Large Synoptic Survey Telescope Camera System Plan	Document # **LCA-279-C** Author(s) J Langton Jack Singal Giulia Lanza Subsystem/Office Systems Integration	Status LSST Camera APPROVED Effective Date 5 Feb 2018
Document Title **LSST Camera Contamination Control Plan**		

1. Change History Log

Revision	Effective Date	Description of Changes
Draft 8	March 3, 2013	
Draft 9	April 22, 2013	
Draft 10	April 25, 2015	
A	June 12, 2016	Formal release per LCN-1613
B	May 11, 2017	Updated RGA and rate of rise testing. Released per LCN-1735
C	February 5, 2018	Clarification of the Camera Body contamination requirements and indications on how to perform the test with silica samples. Released per LCN-2003.

2. Contents

3. Acronyms and Definitions

3.1. Acronyms

AC	Area Coverage (% AC same as % Obscuration in practice)
ANSI	American National Standards Institute
APC	Automatic Particle Counter
ASTM	American Society for Testing and Materials
BRDF	Bi-directional Reflectance Distribution Function
CC	Contamination Control
CCD	Charge Coupled Device
CCE	Contamination Control Engineer (Engineering)
CCM	Contamination Control Manager
CCP	Contamination Control Plan
CQCM	Cryogenic Quartz Crystal Microbalance
CVCM	Collected Volatile Condensable Materials
CWS	Contamination Witness Sample
ECS	Environmental Control System

EOL	End of Life
ESD	Electrostatic Discharge
FAC	Fractional Area Coverage
FED-STD	Federal Standard
FOV	Field of View
GN2	Gaseous Nitrogen
HEPA	High Efficiency Particulate Air
HPLC	High-performance liquid chromatography
IEST	Institute of Environmental Sciences and Technology
I&T	Integration and Test
IPA	Isopropyl Alcohol
ISO	International Organization for Standardization
LSST	Large Synoptic Survey Telescope
MEK	Methyl Ethyl Ketone
MIL	Military
MTF	Materials Test Facility
NVR	Nonvolatile Residue
PAC	Percent Area Coverage (also % AC, same as % Obscuration in practice)
PPE	Personal Protective Equipment
ppm	parts per million
QA	Quality Assurance
QCM	Quartz Crystal Microbalance
QE	Quality Engineering
RGA	Residual Gas Analyzer
ROR	Rate of Rise
SLAC	SLAC National Accelerator Lab
TBD	To Be Determined
TBR	To Be Revised
TML	Total Mass Loss
TQCM	Temperature-Controlled Quartz Crystal Microbalance
VC	Visibly Clean
VCHS	Visibly Clean Highly Sensitive
VCM	Volatile Condensable Materials (see CVCM)
VCS	Visibly Clean Sensitive

3.2. Definitions

Area Coverage: The effective physical area surface obscured by particulate contaminants settled on the surface. The percent area coverage (%AC) is calculated per IEST-STD-CC1246 and the calculation is based upon random settlement of cylinder-hemispherical particles (which is more realistic than spherical particles) in various size ranges.

Biological Contamination: Living organisms such as insects, fungi, bacteria, algae, spores, etc., which are capable of reproducing, and therefore increasing in quantity, in ambient environments.

Cleanliness Level: An established level of maximum allowable particulate and/or molecular contamination ranging from qualitative definition (e.g.: visibly clean in accordance with JSC SN-C-0005) to specific quantitative levels of cleanliness (e.g.: IEST-STD-CC1246 Level R1E-2 or A/100 using the former designation level).

CleanRoom/Clean Zone: An enclosed room or area in which temperature, relative humidity, and airborne contaminants are controlled to within specified limits. Clean rooms are classified by numbers such as ISO 5 (Class 100 and M3.5 equivalent), ISO 6 (Class 1,000 and M4.5 equivalent), ISO 7 (Class 10,000 and M5.5 equivalent) etc., in accordance with ISO 14644, where the first numbers in parentheses describe an approximate maximum number of particles, 0.5 microns and larger, permitted per cubic foot of air and the second number is the metric equivalent. Air particulate cleanliness is maintained by high efficiency particulate air (HEPA) filters that provide 99.99% filtration of particles 0.3 microns and larger.

Contamination: Any unwanted material that causes degradation in the desired performance of an instrument or its hardware.

Contamination Budget: The itemized summary of contamination accumulation and results of cleaning for a given system or subsystem, starting from manufacture through end of its performance lifetime.

Contamination Control: Organized action to minimize the level of contamination to which hardware and the facilities' environment are exposed.

Contamination Controlled Activity: The processing or handling of an unprotected (exposed) object, that cannot be recleaned should it become contaminated, subject to cleanliness requirements in its respective subsystem specification.

Contamination Critical Component: A component that if contaminated directly affects Camera performance.

Contamination Sensitive Component: A component that if contaminated can, by means of cross contamination, subsequently contaminate a Contamination Critical Component

Critical Surface: A surface on which quantitative cleanliness criteria are required. Critical surfaces require precision cleaning and cleanliness measurement and verification.

Exposure duration: Any time span wherein a component is not in a container specifically designated as, and exclusively used for, storage or transport.

Fiber: A particle whose length-to-width ratio exceeds 10:1, with a minimum length of 100 microns.

HPLC grade: Reagent grade purity, suitable for High Performance Liquid Chromatography (HPLC) applications.

Nonvolatile Residue (NVR): Contamination in the form of soluble material remaining on a sensitive surface after evaporation of a volatile liquid, usually measured in milligrams per unit area (or volume, for liquids), which causes degradation in the performance or desired function of the component.

Particle: A small quantity of solid or liquid material with definable shape or mass with a length to width ratio less than 10:1.

Precision Cleaning: A process of fine cleaning accomplished in a controlled manner and environment to achieve precision cleanliness.

Precision Cleanliness: A level of cleanliness (freedom from contaminants) beyond that which can be verified by visual means alone. Measurement and verification of precision cleanliness criteria requires specialized equipment and techniques.

Sensitive Surface: Any surface of hardware that must meet a specified cleanliness level to assure the minimum performance levels. Sensitive surfaces require precision cleaning and cleanliness measurement and verification.

Solvent Spray 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. The solvent is not collected.

Solvent Wash: A method of surface cleaning in which a solvent is washed over a surface and collected. The collected solvent can be filtered and evaporated to measure the molecular contamination level of the surface washed per MIL-STD-1246.

Surface Cleanliness Level: An established level of maximum allowable particulate and/or NVR contamination ranging from visibly clean to specific MIL-STD-1246 levels.

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-1246 particulate cleanliness levels by measuring particulate contamination on a sample of tape that has come in contact with the surface one wishes to examine.

