020 (40)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)
Hip	1040 (41)	1120 (44)	1220 (48)	1320 (52)	1420 (56)	1520 (60)	1630 (64)	1730 (68)	1830 (72)
Trunk	1350 (53)	1420 (56)	1470 (58)	1550 (61)	1600 (63)	1650 (65)	1700 (67)	1750 (69)	1800 (71)
Back yoke	440 (17¼)	470 (18½)	510 (20)	560 (22)	610 (24)	660 (26)	710 (28)	760 (30)	810 (32)
Leg inseam	610 (24)	635 (25)	660 (26)	685 (27)	685 (27)	685 (27)	685 (27)	685 (27)	685 (27)
Sleeve inseam	330 (13)	330 (13)	380 (15)	380 (15)	380 (15)	380 (15)	380 (15)	380 (15)	380 (15)
Wrist	250 (10)	280 (11)	280 (11)	280 (11)	280 (11)	290 (11½)	290 (11½)	290 (11½)	290 (11½)

POINTS OF MEASURE:
Chest: With coverall buttoned, distance around chest, 25 mm (1 in.) below underarm armhole seam.
Waist: With coverall buttoned, distance around center of waistband.
Hip: Distance around hips, measured at bottom of front fly.
Trunk: With front of waistband even with back waistband double the distance between the back collar seam and bottom of the crotch.
Yoke: Measured across shoulders between points where shoulder seams join the arm seams.
Inseam: (Leg): Distance from crotch seam to bottom of ankle.
Inseam: (Sleeve): Distance from armpit to wrist.
Tolerances: ±25 mm (1 in.) for all measurements except the wrist.
±12 mm (½ in.) for wrist measurements.

4.2.11 *ESD Requirements*:

4.2.11.1 It is essential that the garment not be able to hold a high voltage charge during use when personnel are properly grounded. The use of topical and chemical antistatic agents are not acceptable.

NOTE 2—Topical and chemical antistatic agents can lose effectiveness with time, are removed during cleaning, and may contaminate hardware. Garments so treated may fail to meet the NVR requirements in 4.3.3.

4.2.11.2 When the garment is charged to 1500 V and then grounded, the voltage shall decay to 10 % or less of the initial charge within 2 s and below 150 V in 5 s in a 25 ± 5 % maximum relative humidity and 24°C (75°F) maximum temperature environment.

4.2.11.3 The recommended test consists of clamping an insulated probe to each sleeve of the garment, connecting a recording voltmeter to one of the probes and a dc power supply to the other. The test procedure is described in AGMC/MAQC-335c.

4.2.11.4 The garment shall be tested following the initial cleaning (4.1.8) and should be rechecked periodically after cleaning during use.

4.3 *General Fabric Requirements*:

4.3.1 *Linting Characteristics*—Fabrics of which garments are made shall be low linting to minimize airborne particulate contamination. Garments shall meet Test Method F 51 Class A requirements for cleanroom operations.

4.3.2 *Static Dissipation*—The fabric shall meet the NASA/KSC GP-1098 static dissipation requirements when tested per MMA-1985-79. The use of topical and chemical antistatic agents are not acceptable.

4.3.3 *Extractable Matter (NVR)*:

4.3.3.1 The content of extractables, after the initial cleaning in 4.1.8, shall be less than 0.5 % NVR by fabric mass.

4.3.3.2 Periodic retesting of garments for extractables shall be made after laundering.

4.3.3.3 The test method described in Test Method E 1560 may be used.

4.3.3.4 The procedures used for obtaining and measuring non-volatile residues from Soxhlet-extracted wipers described in USAF SD-TR-89-63 may be also used to measure extractables in fabrics.

4.3.3.5 In each test method, the fabric is soaked in a high-purity solvent. The solvent is then filtered into a tared container and evaporated at room temperature, with a final drying at 35°C for 30 min. The NVR is weighed after it has equilibrated to room temperature and humidity conditions.

NOTE 3—The solvent for the extraction should be selected based on the solvent(s) to which the garment could be exposed.

NOTE 4—The SD-TR-89-63 test method uses a mixture of 1,1,1 trichloroethane and ethanol (75 %/25 % by volume). Test Method E 1560 specifies acetone and allows alternate solvents.

