X-624-67-578

NASA-TM-x-63451

ENGINEERING GUIDELINES FOR CLEAN ASSEMBLY AND STERILIZATION OF SPACEFLIGHT HARDWARE

Anne-Marie Crawford
Edward Rich
Laboratory for Atmospheric and Biological Sciences

November 1967

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

Page intentionally left blank

CONTENTS

ILLUSTRATIONS

TABLES

ENGINEERING GUIDELINES FOR CLEAN ASSEMBLY AND STERILIZATION OF SPACEFLIGHT HARDWARE

INTRODUCTION

The engineer who is designing and qualifying scientific experiments for planetary programs encounters several new and perhaps unfamiliar requirements: among these are the subjection of hardware to high temperatures and gaseous atmospheres, to eliminate living organisms; assembling and testing parts in a biologically clean environment, to maintain cleanliness; and finally, remote testing of a terminally sterilized experiment which has been packaged to preserve sterility.

Engineering personnel in this field must work closely with laboratory microbiologists, biologists, and chemists. The engineer's goal is to produce the ultimate in reliability, while the microbiologist attempts to discover and destroy every living microbe on or in the electronic and mechanical assemblies. NASA policy and international mandate require sterilization; at the same time, NASA and GSFC require the highest possible reliability.

Solving the problems involved in assembling a flight system that is both sterile and reliable requires good communications between the engineering personnel and the biological team. Only with mutual understanding between the two groups can a project be successfully completed.

PLANETARY QUARANTINE POLICY

Agreement has been reached on both international and national levels to treat the planets as biological preserves--that is, to prevent contamination of the planets and their atmospheres by viable organisms from the earth. The policy governs both landers and those orbiters with a probability greater than 1×10^{-3} of impacting the planet.[1]

The procedures established for this purpose by NASA (which appear in NASA Standard Procedures for the Microbiological Examination of Space Hardware, NHB,5340.1, August 1967) include the following steps:

1. The spacecraft will be assembled in laminar-flow Class 100 clean rooms.

2. The assembly will undergo frequent microbiological assays and approved sterilization cycles.

3. The sterilized assembly will be packaged in either a flexible or a rigid bacteriological barrier "bio-cannister" to maintain sterility. The container will not be opened until the spacecraft has left the earth's atmosphere and no recontamination is possible.

The sterilization process results in a certification of probability of sterility. This means simply that, when the spacecraft lands or impacts a planet, the chances of its carrying a single bacterium to contaminate the planet is no greater than 1×10^{-3}.[1]

STERILIZATION TECHNOLOGY

Of the many techniques for sterilizing and decontaminating materials, one method may be used where another is not applicable or desirable. However, although some techniques are valid in many fields, only one has been accepted by NASA for use on planetary flight hardware. Table 1 is a short description of these various methods.

APPROVED STERILIZATION CYCLES

Dry heat is the only sterilization method accepted by NASA for terminal sterilization of interplanetary spacecraft: dry heat alone penetrates to the interiors of solid bodies, and the application can be monitored easily and with a high degree of reliability.[2]

Table 2 lists the time-temperature relationships that have been approved for sterilization. The actual time and temperature to be used on any program will be determined and made a requirement by the specific planetary project office.

DECONTAMINATION

In addition to the use of dry heat for sterilization, heat and certain vapors can be used for surface decontamination. These cycles merely reduce the bacterial population without complete sterilization. For higher assurances of sterility and engineering reliability, decontamination is performed periodically throughout the assembly of spacecraft parts and before terminal sterilization.

Table 1

Sterilization Techniques[3]

Agent				Considerations for Use
Physical	Heat	Moist		Internal action only if material is pervious to steam; otherwise effect is essentially that of dry heat
		Dry*		Penetrates
	Radiation	Electromagnetic	Ultraviolet	Limited to surface only; distance from source and time important
			X-Ray	Capable of penetration; requires time
			Gamma ray	Good penetration; dosage and time variable
		Particle	Cathode ray	Artificially accelerated electrons, short times, penetration less than that of X-ray
			Neutrons	Uncharged atomic particles produce artificial activity in material; cannot be used for sterilization
			Alpha Particles	Limited by penetration into matter surface
Chemical	Gaseous or vapor			Limited by penetration into matter surface
	Liquid			Surfaces only
Combinations				Several combinations are possible, e.g., radiation and heat, chemicals and heat; the relative effects are additive.

*Dry heat is the only NASA-approved sterilization method.

