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Lunar Reconnaissance Orbiter Project

Contamination Control Plan

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Goddard Space Flight Center
Greenbelt, Maryland

National Aeronautics and Space Administration

CM FOREWORD

This document is a Lunar Reconnaissance Orbiter (LRO) Project Configuration Management (CM)-controlled document. Changes to this document require prior approval of the applicable Configuration Control Board (CCB) Chairperson or designee. Proposed changes shall be submitted to the LRO CM Office (CMO), along with supportive material justifying the proposed change. Changes to this document will be made by complete revision.

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LUNAR RECONNAISSANCE ORBITER PROJECT

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Item No.	Location	Summary	Ind./Org.	Due Date
1	Section 1.1	Launch Site Contamination Control Plan	Chris Lorenston	2007
2	Table 2-5	Contamination Requirements Matrix at Subsystem Level	Rachel Rivera	2006
3	Section 3.1	Thruster Impingement deposition levels shall be no more than TBD g/cm^2	Glenn Rosecrans	2007
4	Section 4.1.1	S/C Instrument module vents	Glenn Rosecrans	2006
5	Section 6.0	Facility TBD flowrate	Rachel Rivera	2006
6	Table 7-1	Fabrication and Assembly Location and Cleanliness Matrix	Rachel Rivera	2006
7	Section 7.3	TBD Facility	Joanne Baker	2006
8	Section 7.4	Bldg. TBD, TBD Facility	Joanne Baker	2006
9	Section 8.0	Bldg. TBD, TBD Fcaility	Joanne Baker	2006
10	Figure 8-1	I&T Flow from I&T Plan	Rachel Rivera	2006
11	Table 11-2	Verification and Cleaning Schedule	Rachel Rivera/Joanne Baker	2007

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1.0 INTRODUCTION

The Lunar Reconnaissance Orbiter (LRO) is the first of a series of missions under the Lunar Precursor and Robotic Program (LPRP).. The LRO Project is intended as a space exploration program that integrates human and robotic exploration activities. LRO's mission is to obtain those measurements necessary and sufficient to characterize future robotic and human lunar landing sites and to identify potential resources. In particular LRO will characterize the lunar radiation environment, determine a geodetic grid of the moon for future landing sites, assess the resources and environments of the Moon's polar cap regions, and determine the elemental composition, mineralogy, and other regolithic characteristics of the moon's surfaces.

To meet the needs of the RLEP, LRO must make accurate measurements of those lunar parameters that are necessary to provide a clearer physical understanding of the lunar environment, its resources, and topography.

In order to obtain the most accurate data, the instrument and spacecraft must operate at peak performance. Adverse particulate and molecular contamination can degrade instrument and spacecraft performance. This degradation is compounded under the effects of on-orbit ultraviolet radiation and electrostatic contaminant return. Through a carefully planned contamination control program, the instrument and spacecraft can be protected from harmful contamination effects.

1.1 SCOPE OF DOCUMENT

This document defines the LRO contamination requirements necessary for mission success. Methods of contamination control with respect to materials and processes during design, fabrication, assembly, integration, test, and launch for the orbiter and its instruments are addressed in this document. Sources of contamination for LRO will be identified and contamination allowances will be defined. In addition, contamination controls for LRO development and cleaning schedules for LRO hardware will be established. Furthermore, the plan will outline cleanliness monitoring and verification.

This Plan does not cover transportation to the launch site, contamination requirements on the launch vehicle, or contamination requirements during launch site operations. These will be covered in the Lunar Reconnaissance Orbiter Launch Site Contamination Control Plan (431-PLAN-000599). Contamination control for LRO at the Payload Processing Facility and at the Launch Pad facilities will also be covered in the Lunar Reconnaissance Orbiter Launch Site Contamination Control Plan (431-PLAN-000599).

1.2 RESPONSIBILITIES

The Goddard Space Flight Center (GSFC) is responsible for the cleanliness and overall contamination control program for the LRO spacecraft and orbiter.

The GSFC subcontractor contamination control should be consistent with the approach contained in this document and ensure that necessary contamination control requirements are met.

The instruments shall generate an instrument-specific contamination control plan per their respective Instrument Performance Assurance Implementation Plan (PAIP), In addition, the instruments shall meet the instrument and spacecraft compatibility requirements referred to in the Lunar Reconnaissance Orbiter Mission Assurance Requirements (431-RQMT-000174), the LRO to Instrument Mechanical Interface Control Documents (ICD) (431-ICD-000085-90), the Performance Assurance Implementation Plan (PAIP), as defined in this plan, in order to avoid spacecraft to instrument contamination and instrument cross contamination. LRO will review the instrument contamination control plans. Instruments shall verify cleanliness levels upon delivery to the LRO orbiter.

Instrument cleaning from delivery to launch shall be the responsibility of the Instrument Provider unless a detailed agreed upon procedure is provided.

1.2.1 Implementation of Requirements

The following table describes how contamination control and the requirements of this Plan are implemented:

Table 1-1. Implementation

Activity	Responsibility	Verification
Flow down of requirements to subcontractors	Subsystem Engineer	Contamination Engineering
Implement compatibility requirements (i.e. surface cleanliness, outgassing certification, and venting)	Instruments, Subsystem Engineers, Orbiter Manager, Integration and Test (I&T) Manager	Contamination Engineering, Quality Assurance (QA)
Inspections/Cleaning	I&T Manager, Contamination Engineering	Contamination Engineering, QA
Implementation of facility requirements and appropriate control of work area	I&T manager	Contamination Engineering
Incorporate requirements into Work Order Authorizations (WOA)	I&T Manager, Subsystem Engineer, Contamination Engineering	Contamination Engineering, QA
Incorporate requirements into plans and procedures	Instruments, Subsystem Engineers, Orbiter Manager, I&T Manager, Contamination Engineering	Contamination Engineering, I&T Manager
Material lists	Instruments, Subsystem Engineer	Materials Engineer

Activity	Responsibility	Verification
Facility certification and Maintenance	Facilities Contractor	Contamination Engineering, QA
Hardware cleaning (Ground Support Equipment [GSE] and Flight)	Facilities Contractor, Contamination Engineering	Contamination Engineering, QA
Facility monitoring	Facilities Contractor	Contamination Engineering, QA
Facility Maintenance Restrictions	Environmental Test Engineering and Integration, Contamination Engineering, Facilities Management	Contamination Engineering, QA
Purge cart operations and implementation of instrument purge	I&T Manager	Contamination Engineering, QA
Purge manifold and purge lines on orbiter	Mechanical Engineering	Contamination Engineering, I&T Manager
Purging procedure	Contamination Engineering	I&T Manager
Bagging Concept	Mechanical Engineering and Contamination Engineering	I&T Manager
Molecular adsorber mounting and frame hardware	Mechanical Engineering	I&T Manager
Molecular adsorbers	Contamination Engineering	I&T Manager
Molecular adsorber and vent close-outs	Mechanical Engineering, Blanket Shop	Contamination Engineering
Verification of Surface Cleanliness Requirements during I&T	Facilities Contractor, Contamination Engineering	Contamination Engineering, QA
Implementation of bake-outs	Subsystem Engineers, Test Engineer	Contamination Engineering

1.3 DOCUMENTATION

The following documents become part of this document to the extent referenced in this document. When a specific version is specified for a referenced document, only that version applies. For undated references, the latest edition of the referenced document applies.

1.3.1 Applicable Document

431-ANYS-**TBD** Initial Orbiter Level Direct Flux Analyses

431-ANYS-**TBD** Initial Thruster Impingement Analyses

431-PLAN-**TBD**	LRO Thermal Vacuum Plan
431-PLAN-000599	Lunar Reconnaissance Orbiter Launch Site Contamination Control Plan
431-PLAN-000100	Lunar Reconnaissance Orbiter Spacecraft and Orbiter Integration and Test Plan
431-PROC-000600	Lunar Reconnaissance Orbiter Cleaning and Verification Procedure
431-PROC-000601	Lunar Reconnaissance Orbiter Clean Area and Personnel Operations Procedure
431-RQMT-000174	Lunar Reconnaissance Orbiter Mission Assurance Requirements
431-SPEC-000008	Lunar Reconnaissance Orbiter Electrical System Specification
431-SPEC-000602	Lunar Reconnaissance Orbiter Purge System Specification
431-ICD-000085	Lunar Reconnaissance Orbiter Cosmic Ray Telescope for the Effects of Radiation to Spacecraft Mechanical Interface Control Document
431-ICD-000086	Diviner Lunar Radiometer Experiment Mechanical Interface Control Document
431-ICD-000087	Lunar Reconnaissance Orbiter to Lyman-Alpha Mapping Project Mechanical Interface Control Document
431-ICD-000088	Lunar Reconnaissance Orbiter to Lunar Exploration Neutron Detector Mechanical Interface Control Document
431-ICD-000089	Lunar Reconnaissance Orbiter to Lunar Orbiter Laser Altimeter Mechanical Interface Control Document
431-ICD-000090	Lunar Reconnaissance Orbiter Camera Mechanical Interface Control Document
431-SPEC-000091	Thermal Systems Specification

1.3.2 Reference Document

1.3.2.1 Federal Specifications

FED-STD-209	Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones

1.3.2.2 Military Specifications

MIL-PRF-27401D	Propellant Pressurizing Agent, Nitrogen
MIL-STD-1246C	Product Cleanliness Levels and Contamination Control Program

1.3.2.3 NASA Specifications

Web site for replacement of NASA Reference Publication 1124	Outgassing Data for Selecting Spacecraft Materials [http://outgassing.nasa.gov]
546-PG-8700.2.2	Contamination Design, Analysis, Test, and Hardware Implementation Guidelines and Requirements
JSC-SN-C-0005C	Contamination Control Requirements for the Space Shuttle Program
GSFC-TLS-PR-7324-01	Contamination Control Procedures for the Tape Lift Sampling of Surfaces
KTI-5212	KSC Material Selection List for Plastic Films, Foams, and Adhesive Tapes

NASA-STD-6001	Flammability, Odor, Offgassing, and Compatibility Requirements and Test Procedures for Materials in Environments That Support Combustion

1.3.2.4 ISO Documents

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 prove continued compliance with ISO 14644-1
ISO-14644-4	Cleanrooms and associated controlled environments - Part 4: Design, construction and start-up
ISO-15859-3	Nitrogen [Alternative to MIL-P-27401 Propellant Pressurizing Agent, Nitrogen]

1.3.2.5 Other Specifications

ASTM E-595	Methods of Test, Total Mass and Controlled Volatile Condensable Materials from Outgassing in a Vacuum Environment
ASTM F-50	Practice for Continuous Sizing and Counting of Airborne Particles in Dust-Controlled Areas and Cleanrooms Using Instruments Capable of Detecting Single Sub-Micrometer and Larger Particles
IEST-RP-CC-018	Cleanroom Housekeeping -Operating and Monitoring Procedures
IEST-STD-CC1246D	Product Cleanliness Levels and Contamination Control Program