Vapor Degrease: Item to be cleaned is exposed to heated solvent vapors that condense on the part and wash away some of the contaminants.

Visibly Clean: The achievement of a clean surface as seen without optical aids (except corrected vision) as measured by a specified method. Three levels of visibly clean (VC) requirements are defined in JSC SN-C-0005. Visibly clean is the absence of particles as seen by the unaided eye at the distance and light level specified below.

4. Applicable Documents

4.1. Camera Documents

[1] LCA-18-A: LSST Camera Throughput Budget

[2] LCA-15742: LSST Contamination Requirements - Camera Body

[3] LCA-69: Camera Environmental Specification Analysis

[4] LCA-10032: ESD Control Plan

[5] Camera Contamination Confluence Page: https://confluence.slac.stanford.edu/display/LSSTCAM/Contamination

[6] Document-13679: Air Quality Requirements for RTM Assembly Cleanroom

[7] Document-8757: Estimated impact of contamination on LSST camera Throughput

[8] Document-8526: Image Quality degradation by Dust: Camera Contributions

4.2. Government Standards

[5] FED-STD-209: Airborne Particulate Cleanliness Classes in Cleanrooms and Clean Zones

[6] MIL-P-27401: Propellant, Nitrogen: Liquid and Gas

[7] MIL-STD-1246: Product Cleanliness Levels and Contamination Control Program

4.3. ASTM Standards

[8] E-595: Total Mass Loss and Collectable Volatile Condensable Materials from Outgassing in a Vacuum Environment

[9] E-1216: Practice for Sampling for Surface Particulate Contamination by Tape Lift

[10] E-1235: Gravimetric Determination of NVR in Environmentally Controlled Areas for Spacecraft

[11] E-1549: Specification for ESD Controlled Garments Required in Cleanrooms and Controlled Environments for Spacecraft Non-Hazardous and Hazardous Operations.

[12] E-1559: Contamination Outgassing Characteristics of Spacecraft Materials

[13] E-1560: Gravimetric Determination of Nonvolatile Residue from Cleanroom Wipers

[14] E-2042: Standard Practice for Cleaning and Maintaining Controlled Areas and Cleanrooms

[15] F-50: Continuous Sizing and Counting of Airborne particles in Dust-Controlled Areas and Cleanrooms Using Instruments Capable of Detecting Single Sub-Micrometer and Larger Particles

[16] F-303: Sampling Aerospace Fluids from Components

4.4. Other Specifications and Standards

[17] JSC SN-C-0005: NASA Contamination Requirements

[18] MSFC-HDBK-1674: NASA approved materials list available as document

[19] SP-R-0022: NASA preferred polymeric materials

[20] ISO 14644: International Standard for Clean Rooms and Clean Environments

[21] IEST-RP-CC018.2: Recommended Practice for Cleanroom Housekeeping Operating and Monitoring Procedures

[22] IEST-STD-CC1246: Product Cleanliness Levels – Applications, Requirements and Determination

5. Purpose and Scope

This Contamination Control Plan (CCP) defines the overall requirements necessary to achieve hardware cleanliness for the LSST Camera project.

This plan documents the technical and administrative requirements of contamination control to be adhered to by all participants in the LSST Camera program. It has been developed in compliance with government and industry standards and specifications to ensure that the contamination-critical and sensitive items in the Camera are fabricated, assembled, tested, handled, stored, and operated in a way that reduces the likelihood of damage or loss of function due to contamination.

All institutions and facilities engaged in processing of contamination-controlled hardware shall comply with the requirements defined in this contamination control plan. The requirements and programs in this plan apply to all manufacturing and test areas and all Camera operations where contamination-critical and sensitive items are involved.

The CCP establishes guidelines and practices for minimizing contamination of critical hardware during all phases of the program, including engineering, design, developmental test, fabrication, assembly, acceptance test, integration, storage, transport, operations and maintenance.

Requirements for hardware inspections, surface cleanliness measurement techniques, precision cleaning, laboratory analyses of collected contamination, and clean room certification and monitoring are also included.

6. Introduction and Overview

The LSST Camera incorporates a number of devices that are sensitive to damage or performance degradation from molecular or particulate contamination. These contamination-critical components include the charge-coupled devices (CCDs or "sensors") and the optical elements (lenses and filters). These elements are in intimate contact with and proximity to other hardware in the course of their lifecycles, and therefore they are vulnerable to cross-contamination if those adjacent items are not also contamination-controlled. Ultimately, a broad number of items associated with Camera production and operation are subject to the requirements of this CCP expressly to eliminate or minimize the likelihood of cross-contamination of critical components (CCDs and optics).

The CCDs are the most contamination-sensitive component in the Camera due to their fragile optical characteristics. For CCDs, cleaning could pose a risk to future performance in the cryostat, and the resulting difficulty (or impossibility) of recovering full-system performance by removing contamination.

The optical elements, while cleanable, are exposed to a potentially high rate of particulate contamination and are very sensitive to possible performance degradation due to unapproved cleaning procedures.

The early sections of this document define the types of contamination encountered in the Camera lifecycle and the mechanisms by which critical components can become contaminated.

The later sections of this plan establish the contamination-critical and sensitive hardware cleanliness requirements, Camera cleanliness zones specifications, and overall contamination-control requirements for those zones.

The final sections of this plan address process specific methods and requirements to assure that completed components and assemblies minimize the risk of introducing contamination to critical components that otherwise meet their contamination-control requirements.

7. Roles and Responsibilities

Respective subsystem managers have primary responsibility for ensuring people and processes are capable of delivering hardware in compliance with this document and in a condition which minimizes the risk of contamination to critical Camera components.

The Camera contamination control engineer has primary responsibility for ensuring subsystem plans and processes are adequate to provide hardware consistent with the requirements of the contamination control plan.

The contamination control engineer, systems engineers, integration and test manager, and quality assurance engineer shall be responsible for reviewing and approving contamination control measures

developed by subsystem managers, and ensuring said plans are implemented throughout all phases of Camera design, development, assembly, test, integration, operation, and maintenance.

Engineers and technicians engaged in design or processing of contamination-critical or sensitive hardware have primary responsibility of understanding and following the plans and processes of their home institutions to ensure deliverables meet or exceed the requirements of this CCP.

Those involved with contamination-sensitive fabrication, assembly and test will ensure they receive the training necessary to minimize contamination risk.

8. Contamination Types, Sources and Risks

Particulate and molecular material contamination is a major risk variable potentially affecting performance of the LSST Camera optical surfaces (CCD sensor surfaces, lenses, filters).

All Camera-contamination critical or sensitive hardware is vulnerable to one or both of the following mechanisms.