4.3.4 *Shrinkage*—The shrinkage shall be less than 1 % in any direction on a 30- by 30-cm (12- by 12-in.) test panel at 120°C (250°F) for ½h in dry heat, in a relaxed condition.

4.3.5 *Color*:

4.3.5.1 Color shall be as specified by the user based on the availability of fabrics.

4.3.5.2 There shall be no appreciable change in color evident after ten standard launderings when the laundered garment is compared with new, unwashed fabric.

NOTE 5—A change in gloss is to be expected after many launderings. This change is not considered a change in color.

4.4 *Headwear*:

4.4.1 *Hoods*:

4.4.1.1 Recommended hood designs are shown in Fig. 3.

4.4.1.2 Hoods shall fit over the head and cover all but the eyes, nose, and mouth. The fabric shall drape over the front and

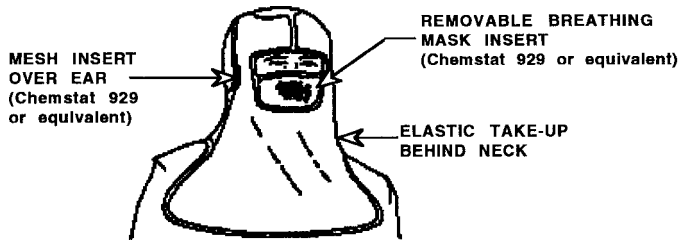


FIG. 3 Hood Detail

back of the upper body and be long enough to stay inside the garment even with extreme head movement.

4.4.1.3 Adjustments shall be provided so that the hood is secure and follows the movement of the head so that the eyes always look through the front. One method is to sew a 25-mm (1-in.) wide elastic band inside the hood behind the neck. External straps may also be used. Snaps may be used for the adjustments provided that the requirements in 4.1.6.2(3) are met.

4.4.1.4 The recommended design has a continuous fabric front, except for the face opening.

4.4.1.5 An alternate design (not recommended) uses snaps to close the front. A snap front has gaps that allow particles to escape from the interior of the hood. The user should weigh the risks of having this gap and using snaps. The placement and number of snaps shall be selected so as to minimize gaps.

4.4.1.6 *Sizes*—Hood sizes shall be available in small to extra large sizes compatible with the coveralls.

4.4.1.7 *Ear Panels*—Polyester mesh ear panels are optional. The material shall be the same as that used for the face masks (4.4.2.2).

4.4.1.8 *Labels*—A label denoting size, manufacturer, date of manufacture, and fiber type shall be sewed to the underside of the solid front panel of the hood. See 4.2.9 for details on labels.

4.4.1.9 *Fabrics*—The hood fabric shall be the same as that used in the coverall.

4.4.2 *Face Masks*:

4.4.2.1 *Attachment to Hood*—A detachable or disposable breathing mask shall be attached with snap fasteners on the inside of the hood. It shall cover all exposed facial regions except the eyes. The portion left open for the eyes shall be wide enough to accommodate prescription or safety glasses.

4.4.2.2 *Material*—The mask shall typically be made of polyester mesh having a permeability of at least 165 cm^3/s (350 cfm) and a maximum density of 50 g/m^2 (1.5 oz/yd^2) to entrap skin particles or facial hair.[20]

4.4.2.3 *Mask Sizes*—Mask sizes shall be available in small to extra large sizes compatible with the hoods.

4.4.3 *Snoods*:

4.4.3.1 A typical snood design is shown in Fig. 4.

SNOOD MUST COVER
HAIR AND EARS COMPLETELY

FIG. 4 Snood

4.4.3.2 The snood shall fully cover only the hair and ears but not the face.

4.4.3.3 Snoods shall have an elastic band sewn across the back and along the sides to allow one size to fit all. When snoods are used, they shall completely cover the hair.

NOTE 6—Snoods will not provide as good a protection of hardware as hoods because of particulate contamination generated from skin flaking, breathing, facial hair, and leakage around the collar of the coverall.