Table 2

Sterilization Time-Temperature Relationships[3]

Temperature (°C)	Sterilization Time (hr)	D Value (hr)
160	3	0.21
155	4	0.31
150	6	0.46
145	9	0.73
140	14	1.1
135	22	1.8
130	34	2.8
125	53	4.4
120	84	7.0
115	132	11.0
110	210	17.5
105	336	28.0

The approved decontamination cycles are as follows:

Approved Cycles for Decontamination with Dry Heat

Temperature (°C)	Time (hr)
145	0.25
135	0.8
130	1.5
120	4
110	12
100	34
90	100
80	280

Use of Ethylene Oxide Gas for Decontamination of Surfaces[3]

Concentration: Not less than 300 mg of ethylene oxide per liter of space in the enclosure

Exposure Time: Minimum 4 hours

Exposure Temperature: Not less than 70°F

Additional Constraints for Use:

a. Before ETO treatment, surfaces shall be exposed to more than 35 percent RH for 72 hours or longer.

b. Proof that decontamination has been achieved shall be obtained in each case by pre- and post-treatment culturing of representative parts from the group treated.

Limitation: ETO shall not be used for internal decontamination and/or terminal sterilization.

Agent	Concentration/Condition
Formaldehyde with steam (closed areas)	One milliliter per cubic foot of air; relative humidity above 80 percent for one hour
Ethylene oxide gas	300 milligrams per liter for 8 to 16 hours
Beta-propiolactone (closed areas)	300 milligrams per cubic foot of air; relative humidity above 75 percent for 30 minutes
Peracetic acid (closed areas)	3 to 3-1/2 percent solution with a small amount (0.1 percent) of detergent

A TYPICAL SEQUENCE OF OPERATIONS FOR THE CLEAN ASSEMBLY AND STERILIZATION OF GSFC SPACECRAFT EXPERIMENTS

The Clean Assembly and Sterilization Laboratory (CASL) in Building 18 at Goddard Space Flight Center will be responsible for the

sterilization of GSFC experiments. Spaceflight hardware delivered to the CASL as subassemblies will undergo the following sequence of operations:

a. Delivery of flight hardware; units will be logged in.

b. Each unit will be assayed for microbial burden. This is the first assay in establishing a profile of the contamination.

c. All units will undergo an electrical test; this is the first step in establishing a profile of subsystem reliability.

d. Units will be stored until needed; during the storage time, they will undergo periodic electrical tests.

e. Microbial assay just before cleaning

f. Chemical cleaning, wet and dry vacuum cleaning, and ultrasonic washing will be done as applicable on the units.

g. Assay for microbial load after cleanup

h. Electrical test of cleaned units

i. Units are sterilized with dry heat in the clean-room sterilizer passthrough.

j. In the clean room, units are removed from the sterilizer after the cycle is complete.

k. Once inside the clean room, the parts and structures will again be assayed for microbiological loading.

l. The subassemblies will be integrated into the spacecraft structures.

m. Periodically during integration, the pieces will be microbiologically assayed.

n. The clean assembly will be sealed in a plastic barrier.

o. The sealed assembly will be passed through the sterilizer and sent to Test and Evaluation (T & E).

p. All T&E testing will be performed.

q. Assembly will be returned to the clean room after testing.

r. A mechanical and electrical evaluation will be performed on the assembly. (Testing in clean room is done remotely.)

s. Final electrical presterilization test

t. Terminal sterilization of experiment in bio-cannister; surface sterilized with ETO or dry heat

u. Umbilical electrical checkout before shipment

v. Shipment to spacecraft integration contractor

A sterility model (to be furnished 6 months before delivery of the first flight model) will be full-scale when integrated, but it can be non-operative. Parts of this model will be destroyed during testing, but it will be used to evaluate the minimum dry-heat and ethylene-oxide cycles required to produce a sterile assembly, and to ensure maximum reliability and sterility in the flight model with a minimum of stress. Occluded and surface microbial counts will be made to determine the probability of sterility.

Figure 1 is a diagram of the work flow.

THE CLEAN ASSEMBLY AND STERILIZATION LABORATORY

The CASL consists of five work areas: the preparation area, the bio-clean room, and the isolation development area (which handle the clean assembly and integration of the spacecraft), and the personnel cleanup area and the bio-monitoring laboratory (which support the CASL personnel and the research activities). Intercommunication is provided between all areas of the CASL.

The capabilities of each area are described below in terms of space and utilities provided for the experiment engineer.

Figure 2 shows the layout of the clean assembly and sterilization laboratory.

