~~Designation:E2217–02(Reapproved2007)~~ Designation: E2217 – 12

Standard Practice for Design and Construction of Aerospace Cleanrooms and Contamination Controlled Areas[1]

This standard is issued under the fixed designation E2217; 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 The purpose of this practice is to provide design and construction guidelines for contamination controlled facilities used in the assembly and integration of aerospace hardware. The guidelines herein are intended to ensure that the facilities, when used properly, will meet the cleanliness requirements of aerospace hardware and processes. The objective is to limit contamination due to the deposition of particulate and molecular contaminants on flight hardware surfaces.

1.2 One cleanliness classification of a facility is the airborne particle concentrations in accordance with ISO 14644-1 and 14644-2. Airborne particle concentrations in accordance with FED-STD-209E are included for reference. This simple classification is inadequate to describe a facility that will support the assembly and integration of spacecraft. The extended duration of hardware exposure during fabrication and testing, the sensitivity of the hardware to hydrocarbons and other molecular contaminants, and the changing requirements during assembly and integration must be considered in addition to the airborne particle concentrations.

1.3 The guidelines specified herein are intended to provide facilities that will effectively restrict contaminants from entering the facility, limit contamination generated by and within the facility, and continuously remove airborne contaminants generated during normal operations. Some items of support hardware, such as lifting equipment, stands, and shoe cleaners, are addressed since these items are often purchased and installed with the facility and may require accommodation in the design of the facility.

1.4 Active filtration of molecular contaminants (such as hydrocarbons, silicones, and other chemicals) is discussed. Such active filtration of molecular contaminants may be required for the processing of highly sensitive optical devices, especially infrared and cryogenic sensors. Control of microbiological contamination is not included although HEPA (High Efficiency Particulate Air) filtration will provide some control of airborne bacteria, spores, and other viable contaminants that are typically carried on particles of sizes 0.3 μm and larger. Control of radioactive contamination and accommodation of very hazardous materials such as propellants, strong acids or caustics, or carcinogens are not addressed.

1.5 No facility will compensate for excessive contamination generated inside the facility. In addition to an effective facility design, the user must also institute a routine maintenance program (see Practice E2042) for the facility, and personnel and operational disciplines that limit the transfer of contaminants through entry doors and contaminant generation inside the facility.

1.6 This practice only addresses guidelines for contamination control in facility design. It must be implemented in compliance with all mandatory government and regulatory building and safety codes. References to related cleanroom standards and U.S. building codes and standards may be found in IEST-RP-CC012.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7.1 The values given in parentheses are provided for information only and are not considered standard.

1.8 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E595 Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment

E1216 Practice for Sampling for Particulate Contamination by Tape Lift

[1] This practice 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.

Current edition approved April 1, ~~2007.~~2012. Published ~~April 2007.~~May 2012. Originally approved in 2002. Last previous edition approved in ~~2002~~2007 as E2217 - 02 (2007). DOI: ~~10.1520/E2217-02R07.~~10.1520/E2217-12.

[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.

E1234 Practice for Handling, Transporting, and Installing Nonvolatile Residue (NVR) Sample Plates Used in Environmentally Controlled Areas for Spacecraft
E1235 Test Method for Gravimetric Determination of Nonvolatile Residue (NVR) in Environmentally Controlled Areas for Spacecraft
E1548 Practice for Preparation of Aerospace Contamination Control Plans
E2042 Practice for Cleaning and Maintaining Controlled Areas and Clean Rooms
E2088 Practice for Selecting, Preparing, Exposing, and Analyzing Witness Surfaces for Measuring Particle Deposition in Cleanrooms and Associated Controlled Environments
F24 Test Method for Measuring and Counting Particulate Contamination on Surfaces
F25 Test Method for Sizing and Counting Airborne Particulate Contamination in Cleanrooms and Other Dust-Controlled Areas
F50 Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas and Clean Rooms Using Instruments Capable of Detecting Single Sub-Micrometre and Larger Particles

2.2 *ISO Standards:*[3]

ISO 14644-1 Cleanrooms and Associated Controlled Environments Part 1: Classification of Air Cleanliness
ISO 14644-2 Cleanrooms and Associated Controlled Environments Part 2: Specifications for Testing and Monitoring to ~~Provide~~Prove Continued Compliance with ISO 14644-1
ISO 14644-3 Cleanrooms and Associated Controlled Environments Part 3: ~~Metrology and~~ Test Methods
ISO 14644-4 Cleanrooms and Associated Controlled Environments Part 4: Design, Construction and Start-up