8.1. Molecular Contamination

Molecular contamination is undesired foreign matter without definite dimension, including corrosive and non-corrosive films, resulting from nonevaporable (i.e.: nonvolatile) substances such as oils, greases, chemical residues, fingerprints, heat and vacuum applications, chemical action, and incompatible materials. Molecular contamination can arise from thermal energy transport, without surface-to-surface contact, primarily in a vacuum environment (i.e.: outgassing products exit a "dirty" surface and condense on the critical surface). Molecular contamination can arise from physical or proximate contact of contaminated elements (i.e.: cross-contamination).

Condensable molecular contamination, namely water, is a unique contamination risk as water is ubiquitous in the environment. Proper hardware design and controlled cleaning process and handling is essential to limiting the risk of water contamination. For the most part, this risk must be mitigated by proper design and operation of the cryostat vacuum system and Camera body purge system.

8.2. Particulate Contamination

Particulate contamination is undesired foreign matter of miniature or microscopic size with observable length, width, and thickness, including fibers. Particulate contamination transport is primarily by gravity- or by viscous forces in non-vacuum environments. Free particulates arise largely through handling, during fabrication and assembly, resulting from flaking or shedding due to abrasion of flexing of incompatible materials including biological materials (skin, hair, etc). For the Camera, particulate contamination can also be due to shedding or abrasion of particulates at contact points in moving mechanisms. These particulates can be associated with one of the parent materials or associated with surface treatments or lubricants applied to a parent material.

8.3. Primary Contamination Risks

The prioritized risk scenarios for Camera contamination, based on the effect on performance and the difficulty of recovery from a "contamination event" are:

1. Non-Evaporable Residue (NVR-molecular contamination) in the vacuum of the cryostat that accumulates on critical surfaces (L3 and sensor surfaces).
2. Accumulation of condensable materials on optical surfaces that are cold relative to their surrounding environment (water on sensor surfaces or the first or second surfaces of the L3 lens).
3. Non-evaporable substances that accumulate on optical surfaces.
4. Accumulation of particulate matter on optical surfaces.

Quantitative analysis of contamination levels and the effect on Camera performance is used to define milestone cleanliness and exposure durations of the critical components. Such analysis is also used to establish cleanliness requirements for associated sensitive hardware.

9. Camera Contamination Critical and Contamination Sensitive Components

The CCDs and optics elements (L1, L2, L3 lenses, filters) are the Camera contamination-critical controlled components. Contamination of these components leads directly to loss or degradation of Camera performance. The CCDs and optics elements are not only vulnerable to contamination by means of mishandling, inappropriate processing or accident, but also to cross-contamination if adjacent components are themselves contaminated.

All components compromised by contamination that could by way of intimate contact or casual proximity contaminate a critical component are by definition contamination-sensitive elements.

Camera contamination-sensitive components are:

- All elements that reside in the Camera cryostat.
- All elements that reside in the Camera body.
- All elements used in the processing of Camera contamination-critical or sensitive hardware (e.g., fabrication, assembly and test tooling and fixturing, storage and transport containers, and packaging).

All components that are defined as contamination-critical or contamination-sensitive shall meet the quantitative molecular and/or particulate cleanliness requirements defined in the following sections.

10. Contamination Critical Hardware

10.1. CCD Cleanliness Specification

The CCD sensor surfaces shall have a cleanliness value of IEST-STD-CC1246 LEVEL R2E-2 (or A/50), 0.6 PAC.

Level R2E-2 (A/50) is 0.02 micrograms per square centimeter coverage and is equivalent to one monolayer of typical NVR.

0.6 PAC is percent surface coverage of particulates independent of particle size.

These values are applicable at time of Camera pre-ship review and acceptance at the I&T site.

Cleaning of the CCD sensor surface is not factored into this cleanliness specification.

The cleanliness specification is the total allowable accumulation of particulate and molecular contamination during all preceding fabrication, test, assembly, transport and storage processes involving the CCDs.

10.2. CCD Exposure Budget Allocation

CCD cleanliness is fundamentally affected by exposure duration during Camera component integration..

Total CCD sensor surface face up-exposure prior to Camera pre-ship review shall be limited to a total duration not exceeding 12 days, in ISO 7 (Class 10,000) or better environment.

One-half allowed exposure (6 days) is allotted to CCD/RTM test and assembly and one-half (6 days) is allotted to Camera/cryostat I&T.

Exposure duration as specified is applicable to the totality of CCD processing wherein the CCD is exposed. “Exposure duration” is defined as any time span wherein a component is NOT in a container specifically designated as, and exclusively for, storage or transport.

10.3. Allowable CCD Exposure Adjustments for Environmental Parameters

It is widely-accepted that orientation during exposure can result in significant variation in particulate accumulation rates.

Exposure duration increases allowed due to orientation:

- 1.5X for 45-degree surface orientation.
- 10X for vertical surface orientation.
- 100X for downward surface orientation.

Orientation increase factors are with respect to upward-facing durations and in compliance with industry-standard factors.

Exposure adjustments are allocated if the clean room or environment is better than ISO 7 (Class 10,000).

Exposure duration increase allowed due to environment:

- 6X for exposure in a ISO 6 (Class 1,000) environment.
- 35x for exposure in a ISO 5 (Class 100) environment.

10.4. Optics Lenses and Filters Cleanliness Specification

The Camera optical surfaces shall have a cleanliness value of IEST-STD-CC1246 LEVEL R5E-1 (A/2) and a maximum 0.15 PAC due to particulates.

Level R5E-1 (A/2) corresponds to a limit of 0.5 micrograms per square centimeter.

0.15 PAC is percent surface coverage of particulates independent of particle size. These values are applicable at the time the Camera cryostat, for L3, or the Camera body, for all other optical surfaces, is closed in preparation for operations (e.g., at the end of any maintenance period). All optical surfaces are required to be clean to the level defined herein at the start of a given lifecycle phase.

All optical surfaces shall be purged of NVR and particulate contamination at prescribed intervals during their lifecycle. The vacuum side L3 surface is understood to be a unique lens surface as it carries special cleaning requirements to avoid cross-contamination of the CCD surfaces.

Stray and scattered light considerations may become important, on a level comparable to that for throughput degradation, depending on the actual size distribution of particles that fallout onto optical surfaces. This is difficult to quantify without measurements of the size and behavior of particulates generated by the shutter and filter exchange mechanisms.

11. Contamination Sensitive Hardware

11.1. Cryostat Contamination Sensitive Hardware Cleanliness Specification

All components included in the cryostat vacuum envelope are in intimate proximity to the CCDs and are therefore contamination-sensitive hardware.

Camera performance requirements limit NVR on sensor surfaces to less than ~50 monolayer total lifetime accumulation. Cross-contamination of CCDs by molecular transport from cryostat contamination-sensitive hardware is the primary source of post-assembly accumulation.