4.5 *Footwear*:

4.5.1 *High-Top Boots*—High-top boots are worn over shoes. In addition to the containment of contaminants, the boots shall fit snugly and be secured so that the shoe can not slide within the boot thereby creating a personnel safety problem.

4.5.2 The upper part of the high-top boots (legging) shall cover the calf of the leg and extend to just below the kneecap, a nominal 450 to 500 mm (18 to 20 in.). Boots are illustrated in Fig. 5.

NOTE 7—Shoe covers that do not enclose the bottom of the pant legs are not recommended because contaminants from inside the coverall are not contained.

4.5.3 *Closures*—A self-locking Teflon-filled Delrin (or equivalent) zipper shall be sewn to the back and shall extend from the sole to the top of the boot. A pull-tab on the zipper inside the heel of the boot may be added to assist in donning the boot. This tab shall be made from polypropylene webbing folded over to form a loop.

4.5.4 *Securing the Boot*:

4.5.4.1 The top of the boot shall be secured with an exterior strap or with an interior elastic cord which shall run through the top hem of the boot. One end shall be fixed to the top hem of the boot while the other end shall run through a sliding catchment for adjusting cord tension. The strap or cord shall firmly hold the boot legging to the leg. A barrel lock of polyacetate has been found to be satisfactory.

4.5.4.2 The foot of the boot shall be secured with an exterior or interior elastic cord that shall run over the instep and around behind the ankle. Both ends of the cord shall run through a fixed polyester lock for adjusting cord tension.

4.5.4.3 The choice of exterior or interior straps depends upon functional requirements and the preference of the user. The requirement is that the boot shall be securely attached to the shoe so that no slippage can occur.

4.5.5 *Boot Soles*:

4.5.5.1 The soles of the boots shall be continuous, non-grooved, and shall extend at least 25 mm (1 in.) up on all sides.

4.5.5.2 The sole shall be fabricated with a nonskid material

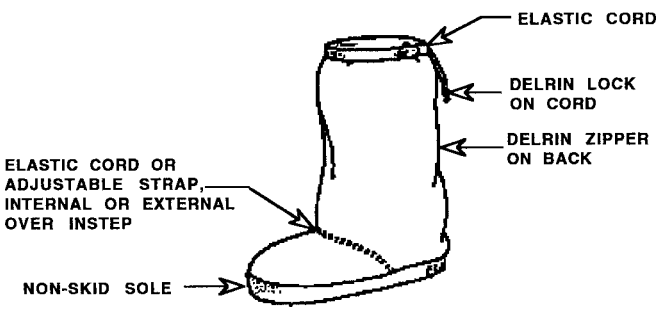


FIG. 5 Clean Room Boots

having a kinetic coefficient of at least 1.45 outside and 1.25 inside per Test Method D 1894.[21]

4.5.5.3 *ESD Properties*:

(1) It is essential that the boot not hold a high voltage charge during use when personnel are properly grounded. The use of topical and chemical antistatic agents are not acceptable.

(2) When the boot is charged to 1500 V and then grounded, the voltage shall decay to 10 % or less of the initial charge within 2 s and below 150 V in 5 s in a 25 ± 5 % maximum relative humidity and 24°C (75°F) maximum temperature environment.

(3) The recommended test for determining the continuity of the cleanroom garment together with the boots consists of clamping an insulated probe to each sleeve of the garment, connecting a recording voltmeter to one of the probes and a dc power supply to the other. The test procedure is described in AGMC/MAQC-335C.

(4) The ESD properties of the boot shall be tested initially and should be rechecked periodically after cleaning.

4.5.5.4 *Combustibility*—Combustibility requirements provide that the soles must self-extinguish before 15 cm (6 in.) of material are consumed. Sparking, sputtering, or dripping of flaming particles is not acceptable. Test Method 1 of the NASA Handbook, NHB 8060.1 C shall be used. This test method conforms to Practice E 535.

4.5.6 *Labels*—The boot size, fiber type, and manufacturer's name shall be printed on a small polyester label sewn inside each boot at the top front of the leg section. See 4.2.9 for details on labels.

4.5.7 *Fabrics*—The boot fabric shall be the same as that used in the coverall.

