



Designation: **E1549 – 06 E1549/E1549M – 13**

Standard Specification for ESD Controlled Garments Required in Cleanrooms and Controlled Environments for Spacecraft for Non-Hazardous and Hazardous Operations¹

This standard is issued under the fixed designation ~~E1549~~E1549/E1549M; 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 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 ~~HES-RP-CC003.2~~IEST-RP-CC003.3.

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 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.7 *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:*³

[D123 Terminology Relating to Textiles](#)

[D204 Test Methods for Sewing Threads](#)

~~D1863~~[D1683 Specification for Mineral Aggregate Used on Built-Up Roofs](#)[Test Method for Failure in Sewn Seams of Woven Apparel Fabrics](#)

[D1894 Test Method for Static and Kinetic Coefficients of Friction of Plastic Film and Sheeting](#)

¹ This specification is under the jurisdiction of ASTM Committee E21 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, Standards and Related Technical Material; 7th Edition, June 2007, ISBN13: 978-0-8031-5684-5, available on request from ASTM Headquarters, 100 Barr Harbor Dr., PO Box C700, West Conshohocken, PA 19428–2959.

³ 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.

[D2257 Test Method for Extractable Matter in Textiles](#)
[D5034 Test Method for Breaking Strength and Elongation of Textile Fabrics \(Grab Test\)](#)
[D6193 Practice for Stitches and Seams](#)
[D737 Test Method for Air Permeability of Textile Fabrics](#)
[E96/E96M Test Methods for Water Vapor Transmission of Materials](#)
[E176 Terminology of Fire Standards](#)
[E535 Practice for Preparation of Fire-Test-Response Standards](#)
[E1560 Test Method for Gravimetric Determination of Nonvolatile Residue From Cleanroom Wipers](#)
[F51 Test Method for Sizing and Counting Particulate Contaminant In and On Clean Room Garments](#)
[F739 Test Method for Permeation of Liquids and Gases through Protective Clothing Materials under Conditions of Continuous Contact](#)
[F1506 Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards](#)

2.2 *U.S. Federal Standards:*⁴

~~[FED-SPEC-191CFR Title 16 Part 1610 Textile Test Method Standard for the Flammability of Clothing Textiles](#)~~
~~[FED-STD-A-A 50195 Thread, Aramid](#)~~
[FED-STD-209E Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones](#)
~~[FED-STD-751a Stitches, Seams, and Stitchings](#)~~

2.3 *U.S. Department of Defense:*

~~[MIL-C-43122EMIL-C-43122G Cloth, Sateen, Cotton, Flame Retardant Treated](#)~~⁵
~~[MIL-C-43339D Coveralls, Industrial: Lint-Free, 7 Nov. 1988](#)~~⁵
~~[MIL-W-43685BMIL-DTL-43685C Webbing and Tape, Textile, Aramid Fiber, 20 Sept. 1989Fiber](#)~~⁵
[MIL-STD-3010B Test Procedures for Packaging Materials](#)⁵
[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](#)⁶
[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](#)⁶

~~[AGMC/MAQC-335e Personnel Garments, Electrostatic Discharge \(ESD\) Requirements for the Protection of ESD Sensitive Items](#)~~⁷

2.4 *NASA:*

[KSC-SPEC-P-0016 Specification for Minimum Requirements for Garment Snap Fastener](#)⁷
~~[MMA-1985-79, KSC-MMA-1985-79, Revision 2, 6, Standard Test Method for Evaluating Triboelectric Charge Generation and Decay](#)~~⁷
~~[GP-1098 STS Safety, Reliability, and Quality Assurance Ground Safety Plan, Launch Complex 39, KSC Industrial Area](#)~~⁹
~~[NHB-8060, INASA-STD-6001 C, NASA Handbook, Flammability, Odor, Flammability, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments that Support Combustion, April 2, 1991, Procedures, Upward Flame Propagation Test \(Test 1\)](#)~~⁸

2.5 *Others:*

~~[NFPA #702-1980ANSI/ESD S20.20 Standard for Classification of the Flammability of Wearing Apparel For the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment \(Excluding Electrically Initiated Explosive Devices\)](#)~~⁹
[ESD ADV1.0-2009 ESD Association Advisory for Electrostatic Discharge Terminology, Glossary](#)⁹
~~[IES-RP-CC-003.2 IEST-RP-CC-003.3 Garments Required In Cleanrooms And Controlled Environment Areas](#)~~¹⁰
[IEST-RP-CC022.2 Electrostatic Charge in Cleanrooms and Other Controlled Environments](#)¹⁰
[NFPA 70E Electrical Safety in the Workplace](#)¹¹

⁴ Available from U.S. General Services Administration, Government Printing Office, Washington, DC.

⁵ Available from U.S. Natick Research Development and Engineering Center, Natick, MA 07160-5014.

⁶ Reprints available from The Aerospace Corporation Library, P.O. Box 92957, El Segundo, CA 90009.

⁷ Aerospace Guidance and Metrology Center, U.S. Air Force, Newark AFS, Ohio, 22 Feb. 1989, NASA Technical Standards Program Office, ED10, MSFC, AL, 35812; Online, available: <https://standards.nasa.gov/documents/ksc>

⁸ NASA Kennedy Space Center, Materials Testing Branch, 15 July 1988.

⁸ NASA Kennedy Space Center, Technical Standards Program Office, ED10, MSFC, AL 35812; Online, available: <https://standards.nasa.gov/documents/nasa>.

¹⁰ Office of Safety and Mission Quality (Code QR), NASA Headquarters, Washington, DC 20546.