1.4 DEFINITIONS

Action Level	The maximum allowable contamination level set by the user in the context of controlled environments and cleanliness, which, when exceeded, requires immediate intervention, including investigation of cause, and corrective action.
Alert Level	The contamination level set by the user in the context of controlled environments and cleanliness, giving early warning of a potential drift from normal conditions. **NOTE**: When alert levels are exceeded, this should result in increased attention to the process.
Cleanroom	Room in which the concentration of airborne particles is controlled to specified limits.
Cold Finger	A cold finger is used in vacuum tests to provide qualitative and quantitative information about the molecular environment of the vacuum chamber at the end of the test. It is a stainless steel cylinder of known surface area, typically one foot squared (ft^2), which is flooded with liquid nitrogen (LN_2) during the last eight hours of a test. When flooded, the cylinder resides at ~80 Kelvin (K) and collects any molecules that hit the cylinder and are condensable at that temperature. When the chamber is brought back to ambient, the cold finger is rinsed with a solvent, and the

	residue is analyzed to determine its mass and constituents. The results from cold finger analyses are used to determine if any unexpected molecular contamination is present.
Contamination	Any unwanted material that causes degradation in the desired function of an instrument or flight hardware.
Contamination Control	Organized action to control the level of contamination.
Fiber	A fiber is a particle whose length-to-width ratio exceeds 10:1 with a minimum length of 100 microns.
Gross Cleaning	Cleaning hardware surfaces to visual inspection standards.
Molecular Adsorber	A zeolite-coated ceramic honeycomb used to adsorb outgassed molecular contaminants. It is also known as a molecular sieve.
Nitrogen Purge	Pressurized flow of clean, dry nitrogen through a system in order to displace impurities and reactive species.
Non-Volatile Residue (NVR)	Soluble material remaining after evaporation of a volatile liquid which usually causes degradation in the desired function of an instrument or flight hardware.
Orbiter	The orbiter consists of the complete LRO flight assembly, all LRO instruments, and all subsystem hardware and bus components.
Particle	A particle is a small quantity of solid or liquid material which has a definable shape or mass with a length to width ratio less than 10:1.
Particle Size	(1) The apparent maximum linear dimension of a particle in the plane of observation, as observed with an optical microscope; (2) The equivalent diameter of a particle detected by automatic instrumentation. The equivalent diameter is the diameter of a reference sphere having known properties and producing the same response in the sensing instrument as the particle being measured; (3) The diameter of a circle having the same area as the projected area of a particle, in the plane of observation, observed by image analysis; (4) The size defined by the measurement technique and calibration procedure.
Percent Area Coverage (PAC)	An alternative method of specifying particle concentration levels on a surface. PAC is the fraction of the surface that is covered by particles. PAC is reported as the sum of the projected areas of the particles divided by the total surface area.
Precision Cleaning	Precision cleaning is cleaning procedure done in a controlled environment to attain a specific level of cleanliness. This procedure follows gross cleaning.
Sensitive Surface	Any surface of flight hardware that must meet a specified cleanliness level to assure the minimum performance levels.

Solvent Flushing	Method of cleaning surfaces with a stream of filtered solvent under pressure, which is directed against a surface to dislodge and rinse away any foreign material.
Solvent Washes	A quantitative method of verifying the Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) molecular cleanliness levels by measuring molecular contamination in a solvent, which was washed over a surface and collected.
Spacecraft	The spacecraft refers to all bus components, structure, electronic boxes, communication hardware, propulsion hardware, and attitude control subsystem hardware in an integrated assembly, not including instruments.
Surface Cleanliness Level	An established level of maximum allowable particulate and/or (NVR) contamination ranging from visibly clean to specific Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) levels (e.g., Level 100A, etc. as shown in Figure 1-1 and Tables 1-2 and 1-3).
Swab Sample	A qualitative method of identifying contaminants by analyzing the residue on a solvent-soaked swab that was wiped over a surface.
Tape Lifts	A quantitative method of verifying MIL-STD-1246C particulate cleanliness levels by measuring particulate contamination on a sample of tape that has come in contact with the surface one wish to examine.
Vapor Degrease	Item to be cleaned is exposed to heated solvent vapors that condense on the part and wash away contaminant.
Visibly Clean	The achievement of a clean surface as seen without optical aids (except corrected vision) as measured by a specified method.

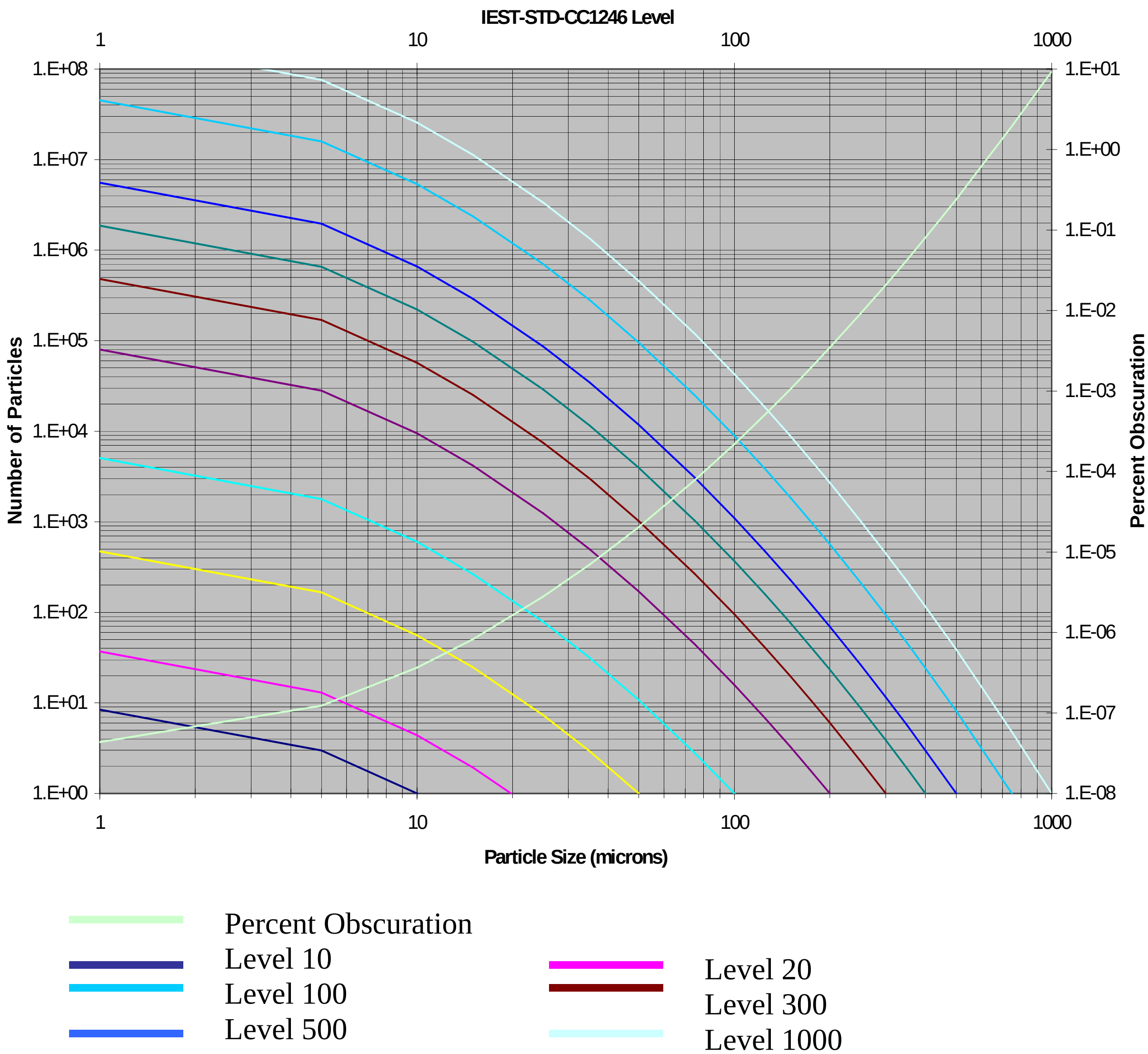

Figure 1-1. Cleanliness Levels (from IEST-STD-CC1246D)

Table 1-2. Classification of Particulate Cleanliness Levels (from Mil-STD-1246C)

Particulate Cleanliness Levels

Level	Particle Size, μm	Count per 1 ft^2	Count per 0.1 m^2	Count per liter
1	1	1.0	1.08	10
5	1	2.8	3.02	28
5	2	2.3	2.48	23
5	5	1.0	1.08	10
10	1	8.4	9.07	84

Level	Particle Size, μm	Count per 1 ft^2	Count per 0.1 m^2	Count per liter
10	2	7.0	7.56	70
10	5	3.0	3.24	30
10	10	1.0	1.08	10
25	2	53	57	530
25	5	23	24.8	230
25	15	3.4	3.67	34
25	25	1.0	1.08	10
50	5	166	179	1660
50	15	25	27.0	250
50	25	7.3	7.88	73
50	50	1.0	1.08	10
100	5	1785	1930	17850
100	15	265	286	2650
100	25	78	84.2	780
100	50	11	11.9	110
100	100	1.0	1.08	10
200	15	4189	4520	41890
200	25	1240	1340	12400
200	50	170	184	1700
200	100	16	187.3	160
200	200	1.08	10	1.0
300	25	7455	8050	74550
300	50	1021	1100	10210
300	100	95	103	950
300	250	2.3	2.48	23
300	300	1.0	1.08	10
500	50	11817	12800	11817
500	100	1100	1190	11000
500	250	26	28.1	260
500	500	1.0	1.08	10
750	50	95807	105000	958070
750	100	8919	9630	89190
750	250	214	231	2140
750	500	8.1	8.75	81
750	750	1.0	1.08	10
1000	100	42658	46100	426580
1000	250	1022	1100	10220
1000	500	39	42.1	390
1000	750	4.8	5.18	48
1000	1000	1.0	1.08	10

Table 1-3. Classification of Molecular Cleanliness Levels (from MIL-STD-1246C)

Non-Volatile Residue Cleanliness Levels

Level	Limit, NVR mg/0.1m^2 [1/] (or μg/cm^2)	Limit, NVR Mg/liter
A/100	0.01	0.1
A/50	0.02	0.2
A/20	0.05	0.5
A/10	0.1	1.0
A/5	0.2	2.0
A/2	0.5	5.0
A	1.0	10.0
B	2.0	20.0
C	3.0	30.0
D	4.0	40.0
E	5.0	50.0
F	7.0	70.0
G	10.0	100.0
H	15.0	150.0
J	55.0	250.0

1/ Limits on non-volatile residue (NVR, mg) for surface, liquid, or gas to meet the level of cleanliness. (One square foot = 0.0929m^2)

2.0 CONTAMINATION CONTROL REQUIREMENTS

The LRO driving contamination requirements are based on instrument contamination requirements, spacecraft contamination requirements, and on-orbit concerns. The instrument contamination requirements consist of internal and external requirements that help minimize performance degradation and take into account requirements for instrument optics, instrument detectors, instrument filters, and thermal control surfaces. Spacecraft contamination requirements are based on Star Tracker (ST) contamination requirements, allowable thermal control surface degradation, Coarse Sun Sensor (CSS) performance requirements, Laser Ranging (LR) contamination sensitivity, and to a lesser extent, Solar Array (SA) performance requirements. In addition, the on-orbit environmental concerns are also considered in deriving the LRO contamination control approach. Those concerns include: outgassing of materials, venting and vent paths, electrostatic return of molecular contaminants, propulsion effluent from thruster firings, polymerization effects, solar activity, and environments of transfer orbits.

Design, fabrication, assembly, integration, testing, packaging, transportation and launch site activities will be performed in a manner that minimizes the probability of contaminating sensitive surfaces.