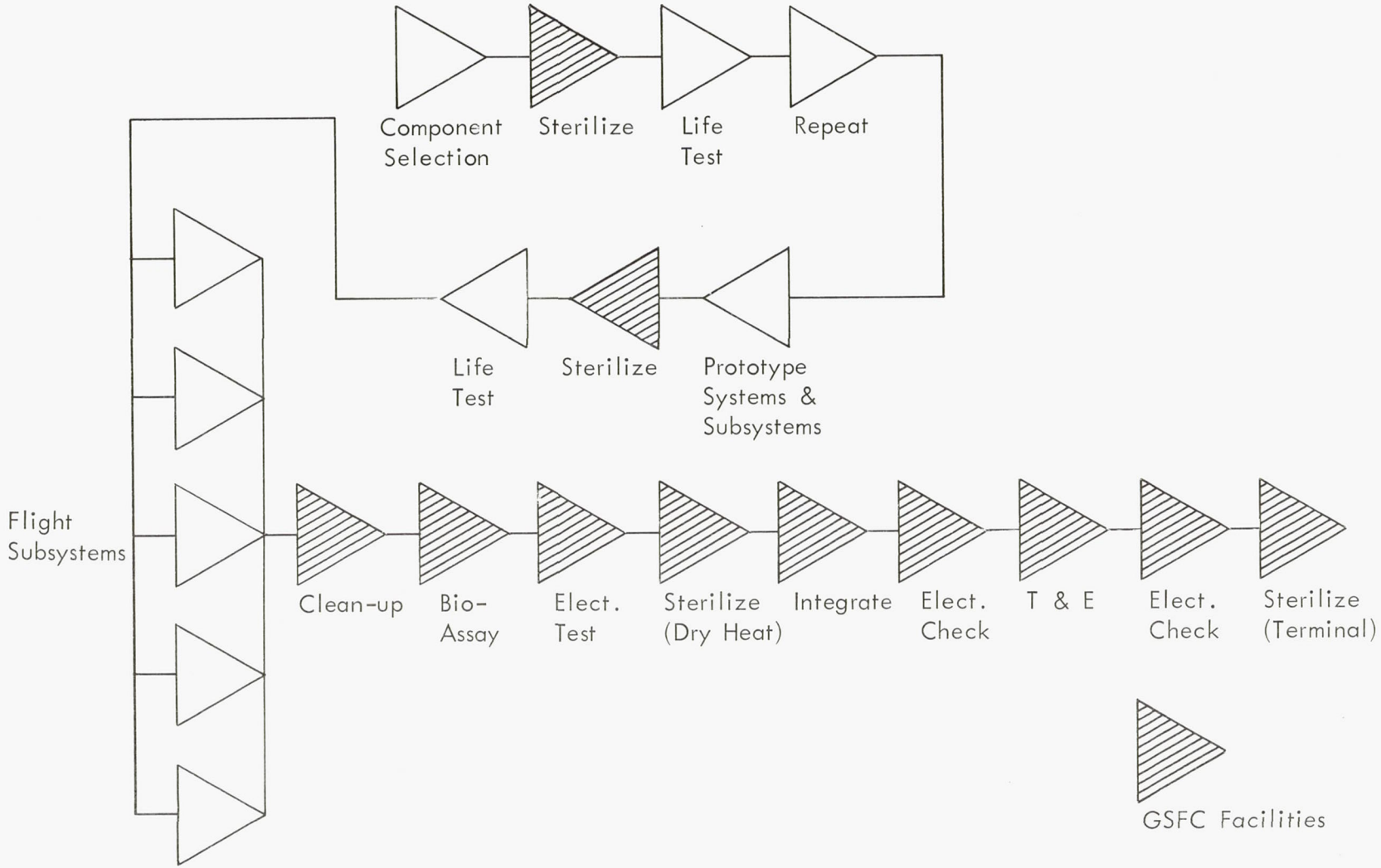
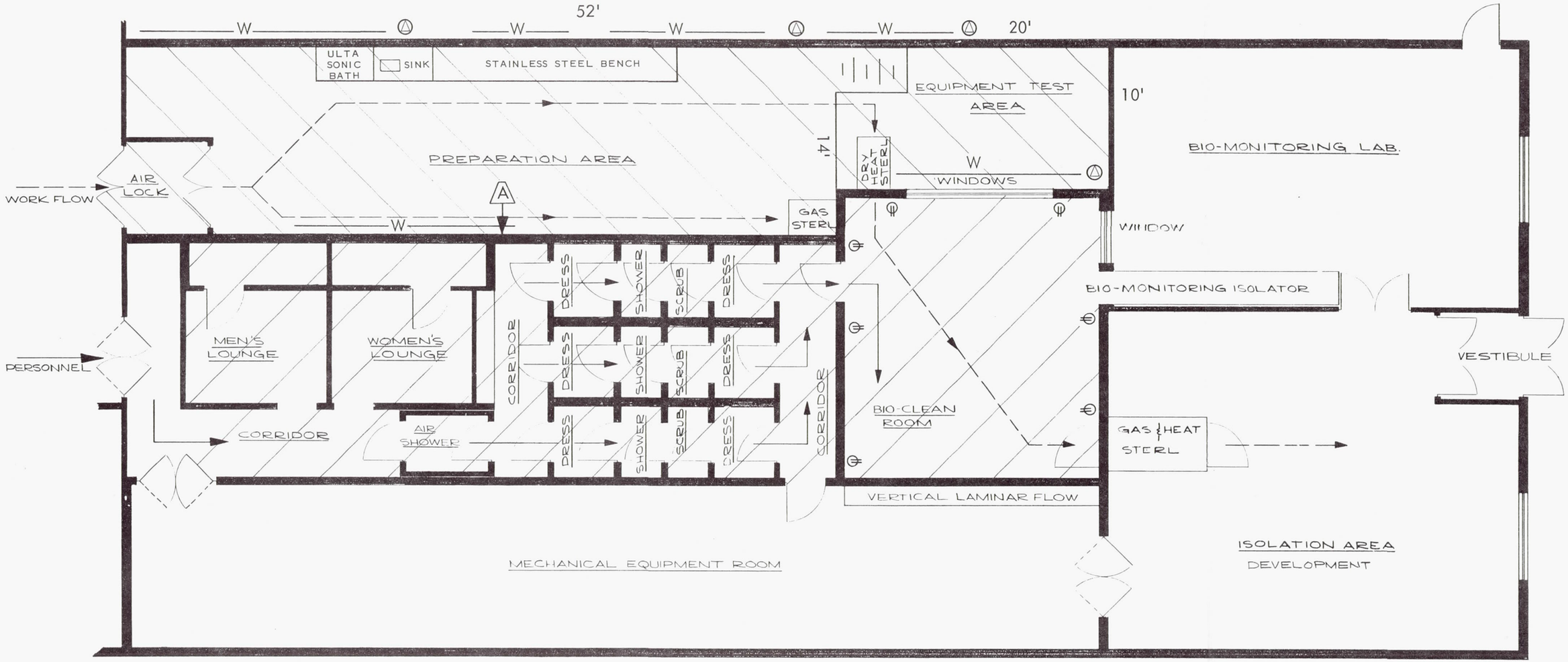