⁹ Available from National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, Electrostatic Discharge Association 7900 Turin Road, Bldg. 3, Rome, NY 13440.

¹⁰ Available from the Institute of Environmental Sciences, 940 E. Northwest Highway, Mount Prospect, IL 60056.

¹¹ Available from National Fire Protection Association (NFPA), 1 Batterymarch Park, Quincy, MA 02169-7471, <http://www.nfpa.org>.

2.6 *International Standards*:¹²

ISO 14644-1 Cleanrooms and Associated Controlled Environments, Classification of Air Cleanliness

ISO 14644-2 Cleanrooms and Associated Controlled Environments-Specifications for testing and monitoring to prove continued compliance with ISO 14644-1

3. Terminology

3.1 Terminology related to textiles is based on Terminology **D123**. Terminology related to fire safety is based on Terminology **E176**.

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.

¹² Available from American National Standards Institute (ANSI), 25 W. 43rd. St., 4th Floor, New York, NY 10036. These standards supersede FED-STD-209E. The latter may still be used if mutually agreed to beby customer and supplier.

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 the ISO 14644 standards.

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- μ m particles.

3.2.6 *NVR (nonvolatile residue), n*—quantity of residual ~~soluble~~, soluble, 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 μ m (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 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 *foreign object debris (FOD), n*—a substance, debris or article which is alien to a vehicle or system which would potentially cause damage.

3.3.13 *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.

3.3.13.1 *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.

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

3.3.15 ~~*Nomex®*~~, *Nomex®*, *n*—a synthetic aramid fiber manufactured by DuPont that meets the requirements of NASA Handbook, NHB 8060.1C, Technical Standard, NASA-STD-6001, Test 1 for flame retardancy.

3.3.16 *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, linkages



are attached directly to two aromatic rings.

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3.3.17 *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,



and para-substituted hydroxy-benzoate units.

~~and para-substituted hydroxy-benzoate units;~~



3.3.18 *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.

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

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

3.3.21 *static dissipative fabric, n*—an inherently static control fabric with surface resistivity between 10⁵ ohms per square and not more than 10⁹ ohms per square.

3.3.21.1 *Discussion*—

The ESD Association defines the upper limit for static dissipative materials as not more than 10^{12} ohms per square¹³ and the acceptable upper limit for static control garments as not more than 10^{11} ohms per square.¹⁴

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

3.3.23 *Teflon®*, *n*—DuPont trade name for tetrafluoroethylene-polytetrafluoroethylene (PTFE) polymer fiber. It is chemically resistant and does not absorb moisture.

3.3.24 *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).

3.3.25 *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.

3.3.26 *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.

3.3.27 *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.

3.3.28 *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).

¹³ ESD ADV1.0-2009 ESD Association Advisory for Electrostatic Discharge Terminology, Glossary.

¹⁴ ANSI/ESD S20.20 Standard For the Development of an Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices).

3.3.28.1 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—Clothing textiles are tested and classified in accordance with the National Fire Protection Association Standard #702-1980, under the classification of wearing apparel. U. S. Code of Federal Regulations Title 16: Commercial Practices - Part 1610 to comply with the Flammable Fabrics Act.~~

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 E96/E96M 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 E96/E96M 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. Refer to FED-STD-A-A 50195.

4.1.6.2 *Seams*—All seams shall be finished completely. Major garment seams shall be double-needle flat felled following FED-STD-751a, Practice D6193, Seam Type LSC-2 and Stitch Type 401, 6.5-mm ($\frac{1}{4}$ -in.) gage. Seams shall pass the standard test methods for failure given in Test Method D1863/D1683.

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 completely 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 and potentially becoming entrapped within hardware as foreign object debris.

(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) When snaps are used they shall be protected from contact with the skin and shall be in accordance with KSC-SPEC-P-0016 or equivalent.

4.1.7.3 *Hook and Loop Fasteners*¹⁵—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.

¹⁵ Such as Velcro.

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<https://standards.iteh.ai/catalog/standards/sist/dbb124eb-4cb5-4c77-9964-07b4cf71cf28/astm-e1549-e1549m-13>

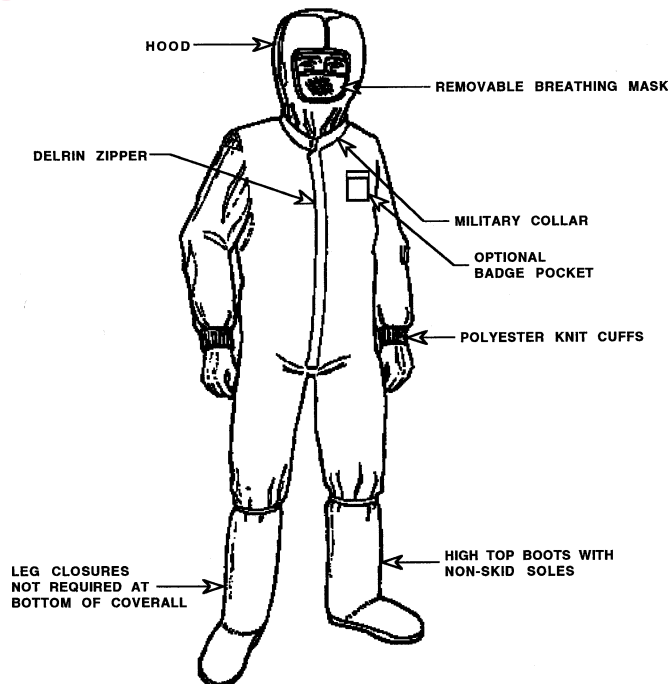


FIG. 1 Clean Room Garment Ensemble