Prior to any assembly, all components must be cleaned and baked as defined by the subsystem and with appropriate Camera-level approval. After the RGA qualification of a reference sample, components exclusively comprising inorganic, vacuum-compatible materials (*e.g.*, metals) do not require RGA qualification. The reference sample will be tested to define the correct cleaning and preparation procedure. The following components must be all RGA tested before installation in the cryostat: Silicon Carbide, all organic materials including each batch of plastic components (*e.g.*, Katpon, PEEK), each manufactured batch of epoxy – by applying a sample to a cleaned and baked medium– (*e.g.*, stycast), components or assemblies with braided material (*e.g.*, thermal straps), and all electronic materials including cabling and tubing.
All assemblies inserted in the Camera Cryostat needs to pass a rate-of-rise test. The requirements for RGA and rate-of-rise testing are described below.

11.1.1. Rate-of-rise Test Requirements

Any cryostat contamination-sensitive component or assembly shall have a total outgassing rate less than 1×10^{-7} Torr-liter per second per square centimeter as measured with rate-of-rise tests. To perform the test correctly the test chamber leak tightness has to be less than $5.0\text{x}10^{-9}$ Torr L/s.
This test shall be conducted on pre-approved equipment that passed the RGA test described below.
For the rate-of-rise measurement, the pressure in the system should increases linearly and the total outgassing rate is obtained from the slope of the curve. The sensitivity of the method is limited by the outgassing of the cryostat and its equipment (walls, valves and gauges) and by the sensitivity of the pressure gauge.
The rate-of-rise test is divided in the following steps:

1. Baseline check of a vacuum chamber
    - Pump down the vacuum system for at least 24h
    - Close the valve of the chamber you intend to measure
    - Let the pressure rise and record it until it stabilize (for a minimum of 6h to a maximum of 12h)
    - The vacuum chamber total outgassing Q_S is

$$Q_S = \frac{\Delta P}{\Delta t} \times \mathrm{V}$$

where V is the vessel volume, ΔP is the change in pressure over the rate-of-rise test, and Δt is the duration of the rate-of-rise test.

2. Outgassing measurement of a component or assembly
    - Pump down the vacuum system for at least 24h
    - Close the valve of the chamber you intend to measure
    - Let the pressure rise and record it until it stabilize (for a minimum of 6h to a maximum of 12h)
    - The component total outgassing, $Q_{C/ASS}$, is

$$Q_{\mathrm{C/ASS}} = \frac{\Delta P}{\Delta t} \times (\mathrm{V} - \mathrm{V}_{C/ASS}) \; - \; Q_S$$

where $V_{C/ASS}$ is the volume of the compoent or assembly, V_C is the volume of the component

3. The component or the assembly is accepted if

$$Q_{\mathrm{C/ASS}} < Q^{LIMIT} \times A_{\mathrm{C/ASS}}$$

where Q^{LIMIT} is $10^{-7} \frac{Torr\, l}{s\, cm^2}$ and $A_{C/ASS}$ is the surface area of the component or assembly.
The signal of the sample $Q_{C/ASS}$ has to be at least 25% higher of that of the empty vacuum system Q_S to be significant. If not the vacuum system is not sensitive enough to obtain a correct rate-of-rise measurement of the assembly the absence of the rate of the outgassing measurement as final test of the component or assembly has to be approved by the Camera management in written form.

11.1.2. RGA Test Requirement

In a baked vacuum system, H_2 is in general the dominant gas. All partial pressures of other gas species have to be lower than that of H_2.

To perform the test correctly the test chamber leak tightness has to be less than 1.5×10^{-10} Torr L/s.

A list of acceptance conditions and partial pressure limits has been defined in table 1. Acceptance limits applies to the RGA scan of the component or assembly at room temperature, after bakeout at 150°C for 24h. Any deviation of the indicated bakeout temperature has to be discussed with the vacuum engineer and the bakeout time should be varied accordingly. If the material can't be baked at a temperature higher than 60°C, it has to pass the rate-of-rise test. The material can't be exposed to air between the bakeout and the RGA test. Any cryostat contamination-sensitive component or assembly shall have undetectable outgassing for AMU greater than 44 using RGA analysis, as defined in Table 1.

Table 1

Description	**Condition**
Base pressure after bakeout at 150C for 24h	$P < 1 \times 10^{-7}$ Torr
Signal of water vapor (18 AMU)	$P_{18} < P_2$
Signal of carbon monoxide (28 AMU)	$P_{28} < P_2$
Signal of carbon dioxide (44 AMU)	$P_{44} < P_2$
Maximum single-peak signal for every peak 12≤AMU≤19,	$P_{(12 \le AMU \le 19)} < P_2$
Maximum single-peak signal for every peak 3≤AMU≤11, 20≤AMU≤27 and 29≤AMU≤43	$P_{(3 \le AMU \le 11)} < P_2/10^2$ $P_{(20 \le AMU \le 27)} < P_2/10^2$ $P_{(29 \le AMU \le 43)} < P_2/10^2$
Maximum single-peak signal for every >44 AMU	$P_{(AMU > 44)} < P_2/10^3$
Noise level	$P_2/\mathrm{noise} > 10^3$

- The RGA used for the test has to be calibrated regularly following the instructions of the manufacturer. The RGA head has to be mounted with its head in direct path of the test-cell single-pump exit. The RGA scan shall be recorded at the maximum resolution achievable by the instrument and for this purpose, the optimized setting at the operational pressure should be discussed with the manufacturer. The RGA setting has to be available to determine acceptance criteria. The RGA scan recording of the entire bakeout process is not requested but recommended in order to assess eventual problems.

- The empty vacuum setup has to be baked at 150°C for 24h and the same acceptance limits mentioned above applies for its RGA scan taken at room temperature. For the test to be meaningful the RGA scan signal of the empty test chamber should be at least 25% lower than the RGA signal of the tested material.

- The conditions in table 1 apply to the RGA scan of the component after subtracting the RGA scan of the empty vacuum setup. If the RGA scan of the empty vacuum setup is not 25% lower than the signal of the tested material the RGA scan of the component has to be evaluated as it is.

- Final RGA scan shall be recorded at room temperature at a base pressure lower than 1×10^{-7} Torr.

Cleanliness requirements for the cryostat contamination-sensitive hardware shall be such that, during Camera operation, cleaning of the L3 vacuum surface shall not be required. Cleaning of the L3 vacuum surface is not required, because it is only possible by venting the cryostat, removing the L3 lens, and exposing the CCDs, which is a high-risk activity.

11.2. Camera Body Contamination Sensitive Hardware Cleanliness Specification

All components included in the Camera body envelope are in intimate proximity to the optical elements of the Camera and are therefore contamination-sensitive hardware.