4.5.8 *Sizes*—Sizes from extra small (XS) to extra large (XL) are available. The boot shall fit snugly over the shoe.

5. Additional Garment Requirements for Nonhazardous Applications

5.1 *Fabrics*:

5.1.1 *Flame Resistance*—Garments in this category shall be flame resistant but not necessarily meltproof. The garments shall, as a minimum, meet the Class 1 requirements of NFPA 702-1980.

5.1.2 *Chemical Compatibility*:

5.1.2.1 Garments in this category must withstand exposure to substances used routinely in aerospace facilities.

5.1.2.2 Protection of personnel from the effects exposure to specific chemicals may require special protective garments. Test Method F 739 contains test methods for determining the resistance of protective clothing to permeation by liquids and gases.

5.1.2.3 The list of potential chemicals used in and around aerospace facilities includes solvents and propellants. Typical solvents are alcohol, methyl ethyl ketone, 1,1,1 trichloroethane, and acetone. Propellants include hydrogen, oxygen, nitrogen tetroxide, hydrazine, nitric acid, sulfuric acid, and hydrogen peroxide.

5.2 *Fabric Recommendations*:[22]

5.2.1 *Yarn*—99 % multifilament Dacron polyester with 1 % carbon/polyester filament yarn, 100 % multifilament.

5.2.2 *Typical Thread Count*—Warp of 172 ends/25 mm; fill of 82 ends/25 mm.

5.2.3 *Weave*—2/1 twill with 6.5-mm (¼-in.) grid of 1 % carbon/polyester and 99 % Dacron polyester filament. The grid may be raised.

5.2.4 *Typical Density*—102 g/m^2 (3.00 oz/yd^2).

NOTE 8—Membrane fabrics are not acceptable because such fabrics do not meet the flame resistance requirements.

5.2.5 *Air Permeability*—The optimum is 6.6 ± 1.9 cm^3/s (14 ± 4 CFM) when tested per FED-STD-191, Method 5450 (Calibrated Orifice Method[23]).

5.2.6 *Tensile Strength*:

5.2.6.1 Tensile strength in the warp direction shall be 402 N (90 lbf) minimum when tested per FED-STD-191, Method 5104 (Ravel Strip Method).

5.2.6.2 Tensile strength in the fill direction shall be 225.5 N (51 lbf) minimum when tested per FED-STD-191, Method 5104 (Ravel Strip Method).

5.3 *Construction Details*:

5.3.1 *Sewing Thread*—The sewing thread shall be continuous filament polyester throughout the garment. Garments shall be sewed with "preset" threads having the same or lower rates of shrinkage than the fabric as described in Test Methods D 204.

6. Additional Garment Requirements for Hazardous Applications

6.1 *Fabrics*:

6.1.1 The requirements of 5.1 shall be met with the additional requirements that follow.

6.1.2 *Flame Resistance*—Garments shall be meltproof as well as flame resistant. Polyester shall not be used because it produces melt burns at temperatures in excess of 250°C (480°F). Fabric shall meet or exceed the requirements of NASA Handbook, NHB 8060.1C, Test 1 for flame resistance.

6.1.3 *Combustibility*—The fabric shall have an average time after flame of not more than 2.0 s and an afterglow time of not more than 6.0 s. Not more than 40 % of a 2.5- by 25-cm (1- by 10-in.) test sample shall be consumed both initially and after 15 launderings (MIL-C-43122E and FED-STD-191, Method 5903). Practice E 535 shall be followed.

6.2 *Fabric Recommendations*:

6.2.1 *Yarn*—99 % multifilament Nomex aramid, with 1 % carbon conductive carbon and polyester filament yarn, 100 % filament, mass of 10 g/450 m (200 Denier).[24]

[21] Conductive Chemstat 939 (Stern & Stern Textiles) has been found to be satisfactory.

[22] This is one recommendation. Other acceptable fabrics differ only slightly in count, weave, and weight. Selguard II (Teijun Textiles), Vidaro B-FORE, Burlington C3, and Chemstat 909 (Stern & Stern Textiles) may be satisfactory. Other acceptable fabrics may also be available.