2.3 *Institute of Environmental Science and Technology Standards:*

IEST-RP-CC001 HEPA and ULPA Filters[4]
IEST-RP-CC006 Testing Cleanrooms[4]
IEST-RP-CC007 Testing ULPA Filters[4]
IEST-RP-CC012 Considerations in Cleanroom Design[4]
IEST-RP-CC022 Electrostatic Charge in Cleanrooms and Other Controlled Environments[4]
IEST-RP-CC034 HEPA and ULPA Filter Leak Tests[4]
IEST-STD-CC1246 Product Cleanliness Levels and Contamination Control Program[5]

2.4 *U.S Government Standards:*

FED-STD-209E Airborne Particulate Cleanliness Classes ~~for~~in Cleanrooms and Clean Zones[6]

2.5 *Other Publications:*

Procedural Standards for Certified Testing of Cleanrooms, National Environmental Balancing Bureau (NEBB)[7]

3. Terminology

3.1 *Definitions:*

3.1.1 *aerosol, n*—a gaseous suspension of fine solid or liquid particles.

3.1.2 *airfilters:*

3.1.2.1 *HEPA (High Efficiency Particulate Air) filter, n*—a particulate air filter having a minimum particle collection efficiency of 99.97 % of particles greater than 0.3 µm in accordance with IEST-RP-CC001.

3.1.2.2 *ULPA (Ultra Low Penetration Air) filter, n*—a particulate air filter having a minimum particle collection efficiency of 99.999 % of particles of sizes equal to and larger than 0.12 µm.

3.1.2.3 *prefilters, n*—air filters that are installed upstream of the HEPA or ULPA filters.

3.1.2.4 *Discussion*—These usually consist of rough filters and medium efficiency filters that remove larger particles than are removed by the HEPA and ULPA filters; They are used to reduce the number of particles trapped on the high efficiency filters, thereby extending the lifetimes of the HEPA and ULPA filters.

3.1.3 *airflow:*

3.1.3.1 *unidirectional airflow, n*—controlled airflow through the entire cross-section of a cleanroom or clean zone with a steady velocity and approximately equal streamlines.

3.1.3.2 *Discussion*—The airflow in a cleanroom may be either vertical down-flow or horizontal with air leaving the room either through nearly continuous floor or wall vents. Equipment and personnel in the room will cause air turbulence, but the airflow is still considered unidirectional.

~~[3] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.~~
[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, CP 56, CH-1211 Geneva 20, Switzerland, http://www.iso.org.
~~[4] Available from the Institute of Environmental Sciences and Technology, 940 East Northwest Highway, Mount Prospect, IL 60056.~~
[4] Available from Institute of Environmental Sciences and Technology (IEST), Arlington Place One, 2340 S. Arlington Heights Rd., Suite 100, Arlington Heights, IL 60005-4516, http://www.iest.org.
[5] This replaces MIL-STD-1246C which is inactive.
[6] This standard was cancelled 29 Nov. 2001 and is replaced by ISO 14644-1 and ISO 14644-2. Copies of FED-STD-209E are available from the Institute of Environmental Sciences and Technology, 940 East Northwest Highway, Mount Prospect, IL 60036, and from U.S. government sources.
[7] National Environmental Balancing Bureau, 8575 Grovemont Circle, Gaithersburg, MD 20877-4121. http://www.nebb.org/contact/.

3.1.3.3 *nonunidirectional airflow, n*—air distribution where the supply air entering the cleanroom or clean zone mixes with the internal air by means of induction.

3.1.3.4 *Discussion*—Air typically enters through registers distributed around the room above the working area and exits through registers at floor level.

3.1.3.5 *mixed airflow, n*—air distribution in a cleanroom or clean zone in which the airflow is a mixture of both unidirectional and nonunidirectional.

3.1.3.6 *Discussion*—Different locations in a cleanroom can have different types of airflow. This is especially true in large cleanrooms. A cleanroom design may include mixed airflow.

3.1.4 *changing room*, *n*—room where people using a cleanroom change into, or out of, cleanroom apparel.

3.1.5 *cleanroom*, *n*—a specialized enclosed room employing control over the airborne particle concentrations, temperature, humidity, pressure, molecular contaminants, and operations.