All Camera body materials shall be assessed and approved to limit molecular and particulate contamination risk based on Camera body airflow characteristics and component proximity to critical optic surfaces. Cross-contamination of optics by viscous flow transport from Camera body contamination-sensitive hardware is the primary source of post-assembly accumulations.

To limit optical element molecular contamination risk, all materials specified for use in the Camera body shall be subject to the requirements specified in the following paragraphs. More specific the material or assembly is acceptable if it meets the Collected Volatile Condensable Materials test and the Allowable Assembly Particulate Mass Loss requirements or if it meets the requirements for the test in operating condition with silica samples

11.2.1. Collected Volatile Condensable Materials Test

All the materials listed in document of reference [18] MSFC-HDBK-1674, that meet the requirement for allowable TML and CVCM listed in table 2 for Camera body assemblies, are considered acceptable. The “collected volatile condensable materials” values shall be tested as specified in ASTM E595.

Subassembly	Allowable Material TML (E595)	Allowable Material CVCM (E595)
Body Housing	1.0%	0.1%
Filter Changer	1.0%	0.1%

Carousel	1.0%	0.1%
Shutter	1.0%	0.1%
Filter loader	1.0%	0.1%
Camera Body Purge	1.0%	0.1%

Table 2
Camera Body Elements Cleanliness Requirements

11.2.2. Allowable Assembly Particulate Mass Loss

All hardware assemblies specified for use in the Camera body shall be subject to total particulate mass generation testing. The allowable assembly particulate mass loss values are listed in Table 3.

Subassembly	**Allowable Assembly Particulate Mass Loss (gram/10K cycles)**
Body Housing	n/a
Filter Changer	7.5
Carousel	7.5
Shutter	0.06
Filter loader	n/a
Camera Body Purge	n/a

Table 3
Camera Body Elements Cleanliness Requirements for Allowable Assembly Particulate Mass Loss, based on 750e3 shutter actuations and 10e3 filter changes per year

11.2.3. Test in operating condition with silica samples

If data about TML (E595) and CVCM (E595) are not available or the requirement listed in table 2 are not met, the subassembly shall be tested in operating condition. The test has to be performed in a closed environment where temperature, sample configuration and enclosure materials should be representative of the actual configuration of the LSST assembly.
Two or more fused silica test samples have to be placed in the closed environment, in positions that keep them exposed to the subassembly outgassing and particle production (nominally one silica coupon above the sub-system and one below the sub-system).

Based on the subsystem analyzed, the length of the test has to be determined so the expected result can be scaled to a year or the time foreseen between two subsequent cleaning of the specific lens. Suggested test duration is available in Table 5.

To establish the throughput degradation, the transmission of the sample has to be measured in the 300-1200nm domain and compared to the transmission measured on a clean sample of the same size and material. Allowable throughput degradations due to molecular (water and NVR) and particulate contamination are specified in Table 4 for all optical surfaces of lenses and filters and in Table 5 for each subassembly.

Element	**Allowed Throughput Degradation**	**Combined Allowed Throughput Degradation**

	Molecular	Particulate	
L1 First Surface	0.37%	0.15%	0.52%
L1 Second Surface	0.3%	1.59%	1.89%
L2 First Surface	0.3%	0.21%	0.51%
L2 Second Surface	0.3%	0.87%	1.17%
Filter First Surface	0.15%	0.36%	0.51%
Filter Second Surface	0.15%	0.5%	0.65%
L3 First Surface	0.3%	0.18%	0.48%
L3 Second Surface	0.3%	1.0%	1.30%

Table 4

The allowed throughput degradation due to molecular and particulate contamination. Values based on document LCA-18-A revision of 11 November 2016.

Subassembly	Source	Allowable Throughput Degradation	Duration for throughput degradation (year)	Minimum Suggested Test Duration (days)
Body Housing	L2S2 20% facing up FS1 20% facing down	0.23% coupon facing up 0.10% coupon facing down	1	**5**
Filter Changer	L2S2 80% facing up FS1 80% facing down	0.94% coupon facing up 0.41% coupon facing down	1	**5**
Carousel	L3S1 15% facing down FS2 15% facing up	0.07% coupon facing up 0.10% coupon facing down	1	**5**
Shutter	L3S1 80% facing down FS2 80% facing up	0.38% coupon facing up 0.52% coupon facing down	1	**5**
Filter loader	L3S1 5% facing down FS2 5% facing up	0.02% coupon facing up 0.03% coupon facing down	1	**5**
Camera Body Purge	L2S1 50% facing down L1S2 50% facing up	0.51% coupon facing up 1.89% coupon facing down	2	**10**

Table 5

The allowed throughput degradation due to each subassembly.

The values present in Table 4 and Table 5 have been calculated on the basis of reference [1] and [2].

12. Contamination Control Zones of the Camera

The Camera is segregated into distinct contamination control zones. Each zone is prescribed an overall cleanliness requirement based on the performance requirements of the contamination-critical components in that zone and/or the assessed risk of cross-contamination to elements in adjacent, communicating zones.

12.1. Camera Exterior

The Camera exterior environment has no cleanliness specification as would be derived from ISO 14644.

The Camera exterior (exterior of the Camera body and utility trunk) is the first line of barrier for entry of contaminants to interior contamination-controlled environments. The Camera exterior should be designed as nearly hermetically-sealed as possible to maintain positive pressure differential with the Camera body zone and to minimize contamination intrusion to the Camera body zone should a negative pressure differential ever occur.

The Camera exterior shall be designed such that cleaning and wipe down can be completed as effectively as possible when the Camera is moved from uncontrolled environments (the telescope dome) to controlled environments (white and clean room).

12.2. Camera Body Zone

The Camera body zone shall be designed such that air flow patterns, flow velocities, exchange rates and filtration are consistent with maintaining an ISO 5 (Class 100) or better environment for particulates as defined in ISO 14644-1.

All components that reside in the Camera body (shutter, carousel, autochanger, purge system electronics and cabling) are contamination-sensitive hardware and as such have cleanliness requirements as defined in section 11.2 to mitigate the generation of particulates and molecular contaminates and to maintain critical hardware (optical elements) cleanliness as defined in section 10.4.

All subsystem elements residing in the Camera body shall be tested for, and verified to meet, their individual cleanliness requirements, as defined in the respective subsystem specifications, prior to integration.

The Camera body purge system shall be designed to maintain the overall cleanliness requirements defined.

12.3. Utility Trunk (UT) Zone

The UT zone shall be designed such that air flow patterns, flow velocities, exchange rates, and filtration are consistent with maintaining a ISO 8 (Class 100,000) or better environment for particulates as defined in ISO 14644-1.

The UT zone does not contain any contamination-critical elements. The UT zone does contain Camera body purge system ducting hardware and communicates purge air with the Camera body zone. Camera body purge air exhausts through the UT.