Figure 1. Typical Work Flow



⊖ 15 amp duplex recept.
-W- Wiremold 115v 15 amp max/recept.
Ⓐ 50 amp 208 single-phase
Ⓐ Compressed air

Clean-room personnel
Supporting personnel
≅ 1/8 = Ft

Figure 2. Clean Assembly and Sterilization Laboratory Layout

Page intentionally left blank

Preparation Area

The preparation area is designed to permit two operations: (a) biological monitoring and cleaning of spaceflight hardware; (b) assembly and functional electrical testing of spaceflight hardware under controlled conditions. It is shared between staff microbiologists and experiment engineering personnel.

Spaceflight hardware first enters the CASL into this room, most of which is used for monitoring and cleaning of the parts and pieces. Clean work stations and bio-isolators are available for the assembly of small electronic subassemblies.

The far end of the room is set aside as an equipment test area where complex electronic equipment is used to test component subsystems or to remote-test the items being assembled in the clean room, where test equipment is not allowed. Special feedthrough panels are installed to mate the test equipment with the work in the clean room.

The preparation area is provided with 117- and 208-volt single-phase power, and with facilities for wet and dry vacuum cleaning, chemical cleaning, and ultrasonic washing. Compressed air and bottled gases will be delivered within 1 day after ordering.

Bio-Clean Room

The bio-clean room contains 60 square feet of table top for the assembly and/or integration of subsystems, systems, or small payloads. It is provided with 117-volt single-phase power, and with accessories for vacuum cleaning through a common system. Closed-circuit television monitors the workers and the overall operation in the clean room; a second TV camera permits remote viewing of special activities. The number of personnel permitted in the clean room at one time is limited to four who must proceed through the cleanup area to gain admittance to the clean assembly area. (See Personnel Cleanup Process.)

As test equipment is not allowed in the clean assembly area, hard wiring to remote equipment must be used; sufficient feedthrough panel space to meet any requirements has been installed.

Items are passed through either of the passthrough sterilizers into the clean room for assembly after appropriate treatment.

Personnel Cleanup Area

As previously stated, all clean-room workers must be processed through the shower and scrub rooms. A complete set of clean-room clothing is provided, including head and face masks, suits, and booties.

Individual compartments for dressing, bathing, and so forth are electrically interlocked to ensure proper use of the cleaning facilities. When a particular operation does not require such stringent controls, the cleanup system may be bypassed in part or whole, allowing workers to enter directly through the shower line without bathing.

Bio-Monitoring Laboratory

The purpose of this area, limited to staff personnel, is to provide equipment and personnel for microbiological assay of the spacecraft hardware being processed, as well as for determining contamination levels in all parts of the CASL.

The results of investigations made by this laboratory directly affect sterilization times and temperatures imposed on the individual experiments. Sterility models will be used to determine which pre-sterilization cleaning methods are most efficient. This area contains equipment for the recovery, culture, and identification of microbial contaminants residing on hardware and in work areas.