3.1.5.1 *cleanroom (alternate), n*—a room in which the concentration of airborne particles, temperature, humidity, pressure, molecular contaminants, and operations are controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of contaminants inside the room.

3.1.6 *cleanroom occupancy states:*

3.1.6.1 *as-built, adj*—condition where the installation is complete with all services connected and functioning but with no equipment, flight hardware and materials, or personnel present.

3.1.6.2 *Discussion*—For contractual purposes, the parties involved should have an agreement that defines this state.

3.1.6.3 *at-rest, adj*—condition where the installation is complete with equipment installed and operating in a manner agreed upon by the customer and supplier, but with no personnel present.

3.1.6.4 *operational, adj*—condition where the installation is functioning in the specified manner, with the specified number of personnel present and working in the agreed upon manner.

3.1.7 *clean zone*, *n*—dedicated space in which the concentration of airborne particles is controlled, which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the zone, and in which other relevant parameters, for example, temperature, humidity, pressure, and molecular contaminants, are controlled as necessary.

3.1.8 *contaminant*, *n*—any particulate, molecular, non-particulate, and biological entity that can adversely affect the product or process.

3.1.9 *contaminant deposition*, *n*—particulate and molecular contaminants that form on surfaces resulting from processes such as fallout, condensation, electrostatic attraction, and other mechanisms.

3.1.10 *contamination controlled area*, *n*—a specialized enclosed facility employing control over the particulate matter in air, temperature, and humidity that may not meet the requirements of ISO 14644-1 or FED-STD-209E because of no HEPA or ULPA type filters.

3.1.10.1 *Discussion*—For example, without a final stage of HEPA or ULPA filters, the airborne particle concentrations may only meet ISO Class 8.5 (FS209E Class 300 000) for particles equal to and greater than 0.3 μm but may meet ISO Class 8 (FS209E Class 100 000) for particles equal to and greater than 5 μm.

3.1.11 *electrostatic discharge (ESD)*, *n*—the rapid, spontaneous transfer of electrostatic charge induced by a high electrostatic field.

3.1.11.1 *Discussion*—Usually, the charge flows through a spark between two bodies at different electrostatic potentials as they approach one another.

3.1.12 *electromagnetic interference (EMI)*, *n*—interference, generally at radio frequencies, that is generated inside systems, as contrasted to radio-frequency interference coming from sources outside a system.

3.1.13 *facility (clean facility)*, *n*—the total real property required to accomplish the cleanroom functions.

3.1.13.1 *Discussion*—This includes all the buildings, cleanrooms, offices, laboratories, storage areas, HVAC equipment, and other support areas for operations and personnel.

3.1.14 *gas phase adsorber cell*, *n*—a modular container for an adsorbent to trap contaminant gases from air and other gases used in processing.

3.1.15 *installation*, *n*—cleanroom or one or more clean zones, together with all associated structures, air-treatment systems, services, and utilities.

3.1.16 *macroparticle*, *n*—a particle with an equivalent diameter greater than 5 μm.

3.1.16.1 *Discussion*—The M descriptor defines the measured or specified concentrations of macroparticles per cubic meter of air. This is defined in ISO 14644-1.

3.1.17 *monitoring*, *n*—observations made by measurement in accordance with a defined method and plan to provide evidence of the performance of an installation.

3.1.18 *nonvolatile residue (NVR)*, *n*—contaminant residue without distinct dimensions. It typically consists of hydrocarbons, silicones, and other higher molecular weight species deposited through condensation, direct contact transmission (that is, fingerprints) or as residue remaining after evaporation of a liquid.

3.1.19 *outgassing*, *n*—the evolution of gas from a material, usually in a vacuum. Outgassing also occurs in a higher pressure environment.

3.1.19.1 *Discussion*—While outgassing is typically considered a vacuum phenomenon, some materials, such as polyvinyl chloride, contain volatile components, such as plasticizers, that will diffuse from bulk materials and evaporate under standard temperatures and pressures. These volatile components are highly contaminating to sensitive aerospace hardware.

3.1.20 *particle fallout*, *n*—particulate matter that accumulates on surfaces due to gravity settling. This matter is often of a particulate size larger than that measured by airborne particle counters.

3.1.21 *radio-frequency interference (RFI)*, *n*—interference from sources of energy outside a system or systems, as contrasted from electromagnetic interference generated inside systems.