2.1 OVERALL CONTAMINATION CONTROL REQUIREMENTS

Cleanliness for LRO instruments and the spacecraft will follow the standards outlined in FED-STD-209E [ISO-14644-1], MIL-STD-1246C [IEST-STD-CC1246D], Contamination Design, Analysis, Test, and Hardware Implementation Guidelines and Requirements (GSFC-546-PG-8700.2.2), and Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005). During all Project phases, an active contamination monitoring and verification program will be in effect for flight hardware, using black light and white light inspections, tape lift particulate measurements, NVR swab samples, molecular washes, in-situ molecular monitors, and/or Optical Witness Samples (OWS). All instruments, subsystems, and/or components shall meet outgassing certification requirements prior to integration. Black and White light inspections, tape lift samples, and wash samples will be performed on a schedule, as defined in Section 8.2, such that the Spacecraft Orbiter will be sustained at the specified levels in Section 2.4. Cleanliness levels may be measured using an equivalent Percent Area Coverage (PAC) level as described in Table 2-1.

Table 2-1. Particulate Cleanliness Levels versus Percent Area Coverage

Cleanliness Level *	Percent Area Coverage
100	0.00022
200	0.0035
300	0.020
350	0.044
400	0.080
450	0.14
500	0.24
550	0.4
600	0.6
650	0.9
700	1.4
750	2.0

*See Table 1-2 for Cleanliness Level Classification per MIL-STD-CC1246D

2.2 LRO INSTRUMENT CONTAMINATION REQUIREMENTS

The instruments on LRO are the Lunar Orbiter Laser Altimeter (LOLA), Lyman-Alpha Mapping Project (LAMP), Lunar Exploration Neutron Detector (LEND), Lunar Reconnaissance Orbiter Camera (LROC), Cosmic Ray Telescope for Effects of Radiation (CRaTER), Miniature Radio Frequency (Mini-RF), and Diviner Lunar Radiometer Experiment (DLRE).

All LRO Instruments shall be delivered at the external cleanliness levels specified in Table 2-2 to ensure instrument to instrument compatibility. These external surface compatibility requirements shall be verified via tape lift samples and wash samples on representative instrument surfaces. Black and white light inspections may also be performed to the criteria of the Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005). Some instruments may have stricter requirements on their respective contamination sensitive surfaces. The instrument sensitivity levels of Table 2-2 are derived from the most stringent instrument sensitivity requirements and act as the drivers for the set requirements. Actual instrument sensitivity levels should be verified in the configuration management (CM) version of the Instrument’s contamination control plan.

Table 2-2. Contamination Budget for LRO Instruments

INSTRUMENT	COMPONENT	Delivery to LRO	I&T	At Launch	BEGINNING -OF-LIFE (BOL)	END-OF-LIFE (EOL)
LOLA	Internal Laser[1]	300 A/2	300 A/2	300 A/2	300 A/2	300 A/2
	Flight Optics[1]	300 A/2	300 A/2	300 A/2	300 A/2	300 A/2
	External Surfaces	450 A/2	450 A/2	450 A	500 A	550 B
LEND	External Surfaces	450 A/2	450 A/2	450 A	500 A	550 B
LAMP	Internal Surfaces[1]	400 A/20	400 A/20	400 A/20	400 A/20	440 A/15
	External Surfaces	450 A/2	450 A/2	450 A	500 A	575 A
LROC	External Surfaces	450 A/2	450 A/2	450 A	500 A	550 B
	Internal Surfaces[1]	250 A/5	250 A/5	250 A/5	250 A/5	250 A/5
CRaTER	External Surfaces	450 A/2	450 A/2	450 A	500 A	550 B
DIVINER	Optical Bench Assembly[1]	400 A/2	400 A/2	400 A/2	400 A/2	450 A
	External Surfaces	400 A/2	450 A/2	450 A/2	500 A	550 B
Mini-RF	External Surfaces	450 A/2	450 A/2	450 A	500 A	550 B

1 The actual instrument internal sensitivity levels should be taken from the individual instrument contamination control plans and are to be included here only as a relative estimate of the instrument internal contamination control requirements. Actual levels should be verified in the configuration management version of the instrument's Contamination Control Plan.
The instrument external sensitivity levels are derived from the most stringent S/C or instrument sensitivity requirements. These requirements act as the drivers for the above set requirements. Actual instrument external levels should be verified in the configuration management version of the instrument's Contamination Control Plan.
*See Table 1-2 and Table 1-3 for Cleanliness Level Classification per MIL-STD-CC1246D

2.2.1 Instrument Outgassing Certification Requirements

The instruments shall meet an outgassing certification requirement during thermal vacuum testing or at the end of the instrument bakeout, prior to delivery to LRO, as defined in Table 2-3. The bake-out/outgassing certification performance shall be measured using a Temperature-controlled Quartz Crystal Microbalance (TQCM) at chamber pressures below **1x10^{-5}** torr. This device provides information to enable a determination of the duration and effectiveness of the thermal vacuum bakeout as well as measures compliance to the outgassing certification requirements. During certification, the flight hardware shall be maintained at **10** degrees centigrade (^{o}C) above the maximum on orbit operational temperature, this includes both operational on and off conditions of internal boxes, as per the Thermal System Specification (431-SPEC-000091) Table 2-1a. During certification, the TQCM shall be controlled at **–20** ^{o}C or lower throughout the test to measure the total outgassing of volatile outgassed condensables. The TQCM must be mounted within the chamber such that the TQCM has a representative view of the flight hardware or is monitoring the hardware vent.

The outgassing certification test will be deemed successful when the outgassing rates in Table 2-3 are achieved for at least **five** consecutive hours during the certification phase. It is also required that a cold finger or scavenger plate be used to provide a qualitative assessment of the instrument outgassing effluent at the end of the certification test. Cold finger or scavenger plate data will include total mass amount and chemical species sub-group .The results of the thermal vacuum bakeout / outgassing certification test shall be verified and provided to the LRO Project for approval. The data set shall be recorded at least once every **30** minutes during testing and shall contain, as a minimum, TQCM data, temperature of hardware, chamber/shroud temperature, TQCM temperature, and chamber pressure. In addition, the chamber configuration and cold finger data will be delivered with the results. All instruments unable to satisfy the outgassing certification requirement must obtain a waiver and see the LRO contamination control engineer for more details.

Table 2-3. Outgassing Requirements for Instruments

LRO Instruments	Required Outgassing Rate or Level (g/cm^2/sec)	Predicted Max Operating temperature (deg C)
CRaTER	<5.0E-11	35^{o}C
LEND	Electronics box (ebox) module <5.0E-11 Doppler Aperture <5.0E-11	50 ^{o}C
LOLA	Laser Bench <5 E-13 Ebox mod <5.0E-11 Radiator <5.0E-11	35^{o}C 45^{o}C
Diviner	<5.0E-11	50^{o}C
LAMP	<5.0E-11	35^{o}C
LROC/NAC1	<5.0E-11	40^{o}C
LROC/NAC2 (same as NAC1)	<5.0E-11	40^{o}C
LROC/WAC	<5.0E-11	40^{o}C
LROC/SCS (eboxes)	<5.0E-11	50^{o}C
Instrument MLI (all)	<2.5E-12 g/cm^2/sec	40^{o}C

Note: Most instruments will have more stringent outgassing requirements than the external surface requirements.
In order to facilitate the satisfaction of outgassing certification rates, it is recommended that component part bakeouts be performed at higher temperatures and prior to the instrument system-level bakeouts.

LRO shall be responsible for analytically converting the outgassing certification requirement to an equivalent TQCM rate given the instrument unique test configuration. In order to perform this analysis, the instrument will submit the unique test configuration and chamber data to GSFC at least **30** days prior to the outgassing certification test in order to allow adequate time for GSFC to calculate the equivalent TQCM rate. Required data includes: test configuration, chamber dimensions, pumping efficiency, shroud and hardware temperature, location of scavenger plates, cold plates, and cold finger, and location of the TQCM relative to the hardware.

2.2.2 General Instrument Integration and Test Requirements

The instruments shall be integrated to the Orbiter in an operational Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones (FED-STD-209E) Class **10,000** (ISO Class **7**) cleanroom.

2.2.2.1 Doors, Apertures, Covers

Instrument protective covers will remain on unless integration and test activities prohibit this. Instrument use of protective covers should be defined in the respective instrument's Contamination Control Plan. Instrument doors, if any, should be opened within a cleanroom determined and approved by the instrument contamination engineer, with the possible exception of thermal vacuum testing.

2.2.2.2 Bagging

The instruments will be bagged whenever possible. Instrument doors may be opened within a cleanroom determined and approved by the instrument contamination engineer.

2.2.2.3 Purge

A nitrogen purge can be available to the instruments during integration, test (except during thermal vacuum testing), and storage. Nitrogen or clean, dry air can be provided during transportation to the launch site. Purge requirements are discussed in Section 8.4. Purge rates and interface requirements can be found in the Contamination Control Requirements Section of the respective instrument's Lunar Reconnaissance Orbiter Spacecraft to Instrument Mechanical Interface Control Document and/or the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602). Purge System descriptions and requirements will also be found in the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602).

2.3 LRO SPACECRAFT SUBSYSTEM REQUIREMENTS

Some spacecraft subsystem surfaces are considered to be contamination sensitive. These surfaces and their respective contamination sensitivity levels are listed in Table 2-4. To prevent cross contamination, the subsystem components listed in the table will be cleaned to the orbiter contamination levels or the contamination levels listed in Table 2-4, whichever, is cleaner.

Table 2-4. Contamination Budget for LRO Subsystem

Sub-System	Delivery to GSFC	I&T	At Launch	BEGINNING -OF-LIFE (BOL)	END-OF-LIFE (EOL)
Propulsion	450 A/2	450 A/2	450 A	500 A	550 B
Radiators	450 A/2	450 A/2	450 A	500 A	550 B
Solar Array	450 A/2	450 A/2	450 A	500 A	550 B
Star Trackers	450 A/2	450 A/2	450 A	500 A	550 B
Course Sun Sensors	450 A/2	450 A/2	450 A	500 A	550 B
Reaction Wheels	450 A/2	450 A/2	450 A	500 A	550 B
Inertial Measurement Unit	450 A/2	450 A/2	450 A	500 A	550 B
Laser Ranging	450 A/2	450 A/2	450 A	500 A	550 B
OMNI Antenna	450 A/2	450 A/2	450 A	500 A	550 B
High Gain Antenna	450 A/2	450 A/2	450 A	500 A	550 B
Battery	450 A/2	450 A/2	450 A	500 A	550 B
S/C Bus	450 A/2	450 A/2	450 A	500 A	550 B
Harnesses	450 A/2	450 A/2	450 A	500 A	550 B
MLI	450 A/2	450 A/2	450 A	500 A	550 B

The Contamination Requirements Matrix for all spacecraft subsystems can be found in Table 2-5. This table will list each box or component on the spacecraft, its assembly requirements, exterior cleanliness requirements at delivery, bakeout requirements, outgassing certification requirements, and special storage and handling requirements. In general, the subsystems will be maintained at a level **450 A/2** per Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) during assembly. During spacecraft integration, all mating surfaces will be cleaned to and verified to level **450 A/2** per Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) before becoming inaccessible. All box exterior surfaces, interior to the spacecraft bus, will be cleaned and verified to Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) level **450 A/2** prior to Orbiter integration. Upon completion of integration, all exterior surfaces on the orbiter and subsystems will be cleaned and verified to a Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) level **450 A/2.** Tape lifts and wash samples can be taken at regular intervals. Black and white light inspections can be made frequently during integration. A detailed cleaning and monitoring schedule can be found in Table 11-1.