[23] An air permeability apparatus of the type described in Method 5450 may be purchased from the Fratzier Precision Instrument Co., 210 Oakmont Ave., Gaithersberg, MD 20760.

[24] Chemstat 919 (Stern & Stern Industries, Inc) has been found to be satisfactory. Bismalyde fabrics may also be acceptable.

6.2.2 *Thread Count*—Warp of 101 ± 2 ends/25 mm; fill of 75± 2 ends/25 mm.

6.2.3 *Weave*—2/2 twill with 6.5-mm (¼-in.) raised grid of 1 % carbon/polyester copolymer and 99 % Nomex filament.

6.2.4 *Density*—170 ± 10 g/m^2 (5.0 ± 0.3 oz/yd^2), minimum 135 g/m^2(4 oz/yd^2).

6.2.5 *Air Permeability*—The optimum is 4.72 ± 2.35 cm^3/s (10 ± 5 CFM) per FED-STD-191, Method 5450 (Frazier Test).

6.2.6 *Tensile Strength*—Warp of 843 N (190 lbf) minimum; fill of 515 N (116 lbf) minimum per FED-STD-191, Method 5104 (Ravelled Strip).

6.2.7 *Color:* natural.[25] Laundering shall not result in color changes as described in 4.3.5.2, nonhazardous.

6.3 *Construction Details*:

6.3.1 *Sewing Thread*—The sewing thread shall be continuous filament, flame-resistant Nomex® aramid, MIL-T-43636 or equal, throughout the garment. Garments shall be sewed with "preset" threads having the same or lower rates of shrinkage than the fabric as described in Test Methods D 204.

6.3.2 *Seams and Edges*—All seams shall be finished completely. The construction shall be the same as 4.1.5 except that Nomex® yarn shall be substituted for polyester yarn.

6.4 *Safety Harnesses (Optional)*:

6.4.1 Safety harnesses have been required on Nomex® garments used at the NASA Kennedy Space Center. Grab straps have been used because of concern that the rescue of personnel would be difficult without the straps.

6.4.2 The choice of safety harnesses involves trade-offs between the risk to personnel by not using the straps and the potential risk to hardware by the straps snagging on components.

NOTE 9—There is not a consensus on this issue within the aerospace safety community.

6.4.3 Safety harnesses, if used, shall be manufactured from olive green Nomex® parachute webbing per MIL-W-43685, Type II. The webbing shall be cut with a hot knife to seal raw edges. Straps shall be 40 mm (1½ in.) wide and shall be able to withstand a pull of 900 N (200 lbf). Straps shall be sewed securely on the legs, torso, shoulders, and back of the coverall, as shown in Fig. 6 and Fig. 7.

7. Operational Processing

7.1 Operational processing is not a mandatory part of this specification. Information is provided for reference only.[26]

7.2 Facilities for laundering cleanroom garments should provide a Class M3.5 (Class 100) per FED-STD-209, or better environment, for cleaning and packaging garments.

7.2.1 *Laundering*—Soiled garments should be washed in detergent and hot water to remove water soluble contaminants including salts from perspiration.

7.2.2 *Dry Cleaning*—Garments should be dry cleaned after aqueous laundering to remove organic contaminants such as oils, greases, and fatty acids. This is required only when the garment is exposed to such contaminants.