3.1.22 *test aerosol*, *n*—a gaseous suspension of solid or liquid particles, or both, with known and controlled size distribution and concentration.

4. Significance and Use

4.1 This practice describes and defines factors to be taken into consideration when designing and fabricating a cleanroom or controlled area that is used for aerospace operations and fabrication. Following the suggestions herein should provide a facility that is more capable of meeting performance requirements and that will offer protection against contamination for objects fabricated and processed in such a facility.

5. Planning and Development of Performance and Design Requirements

5.1 *Purpose of a Cleanroom*—A cleanroom provides three functions for a process:

5.1.1 Clean air with temperature and humidity control,

5.1.2 Control of contaminants generated within the room, and

5.1.3 Control of the transfer of contaminants from outside the room.

5.2 *Planning*—The first step is to determine the types of operations to be performed in the cleanroom and cleanliness requirements of the hardware to be processed. Alternative designs are studied and preliminary requirements are developed during the planning phase.

5.3 *Performance and Design Requirements*:

5.3.1 The cognizant program materials and processes engineer or contamination control engineer and facility engineer determine the requirements for a cleanroom or contamination-controlled area. These requirements may include, but are not limited to the following:

5.3.1.1 Maximum allowable airborne particle concentrations in the operational condition,

5.3.1.2 Types of airflow,

5.3.1.3 Room air change rates or air velocities,

5.3.1.4 Maximum allowable particle deposition,

5.3.1.5 Maximum allowable airborne and surface concentrations of molecular contaminants,

5.3.1.6 Types of air filters,

5.3.1.7 Need for and properties of piped in fluids (compressed air, nitrogen, helium, water, and so forth),

5.3.1.8 Need for built-in equipment (cranes, platforms, hoists, and so forth),

5.3.1.9 Overall layout and process flow,

5.3.1.10 EMI and RFI requirements, and

5.3.1.11 ESD requirements.

5.3.2 The cleanroom and clean facility requirements are based on the cleanliness requirements of the hardware to be processed and the types of operations to be performed in the cleanroom. The requirements should consider, as much as possible, future changes in requirements so that the facility does not become obsolete in a short time. Some enhancements do not result in a significant increase in cost if implemented in the original design. Another approach is designing to allow enhancements to be added later if required.

5.3.3 A contamination sensitivity analysis may be performed and contaminant allocations derived to determine facility cleanliness requirements during each phase of assembly and integration. Further information on determining cleanliness requirements is found in Practice E1548.

5.3.4 Cost analyses are necessary to evaluate the alternative design approaches.

6. General Design Practice

6.1 *Design Considerations*:

6.1.1 The purpose of a cleanroom is to protect the hardware and processes. Ideally, the cleanroom should be designed around the processes and operations to be performed in the cleanroom. However, a typical situation involves designing a multipurpose cleanroom. Each space system is unique and may have different requirements. Consideration should be given to including multiple requirements in the design. This can be accomplished in the initial construction or by allowing for the inclusion of additional performance in the future when needed. Cost-benefit analyses should be used to evaluate alternative designs.

6.1.2 Spacecraft assembly and integration are usually considered batch processes. Operations are performed sequentially on each spacecraft, and different operations may have different cleanliness requirements. Design of the clean facility should consider these different operations and requirements.

6.2 ISO 14644-4 and IEST-RP-CC012 provide guidelines for the design and construction of cleanrooms. The cognizant contamination control and facility engineers should do detailed design and operational analyses to select the design that meets the spacecraft processing requirements.

6.3 *Clean Zones*:

6.3.1 Under some circumstances, cleanliness requirements can be achieved using inexpensive localized controls such as soft wall enclosures (clean tents) and portable hard-walled enclosures. These can provide either unidirectional or nonunidirectional, filtered airflow. They must be located within a facility that provides the necessary temperature, humidity and molecular contaminant controls required to support the requirements for the hardware unless they have their own HVAC system. When required, self-contained temperature and humidity control can be provided.

6.3.2 Air curtains and other methods of controlling air distribution can be used to protect clean zones from airborne contaminants.

6.3.3 Operations and procedures can be controlled to reduce contamination from people and activities in the specified clean zone.

6.4 *Hazards*:

6.4.1 Cleanroom facility design should consider potential hazards to personnel and products. Risk-cost-benefit analyses should be performed to determine the design features that are required to achieve acceptable risks. Operational solutions to meeting the risk requirements should be considered in coordination with design solutions.

