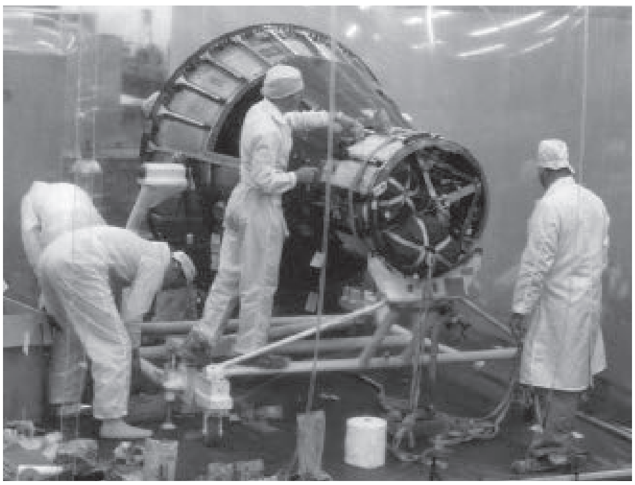
The History of Cleanroom Garments

Jan Eudy



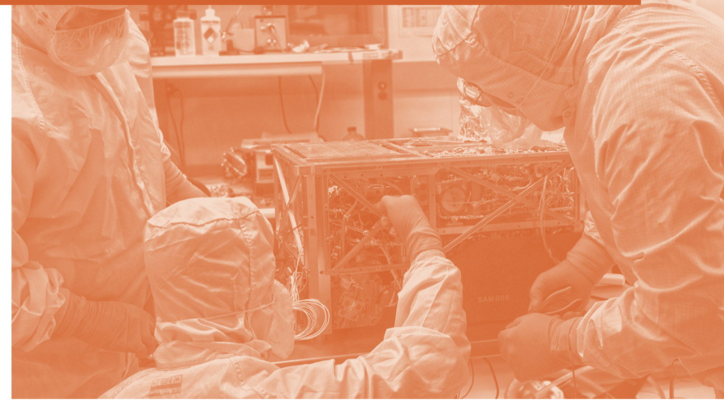
1960s: Technicians in clean room garments work on Project Mercury spacecraft production at McDonnell Aircraft. Photo: NASA

Clean manufacturing was developed during World War II to improve the quality and reliability of war machinery.

Human sources—equipment, production materials, product and people—are the chief contributors to contamination and compromised integrity in cleanrooms and controlled environments. To control this contamination, equipment is manufactured with components and surfaces that are compatible with the classification of cleanroom in which they are used. Production materials and product may be contained or encapsulated within equipment or packaging. But the number-one control method for preventing human-sourced contamination is the correct selection, donning, wearing and doffing of cleanroom garments designed to encapsulate viable and non-viable particles shed by cleanroom operators.

Just as equipment has evolved to be cleanroom compatible, cleanroom garment systems have also evolved to be cleanroom compatible and more comfortable to wear.

Prior to the Willis Whitfield ultra-clean room at Sandia Corporation in the 1960s, clean manufacturing was developed during World War II to improve the quality and reliability of war machinery such as guns, tanks, aircraft and ships. Concurrently, emerging research in biological and chemical warfare by the chemical and pharmaceutical industries also indicated the need for



NASA Scientists work on the NASA Curiosity rover.
Photo: NASA Goddard Space Flight Center

increased contamination control. Employees of these industries began to wear 100% cotton shirts, pants and lab coats on the job to help minimize contamination. At the same time, the importance of contamination control in hospitals was also being realized; soon hospital employees began to wear the same types of cotton clothing.

1960s

This was an exciting decade that saw the development Of the first clean rooms, filtration and the concept of "laminar flow" (which is actually unidirectional airflow). Laminar flow and the commercial availability of high-efficiency particle air (HEPA) filters significantly reduced the number of particles in the first clean rooms. Particles were still being generated by the clean room operators, however.

1965: A NASA employee and a Sandia National Laboratories employee inspect the sterilization of an interplanetary lander in a Sandia clean room. Photo: Sandia National Laboratories

In March 1967, the Garment and Laundry Committee of the American Association for Contamination Control (A2C2) published "Clean Room Garments and Laundry – A State of the Art Report." The committee consisted of Sy Weisinger as Chairman, with Leon Hertzson, Carl Robinson, Irving Rosen and Thomas Williamson as members. This document states that Federal Standard 209 required that clothing worn in clean rooms be "lint-free."

Additionally, the document states the US Air Force Technical Order No. 00-25-203 required that the garments worn in clean rooms be constructed of a "synthetic fabric with limited linting properties." The document recommended using filament Dacron polyester yarn in the fabric of choice. The two primary fabric weaves were taffeta and herringbone. Generally, taffeta weaves were used for frocks or smocks, surgical style caps and shoe covers, whereas herringbone weaves were used for coveralls. The same Air Force technical order stated:

> *Coveralls and smocks should have no pockets, no pleats, no dust collecting ridges and no raw edges. All seams should be double needled and sewn with 100% Dacron continuous filament thread. Both coverall and smock should have adjustable neck bands and cuffs to allow for tight closure.*

Editor's note: This article uses terminology appropriate to the era under discussion: "clean room" before 1980, "cleanroom" afterward, except for titles of books and articles.