Isolation Development Area

Isolation of hardware after sterilization and during transportation to T&E and other geographical locations is a severe problem. The isolation development area is devoted to problems of containment in plastic or metal devices, biological monitoring, and the detection of compromise of the "barrier."

Hardware shipped out of GSFC to JPL, for example, will probably be sterilized in a plastic bag, with an umbilical feedthrough for testing, and then further packaged in a metal container or so-called bio-cannister. Because the complete payload will remain inside the same barrier that will be used to protect it during launch, the hardware for umbilical-type testing must be designed as pull-away devices.

THE PERSONNEL CLEANUP PROCESS

The very high biological burden carried by people makes it necessary to protect the clean-assembly process in the clean room by reducing this persistent source of contamination. This is accomplished in the personnel cleanup area of the CASL.

The procedure consists of several steps:

1. Upon entry to the area, the worker passes through an air shower to remove large particulates from his clothing.

2. A sealed bag of sterile garments is picked up from the shelf provided in the vestibule.

3. The worker enters the first dressing room and removes all clothes.

4. In the second room, he takes a wet shower.

5. In the next cubicle, he performs a germicidal scrub.

6. In the last dressing room, he dons the sterile garments.

7. From this area, he enters the bio-clean room.

The sequence is reversed as workers leave the bio-clean room, but scrubbing and showering are not required.

MATERIALS COMPATIBILITY WITH STERILIZATION ENVIRONMENTS

Many materials have been tested for compatibility with the two major sterilization and decontamination methods: dry heat and ethylene oxide.

Testing consists of contaminating the materials or parts with test microorganisms, subjecting them to the decontamination or sterilization cycles, and testing them for both sterility and engineering reliability.

This section lists some of the materials that have undergone this testing, with results of the tests.[3]

Metals

Aluminum Alloys—

Alloy	Sterilizability	Description
1100	St (non-load-bearing structures)	Commercially pure Aluminum
2014	St	Heat-treatable
2024	St	Heat-treatable
3003	N. St	Higher strength than 1100
5052	St	Non-heat-treatable
6061	St	Heat-treatable
7075	St (considerable loss in strength from overaging)	Heat-treatable Very good strength
356	St	Heat-treatable Casting alloy
C355	St	Heat-treatable Casting alloy
A356	St	Heat-treatable Casting alloy

St = sterilizable

N. St = not sterilizable

Magnesium Alloys—

Alloy	Sterilizability	Description
AZ31B	N. St	Low-cost wrought alloy; non-heat-treatable
AZ61A	N. St	Non-heat-treatable
AZ91C	St	Pressure-tight castings
HK31A	St	High strength at elevated temperatures; heat-treatable
LA 141 (Mg-Li)	N. St	
MI-A	N. St	Non-heat-treatable
ZE41A	N. St	Good castability Heat-treatable
ZK60A	N. St	Heat-treatable High-strength

St = sterilizable N. St = not sterilizable

Beryllium Alloys—The thermal heat cycles should not bother Beryllium alloys. They have a maximum service temperature approaching 1000°F.

Titanium Alloys—The thermal sterilization environment is well within the capability of titanium and does not restrict its use.

Steel Alloys—Sterilization does not restrict the use of steel alloys. The effect of heat sterilization on the structural properties of most room-temperature steel alloys is insignificant.

Copper Alloys—

Alloy	Sterilizability	Description
Electrolytic copper	St	99.95 copper
Phosphor bronze	St	95 copper 5 tin and phosphorous; work-hardenable
Bearing bronze 844 bronze	St	Lead tin zinc bronze
High-silicon bronze	St	Work-hardenable; 95 copper 3 silicon alloy
Aluminum bronze	St	Heat-treatable alloy; 91 copper/9 aluminum, or 81 copper/10 aluminum/ 5 nickel/2.5 iron/1 manganese
Beryllium copper	St	Heat-treatable

St = sterilizable N. St = not sterilizable

Magnetic Alloys—

Alloy	Sterilizability	Description
Cunife	St	Copper (60)-nickel (20)-iron (20) alloy
Remalloy	St	Cobalt (12)-molybdenum (20)-iron alloy
Alnico II	St	Aluminum (10)-nickel (17)-cobalt (12.5)-copper (6)-iron alloy
Alnico V	St	Aluminum (8)-nickel (14)-cobalt (24)-copper (3)-iron alloy
Silicon steel	St	3% silicon steel
Alloy 4750	St	Nickel (47-50%)-iron alloy
Supermalloy	St	Nickel (79)-molybdenum (5)-iron alloy
Numetal	St	Nickel (77)-copper (5)-chrome (1.5)-iron alloy