Table 2-5. LRO Contamination Requirements Matrix for Spacecraft Systems

Subsystem	Box/ Component	Number of Boxes/ Components	Built in-house or out-of-house	Interior or Exterior to S/C bus	Assembled in Cleanroom	Exterior Cleanliness Requirements	Thermal Vacuum (TV) test at GSFC	Bakeout (B/O) require	B/O performed at vendor or GSFC	B/O Requirements
TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

2.3.1 Spacecraft Subsystem Outgassing Certification Rates

All flight hardware shall meet outgassing certification rates prior to integration to the spacecraft (S/C) per Table 2-5. Outgassing rates shall be measured with a TQCM, set at the temperature requirements in the Contamination Requirements Matrix (Table 2-5) at chamber pressures below **$1x10^{-5}$** torr. TQCM reading equivalents to the required certification rates will be calculated by LRO Contamination Engineering based on the unique test set-up/chamber configuration. All bakeouts will be conducted at the maximum hardware temperature without damage. Outgassing certification must be done at 10°C above the maximum operational on-orbit temperature per the Thermal Systems Specification (431-SPEC-000091). The TQCM must be mounted within the chamber such that the TQCM has a representative view of the flight hardware or is monitoring the hardware vent. The hardware outgassing certification shall be deemed successful when the outgassing requirements are achieved for at least **five** consecutive hours. For all bake-outs performed at GSFC, an eight hour cold finger sample shall be taken at the end of the certification test prior to vent-back for a qualitative assessment of hardware outgassing effluent at the end of the certification test. Vendor supplied items shall capture NVR data collected through the use of a cold plate, scavenger plate, or cold finger at the end of hot soak/cycle and at the end of certification. All vendors unable to satisfy the outgassing certification requirement must obtain a waiver and see the LRO contamination control engineer for more details.

Support equipment used in the vacuum chamber must meet the minimum flight hardware material requirements (Collected Volatile Condensable Materials [CVCM] 1%, total mass loss [TML] 0.1%). It is also required that a pre-test chamber bake-out, with GSE and cables, and an outgassing background measurement, with a TQCM, be performed prior to loading the flight hardware in the chamber. This assures that the chamber and GSE will not contaminate the flight hardware and will provide a TQCM background measurement to be subtracted from the TQCM measurements recorded during the actual test. Without the background measurements, the outgassing background in the chamber is assumed to be negligible during the certification test. The pre-test chamber bakeout requirement may be waived by the LRO Contamination Engineer if chamber cleanliness can be verified.

The results of the thermal vacuum bakeout/outgassing certification test shall be verified and provided to the LRO Project for review and approval. The data set shall be recorded at least once every **30** minutes during testing and shall contain, as a minimum, TQCM data, temperature of hardware, chamber/shroud temperature, TQCM temperature, and chamber pressure. In addition, cold finger and scavenger plate data shall be delivered with the results. All subsystems unable to satisfy the outgassing certification requirement must obtain a waiver. Contact the Contamination Engineer for more test details.

Table 2-6. LRO Subsystem Outgassing Requirements

LRO Subsystem (Part 1)	**Desired Outgassing Level** ($g/cm^2/sec$)	**Predicated Max On-orbit Operational temperature (cert at) (deg C)**	**Outgassing Mitigation Required/when verified**
Upper Bus Structure	<5E-11 $g/cm^2/sec$	40°C	Thru bus vent (-X dir.): at subsystem level BO or S/C TV
Lower Bus Structure incl. Aft Deck	<5E-11 $g/cm^2/sec$	40°C	Thru bus vent (-X dir.): at subsystem level BO or S/C TV
Instrument (optical) Deck	<5E-11 $g/cm^2/sec$	40°C	Seam vent in –X and –Z (anti-nadir) dir.
Ebox (-Z) Radiator	<5E-11 $g/cm^2/sec$	40°C	At subsystem level thermal cycling
Mini-RF (assumed blanketed backside)	<5E-11 $g/cm^2/sec$	50°C	At subsystem level
Solar Array (cell side (cs) and completed backside(bs))	<5E-11 $g/cm^2/sec$(cs) <1E-11 $g/cm^2/sec$(bs)	70°C (cs)[1] 50°C(bs)	At subsystem level (vendor): verify OGR on both sides
SA gimbal assembly (ga) & hinges (h)	<5E-10 $g/cm^2/sec$(ga) <5E-11 $g/cm^2/sec$(h)	50°C (ga) 80°C (h)	At component or completed subsystem level
HGA incl. dish (d) and gimbal assemblies (ga)	<5E-10 $g/cm^2/sec$ (d & ga)	90°C (d) 50°C(ga)	At completed subsystem level
S/C MLI	2.5E-12 $g/cm^2/sec$	40°C	At completed subsystem level
Omni antennas	<5E-11 $g/cm^2/sec$	80°C	At completed subsystem level
Star Cameras (Trackers) incl. electronics	<5E-11 $g/cm^2/sec$	50°C	At completed subsystem level

Sun Sensors & electronics	<5E-11 g/cm^2/sec	135^{o}C	At completed subsystem level
Bus vent(s)	<1E-10 g/cm^2/sec	40^{o}C	Verify at S/C TV (Hot soak)
S/C harness and connectors	<5E-11 g/cm^2/sec	40^{o}C	Verify prior to installation on structure & without Cu wrap or expando sleeving
Propulsion non-metallic components	<5E-11 g/cm^2/sec	40^{o}C	Silicone grommets and washers (P-clamps); Verify at component level
Propulsion harnesses	<5E-11 g/cm^2/sec	40^{o}C	Verify at component level (vendor) & prior to installation with Prop system on bus
PDE- Propulsion and Deployables Electronics (in Prop Module)	<5E-11 g/cm^2/sec	40^{o}C	Verify at component level and then at s/c system level Directional venting in –Y dir from ebox
Propulsion Module	<5E-11 g/cm^2/sec	40^{o}C	Directional venting in –Y dir from ebox
Internal eboxes in Avionics Module	<5E-11 g/cm^2/sec	Varies, 40^{o}C-70^{o}C	Verify at component level Directional venting in –Z (anit-nadir) from Module

[1] From PDR thermal predictions the Solar Array could obtain operational temperatures up to 135oC for some periods and has a survival limit of 145^{o}C. The actual nominal time-averaged operating temperature is expected to be less than these maximum values, therefore the certification phase may be a requested at or near the temperatures listed in the table.

As stated above, LRO Contamination Engineering shall analytically convert the outgassing certification requirement to an equivalent TQCM rate given the instrument unique test configuration. If this analysis is desired, the subsystem will submit the unique test configuration and chamber data to LRO Contamination Engineering at least **30** days prior to the outgassing certification test in order to allow adequate time for LRO Contamination Engineering to calculate the equivalent TQCM rate. Required Data includes: test configuration, chamber dimensions, pumping efficiency, shroud and hardware temperature, location of scavenger plates, cold plates, and cold finger, and location of the TQCM relative to the hardware. For sub-systems not listed or those listed as TBDs in Table 2-6, certification maybe satisfied through T/V cycling and with the approval of the LRO Contamination Control Engineer.

2.4 LRO ORBITER REQUIREMENTS

All orbiter surfaces will meet an exterior contamination cleanliness level of **450 A/2** per Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) during final assembly and integration. All mating surfaces as they become inaccessible will be cleaned to level **450 A/2.** All internal spacecraft surfaces will be cleaned to a level **450 A/2**. Upon completion of integration, all exterior surfaces will be cleaned to level **450 A/2** and maintained at that level through testing until launch. Table 11-1 contains a detailed cleaning and monitoring schedule.

2.4.1 Orbiter Bagging

Because of contamination sensitivities, when the Orbiter is outside of the Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones (FED-STD-209E) Class **10,000** (ISO Class **7**) cleanroom, it must be bagged. The only exception is when I&T activities would prohibit bagging. This exception will require a WOA and LRO Project approval. Additionally, when the orbiter is not being worked on in the cleanroom, for an extended period of time, it must be protected with a bag, cover, or drape, if possible, to protect from particulate fallout and minimize required cleanings. During any type of transportation outside the facilities, as in the case of launch site transportation, or during storage, the orbiter should be bagged in approved bagging film and stored in a shipping container.

LRO shall be bagged using a contamination and electrostatic discharge (ESD) acceptable film. The bags will be designed especially to accommodate the configuration of LRO with special attention to required lifting points. The film will be precision cleaned to orbiter levels prior to final assembly in the cleanroom environment. The assembly of the bag will be implemented in the cleanroom. A designated number of bags will be made to assure that rupture of a bag being used will not interrupt LRO bagging for a prolonged period.

The bagging concept will be formulated by Mechanical Engineering (if support structures are needed) and Contamination Engineering prior to the LRO Orbiter Critical Design Review.

Individual instrument bags shall be provided by the instrument provider, unless a detailed design is provided to LRO. These bags will protect the instrument prior to and after integration to the orbiter.

Llumalloy is the bagging material approved for use on LRO. The selection criterion is based on ESD, ESD for low voltages, hypergolic compatibility, cleanliness, flammability, and non-shedding. Test methods for evaluating flammability, ESD, and hypergolic compatibility are referenced in the KSC Material Selection List for Plastic Films, Foams, and Adhesive Tapes (KTI-5212). Additional ESD requirements can be found in the Lunar Reconnaissance Orbiter Electrical System Specification (431-SPEC-000008).

2.4.2 LRO Cleanliness Levels from Assembly to End-of-Life

The following table defines internal and external surface cleanliness levels for instruments, subsystems and the integrated orbiter from instrument delivery to EOL.

Table 2-7. LRO Surface Cleanliness Levels from Instrument Delivery to End-of-Life

Event	External Surfaces	Internal Surfaces

Instruments delivered to GSFC	Level 450 A/2	Level 450 A/2
Subsystems delivery to Integration	Level 450 A/2	Level 450 A/2
Orbiter at start of Integration	Level 450 A/2	Level 450 A/2
Orbiter at end of I&T	Level 450 A/2	Level 500 A
Orbiter during Launch Site Preps	Level 450 A/2	Level 500 A
At Encapsulation	Level 450 A/2	Level 600 A
At launch	Level 450 A	Level 600 B
Orbiter at Orbit Insertion	Level 500A	Level 650 B
Orbiter at EOL	Level 550 B	No Requirement

2.4.3 LRO Orbiter Thermal Vacuum Testing/Outgassing Certification

The LRO Orbiter will be subjected to orbiter level thermal vacuum testing. The LRO Orbiter level thermal vacuum test will be performed in chamber **Space Environment Simulator (SES)**. The chamber is maintained at a class **10,000.** Full cleanroom garments will be worn while working within the chamber.

The thermal vacuum test will be monitored with a series of TQCMs and the following instrumentation: passive fallout witness samples, cold finger, scavenger plates and optical witness plates. The outgassing certification portion of the LRO orbiter thermal vacuum test will be used to verify the on-orbit contamination analyses. All temperature transitions will be controlled to minimize contamination. In addition, cold plates will be used, as required, to minimize contamination from known high outgassing sources. An analysis will be performed prior to the thermal vacuum test to verify no subsystem or instrument will be susceptible to contamination and so that precautions can be taken to minimize contamination to problem areas.