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The A2C2 document recommended that all garments worn in a clean room should be processed in a suitable, environmentally controlled laundry. The document specified water washing and dry cleaning parameters for the garments, as well as packaging specifications. Steam, ethylene oxide (ETO) or dry heat sterilization were recommended for garments worn in pharmaceutical manufacturing.

In 1968, the American Society for Testing and Materials published ASTM F-51, "Standard Test Method for Sizing and Counting Particulate Contaminant In and On Clean Room Garments." It was reapproved in June 1989 and again in 2007, with minor editorial changes. This test method counts particles greater than five micrometers (µm) and fibers microscopically. Clean room industries specified that garments worn in their clean rooms must meet Class A particle cleanliness, which is fewer than 999 particles larger than five µm, and ten fibers per 0.1 square meters of fabric.

In May 1969 the A2C2 Garments and Laundry Committee expanded its original 1967 work to clarify fabric and construction recommendations for clean room garments. Because most clean room garment users had partnered with commercial precision laundries that specialized in laundering the garments, the revised report detailed the requirements for water washing or dry cleaning and packaging. The report also emphasized that "No item of clean room apparel should be issued as received from the manufacturer. It must be laundered first to remove all loose threads and other contaminants possible to adhering to the surface."

1970s

Nonwoven fabrics were developed and disposable garments for clean room use were developed using DuPont's Tyvek, a durable, chemical- and liquid-resistant flash-spun bonded polyolefin formed into an air-impermeable sheet. Because it could also be sterilized, disposable Tyvek garments were worn in pharmaceutical clean rooms.

Calf-high boots were developed because coveralls sometimes did not reach to the shoe covers, allowing particles from inside the coveralls to shed onto the floor. Hoods were developed for clean room operators with long hair, beards and/or moustaches. Kanebo, EV-Guard and Selguard, the first polyester clean room fabrics with carbon yarns to dissipate static electricity, were developed for the semiconductor, microelectronics and aerospace industries.

Workers assemble and test fiber optic systems.
Photo: Steve Jurvetson / Wikimedia Commons / CC- BY-2.0

New drives for notebooks roll off Seagate factory lines
Photo: Robert Scoble / Wikimedia Commons / CC- BY-2.0

AlcatelGowning room with contamination control procedures at Alcatel, London.
Photo: Sam907 / Wikimedia Commons

1980s

In the 1980s, industry leaders and Institution of Environmental Science (IES) members agreed that "cleanroom" should be one word, noting the uniqueness of the filtered, pressurized controlled environments being built throughout the world.

1986: Employee at Sandia National Laboratories is uniformed for work in a cleanroom.
Photo: Sandia National Laboratories

By 1987, the A2C2 Garments and Laundry Committee had been incorporated into the IES. In that same year the committee wrote the tentative recommended practice IES-RP-CC-003-87-T: "Garments Required in Clean Rooms and Controlled Environmental Areas." This document was published in October 1989 as IES-RP-CC-003-89, "Garments Required in Cleanrooms and Controlled Environmental Areas." This recommended practice included the ASTM F-51 test, as well as the Helmke tumble test, particle containment test and extractables test for cleanroom garments. This recommended practice became the basis for the manufacture, cleaning and testing of cleanroom garments. Its 2011 revision, IEST-RP-CC003.4: "Garment Considerations for Cleanrooms and Other Controlled Environments" is still used today.

In the 1980s, W.L. Gore and Associates, Inc., developed Gore-Tex, a laminate that bonds a polytetrafluoroethylene membrane with a pore size of 0.2 µm to a layer of woven polyester and carbon (ESD) yarns. This fabric was used primarily in the semiconductor and microelectronics industries from the 1980s and until the late 1990s.

Medical device and pharmaceutical companies used cleanroom garments constructed of high-density taffeta without any ESD yarns. But garments constructed of this fabric caused tribo-charging, which created static electricity and static discharges. The semiconductor and microelectronics industries used polyester fabric woven with carbon yarns in a grid pattern to better control tribo-charging. As static discharges became more of a problem in the pharmaceutical and medical device industries, they also changed to high-density ESD stripe fabrics.

1990s

During the 1990s, high-density ESD stripe and grid taffeta weave fabrics (C-3 and Maxima ESD) were developed by Burlington Industries. Precision Fabrics Group (PFG) developed high-density ESD stripe and grid taffeta weave fabrics suffused with a durable antimicrobial and Teflon shielding (Integrity 2000 and Integrity 1800). These fabrics had a smaller pore size, durable polyester-carbon ESD yarn and lightweight taffeta weave. Garments manufactured using these new fabrics could also be sterilized by gamma radiation.