6.4.2 Equipment failures and human errors can result in damage to hardware and injuries to personnel. It is important to consider single point failure modes, equipment and human, and their possible effects on products, processes, and personnel. Designing so that two or more failures are required to result in a system failure reduce the probability for a system failure.

6.4.3 *Electrical Power*—Electrical power failures will shut down equipment, instrumentation, and lighting. Critical items should have an alternative source of power. The switch from the main power source to the alternative power source may result in a short time of power interruption and transient effects. Equipment and processes should be able to survive these effects. Equipment that is not critical should automatically shut down in a safe mode. Restart when power resumes should not damage equipment or processes. Manual restart should be considered to ensure that the equipment is operating properly.

6.4.4 *Cooling Water*—Cooling water failure can shut down many types of equipment. Equipment should be able to shut down safely without damage to the equipment or to the process.

6.4.5 *HVAC*—The shut down of the HVAC system or failures of components such as filters, fans, and air conditioning should be evaluated for effects on hardware and processes. Both facility design and operational procedure solutions should be considered.

6.4.6 *Seismic and Weather Events*—Severe natural events, such as earthquakes and hurricanes, should be considered in the design of clean facilities. The probability of occurrences and severities should be considered. Design should consider various levels of severity. One level is the ability for the hardware and processes to survive with no damage or down time. The next level is the ability for the facility to survive, but some damage to hardware and processes is allowed. The third level is that damage to hardware, processes, and facility structure is allowed, but personnel are protected.

7. Detail Design Guidelines

7.1 *Airflow and Pressure*:

7.1.1 *Airflow Parameters*—The airflow patterns and velocities and room air change rates in a cleanroom affects the class of cleanliness that can be maintained during a given operation. Non-unidirectional flow cleanrooms rely on air dilution to continuously remove contaminants generated within the room. Unidirectional flow is more effective in continuously sweeping particles from the air, but must be properly balanced and maintained with associated higher airflows and thus higher operating costs.

7.1.1.1 *Air Change Rate*—The desired air change rate is based on the required cleanliness class of the room air under operational conditions and the generation of contaminants (density of operations) expected in the room. The level and types of activities in the room affect the numbers of particles generated. Five to twenty air changes per hour are typical for a large, low density nonunidirectional airflow cleanroom. The lower the class of air for operational conditions, the greater the number of air changes is required to remove sufficient particles to meet requirements. In unidirectional flow cleanrooms, the air change rate is a result of the required filter face velocity and the size of the room. The design may allow for variable air change rates. This can be used to reduce electrical power consumption when the process does not require the high air change rates or when the cleanroom is not being used.

7.1.1.2 *Filter Face Velocity*—Filter face velocity is specified in unidirectional flow cleanrooms. Typical filter face velocities are 0.46 to 0.56 m/s (90 to 110 ft/min). Lower face velocities may not be effective in removing airborne particles but may reduce air turbulence. Higher face velocities may stress the filters and cause excessive air turbulence.

7.1.1.3 *Unidirectional Flow*—Filter face velocities must be balanced to within ±10 % to achieve effective, uniform, unidirectional airflow. The configuration of the room and the location of large equipment must also be carefully considered to prevent dead zones, turbulence, and reverse flow. A "smoke test," in which a cleanroom compatible white vapor is released from a capsule or a smoke generator to indicate air currents, may be useful to reveal problem areas. Water droplets have been used to avoid permanent contamination from solid and liquid aerosols. Strips of thin metallized films may also be used to determine the directions of flowing air.

7.1.2 *Positive Pressure*:

7.1.2.1 A positive pressure must be maintained over the pressure in adjacent areas of lesser cleanliness to prevent infiltration of external contamination through leaks and during the opening and closing of personnel doors. Pressure differentials in the range of 5 to 20 Pa (0.02 to 0.08 in. of water) are frequently used. Where several cleanrooms of varying levels of cleanliness are joined as one complex, a positive pressure hierarchy of cleanliness levels should be maintained, including airlocks and changing rooms.

7.1.2.2 Higher pressures may be required when outside air pressures exceed inside pressures and result in an increased leakage into the cleanroom. An example is higher pressures resulting from high winds.