Support equipment used in the vacuum chamber must meet flight hardware material requirements. A pre-test chamber bake-out, with GSE and cables, and an outgassing background measurement, with a TQCM, shall be performed prior to loading the flight hardware in the chamber. This assures that the chamber and GSE will not contaminate the flight hardware. The pre-test outgassing levels shall be measured and verified to meet the chamber certification levels defined in Lunar Reconnaissance Orbiter Thermal Vacuum Plan (431-PLAN-**TBD**). The pre-test chamber bakeouts will occur at the same certification temperatures as the flight hardware bakeouts. They will occur until at least 10% of the outgassing rates of flight hardware going into the chamber have been met, unless otherwise specified in Lunar Reconnaissance Orbiter Thermal Vacuum Plan (431-PLAN-**TBD**).

Outgassing certification rates shall be verified during the last hot cycle of thermal vacuum testing. During certification, the flight hardware shall be maintained at its maximum on-orbit operation temperature. The hardware outgassing rate shall be measured with a series of TQCMs for at least **five** consecutive hours. The TQCMs must be mounted within the chamber such that each TQCM has a representative view of the flight hardware or is monitoring a hardware vent. The TQCM temperatures shall be defined in the Lunar Reconnaissance Orbiter Thermal Vacuum Plan (431-PLAN-**TBD**). If the flight hardware does not meet the outgassing certification requirements, the orbiter shall be subjected to a contingency bakeout.

3.0 CONTAMINATION SOURCES AND ANALYSES

Quantitative estimates of contamination sources and deposits will be made for critical surfaces through the analyses as listed below. A physical description of the contamination environment (molecular/particulate) of the surrounding critical surfaces will be provided by LRO Contamination Engineering. The analyses will consider the locations, geometry, and operation of sensitive surfaces relative to potential contamination sources.

Possible sources of contamination must be identified in order to protect LRO from contamination and to effectively clean contaminated components. Table 3-1 is a listing of possible contamination sources at various development stages.

Table 3-1. Contamination Sources for LRO

Mission Phase	Molecular	Particulate
Fabrication	Machining oils, fingerprints, air fallout	metal chips, filings, air fallout, personnel
Assembly and Integration	air fallout, outgassing, personnel, cleaning, solvents, soldering, lubricants, bagging material	air fallout, personnel, soldering, drilling, bagging material
Test	air fallout, outgassing, personnel, test facilities, purges	air fallout, personnel, test facilities, purges, redistribution
Storage	bagging material, purges, containers	bagging material, purges, containers
Transport	bagging material, purges, containers	bagging material, purges, containers, vibration
Launch Site	bagging material, air fallout, outgassing, personnel, purges	bagging material, air fallout, personnel, checkout activities, other payload activities, purges
Launch	Outgassing, venting, launch vehicle	vibration and/or redistribution, launch vehicle
LRO On-Orbit	Outgassing, atomic oxygen, propulsion effluent, glow, electrostatic return, polymerization effects	LRO cloud, micrometeoroid and debris impingement, material erosion

3.1 THRUSTER IMPINGEMENT

The spacecraft should be designed to minimize thruster impingement on contamination sensitive surfaces. The spacecraft propulsion system will be using ultra-pure hydrazine as a propellant. An analysis will be performed to determine the thruster effluent deposition levels on the instruments' exterior surfaces through mission to end of life on-orbit. The deposition levels shall be no more than **TBD** (g/cm^2). The effects from orbit insertion burns, attitude correction burns, and any required special maneuvers are to be included in the analyses.

3.2 ON-ORBIT ANALYSIS

Contamination mass transport analyses of on-orbit contamination will be performed by the GSFC Contamination Engineering for the LRO orbiter. The molecular impingement rate on sensitive surfaces as well as the total amount of contaminants depositing on those surfaces will be calculated over the life of the mission. The contaminant flux to each instrument aperture, as well as other contamination sensitive surfaces, will be provided to each instrument provider. The mass transport analyses will take into account on-orbit outgassing, electrostatic return mechanisms, instrument and spacecraft venting, and propulsion plume impingement. The analyses are to be documented and available for review.

The subsystem and spacecraft outgassing requirements (Tables 2-1 and 2-2) will be derived from the on-orbit analyses, based on instruments contamination requirements. In addition, the analyses will verify the effects of the propulsion system and choose the optimal orbiter vent locations.

3.3 PARTICLE REDISTRIBUTION ANALYSIS

The GSFC Contamination Engineering will perform a particle redistribution analysis for the LRO Orbiter, if necessary. The analysis will predict particle redistribution on the Orbiter due to launch forces, launch vibration, and launch vehicle cleanliness. The change in exterior particulate cleanliness levels on sensitive surfaces during launch will be calculated.

3.4 VENTING ANALYSES

Contamination Engineering will perform an LRO de-pressurization analysis to size the spacecraft vent with respect to bus volume. The vents will be sized to keep the maximum delta-pressure on the spacecraft below **.1** absolute pressure per square inch (psia). Spacecraft vent placement on the spacecraft bus will be determined by the results of this analysis. The size and efficiency, if any, of the molecular adsorbers, located in the spacecraft bus, will be calculated. Section 4.1.1 provides the details for the spacecraft vent.

In addition, venting analyses will be used to verify instrument and subsystem vent locations to prevent spacecraft to instrument cross contamination and instrument-to-instrument contamination.

3.5 MISCELLANEOUS ANALYSES

A number of other analyses will be performed by the GSFC Contamination Engineering for the LRO program to include:

- The LRO thruster impingement analyses will be performed to verify thruster placement with respect to effluent impingement, pressure, and heating effects. Trade study results can be requested from the LRO Contamination Engineer.

- Contaminant polymerization studies will be performed by GSFC, if needed, based on the need of the instruments.

4.0 DESIGN, MATERIALS, AND PROCESSING REQUIREMENTS

4.1 VENTING

The Orbiter exterior components, spacecraft vents, and Instruments must be designed such that all outgassing and propulsion plume products are vented away from instruments and sensitive parts of the Orbiter. Sensitive components include apertures, thermal control surfaces, STs, CSS, and SAs. Correct venting design may require the use of directional venting, baffles, filters and/or labyrinth seals.

Venting analyses will be performed by GSFC Contamination Engineering to verify instrument and subsystem vent locations in order to prevent spacecraft to instrument cross contamination and instrument to instrument contamination. Details of the instrument vent locations should be defined in the applicable Instrument Mechanical Interface Control Drawings (Mechanical Implementation Details) of each Spacecraft to Instrument Interface Control Document.

4.1.1 Spacecraft and Instrument Module Vents

TBD

4.2 MATERIALS

In order to control contamination and protect sensitive surfaces, the use of minimal contaminating materials and the use of covers and protective shields must be considered. Manufacturing materials should be low outgassing, non-shedding and non-flaking. The materials should be chosen from the following web site: http://outgassing.nasa.gov which is a replacement for NASA Reference Publication 1124. Manufacturing materials not listed in the reference publication shall be tested by Code 541, Materials Branch, in accordance to the Methods of Test, Total Mass and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment (ASTM E-595).

Materials shall meet the CVCM level of 0.1% and TML of 1.0% by weight, in order to be used in fabrication and assembly. If a material does not meet these standards, it must be discussed with the Contamination Engineer (GSFC 546) and Materials Engineer (Code 541) for a possible waiver.

4.2.1 Material Restrictions

The following materials are known to cause outgassing or surface contact contamination problems and shall be prohibited or the quantity used shall be tightly controlled and demonstrated to not pose a threat to contamination sensitive surfaces.

- Silicones shall be prohibited/limited in areas where mass transport modeling demonstrates that they may be transported to contamination critical surfaces unless specifically approved by the LRO Contamination Engineer and the LRO Materials

Engineer. Silicones are difficult to remove using either chemical or vacuum baking cleaning techniques. Silicones may creep due to low surface tensions. Silicones also polymerize into a dark highly absorbing contaminant deposit.

- Silicones used in other areas shall be limited and minimized in quantity. Those used will have the lowest TML and CVCM outgassing properties available for the application.
- Foams
- Non-flight adhesives (in masking tapes, temporary bonding activities, and other fabrication and test activities) for ground operations shall be generally prohibited. Where use is unavoidable, the quantity used will be minimized and all residues shall be removed from flight hardware surfaces as well as any surfaces where there is a possibility of transfer to a flight surface.
- Silicone-based Kapton tape

In addition, some materials are known particle generators and usage of such materials shall be controlled and monitored, particularly near contamination sensitive surfaces.

- Paints which can become particle generators when improperly applied (e.g., over spray or excessive thickness) or cured (insufficient humidity or temperature or insufficient or excessive curing of a base layer prior to application of second layer). Silicates may present particle generating hazards.
- Some surfaces become particle generators when over-handled -- e.g., painted surfaces and surfaces with flexible substrates with metallic or paint coatings.
- Paints containing large pigment particles.
- Some dry lubricants
- Surfaces prone to corrosion or oxides.
- Fabrics with brittle constituents (e.g., composites, graphite or glass).
- Perforated materials when insufficient post-cleaning is performed or material is highly susceptible to tear propagation (e.g., multilayer insulation [MLI]).
- Metal oxides (bare [untreated] aluminum and magnesium, iron, non-corrosion resistant steel, etc.).
- Materials containing fabric or fabric scrim (these materials must have all edges sealed with tape if used in optic cavities or near optic cavities.
- Braided metallic or synthetic wires, ropes, slings, etc. (these must be sheathed entirely).
- Woven materials especially cut or unfinished ends (metal braid, Electromagnetic Interference [EMI] shielding, lacing cord, expando sleeving).

- Materials with thin films that might erode or crack and flake (Indium Tin Oxide [ITO] Teflon MLI, metallized packaging materials).
- Velcro use should be limited, particularly near sensitive surfaces. Its use should be quantified and provided to the LRO Contamination Engineer for approval.

4.3 MECHANISMS AND DEPLOYMENTS

Mechanisms and hardware deployments shall not generate particulate debris or molecular contaminants that will adversely impact adjacent external surfaces or other external contamination sensitive surfaces. Design of internal mechanisms shall restrict or prohibit the venting of lubricant via a labyrinth seal, if possible. In addition, effluent from vents in mechanisms will not impinge upon external contamination sensitive surfaces. Particulate debris generation and molecular contamination generation of mechanisms and hardware deployments will be verified via test data or analyses.

4.4 PROCESSING REQUIREMENTS

Contamination control measures should be used during all manufacturing phases and storage/ transportation. Surfaces should be kept clean, and if any debris is generated during the manufacturing process it should be immediately vacuumed with an ESD compatible vacuum or wiped off with solvent dampened extracted wipes. Some surfaces cannot be wiped with a solvent. ITO is such a surface. Germanium surfaces may be wiped, but require gentle handling. Kapton can be wiped with a solvent dampened extracted wipe without excessive concern for the surface. Black Kapton can be wiped with an extracted wipe dampened with a solvent, but excessive solvent use is not advisable. Detailed information and cleaning procedures for LRO surfaces will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

All ground support equipment should be cleaned and inspected to **visibly clean** (**VC**) per the Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005) before it enters the cleanroom. Cables should be bagged and all suspect equipment should be precision cleaned. Equipment with cooling fans must remain downstream from sensitive hardware or remain outside of the cleanroom. Support equipment used in the vacuum chamber must meet flight hardware material requirements and will be subjected to a bakeout prior to hardware bakeout and thermal vacuum testing. Whenever hardware is not being worked on for an extended period of time, it should be covered or bagged. Covering materials and drapes must be contamination and ESD approved. Protective bagging and covering materials at the launch site must also be hypergolic compatible and pass flammability acceptance levels as per NASA-STD-6001. Additional bagging requirements can be found in Section 2.4.1.