1989: Technicians are dressed to work in a unidirectional-flow cleanroom for processing semiconductor wafers. Photo: Sandia National Laboratories

In previous decades, ETO or autoclave steam sterilization had been used to sterilize cleanroom garments. But Tyvek disposable garments sterilized using ETO required a 24 hour out-gassing cycle before delivery to the customer. It became apparent that synthetic cleanroom garments should not be ETO sterilized. Garments sterilized using autoclave steam sterilization immediately became wrinkled and shrank 10–15%. The PFG Integrity 1700 ESD fabric with a twill weave is more common in Europe and the Teijin Seirin ESD fabrics with a twill weave are more common in Asia.

During this decade, 100% polyester nonlinting undergarments or tech suits replaced the 100%-cotton linting scrubs worn under coveralls, hoods and boots in ISO Class 3, 4 and 5 cleanrooms.

DuPont developed its flame-resistant meta-aramid Nomex filament yarns to be used in the fabric and construction of flame-resistant cleanroom garments. Burlington Industries and Stern & Stern began to manufacture flame-resistant cleanroom fabrics using the Nomex filament yarn.

Technicians and scientists in cleanroom garments check out one of the Webb telescope's first two flight mirrors in the clean room at NASA's Goddard Space Flight Center in Greenbelt, Md. Photo: NASA Goddard Space Flight Center

Students in the clean room facility at NMDC in University of Alabama in Huntsville, doing a wet etching experiment that involves level 4 toxic material
Photo: Yorudun / Wikimedia Commons / CC BY-SA 3.0

2000s

In 2003, the Institute of Environmental Sciences and Technology published IEST-RP-CC003.3, "Garment Considerations for Cleanrooms and Other Controlled Environments," which revised and standardized the manufacture, cleaning and testing of cleanroom garments for the twenty-first century. Fabrics noted included high-density ESD reusable fabrics and additional nonwoven fabrics for disposable cleanroom garments, as well as other polyester-based materials used in the manufacture of cleanroom garments such as sewing thread, zippers and boot straps.

The document noted that because the use of silicone in the manufacture of cleanroom garments may cause airborne molecular contamination, its use was not recommended. A round-robin testing program using the same 10 cleanroom garments was performed by three laboratories and three cleanroom laundries using the revised Helmke tumble apparatus and procedure to determine limits for garment cleanliness at both 0.5 µm and 0.3 µm. The precision laundering and packaging of cleanroom garments was detailed and standardized. Quality management systems were recommended. By 2000, the major cleanroom garment laundries were ISO 9001 registered.

2010–present

The McIlvaine Marketing Research Company estimates that over 14 million people worked in cleanrooms throughout the world in 2015. That number can only increase: With continuous innovations in nanotechnology; three-dimensional printing; novel biologicals, pharmaceuticals and medical devices; the development of smaller, more powerful computers in the semiconductor and microelectronics industries; as well as ongoing work in the food industries, industry will continue to need cleanroom operators and cleanroom garments.

Scientists wear cleanroom suits at the at the Netherlands Organisation for Applied Scientific Research Van Leeuwenhoek Laboratory in Delft. Photo: ESO / TNO / Fred Kamphues / Wikimedia Commons / CC BY 3.0

As I researched information for this article, I was amazed at the detail of recommendations for cleanroom

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garments in 1969 and the actual practices of cleanroom garment end users, manufacturers and laundries since the 1980s. Thanks to developments like those chronicled here, when current cleanroom garments are donned, worn and doffed correctly, there is reduced human-sourced contamination and increased control of the cleanroom environment. ■

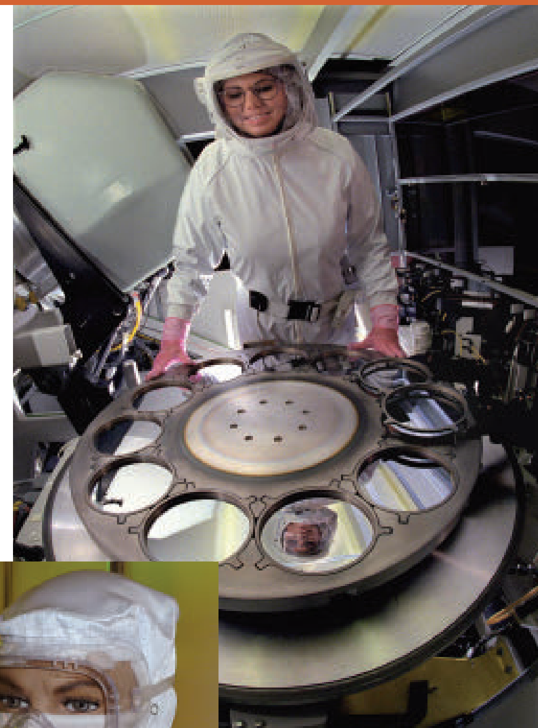

Photo: Sandia National Laboratories

Typical cleanroom head garment
Photo: RudolfSimon - Own work, CC BY-SA 3.0, via Wikimedia Commons

About the author

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