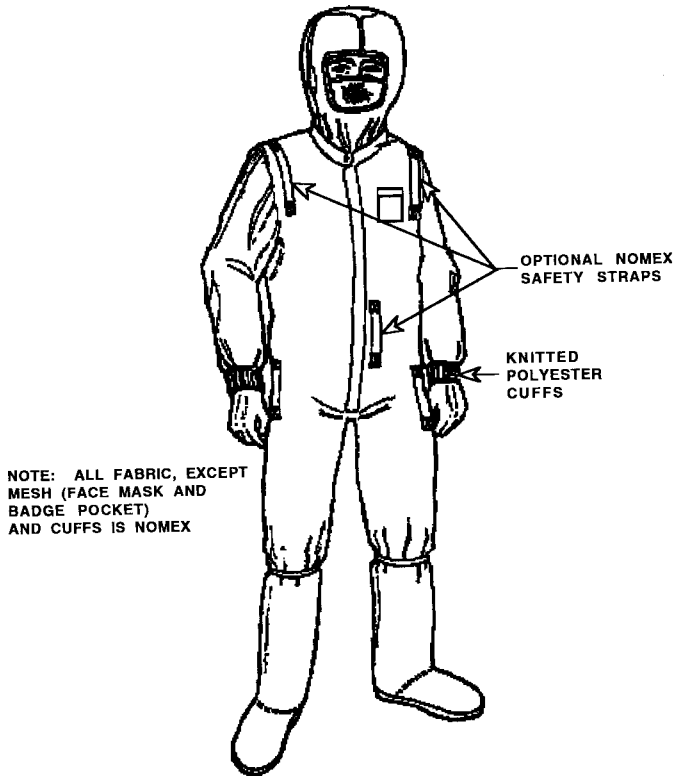


FIG. 6 Special Features of the Nomex Garment Ensemble

7.2.3 *Inspection and Repair*:

7.2.3.1 Garments should be inspected after each use and repaired or replaced if excessive signs of wear are observed. These signs include openings at seams, fraying or lack of integrity of fabric, exposure of any of the conductive yarns, and snaps, zippers, labels or any other attachments not securely attached to the garment.

7.2.3.2 Repairs and the removal of spots and stains should be performed before cleaning.

7.2.4 *Packaging*:

7.2.4.1 After cleaning, garments should be packaged in the clean environment.

7.2.4.2 Garments should be hermetically sealed in clean polyethylene bags.

7.2.4.3 Each garment should be packaged individually except boots may be packaged in pairs.

7.2.4.4 Each apparel package should be marked as to size or packed such that garment size marking is clearly visible. Bar codes may be used to provide control over each item.

7.2.4.5 Garments should be delivered in numbered lots that can be traced to a known cleaning load. The size of the lot should be carefully chosen since the entire lot may be rejected and returned to the processor for recleaning.

8. Quality Assurance

8.1 New garments shall be inspected upon receipt for compliance to the purchase specification.

8.2 Quality control criteria should be agreed upon by buyer and seller so as to minimize disagreements on acceptance and rejection criteria.

[25] At this time, only natural is available. Other colors are acceptable provided that the other requirements are met.

[26] T.O. 00-25-203, Contamination Control of Aerospace Facilities, U.S. Air Force, 1 Dec. 1972, Change 13, 20 Aug. 1990.