All WOAs involving hardware-related work on the spacecraft (including mechanical operations, blanket installation, electrical mating and/or rework, subsystem installation, etc.) must include steps to verify all tools and materials are clean prior to work and are accounted for when work is complete. In addition, a visual inspection for molecular and particulate contamination must be performed and the area cleaned in accordance to the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

To prevent ESD damage to any of the electronic components, precautions beyond contamination control measures will be required. This may mean using antistatic packaging films that also meet the contamination requirements of Section 2.4.1, ESD approved garments, and grounded wrist straps. Additionally, the temperature and humidity of the work environment will have to be controlled. Concerns pertaining to ESD should be brought to the attention of QA. Additional ESD requirements can be found in the Lunar Reconnaissance Orbiter Electrical System Specification (431-SPEC-000008).

5.0 MOLECULAR ADSORBERS

Molecular adsorbers may be incorporated into the LRO spacecraft venting design. The purpose of the molecular adsorbers is to control on-orbit outgassing, particularly electrostatic return, and to reduce the number and duration of spacecraft box bakeouts. Molecular adsorber consists of honeycomb pucks coated with a Zeolite coating. The outgassed effluent from the internal components should be directed through the spacecraft vents and the molecular adsorbers when exiting the spacecraft volume. The Zeolite pucks have a high efficiency for adsorbing these contaminants.

6.0 CLEANROOM FACILITIES AND OPERATIONAL REQUIREMENTS

Integration of LRO shall occur in a FED-STD-209E Class 10,000 (ISO Class 7) or cleaner facility. The facility shall provide a High Efficiency Particulate Air (HEPA) filtered bank at flow rate **TBD**. The most sensitive hardware will be placed closest to the HEPA filters in the cleanroom and less sensitive hardware will be kept downstream from the more sensitive hardware. Typical cleanroom temperature will be maintained at 70±5 degrees Fahrenheit (°F) and the relative humidity will be maintained at 30 to 50%. If these environmental conditions are not maintained, activities will stop until the I&T manager, facilities manager, or the Contamination Control Engineer, have evaluated the conditions and corrective measures have been taken.

Spacecraft hardware and GSE shall be cleaned to the required levels by Contamination Control Technicians in the Precision Cleaning Room. All hardware cleaned in the Precision Cleaning Room shall be double bagged for transportation to the cleanroom facility. For convenience, a precision cleaning station may be set up outside the cleanroom facility.

6.1 CLEANROOM GARMENTS

Personnel entering the cleanroom are required to use the shoe cleaner, walk on a series of tacky mats, and use the air shower. Cleanroom type garments will be worn in the cleanroom at all times. The best garments are usually made of polyester or nylon and are efficient particulate filters to human generated contamination. In addition, garments must meet ESD standards. Full cleanroom garments, including bunny suits, face masks, hoods, boots, and Nitrile gloves shall be worn on the LRO Project. Details on gowning and personnel operation procedures will be found in the Lunar Reconnaissance Orbiter Clean Area and Personnel Operations Procedure (431-PROC-000601).

6.2 NON-VOLATILE RESIDUE LEVELS IN THE FACILITY

Molecular witness plates will be used to monitor the molecular contamination level in the facility. At least **two** plates will be exposed at any given time. The plates will be analyzed **once** per month, staggered so one plate is measured every **60** days. The acceptable level of NVR on the plate after 2 months is **Level A/2** per Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C), **0.5 mg/0.1m^{2}.**

6.3 PARTICLE COUNTS IN THE FACILITY

The facility environments will be continuously monitored with a particle counter near the personnel work area. If the particle counts exceed Class **10,000**, personnel will leave the facility and/or contamination-generating operations will stop, as directed by the I&T Manager, the I&T Manager's representative, or QA.

6.4 CLEANROOM MAINTENANCE

The facility will be cleaned twice per week or more often as necessary. The cleanroom will be vacuumed, than mopped with deionized water and low-residue, non-ionic detergent. Scaffolding and other work fixtures will be cleaned at that time. **ManTech** will perform the facility cleaning operations using the procedures outlined in the Lunar Reconnaissance Orbiter Clean Area and Personnel Operations Procedure (431-PROC-000601).

6.5 SUPPORT MATERIALS

Tools, GSE, and any other items containing materials that shed, slough, or flake particles or outgas molecular contaminants at room temperature are prohibited from the cleanroom. The cleanliness requirements for tools and GSE are given in Section 8.1.

In addition, only non-retractable ball point pens will be used for writing in the cleanroom. Documents needed in the cleanroom will be on lint-free cleanroom paper, cleaned, and bagged for transport. If this practice is not possible, the documents shall be bagged and sealed in clean bagging material and remained bagged while in the cleanroom. All documents shall be kept downstream of flight hardware.

Additional material and personnel regulations will be found in the Lunar Reconnaissance Orbiter Clean Area and Personnel Operations Procedure (431-PROC-000601).

A list of approved cleaning materials will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

6.6 FACILITY/MAINTENANCE RESTRICTIONS

The following table describes the facility and maintenance restrictions while LRO is in the Building 7/10/15/29 complex.

Table 6-1. Facility/Maintenance Restrictions

Activity	Restrictions	Restriction Time Period
Combustion Engine Operation Standard Operations (Mowing Grass, normal deliveries)	No restrictions	From LRO assembly to shipping date
Combustion Engine Operation (Buses, idling trucks, etc)	Not permitted outside near air intakes	From LRO assembly to shipping date
Combustion Engine Operation Non-standard Operations (cranes, forklifts, trucks, construction, generators, etc)	Need Approval. May be allowable depending on location of flight hardware	From LRO assembly to shipping date

Activity	Restrictions	Restriction Time Period
Herbicides / Pesticides	Not permitted outside/inside building 7/10/15/29.	From 1 months prior to LRO assembly to shipping date
Painting (exterior)	Ask for approval prior to painting outside building 7/10/15/29	From 2 weeks prior to LRO assembly to shipping date
Painting (interior)	Ask for approval, some bldg 7/10/15/29 locations acceptable.	From 2 weeks prior to LRO assembly to shipping date
Roofing / Roofing Repairs	None within ½ mile of Bldg 7	From 2 weeks prior to LRO assembly to shipping date
Paving	None within ½ mile of Bldg 7	From 2 weeks prior to LRO assembly to shipping date
Facility floor cleaning/stripping/waxing	Ask for approval. Not permitted within building housing LRO flight hardware.	From LRO assembly to shipping date
Facility Floor Maintenance (Pouring/replacing/repairing floors)	Ask for approval within 7/10/15/29 complex	From 2 weeks prior to LRO assembly to shipping date
Solvent usage in Building 7 high bay	Non typical solvent use (i.e., Isopropyl Alcohol [IPA], Acetone, Freon) requires approval	From LRO assembly to shipping date
Sealants, caulks (Windows, bathrooms, ceiling tiles, HEPA filters, etc)	Ask for approval within building 7/10/15/29 complex	From 2 weeks prior to LRO assembly to shipping date
Adhesive bonding, gluing (installation of carpets, base board molding, flooring, etc)	Restricted in Bldg 7/10/15/29 complex; Ask for permission based on specific location within building	From 2 weeks prior to LRO assembly to shipping date
Sandblasting, sanding, grinding, jack hammering	Not permitted near air intakes in Bldg 7/10/15/29	From 2 weeks prior to LRO assembly to shipping date
Repair, replacement, or lubricant of cleanroom equipment (Air handling equipment, cranes, doors, etc)	Ask for approval. Not permitted within building housing LRO flight hardware.	From 2 weeks prior to LRO assembly to shipping date
Use of equipment with air bearing	Notify project to allow protection of critically sensitive operations if in same facility	From LRO assembly to shipping date

The facility restrictions listed in Table 6-1 also apply to facilities housing complete LRO subsystem components at GSFC. The Contamination Control Engineer will determine at what point during the assembly phase, normally before major components become inaccessible, these restrictions will be enacted. The Contamination Control Engineer will also evaluate the various facilities housing sub-system components at GSFC during assembly and processing to understand the work environment. Additionally, an LRO contamination representative will attend weekly facility meetings to stay informed of upcoming facility activities in order to take appropriate remedial action and vice versa, to inform facilities of LRO sensitivities and facility restrictions.

7.0 CONTAMINATION CONTROL DURING FABRICATION AND ASSEMBLY

7.1 LRO INSTRUMENTS DURING FABRICATION AND ASSEMBLY

The Instrument Providers are responsible for the contamination Control of their instruments during instrument fabrication and assembly at the instrument facilities and transportation to GSFC per the Instrument's contamination control plan and other applicable instrument documentation. Instruments shall be delivered to LRO meeting the cleanliness compatibility requirements specified in Section 2.2.

7.2 LRO SUBSYSTEMS DURING FABRICATION AND ASSEMBLY

LRO subsystems will be maintained at level **450 A/2** per the Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C) throughout the fabrication process and as surfaces become inaccessible they must be cleaned to **450 A/2** per the Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C). Detailed procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600). The following guidelines apply during subsystem fabrication and assembly.

Internal electronic box level and board level fabrication and assembly shall be governed by the proven cleanliness practices of the box vendor.

During manufacturing operations such as machining, welding and soldering contaminants should be cleaned off of the hardware by wiping and/or vacuuming. Lubricants and cutting oils (i.e. oils and greases) should be cleaned off as soon as possible after the manufacturing operation using appropriate solvents. Prior to priming or painting, the surface should be cleaned free of particulate or molecular deposits and be inspected to a **450 A/2** per the Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C). If an area becomes inaccessible during fabrication, it must be cleaned and inspected to **450 A/2** before becoming inaccessible. Upon completion of a fabrication operation, the components will be subjected to a gross cleaning procedure involving solvent washes and particulate removal. The clean fabricated components will then be bagged. Detailed procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

Assembly of fabricated components will take place in a clean area as defined in Table 2-2 and Table 7-1. During assembly, parts will be inspected and cleaned to **450 A/2** prior to becoming inaccessible. The following guidelines should be adhered to in the assembly process. Detailed procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

Parts, surfaces, holes and so forth must be cleaned with IPA moistened wipes or swabs. Only approved wipes, that are low in particulate generation and low NVR, shall be used. Wiping should be in one direction only and each pass should be with a new clean area on the existing wipe or using a new wipe. In some instances, wipes will be ineffective and extracted swabs moistened with alcohol may be used. Parts may also be cleaned in the Quadrex. The Quadrex is a shear stress precision cleaning system, which is housed in the Space Systems Development and Integration Facility (SSDIF) precision cleaning room at GSFC. Cleaning will continue until all surfaces are visibly clean, highly sensitive upon inspection. Any cleaning of painted surfaces will be done according to the procedure recommended by the manufacturer or be performed by the GSFC Contamination and Coatings Engineering, Code 546. Prior to any final assembly, all surfaces must be vacuumed and wiped with the appropriate solvent, giving special attention to holes, crevices and riveted regions. Assemblies will be inspected for oil or grease deposits, and if any are found, the areas will be wiped with IPA moistened wipes or other appropriate solvent, using a clean wipe area for each pass and wiping in one direction.