7.1.2.3 When hazardous materials, such as propellants and some biological materials, are being processed, it is necessary to maintain the room at a lower pressure than surrounding rooms. This is necessary to reduce the probability of the hazardous material escaping from the room. The design of facilities for the handling of hazardous materials must consider the required operations to be performed as well as the type of hazards involved.

7.2 *Materials of Construction*:

7.2.1 *General Materials Selection*—Cleanrooms must be constructed of abrasion resistant, non-shedding materials. Conventional materials of construction such as wood, carpet, flat latex paint, and acoustic tile shed particles continuously during their life and are not acceptable for use in cleanrooms.

NOTE 1—Materials and equipment specified for use in cleanrooms are sometimes described as compatible with or meeting the requirements of a particular class of cleanroom air per ISO 14644-1 or FED-STD-209. These documents only apply to concentrations of airborne particles and do not contain any requirements for materials and equipment.

7.2.2 *Outgassing*—Outgassing from materials is a potential contaminant for spacecraft. Materials of construction should be selected to minimize outgassing and VCM at the expected operating temperatures in the cleanroom. Additional requirements may be added if the spacecraft contains components that have specific, known sensitivities. Materials maybe selected based on the Test Method E595 screening test, and existing databases for spacecraft materials may be used. However, some materials suitable for use at normal cleanroom temperatures will decompose when subjected to the 125°C test temperature. Performing the Test Method E595 test at a lower temperature, such as 65°C, has been successful for the screening of cleanroom materials.

7.2.3 *Cleaning*—Due to the frequent cleaning performed on cleanroom surfaces, materials that are hydrophilic or degrade in water are generally unacceptable.

7.2.4 *Textured Surfaces*—All materials shall have a smooth, cleanable finish. Textured surfaces should be limited to those required for safety reasons (such as floors). Textures used must be compatible with planned cleaning methods.

7.2.5 *Preferred Materials*—Uncoated materials recommended for use in cleanrooms include stainless steels, Formica, fluoropolymers, polypropylene, polyester, and anodized aluminum. Bare polished or brushed aluminum may be acceptable provided it is protected from exposure to relative humidities above 60 %. Properly anodized aluminum is recommended to control corrosion and reduce particle generation.

7.2.6 *Electrostatic Discharge (ESD)*—Many of the non-metallic materials suitable for use in a cleanroom will also generate an electrostatic charge. Precautions must be taken in facility design and operations to prevent damage to ESD sensitive equipment from facility materials of construction.

7.2.7 *Excluded Materials*—Materials that are unacceptable for use in cleanrooms include wood, cork, carpet, fabric curtains, exposed gypsum board, exposed plaster, and acoustic tile. Steel and other non-corrosion resistant metals must be painted or treated to prevent corrosion. Zinc and cadmium treated steels are not recommended for use in spacecraft cleanrooms since particles released from these materials are unstable in a vacuum. Cadmium is toxic and is being removed from use per federal mandate.

NOTE 2—Fabrics impregnated with low outgassing, cleanable polymers, such as fluorocarbons, are acceptable in cleanrooms. These are frequently used as movable walls and other enclosures.

7.3 *Materials Application*:

7.3.1 *Surface Preparation*—Proper surface preparation prior to the application of a paint or coating in a cleanroom is critical to the success of the application. The manufacturer's instructions must be followed precisely, including all precleaning and surface texturing. For applications such as troweled epoxy flooring, only experienced and qualified contractors should be used.

7.3.2 *Corrosion Protection*—All cleanroom materials and equipment must be protected from corrosion prior to and during installation. At no time should cleanroom interior material, equipment, ducts, or HVAC system components be stored outdoors without proper protection.

7.4 *Enclosure*:

7.4.1 *Floors*—All cleanroom floors must, as a minimum, provide a complete air seal and vapor barrier. Cleanrooms built over non-humidity-controlled basements, as well as those on exposed or slab foundation, must protect the floor treatment or paint from moisture permeation.

7.4.1.1 *Floor Finishes*—The preferred floor finish for aerospace cleanrooms is a troweled epoxy. A primer must be used to ensure proper adhesion to the base material. Melamine laminate, including melamine laminate computer flooring, is also acceptable. These materials are also available with static-dissipative additives. Vinyl flooring may be unacceptable in some aerospace cleanrooms due to the presence of plasticizers. Compatibility with solvents and chemicals to be used in the room must be considered.

7.4.1.2 *Coving*—A coving or fillet seal should be used between the floor and the wall. A radius of 25 mm (1 in.) or greater is