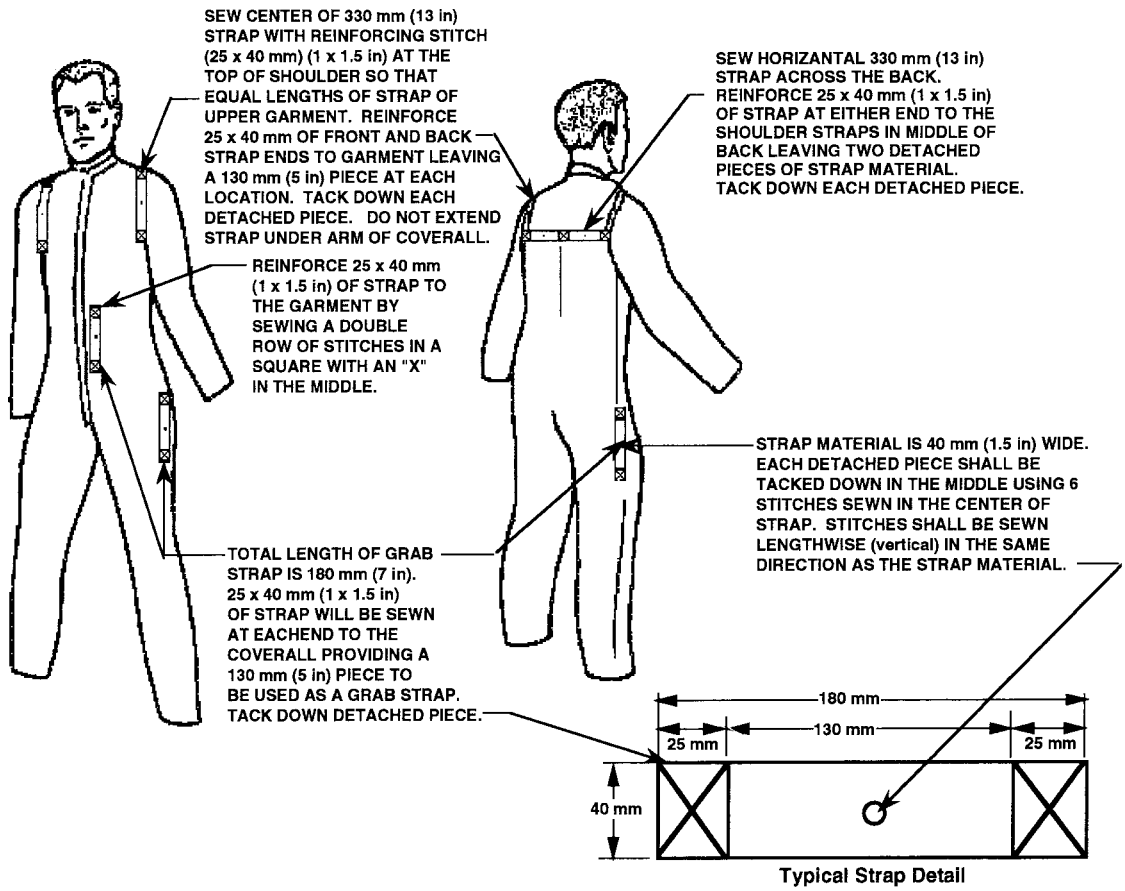


FIG. 7 Details of Safety Grab Straps

8.3 Garments shall be inspected following the initial cleaning (Section 4.1.8) for compliance to the purchase specification. Cleanliness requirements following cleaning are governed by the agreements between the user and the cleaning organization and are not a part of this specification.

9. Precision and Bias

9.1 Accuracy, precision, and bias of NHB 8060.1C, Test Method 1, and MMA-1985-79, Revision 2, have not yet been determined.

10. Keywords

10.1 cleanroom; contamination control; garments; spacecraft

APPENDIX

(Nonmandatory Information)

X1. RATIONALE FOR HAZARDOUS GARMENT REQUIREMENTS

X1.1 *ESD Risk*—All types of fabrics made of synthetic fibers generate static dissipative charges when subject to abrasive forces. This effect is amplified in low-humidity environments. Carbon fibers interwoven in the cloth and care in garment construction help reduce the risk of possible damage to critical payload components from electrostatic discharge. Electrostatic discharge in a combustible atmosphere may result in a fire or explosion.

X1.2 *Chemical Exposure Risk*—Cleanroom garments provide protection of personnel from the typical solvents used in aerospace facilities. Personnel working with fluid propellants must wear special, sealed protective clothing provided with breathing air. Compatibility with propellants means that the fabric shall not react exothermally with these chemicals. Safety procedures are strictly enforced during normal operations to minimize the probability of exposure of personnel to propellant liquids and vapors. Personnel working with solid propellants generally wear static dissipative, Nomex® coveralls.

X1.3 *Fire Risk*—All fabrics of natural or regenerated cellulose, as well as most types of finished and unfinished fabrics made from other natural or synthetic fibers, are combustible and many are relatively flammable.

X1.3.1 NFPA 702-1980 applies to methods for testing the flammability of textiles used or intended for use in wearing apparel, establishes classes of flammability and sets forth the requirements which textiles shall meet to be so classified.

X1.3.2 Fire risk is a quantitative description of the potential for injury or loss. The risk of loss of property will depend upon the probability of the occurrence of an ignition, the fire-test-response and fire performance characteristics of the materials, products, and assemblies in a given situation, and the existence of fire-containment or extinguishing systems. Where the risk is that of injury or death, consideration must also be given to the probability of human exposure and the physiological and psychological response of persons to the fire.

X1.3.3 Risk is a scalar quantity that may have a range of values and does not describe the acceptability of that value to an individual or society. The age, mental and physical alertness, and reaction time of the person(s) involved are very important factors in determining the consequences of a fire accident.