St = sterilizable N. St = not sterilizable

Special-Purpose Metals and Alloys—

Alloy	Sterilizability	Description
Evanohm	St	Nickel-base alloy; 20 chrome, 3 aluminum, 3 iron
Kanthal	St	Iron-base alloy; 23 Cr, 5 Al, 0.5 Co
Nichrome V	St	Nickel 80-chrome 20
Invar 36	St	Nickel (36)-iron alloy
Invar 49	St	Nickel (47-50)-iron alloy
Kovar	St	
Iso-elastic	St	Nickel and cobalt (37)-chromium (7)-iron alloy
Ni-span C	N. St	
High-expansion alloy 22-3	St	Nickel (22)-chromium (3)-iron alloy
High-expansion manganese alloy	St	Copper (18)-nickel (10)-manganese alloy
Nickel	St	
Dumet	St	
Consil	St	Oxidation-hardening silver alloy
Solder 60-40	St	Solder alloy, 60 tin
Silver-MoS_2 - graphite	St	Composite sintered product
Bismuth	St	Hemispheres
Graphite pyrolytic	St	Pyrolytic graphite hemispheres
Gold	St	Plated film
Rhodium	St	
Bismuth	St	
Lead	St	
Gallium	N. St	
Indium	N. St	
Nickel	St	
Ni-P	St	

St = sterilizable N. St = not sterilizable

Plastics

Plastics must be carefully tested, because information is lacking about their characteristics after heat sterilizations. Each plastic must be tested for compatibility. They are on the whole far more susceptible to creep than most metals.

On spacecraft, they are typically used in items such as washers, gaskets, valve seats, insulation, adhesives, and structural parts.

Ceramics

Ceramics show no degradation from the heat-sterilization process. Their normal use temperatures are considerably higher than those of dry-heat sterilization.

Adhesives

Material	Sterilizability	Description
PD - 454	St	Clear adhesive, epoxy modified
458	St	
459	N. St	
RTV 102	St	Silicone rubber adhesive
RTV 511	St	
RTV 560	St	
Eccobond 45	N. St	Adhesive epoxy
Eccobond 57C	St	Electrically conductive epoxy adhesive
Eastman 910	N. St	Cyanoacrylate adhesive
FM 1000	N. St	Adhesive, epoxy nylon
FM 47	N. St	Adhesive, film
RTV 60	St	Adhesive, silicone
Eccobond 60L	St	Thermally conductive epoxy adhesive
Pilobond	N. St	Synthetic rubber adhesive
MSD 107	N. St	Impact-resistant two-compound polyurethane
Epon VIII	N. St	Epoxy adhesive
Epon 815	N. St	Epoxy adhesive blended with TETA to bond substrate sheets
TETA	N. St	Triethylene tetramine

St = sterilizable N. St = not sterilizable

Honeycomb

Aluminum—Aluminum honeycomb for impact absorption is not inhibited by dry heat sterilization; the limiting factor in its use is the selection of an adhesive.

Plastic—Reinforced plastic honeycomb is not limited by sterilization requirements.

Thermal Insulating Materials

Material	Sterilizability	Description
Tissue-glass type 200-A	St	Insulation, thermal
Amfab TV20-60 fabric	St	Teflon-impregnated 108 style glass fabric
Textolite 11555, 11556, 11559	N. St	Silicone/glass laminates, type GSG; low thermal conductivity
Textolite 11546	N. St	Laminate, epoxy glass
Polyester film	N. St	Photosensitized flexible mylar-type film
Epoxy glass	St. In	Rigid epoxy glass
Irradiated polyolefin	N. St	
Aluminized mylar	St. preshrink at 350 F	Aluminum-coated plastic film

St = sterilizable N. St = not sterilizable St. In = sterilizable in an inert atmosphere

Encapsulants—

Material	Sterilizability	Description
PR-1538	N. St	Clear or black flexible urethane compound
Barrier coating	St	Modified RTV-60 compound for glass surfaces
Polyurethane foam	N. St	
Corfil 615	St	Honeycomb edge and inert filler
LTV-602	St	Clear low-viscosity silicone-rubber potting compound
MPC-49	N. St	Lightweight epoxy compound for potting
MPC 52	N. St	Syntatic epoxy foam encapsulant
Viton A rubber	N. St	Elastomer
Teflon	St	Multiuse plastic resin
Buna N	N. St	Elastomer
Neoprene	N. St	Elastomer
Silicone LC-60 SE 362	St	Elastomer
Nylon	N. St	Thermoplastic resin
SMRD 100	St	Clear compound
SMRD 150	St	Filled potting compound