Additionally all UT subsystem elements are intimately located with cryostat vacuum and electronics hardware, and maintenance on said hardware carries a cross-contamination risk.

The UT purge system shall be designed to maintain the overall cleanliness requirements defined.

12.4. Cryostat Zone

As defined in ISO 14644-1, the cryostat zone vacuum pumping system, conductance barrier geometry, and hardware processing shall be designed to maintain an ISO 2 (Class 1) or better environment for particulate and molecular contamination.

All components that reside in the cryostat (electronics, focal plane structural supports, thermal control hardware) are contamination-sensitive hardware and as such have cleanliness requirements as defined in

section 11.1, to mitigate the generation of particulates and molecular contaminates and to maintain critical hardware (sensors) cleanliness as defined in section 10.1.

All subsystem elements to reside in the cryostat shall be tested for, and verified to meet, their individual cleanliness requirements, as defined in the respective subsystem specifications, prior to integration.

13. Contamination Control in Engineering and Design

13.1. Materials

A Material Test Facility (MTF) has been established for the express purpose of qualifying materials for use in Camera hardware. The MTF is the final arbiter for validating material acceptability.

Upon acceptable results of testing at the MTF, materials will be added to the LSST Camera approved materials list, approved for use in specific Camera contamination-control zones.

Pending MTF test, a useful guideline for possible materials is the NASA materials list (MSFC-HDBK-1674). Also reference NASA document SP-R-0022 for preferred polymeric materials.

Provisionally acceptable materials from the NASA materials lists are those with less than 1% total mass loss (TML) and less than 0.1% collected volatile condensable material (CVCM).

Outgassing requirements shall be met by all subsystems and/or components through proper selection of materials and appropriate fabrication, cleaning, and processing of parts, components, and subsystems.

Electronic circuit boards are a special case partly because the Camera has a large number of circuit boards within the cryostat volume and partly because the NASA specifications are rather dated. For that reason, the LSST project maintains its own standards for circuit board materials and cleaning operations for those boards. All circuit board material used in the cryostat shall be lowest reasonably obtainable outgassing rates for both CVCM and water as per ASTM E595. At the moment, ISOLA 370HR is the preferred material but other vendors may provide equivalent or better materials in the future.

13.2. Restricted Materials

A number of materials pose an unacceptable contamination and/or cross-contamination risk if used in proximity to unprotected or exposed contamination-critical or sensitive hardware. These materials are therefore restricted from use in any aspect of Camera activities, and they are prohibited in all Camera clean rooms.

Such materials are:

- Wood, wood by products (composite pressboards), cardboard.
- Non-cleanroom approved paper.
- Silicone, including adhesives, tapes, lubricants, gaskets, etc.
- Vinyl.
- PVC.
- Rubber.
- Part marking inks that have not been previously approved.
- Polymers with surfactants.
- Perfumes and cosmetics.

13.3. Basic Design practices for Minimizing Contamination

Some basic design practices for mitigation of contamination and good vacuum system practice are:

- Avoid designs that can lead to traps and voids in completed assemblies.
- Avoid designs, features, or interfaces that can generate particulates.
- Avoid interfaces between materials that can lead to corrosion.
- No blind holes unless absolutely necessary.
- Blind vias in PCBs to be filled.
- Vent blind holes, no vented hardware. It is easy to mistakenly install non-vented hardware.
- Be aware that assemblies will be completed by people wearing gloves and masks.
- Be aware of parts and assemblies that cannot be cleaned/ recleaned.
- Design for fabrication of parts using only single point cutters. No grinding or sanding of malleable materials (i.e. metals) shall be allowed, as those processes lead to micro-trapping of contaminants.
- The documentation for all critical or sensitive parts and assemblies shall be clearly labeled, indicating that such parts require special handling (i.e., part and assembly drawings get labels reading “contamination sensitive hardware: process per specification XXX”).
- Proper design, processing, qualification test and fabrication of all critical and sensitive parts is essential in mitigating the contamination risk. All such parts must be reviewed and documented with the express focus on the contamination risk.

13.4. Part Design

All parts ultimately subject to contamination control requirements shall be constructed of approved materials and processed using contamination mitigation approved processes, tools, cutting fluids and handling equipment in a manner consistent with contamination-control requirements.

“Parts” are defined as single component pieces with no joints or surface-to-surface interfaces, and as such are nominally cleanable. Unapproved processes can create micro-traps or other surface conditions that limit the ability to clean the final product.

13.5. Assembly Design

Assembly design for minimizing contamination risk requires a thorough and detailed assessment of individual part flow, processing, cleaning, and handing requirements as the parts mature to final assembly configuration.

Careful attention must be given to noticing when it is no longer possible to clean or re-clean an assembly or subassembly. Such a non-recleanable condition must be clearly indicated on component packaging and in documentation. If processing that is inconsistent with required cleaning methods, all assemblies at some point become non-recleanable due to the creation of traps and obscured voids between parts or due to the joining of dissimilar materials.

The process step when an assembly or subassembly is no longer re-cleanable defines the point at which the contamination budget for that hardware is applicable. Subsequent processing of non-recleanable assemblies must be completed in a fashion consistent with their final cleanliness requirements.

13.6. Fabrication and Assembly tooling

All tooling intended for use in processing critical or sensitive hardware shall be constructed of materials consistent with the needs of contamination control and minimizing cross-contamination risk. All tooling shall be subject to the same cleanliness standards as the Camera hardware that it is associated with, to be in contact with. All contamination sensitive tooling shall be measured to be in compliance with the cleanliness standards that apply.

Documentation of tooling cleaning and cleanliness inspection history shall be maintained as part of project documentation.

When not in use all contamination sensitive tooling shall be stored in such a fashion as to minimize or eliminate the risk of contamination accumulation.

14. Contamination Control in Procurement and Vendor Relations

The lifecycle event history of all contamination-critical or sensitive hardware shall be documented. Such documentation is essential to ensure only contamination-free hardware is used in Camera assembly. Such documentation also serves to ensure any contamination "events" can be rapidly contained and corrected by providing traceability and activity history. This may include the following information:

- Buyer/seller roles and responsibilities.
- On-site spot inspection requirements.
- Pre-ship and post-receipt acceptance test requirements.
- Final deliverable cleanliness levels.
- Non-conformance corrective action protocol.
- Component-level specification, validation and approval, including information on the following:
  - Substitution restrictions.
  - Part and subassembly retest.
- Test records documentation.
- Completed travelers, including cleaning records/solution pedigree, QA enclosures, material certifications, and information on the following:
  - Sub-vendor fabrication, processing, testing, and documents.
  - Production tooling and fixture requirements.
- Acceptable part marking methods.
- Storage, packaging, shipping environments and requirements.