Table 7-1. Fabrication and Assembly Location and Cleanliness Matrix

Instrument or Sub-Assembly	Component	Fabrication Area and Cleanroom Class	Assembly Area and Cleanroom Class	Hardware Cleanliness Level
TBD	TBD	TBD	TBD	TBD

7.3 MECHANICAL STRUCTURE FABRICATION, BUILD, AND ASSEMBLY

The instrument module, non-flight structural verification unit, flight spacecraft bus, and propulsion module will be built and assembled in the **TBD** facility area. The hardware will be maintained at a **450 A/2** per the Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C). All flight hardware will be cleaned and baked prior to delivery to spacecraft/orbiter integration in the building **TBD**, FED-STD-209E Class **10,000(**ISO Class 7) **TBD** facility. Detailed cleaning procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

7.4 LRO ORBITER DURING FABRICATION AND ASSEMBLY

The Orbiter integration will occur in the building **TBD**, FED-STD-209E Class 10,000 (ISO Class 7) **TBD** facility. Parts from a less controlled fabrication and assembly area will be cleaned to the required levels, defined in Table 2-2, prior to entry into the cleanroom.

Accessible areas of the assembled orbiter will be cleaned to the required cleanliness levels according to the schedule in Section 2.2. All exterior surfaces will be cleaned to a level **450 A/2** and interior spacecraft surfaces will be cleaned to level **450 A/2**, as they become inaccessible. Parts that have been machined, welded, or riveted will be inspected to a **450 A/2** level with white and black lights and the required MIL-STD-1246C level prior to entering the cleanroom. Detailed cleaning procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

Solar panels, coarse sensors and radiators will be cleaned according to the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600). Instrument providers are responsible for instrument cleaning, unless permission and a detailed cleaning procedure are provided to GSFC.

8.0 CONTAMINATION CONTROL DURING INTEGRATION AND TEST

LRO will be integrated at GSFC in the building **TBD**, Fed-Std-209E Class 10,000 (ISO Class 7) **TBD** facility. Room temperatures will be in the 18°C to 28°C (65 to 75°F) range and typical humidity requirements are 30 to 50%. Personnel working in the cleanroom will wear full cleanroom outfits, booties, hoods, masks and approved gloves. When working with solvents, polyethylene or low NVR Nitrile gloves should be worn. Detailed gowning procedures and personnel operating procedures will be posted if different than standard operating procedures for the facility. The approved bagging material for the LRO Project is listed in Section 2.4.1.

8.1 GROUND SUPPORT EQUIPMENT

Tools and GSE required for testing will be cleaned to **VC** per the Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005C) with IPA and bagged prior to entry into the cleanroom. Large pieces of GSE may be cleaned and inspected outside the facility roll up door and immediately taken into the cleanroom after cleaning and inspection, without being bagged. In addition, tools and GSE that comes into contact with flight hardware must be inspected to Visibly Clean-Highly Sensitive (**VCHS)** level under black light and white light per the Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005C) prior to entering the cleanroom. If at any time, the tools or GSE become visibly contaminated, the hardware will be re-cleaned and inspected. Detailed cleaning procedures will be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Plan (431-PLAN-000600).

Tools and GSE containing materials that shed, slough, or flake particles or transfer or outgas molecular contaminants at room temperature are prohibited from the clean room. Critical GSE containing fans must be positioned downwind from the instrument module, spacecraft, and/or orbiter with respect to the HEPA filters. Printers are not allowed in the cleanroom. Additional material restrictions can be found in Section 4.2.1.

8.2 CONTAMINATION CONTROL FLOW

The Contamination Control Flow throughout I&T can be found in Figure 8-1 (TBD). Figure 8-1 will be a simplified LRO I&T flow and will be intended to show cleanliness inspections and cleanings with respect to activities, not detailed I&T activities. Detailed I&T flow can be found in the Lunar Reconnaissance Orbiter Integration and Test Plan (431-PLAN-000100).

Figure 8-1. Contamination Control Flow throughout the I&T Process (TBD)

8.3 INSTRUMENTS DURING INTEGRATION AND TEST

Prior to delivery to LRO, all LRO Instruments must pass the outgassing certification requirement as defined in Section 2.2.1. If the instrument outgassing requirements are not met, the instrument must obtain a waiver from the LRO Project/Contamination Engineer or be baked-out to the required levels. Upon delivery to LRO the instrument exterior cleanliness level will be inspected to the levels in Section 2.2. Instruments not meeting the cleanliness requirements must be cleaned by their instrument support team and then re-inspected.

Instrument bench acceptance testing will be performed in a FED-STD-209E Class **10,000** (ISO Class **7**) clean tent or cleanroom environment for the contamination sensitive instruments. The instrument will be purged per the requirements in the respective Spacecraft to Instrument Mechanical Interface Control Document and/or the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602). Following these inspections and testing, the instrument will be bagged and delivered to the appropriate cleanroom facility for integration.

If needed and when instrument dependant, the instruments will be continuously purged with dry, filtered nitrogen throughout I&T, as required and defined in the Spacecraft to Instrument Mechanical Interface Control Document. If the purge must be interrupted, the duration of the interruption shall not exceed instrument requirements. GSFC personnel will inspect instruments to the cleanliness levels in Section 2.2, per the schedule in Section 11.2. If an instrument does not meet the required cleanliness level, the instrument shall be cleaned until it meets the requirement. Those instruments that are contamination sensitive, will be bagged and purged during all periods of inactivity, or if the hardware is outside of the cleanroom. If an instrument or hardware is removed from the cleanroom for testing in an unbagged condition, or some other reason such as calibration, it must be re-verified to the external cleanliness requirements in Section 2.2 or 2.3, before it can reenter the cleanroom. The instrument support team is responsible for cleaning and maintaining their respective instruments during orbiter integration and testing. GSFC will clean external instrument surfaces with permission and a detailed written procedure from the instrument provider.

8.4 PURGING REQUIREMENTS

A nitrogen purge will be available for LRO instruments as required, during I&T until launch. The nitrogen purge will be filtered to **0.5** microns or smaller and shall conform to Propellant Pressurizing Agent, Nitrogen (MIL-PRF-27401D, Grade **C)** and Nitrogen Propellant Pressurizing Agent, Nitrogen (ISO 15859-3). At the launch site, the use of a t-0 purge line will be necessary.

The purge interfaces and purge rates will be defined in the Spacecraft to Instrument Mechanical Interface Control Documents and/or the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602).

The purge system, purge panel, and associated safety requirements will be defined in the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602).

8.5 INTEGRATION OF SUBSYSTEMS AND THE ORBITER

All subsystems and/or components must meet an outgassing certification requirement prior to integration per Section 2.3.1. At the time of integration, components or subassemblies will be inspected to their required cleanliness levels. All spacecraft hardware and ground support equipment shall be cleaned, by the appropriate support personnel, prior to the hardware entering the designated integration facility.

Oils, greases and other similar agents that may be contamination hazards will not be used during integration without the permission of the Contamination Engineer. Joints or crevices will be covered during integration to minimize the build up of contaminating debris. Rivets, bolts, nuts and so forth must be cleaned to remove any type of contamination such as lubricants and machining oils prior to integration and test.

Frequent white light and black light inspections will be made during integration to ensure that the spacecraft is maintained at the levels specified in Sections 2.3 and 2.4.

Electronic boxes, which are sensitive to ESD, will be handled only when personnel are grounded with wrist straps. Work areas will be grounded. Additional requirements will be found in the Lunar Reconnaissance Orbiter Electrical System Specification (431-SPEC-000008).

The completed orbiter will be cleaned to the levels as specified in Sections 2.2, 2.3, and 2.4. Direct sampling of the orbiter surfaces can involve taking tape lifts, solvent wash samples, swab samples, and black/white light inspections. Particular attention should be given to areas, which will become inaccessible during integration. All areas as they become inaccessible will be cleaned to the required cleanliness levels defined in Section 2.3. The cleaning procedures may entail vacuuming, Carbon Dioxide (CO_2) snow cleaning, and/or solvent wiping per upcoming Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600).

The orbiter (except attach points) should be bagged per Section 2.4.1 with approved bagging film during crane operations.

8.6 TEST FACILITIES

Following integration, LRO will be subjected to environmental testing. Figure 8-1 will be a simplified flowchart of the environmental testing sequence. In the testing facilities, the instruments will be bagged individually and continuously purged with nitrogen. In addition, the orbiter will also be bagged, when possible. Testing facilities will be held at 65 to 75°F temperature and 30 to 50% humidity conditions. If a particular test requires the removal of bagging, the facility will be cleaned and the personnel who come in contact with the orbiter and instruments must be wearing cleanroom bunny suits, booties, hoods, masks and gloves. If solvents are used, polyethylene or low NVR nitrile gloves (blue) must be worn.

8.6.1 Electromagnetic Compatibility/Electromagnetic Interference Facility

At GSFC, the Electromagnetic Compatibility (EMC)/EMI facility is a Class 10,000 cleanroom adjacent to the Spacecraft Checkout Area (SCA). Personnel requiring access to the facility may need additional cleanroom training. The facility has humidity and temperature control. The instruments and spacecraft shall remain bagged as much as possible, unless I&T activities in the EMC/EMI room prohibit bagging. The instruments will be purged continuously.

8.6.2 Vibration Cell

The vibration cells are not cleanroom facilities; however, they will be operated as a Class 10,000 cleanroom through facility cleanings, materials restrictions, and implementation of personnel cleanroom protocol. Full cleanroom garments will be worn. Personnel in the facility will be limited. The cell will be cleaned prior to orbiter arrival and maintained clean while the orbiter is in the facility. The doors to the cell will remain closed to maintain the room cleanliness, unless operations require temporary door opening. The instruments will remain bagged and purged at all times while in the vibration cell. The orbiter will be bagged as much as possible, unless prohibited by test activities.

8.6.3 Acoustic Facility

The Acoustics Facility is classified as a Class 100,000 cleanroom, but can be operated as a Class 10,000 cleanroom through facility cleanings, materials restrictions, and implementation of personnel cleanroom protocol. All personnel working in the Acoustics Facility will wear full cleanroom garments. The room shall be cleaned prior to orbiter arrival and maintained clean while the orbiter is in the facility. The instruments will remain bagged and purged at all times. The orbiter will be bagged as much as possible, unless prohibited by test activities.

8.6.4 Thermal Vacuum Chamber (SES)

The **SES** thermal vacuum chamber will be operated as a Class **10,000** cleanroom. Additional cleanroom training may be required by personnel working in the **SES** chamber, to become familiar with unique **SES** chamber protocol and restrictions. All personnel will enter the chamber through the gowning area. Full cleanroom garments will be worn. Personnel will be kept to a minimum inside the chamber. A GSE, tool, and hardware cleaning station will be set up outside the gowning area. Care must be taken to account for all materials, tools, and equipment brought in and out of the chamber. The chamber will be cleaned and inspected prior to loading LRO into the chamber. A crane may be used to load LRO into the **SES** chamber. The orbiter must be draped with clean bagging film anytime the chamber lid is opened during thermal vacuum preparations. The chamber will be inspected and re-cleaned, if necessary, after all work is completed prior to closing the doors. The red tag covers on contamination sensitive components shall be removed at the last possible moment. The instruments will remain bagged and purged until the last possible moment prior to closing the chamber doors.