St = sterilizable N. St = not sterilizable

Coatings—

Material	Sterilizability	Description
Parson's black	N. St	Optical black lacquer
D4D paint	St. In	Aluminum-pigmented silicone-alkyd thermal-control coating
Vitavar PV-100	St. In	TiO_2-pigmented silicone-alkyd thermal-control coating
Wash primer	St. In	Penetrant primer; formula 117
Zinc chromate primer	St. In	Low moisture sensitivity, corrosion-inhibiting primer
Silicone primer SS 4101	St	Primer, silicone
Lowe Bros. 47865	St. In	Heat-resistant glyceryl pthalate, instrument black, air-drying enamel
MSD 105	St	Zinc oxide-silicate coating

St = sterilizable N. St = not sterilizable St. In = sterilizable in an inert atmosphere

Solid Lubricants—

Material	Sterilizability	Description
Sintered molybdenum	St	Constant coefficient of friction to 392°F
Sintered molybdenum-MoS_2	St	Constant coefficient of friction to 392°F
Molybdenum disulfide	St. In	Dry film lubrication
Duroid	St	Teflon plus MoS_2; use temperature to 572°F
PbO	St	Use temperature to 500-1000°F
PbO + 5% SiO_2	St	Use temperature 1000-1250°F
Teflon, TFE, FEP	St	Melt temperature 620°F
Copper-Teflon	St	Sintered copper, impregnated to 1-mil depth with Teflon TFE; coefficient of friction constant to 482°F
Polyamide	St. In	Continuous use at 500°F
Hi-T-Lub	St	MoS_2 film; use temperature to 400°F
Dry-film lubricant	St. In	Dry-film molybdenum disulfide
Fabroid	St	Glass-reinforced Teflon for bushings, bearings
Solid-film lubricant	St. In	Low-friction coatings

St = sterilizable N. St = not sterilizable St. In = sterilizable in an inert atmosphere

Greases and Oils—

Material	Sterilizability	Description
Silicone		
Grease G-300	St	Low-evaporation-rate bearing lubricant
Octoil	St. In	Damping fluid
CS 4073	St. In	Filled radiation-resistant silicone grease
MSD 104	St. In	Silver filled CS 4073; thermally and electrically conductive joint filler
Synthetic oil	St	Use temperature to 350°F
Synthetic grease	St	Grease; use temperature to 450°F
MoS_2 grease	St. In	MoS_2 in silicone grease carrier
Instrument oil	St. In	Light instrument bearing lubricant

St = sterilizable St. In = sterilizable in an inert atmosphere

Metal Compatibility with Ethylene Oxide

Material	Compatibility		
	ETO	ETO/Freon 12%/88%	ETO/CO_2 10%/90%
Mild steel	yes	yes	yes
Cast iron	yes	yes	yes
Tin	yes	yes	yes
12-Cr steel	yes	yes	yes
17-Cr steel	yes	yes	yes
18-8 stainless steel	yes	yes	yes
316 stainless steel	yes	yes	yes
Durimet 20	yes	yes	yes
Worthite	yes	yes	yes
Si-iron	yes	yes	yes
Copper	questionable		
Sn-bronze	questionable		
Al-bronze	questionable		
Red brass	questionable	yes	
Yellow brass	questionable	yes	
Si-bronze	questionable		
Monel	yes	yes	yes
Nickel	yes	yes	yes
Inconel	yes	yes	yes
Hastelloy B & D	yes	yes	yes
Aluminum	yes	yes	yes
Lead	yes	yes	yes
Titanium	yes	yes	yes
Zirconium	yes	yes	yes
Gold	yes	yes	yes
Platinum	yes	yes	yes
Tantalum	yes	yes	yes
Silver	questionable		
Magnesium alloys	questionable		
Nitrite-coated steel	yes		
Phosphate-coated steel	no		
Anodized aluminum	no		
Dimetcote #3	no		
Sauereisen silicate coating	no		
Mercury coatings	questionable		

Yes = compatible no = incompatible

Nonmetal Compatibility with Ethylene Oxide

Material	Compatibility		
	ETO	ETO/Freon 12%/88%	ETO/CO 10%/90%
Plastics and resins:			
Polyvinyl chloride	yes	yes	yes
Saran	yes	yes	yes
Teflon	yes	yes	yes
Polystyrene	yes	yes (limited)	yes
Polyethylene	yes	yes	yes
Polymethyl methacrylate	no	yes (limited)	yes
Tygon		yes	yes
Kel-F	yes	yes	yes
Nylon	yes (some types)	yes	yes
Polyvinyl butyral	yes	yes	yes
Cellulose acetate		yes	yes
Fluorthane	yes		
Polybutyl methacrylate	no		
Cellulose	no		
Vinyl, type R-1	yes		
Rubbers and elastomers:			
Neoprene	yes	yes	yes
Hycar		yes	yes
Buna N	yes	yes	yes
Natural rubber	some formulations yes		
GRS rubber	yes		
Nonelastomeric Packing:			
Pyroid style 650	questionable		
Pyroid 10,000	questionable		
Teflon-impregnated asbestos, white	no		
Teflon, impregnated asbestos, black	questionable		
Lubricants:			
Fluorinated hydrocarbons	yes	yes	yes
Silicone grease, thin film	yes (limited)	yes	yes
Petroleum-based lubricants	no		
Miscellaneous:			
Glass	yes	yes	yes
Stoneware	yes	yes	yes
Asbestos	yes	yes	yes
Graphite	yes	yes	yes
Concrete	yes	yes	yes
Garlock 7021 and 734			
Teflon-impregnated string	questionable		
Calcium-silicate insulation	yes		
Magnesia insulators	no		
Black-foamed glass	no		