15. Contamination Control in Development and Test

Good contamination-control practices should be included as early as reasonable in the development and test project phase. Thorough, complete, development cannot be established without thoughtful

consideration of contamination-control requirements. Test results cannot be validated with contamination uncertainties unresolved.

15.1. Process Development and Documentation

During process development and developmental testing, protocol is best completed by exercising "ALARA" (As Low As Reasonably Achievable) principals with regard to contamination levels. This is independent of completed qualitative analysis for component and assembly-required cleanliness as it regards impact on Camera performance.

As it relates to contamination control, hardware can never be too clean.

The sooner that hardware development efforts can incorporate cleanliness testing and documentation protocols that are predicted to meet contamination-control requirements, the easier and more thorough the qualification process will be. Should such cleanliness protocols prove predictions correct, developmental hardware fabrication and testing focused exclusively on cleanliness qualification could be significantly reduced or eliminated.

Likewise, cleaning and handling protocols should be thoroughly documented as, allowing successful testing and supporting analysis, such documentation provides the basis for production hardware travelers and pedigrees.

15.2. Hardware and Process Qualification Test and Validation Procedures

Hardware development qualification testing shall be completed prior to release of any contamination-controlled hardware for production. Qualification tests results are to be reviewed and approved by the contamination control engineer, subsystem manager, and responsible engineering staff. Results shall be consistent with the subsystem specification values for cleanliness and the CCP cleanliness calculations and parameters (sections 12, 13 and 14).

Developmental qualification tests are to be validation of the hardware components and assemblies AND processes, facilities, tests and test protocols, packaging, transport containers, etc as planned for production work. As such, each element in the sequence should be as close to production-planned methodology as reasonably achievable. Conversely, by definition, any element of developmental qualification should be de-facto production configuration. Any modifications incorporated post-qualification test and approval shall be re-qualified and re-approved.

Qualification tests are more stringent and thorough than production hardware acceptance tests. Production tests are a subset of the qualification tests selected to compliment the qualification results and to minimize contamination risk while maximizing productivity.

16. Contamination Control in Fabrication, Assembly and Test

All contamination-critical or sensitive components and piece parts shall be precision cleaned prior to delivery to designated clean areas/rooms for contamination-controlled processing, independent of process sequence, cleanliness requirements or re-cleanability of subsequent subassemblies.

16.1. Precision Cleaning

When precision cleaning is required, the cleaning process shall be performed in an approved manner, in a controlled environment, at an approved facility, using documented procedures. The resulting level of cleanliness shall be measured and recorded in relevant process travelers. The precision cleaned article shall be packaged in an appropriate manner prior to removal from the cleaning facility. N2 blowdown and plasma cleaning will play a role with keeping some components at the cleanliness requirement level.

16.2. Part Marking

Only approved part-marking methods shall be used on critical or sensitive hardware. Approved methods include vibro or laser-etching or machined text profiles to a shallow depth. In general, marking inks should not be used unless explicitly tested in the MTF and approved for use.

16.3. Designated Clean Areas

All Camera contamination-controlled activities shall be restricted to designated clean areas.

Contamination-controlled activities are those that process or handle unprotected (exposed) hardware subject to cleanliness requirements in their respective subsystem specifications; hardware that cannot be re-cleaned should it become contaminated.

Documented approval from the contamination control engineer is required in all designated clean areas of ISO 7 (Class 10000) or better clean room environments.

In addition to overall clean room/clean environment requirements, all contamination-critical hardware shall be processed in accordance with documented traveler work flow exposures.

16.4. Clean Room Requirements

All LSST Camera project cleanrooms used in the processing of contamination-critical or sensitive hardware shall meet the requirements set forth in ISO 14644 “Cleanrooms and Associated Controlled Environments”.

Prior to use for processing Camera contamination-controlled hardware, all clean rooms must be certified to meet air cleanliness requirements per ISO 14644-1 “Classification of Air Cleanliness” (FED-STD-209 conformance allowed).

All such clean rooms must be ISO 7 (Class 10,000) or better certified.

All clean rooms must be tested and monitored in a manner, following a test frequency, and documentation protocol as per requirements defined in ISO 14644-2, “Specifications for Testing and Monitoring to Prove Continued Compliance with 14644-1”. All clean room test apparatus and protocol shall meet requirements as established in ISO 14644-3 “Test Methods.” Note ISO 14644-2 and ISO 14644-3 are applicable to the certification or recertification for ISO 14644-1.

As such, all LSST clean rooms shall have documented environmental-monitoring programs. Such monitoring and documentation shall include information on location and frequency of inspection for NVR collection plates, particle counters and particle fallout sensors, temperature and humidity sensors, and filter inspection and replacement schedules.

All LSST Camera approved clean rooms shall meet requirements set forth in ISO 14644-5 “operations.”As such, all clean rooms shall have appropriate ingress areas (i.e, isolated changing and/or wipe-down areas). Gowning requirements and procedures shall be prominently displayed in such areas. Ingress areas shall be equipped with shoe scrubbers, sticky mats, personnel effects storage facilities, ESD PPE and other such equipment as appropriate to the particular clean areas to be accessed and processes to be supported.

Cleaning and normal custodial maintenance of the clean room and changing room/area will be consistent with ISO 14644-5 “operations” (ASTM E-2042 conformance allowed) and IEST-RP-CC018.2.

All clean rooms will be re-certified annually.

16.5. Measurement of Hardware Cleanliness

All contamination-critical or sensitive hardware shall be subject to testing to establish required cleanliness prior to integration at the Camera level.

Possible tests include:

- Visual inspection: Gross defects, particulates, with use of UV (black) light enhancement possible
- Tape lift: use for particulate counting
- Vacuum Rate-of-rise: Provides baseline outgassing spectrum and rate
- Vacuum Throughput / Trend: long term vacuum test to assess virtual leak data and time dependent outgassing trends
- Destructive testing: Sectioning and thermal cycling to assess risks and mitigations or localize contamination sources of failed components
- Fabrication, test, assembly and storage-transport equipment will be subject to testing and qualification equivalent to the cleanliness requirements of the associated product.

All measurements will be logged via eLog and/or eTraveler

16.6. Component and Subassembly Acceptance Criteria

Critical and sensitive elements shall have contamination cleanliness criteria included in respective subsystem specifications.

Acceptance criteria shall be established based on critical component contamination calculations and expected cross-contamination risk.

16.7. Purging and Purge Gas

Dry nitrogen purge gas must be 99.99% purity grade or better and certified for moisture and hydrocarbon requirements per Grade B, Type I nitrogen gas requirements of MIL-P-27401C:

- Moisture = 11.5 ppm.
- Hydrocarbon = 5 ppm (methane equivalent).