Contamination monitoring during the orbiter thermal vacuum test is addressed in Section 2.4.3. All test instrumentation shall be installed on the orbiter in the **TBD** facility or comparable cleanroom prior to moving the spacecraft to the **SES** thermal vacuum chamber. After installation of instrumentation is complete, the orbiter will be double bagged and transported to the **SES** chamber.

The LRO I&T Plan 4431-PLAN-000100 should be referenced for the latest thermal vacuum chamber location and supersedes the chamber baselined in this document.

9.0 CONTAMINATION CONTROL DURING TRANSPORTATION AND STORAGE

After delivery, all instruments will be bagged and purged during storage or transportation. Subsystems and subassemblies, which do not have any special requirements for handling and storage prior to integration, will be cleaned to their respective cleanliness requirement and bagged unless integration or test activities prohibit it. All systems will be stored in an air-conditioned area with controlled access. The orbiter will be bagged with approved bagging material per Section 2.4.1 when outside of the cleanroom, unless I&T activities prohibit it.

For transportation outside the GSFC I&T complex, the orbiter shipping container will be used for protection. The orbiter shipping container will be pre-cleaned, prior to use, to Level **VCHS** per the Contamination Control Requirements for the Space Shuttle Program (JSC-SN-C-0005C)**.** Nitrogen or dry, filtered ultra high purity air will be used to purge the shipping container per the Lunar Reconnaissance Orbiter Purge System Specification (431-SPEC-000602) and the instrument interface control documents. Temperature and humidity will be controlled and monitored in the shipping container to meet LRO orbiter requirements. In addition, witness plates and NVR monitors will be mounted inside the shipping container to monitor the contamination environment during transportation.

10.0 CONTAMINATION CONTROL AT THE LAUNCH SITE

This Plan does not cover launch site processing. The LRO launch site contamination control requirements for the orbiter, the facilities, and the launch vehicle will be delineated in the Lunar Reconnaissance Orbiter Launch Site Contamination Control Plan (431-PLAN-000599). The LRO Contamination Engineer and the launch vehicle and facilities staff will coordinate the launch site activities.

11.0 IMPLEMENTATION OF CONTAMINATION CONTROL REQUIREMENTS

The I&T Manager, QA, and Contamination Engineer will be responsible for ensuring that contamination control measures are implemented throughout the design, fabrication, assembly, integration, testing, storage and transportation.

11.1 CLEANLINESS INSPECTION AND MONITORING METHODS

Cleanliness inspection and monitoring methods, which will be used for the LRO mission, are witness plates; OWS, black and white light inspections, washes, swab sampling, tape lifts, and a real time NVR monitor. Details on these inspection and monitoring methods can be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600). Descriptions of these techniques are as follows:

a. Witness Plates:

Witness Plates are used to determine particulate levels, particle fallout rates, and NVR levels. Witness plates collect particulates passively during cleanliness monitoring procedures. Witness plates should be placed as close as possible to contamination sensitive areas, to obtain the most accurate particulate readings. The spacecraft particle witness plates at GSFC are generally silicon wafers because of the image analyzer's ability to process the wafers and determine pretest cleanliness. Occasionally, Teflon grids are used. Facility fallout plates are usually 1 ft^2 stainless steel plates that are washed and analyzed for molecular or particulate contamination.

b. Optical Witness Samples:

OWS consist of quartz glass with a thin film of aluminum and a magnesium fluoride coating to represent an optical surface. Molecular contamination is allowed to deposit on the samples during cleanliness monitoring. After monitoring, the reflectance degradation of the OWS is measured.

c. Light Inspections:

Visual Inspection is done periodically using black (UV) light or white light. Visibly clean, using white light is the absence of all particulates and non-particulates visible to the normal unaided eye (except corrected vision). The three levels of visibly clean and observational distances are listed in Table 11-1. UV inspection light sources are no less than 100 watts and located no more than 50cm from the inspected item. During UV inspection, light from other sources should not be more than 5 ft-candles. If visual contamination is evident, the hardware must be cleaned and then re-inspected under the same light conditions. If during UV inspection there is any evidence of fluorescence the item/surface must be re-cleaned. If re-cleaning does not reduce the fluorescence, it must be determined whether the fluorescing material is a contaminant or the substrate surface.

**Table 11-1. Visibly Clean Levels and Inspection Criteria
(From JSC-SN-C-0005C)**

VC Level	Incident Light Level (1)	Observation Distance	Notes
Standard	≥ 50 foot-candles	5 to 10 feet	(2) (3) (5)
Sensitive	≥ 50 foot-candles	2 to 4 feet	(2) (3) (5)
Highly Sensitive	≥ 50 foot-candles	6 to 18 inches	(3) (4)

NOTES: (1) One foot-candle (lumens per square foot) is equivalent to 10.76 lumens per square meter.
(2) Cleaning is required if the surface in question does not meet VC under the specified incident light and observation distance conditions.
(3) Exposed and accessible surfaces only.
(4) Initial cleaning is mandatory; Note (2) applies thereafter.
(5) Areas of suspected contamination may be examined at distances closer than specified for final verification.

d. Washes:

A surface, which is to be inspected, is washed with alcohol or an appropriate solvent and the solvent and residue is collected. This rinse is then subjected to a quantitative and qualitative analyses and the type of contaminant residue is chemically identified.

e. Tape Lifts:

Tape lift samples are taken of the inspection surface to determine the surface particulate cleanliness level according to Product Cleanliness Levels and Contamination Control Program (MIL-STD-1246C). The tape lift samples are prepared, taken and read by GSFC according to the Contamination Control Procedures for the Tape Lift Sampling of Surfaces (GSFC-TLS-PR-7324-01). Tape lifts can not be taken on painted surfaces, ITO coated surfaces, or on other delicate coatings.

f. Real Time Non-Volatile Residue Monitor:

A real time non-volatile residue monitor can be utilized on the LRO Project. The monitor can measure NVR build up over time. The NVR is measured electronically with a surface acoustic wave sensor. This monitor can be placed in the vicinity of the orbiter.

11.2 VERIFICATION AND CLEANING SCHEDULES

Cleanliness verification and monitoring will occur as listed below at a minimum and more frequently if the LRO Contamination Control Manager deems that extra cleanliness monitoring is necessary. The hardware surfaces will be inspected for compliance to the cleanliness requirements in Table 11-2. If the contamination levels on the hardware exceed the cleanliness requirements, a cleaning will be scheduled. Each cleaning will be conducted under a WOA developed for the specified cleaning. The cleanings shall be performed by ManTech Contamination Control Technicians or by the GSFC Contamination Engineering Group. The detailed cleaning procedures can be found in the Lunar Reconnaissance Orbiter Cleaning and Verification Procedure (431-PROC-000600). The instrument providers will be notified for cleanliness inspections and hardware cleanings affecting or in the vicinity of the instruments. Results from the inspection methods and cleanliness verification on the orbiter will be provided to the instrument providers. Instrument unique cleanliness verification and witness sample change-out will occur per the requirements in the respective Spacecraft to Instrument Interface Control Document. The instrument providers are responsible for cleaning the instruments unless permission is given and a detailed cleaning procedure is provided.

Table 11-2. Verification and Cleaning Scheduled

Reason for Inspection or Cleaning	Item to be inspected or cleaned	Cleanliness Requirement	Method
Instrument Delivery	Instrument	**TBD**	**TBD**
Sub-System Delivery	Sub-Systems	**TBD**	**TBD**
Integration	Instrument, Sub-Systems, Orbiter	**TBD**	**TBD**
Post Integration	Orbiter	**TBD**	**TBD**
Vibration Testing	Orbiter	**TBD**	**TBD**
Post Vibration Testing	Orbiter	**TBD**	**TBD**
Acoustics Testing	Orbiter	**TBD**	**TBD**
Post Acoustics Testing	Orbiter	**TBD**	**TBD**
Pre-Thermal Vac	Orbiter	**TBD**	**TBD**
Thermal Vac	Orbiter	**TBD**	**TBD**
Post Thermal Vac	Orbiter	**TBD**	**TBD**
Post Mass Properties	Orbiter	**TBD**	**TBD**
Pre-Ship	Orbiter	**TBD**	**TBD**
Shipping	Orbiter	**TBD**	**TBD**
Transportation	Orbiter	**TBD**	**TBD**
Launch Site	Orbiter	**TBD**	**TBD**

12.0 EMPLOYEE TRAINING

Contamination Control and Cleanroom Practices training should be conducted for all personnel involved in the fabrication, assembly, integration, testing, transportation, storage, and launch site activities of the LRO instruments, subsystems and orbiter. Areas which can be studied in the training sessions are as follows: Definition of contamination and how it affects the LRO mission; the importance of maintaining contamination control from fabrication through launch; reviewing instrument and subsystem sensitivities; knowledge of the instrument and spacecraft contamination control plans and related contamination documents; specific techniques for cleaning, inspection, and packaging; monitoring techniques in the cleanroom and in the shipping containers; and cleanroom dressing procedures and rules for working in a controlled cleanroom area.

Appendix A. Abbreviations and Acronyms

Abbreviation/ Acronym	DEFINITION
ANYS	Analysis
ASTM	American Society for Testing and Materials
B/O	Bakeout
BOL	Beginning of Life
CCB	Configuration Control Board
CCE	Contamination Control Engineer
CM	Configuration Management
CMO	Configuration Management Office
cm^2	Centimeters Squared
CO_2	Carbon Dioxide
CRaTER	Cosmic Ray Telescope for Effects of Radiation
CSS	Course Sun Sensors
CVCM	Collected Volatile Condensable Materials
DLRE (DIVINER)	Diviner Lunar Radiometer Experiment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EOL	End-of-Life
ESD	Electrostatic Discharge
FED-STD	Federal Standard
ft^2	Feet Squared
g/cm^2	Grams per centimeter squared
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HEPA	High Efficiency Particulate Air
I&T	Integration and Test
ICD	Interface Control Document
IEST	Institute of Environmental Sciences and Technology
IPA	Isopropyl Alcohol
ISO	International Organization for Standardization
ITO	Indium-Tin Oxide
JSC	Johnson Space Center
KSC	Kennedy Space Center
LAMP	Lyman-Alpha Mapping Project
LEND	Lunar Exploration Neutron Detector
LN_2	Liquid Nitrogen
LOLA	Lunar Orbiter Laser Altimeter
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera

m^2	Meters Squared
mg	Milligrams
MIL-STD	Military Standard
Mini-RF	Miniature Radio Frequency
MLI	Multi-Layer Insulation
NASA	National Aeronautics and Space Administration
NVR	Non-Volatile Residue
OWS	Optical Witness Sample
PAC	Percent Area Coverage
PAIP	Performance Assurance Implementation Plan
PROC	Procedure
psia	Absolute pressure per square inch
QA	Quality Assurance
RLEP	Robotic Lunar Exploration Program
SA	Solar Array
S/C	Spacecraft
SCA	Spacecraft Checkout Area
SES	Space Environment Simulator
SPEC	Specification
SSDIF	Space Systems Development and Integration Facility
STs	Star Trackers
STD	Standard
TML	Total Mass Loss
TBD	To Be Determined
TBR	To Be Reviewed
TQCM	Temperature-Controlled Quartz Crystal Microbalance
T/V	Thermal Vacuum
UV	Ultra Violet
VC	Visibly Clean
VCHS	Visibly Clean Highly Sensitive
WOA	Work Order Authorization
µg	Microgram
°C	Degrees Centigrade
°F	Degrees Fahrenheit