yes = compatible no = incompatible

Chemical Compatibility with Ethylene Oxide

The following chemicals react with ETO. The Freon in the decontaminating mixture of 88/12 Freon/ETO is inert but acts as a solvent for some substances.

Acetals
Acetoacetates
Acetonitriles
Acetylenes
Amines
Amides (acid)
Aldehydes
Ammonia
Azides
Acyl halides
Antimony chloride
Acid anhydrides
Alkyl halides
Aluminum chloride
Aniline
Aluminum oxide
Alkoxides
Alcohol
Anhydrous iron chloride
Anhydrous tin chloride
Arsenic chloride
Alkyl hydroperoxides
Aminothiols
Aryldichloroarsines
Aryllithiums
Acetic acid
Bismuth chloride
Arsenic chloride
Bromine
Barium oxide
Bismuth oxide
Carbon disulfide
Cyanates
Cellulose starch
Carbonyl chloride
Cyanoacetates
Chlorine
Cobale oxide
Chromium oxide and chloride
Cadmium oxide
Carbon
Dibroanes
Diethylene glycol
DDT
Dibutylamine
Diethylamine
Ethylene glycol
Ether (diethyl)
Fatty alcohols
Fatty acids
Guanidine
Grignard reagents
Hyrofluroic acid
Hydrogen sulfide
Hydrogen cyanide
Hydrochloric acid
Halohydrins
Iodine
Iron oxide
Ketones
Lanolin
Lauric acid
Malonate
Mercury fulminate
Magnesium chloride
Manganese chloride
Molybdenum oxide
Metal alkyls
Mercaptobenzothiazole
Nitric acid
Nitrogen tetraoxide
Nitrosyl chloride
Phenyl magnesium bromide
Polyvinyl alcohol
Phenols
Phosgene
Phosphoric acid
Phosphorous acid
Phosphorous oxychloride
Phthalimide
Polybasic organic acids
Potassium
Potassium hydroxide
Pyridine
Quinoline
Sodium sulfide
Sodium sulfite
Sodium dioxide
Sodium thiosulfate
Silicon tetrachloride
Sulfuryl chloride
Silver oxide
Stannous chloride
Stannic chloride
Sulfur
Sodium
Sodium hydroxide
Sodium nitrite
Stearic acid
Thiourea
Thiocyanates
Thiolacids
Thiols
Thionyl chloride
Thorium chloride
Tantalum oxide
Titanium oxide
Tannic acid
Triethanolamine
Urea
Zinc chloride
Zinc oxide

GLOSSARY

Assay—the examination and determination of an item with respect to certain and specific properties

Bio-assay—the determination of the number of viable organisms residing in or on an item

Bio-cannister—the containment device for terminally sterilized space-flight hardware (also known as bio-barrier)

Burden—the level of microorganisms on an item

Class 100 clean room—according to Federal Specifications 209, a laminar flow room, the air of which contains less than 100 particles per cubic foot (particle size being no greater than 0.5 microns)

Compromise—the invalidation of the sterilization process because of a breach in procedures that allows bacteria to enter

Contaminant—unwanted matter, either living or nonliving

Contamination, internal—contamination within the materials that make up a component as opposed to that on the surface

Contamination, occluded—contamination that was on the surface, but that surface is inaccessible after assembly

D-value—the time at a particular temperature needed to kill 90 percent of the population of microorganisms

Decontamination—the process of removing unwanted matter; in NASA, the reduction of the biological burden to a state still greater than zero

Planetary quarantine—the concept or application of keeping earth life from being transferred to the planets

Sterilization—the reduction of a microbiological population to zero

Sterilization, terminal—the final sterilization procedure whereby items are packaged and sterilized; all subsequent testing and repair is done remotely and in a sterile manner

REFERENCES

1. COSPAR Resolution 26.5, 1965

2. Letter memorandum from NASA Planetary Quarantine Officer to Director of Lunar and Planetary Programs, "Sterilization Cycles," July 21, 1965

3. General Electric Spacecraft Department, "Procedures Manual for Planetary Spacecraft to be Sterilized by Heating," vol. I and III. NASA, George C. Marshall Space Flight Center