If the purge gas is air, the purity shall be Ultra High Purity (UHP)/Zero Grade manufactured air (not medical-grade breathing air) with the same moisture and hydrocarbon requirements for dry nitrogen gas as stated above.

Purge gas delivery systems (including all lines, regulators, valves, etc.) and purge gas supplies must be pre-certified at the point of use to meet cleanliness requirements prior to connection to the Camera hardware or storage containers. The gas sampling locations for pre-certification shall be at or close to the point of use. Any time a connection break occurs, the ends of the purge connectors must be immediately bagged (or capped) and then tape-sealed to prevent recontamination. Recertification of the purge line is required if the line is not tape-sealed for protection. Certification records should be held along with other facility records.

An acceptable purge rate for each component shall be defined, along with a maximum period of purge interruption.

16.8. Control of Electro-Static Discharge (ESD Control)

All elements of this contamination control plan, program and activities shall be simultaneously compliant with the LSST Camera ESD Control Plan (LCA-10032).

16.9. Packaging, Storage and Transport

Cleaned parts waiting assembly must be packaged and stored in such a way to avoid contamination, either due to time or inadvertent exposure to unclean environments. Ideally, such parts are sealed in a moisture-resistant clean approved bag with nitrogen gas backfill. Less-ideally parts can be wrapped in lint-free cloth and dry aluminum foil, then stored in sealed containers.

All such packaged parts shall have appropriate identification, legible without the need for unnecessary handling (i.e., without violating package integrity).

Camera hardware that requires extended storage periods shall be protected from damage and contamination by storing in rigid containers or similar acceptable protective enclosure.

As a guideline, contamination-critical or sensitive hardware typically requires double-layer bagging with nitrogen purge.

For short-term storage in clean rooms, hardware can be protected with nominally-sealed covers or sheeting material. Use of dry nitrogen purged cabinets or other rigid containers with desiccators are also acceptable for short-term or medium-term storage in clean rooms.

For long-term storage, tent enclosures built with approved clean room materials may be constructed to protect and isolate clean materials if access restriction and protection from long-term particulate fallout is desired.

Contamination (and or humidity) critical or sensitive hardware, when not in a clean room environment, shall be stored in nitrogen-purged containers.

All ESD-sensitive materials shall be packaged with ESD-approved methods per the Camera ESD control plan.

Packages or bagging containing moisture-sensitive hardware shall be evacuated and filled completely three times with pre-certified dry nitrogen gas, then sealed. Double bagging with dry nitrogen purge in each layer and with a moisture indicator in the outer bag may be useful. All contamination-critical or sensitive hardware shall be packaged in approved materials prior to shipping.

Hardware that is heavy or requires special handling or lifting equipment should be bagged with the handling equipment in mind. In particular, hardware should be housed in an external container that will not be brought into a clean room. The hardware—in a sealed bag or internal container—must be able to be lifted out of the external container, wiped down, and moved into the clean room with minimal access to clean internal components.

Prior to any transport operation, any shipping container used shall be pre-cleaned to the cleanliness level of the hardware for which it is to be used. Shipping containers must be able to accommodate any required nitrogen purge for the duration of the transport, and must also provide the necessary level of temperature and humidity control. Any environmental control system integrated into the shipping container to provide temperature and relative humidity control should utilize an air filtration system to maintain an acceptable airborne particulate level. Sealed shipping containers shall also provide for pressure equalization to accommodate air transportation. Pressure equalization vents should be designed to prevent unnecessary particulate or other contamination from entering the container.

Temperature and relative humidity shall be monitored continuously inside the shipping container during hardware transport. In addition, witness samples may be mounted inside the container and/or inside the hardware bagging layer to monitor hardware exposure to contamination during transport.

17. Contamination Control in Project Management

Project management in all aspects of contamination-controlled activities is essential to ensuring the Camera achieves required cleanliness standards.

Based on the contamination requirements defined in the CCP, project management must also either develop or "borrow" supporting documents in order to implement the program defined in the CCP. The following documentation list represents the type of supporting documents which may be required for any specific subsystem/project and/or institution:

- CCP Implementation Plan.
- Hardware Cleaning Procedures.
- Hardware Cleanliness Verification Procedures.
- Molecular Wash Method.
- Molecular Wipe Method.
- Particulate Tape Lift Sampling Procedure.
- Particle Counting Method.
- Optical Measurement Methods.
- Actual instrument throughput/performance measurements.
- Witness Plate Measurements.
- Cleanroom Personnel Training/Certification documents.
- Cleanroom Personnel Operations Requirements.
- Cleanroom Operating Procedures.
- Approved Materials Lists.
- Cleanroom Monitoring Methods.
- Purging Plans.
- Hardware Bagging Requirements.
- Contamination Protection Methods.
- Material/Hardware Outgassing Certification Plans.
- Thermal Vacuum Bake-out Plans.
- Transportation/Storage Cleanliness Plans.
- Hardware Certification Logs and Anomaly Reports.

Oversight of, and adherence to, established plans, standards, training and the like is essential to achieving required cleanliness levels to meet requirements and essential to enable rapid and effective identification of root cause, and recovery from, out-of-specification hardware or processes.

17.1. Training

Contamination control and clean room practices training shall be conducted for all unescorted personnel involved in the fabrication, assembly, testing, transportation or integration of contamination-critical or sensitive hardware.

Training directed to use of clean areas or clean room facilities shall address both facility standard operating procedures as well as contamination sensitivities and protocols specific to the Camera hardware in production at the facility.

The following topics should be included in, but not limited to, personnel training sessions:

- Defining contamination and how it affects the project and hardware being produces.
- Reviewing Camera hardware contamination sensitivities.
- Clarifying the importance of maintaining contamination control in all the phases of production and testing.
- Review of established contamination-control plans and related contamination documents.
- Demonstrating clean room dressing procedures and rules for working in a clean room area.
- Component or process -specific procedures and techniques for cleaning, inspection, and packaging.
- Monitoring techniques, locations, and schedules in the clean room and in the shipping containers.

Training records should be held with other personnel training information, with periodic re-training performed as defined in the facility plan.

Such training requirements apply to employees and workers at collaborating institutions AND to any vendor or sub-vendor contracted to complete work on contamination-critical or sensitive hardware.

17.2. Process Control

A well-conceived and documented fabrication and assembly process is critical for maintaining the cleanliness of contamination-controlled hardware.

All contamination-critical or sensitive parts and assemblies shall have all aspects of fabrication, assembly, handling, storage, and test processing fully documented. Such process control shall be of sufficient detail to ensure rapid identification of root cause and correction of any out-of-specification hardware, activity, or facility.

17.3. Documentation, Travelers and Pedigree

The lifecycle event history of all contamination-critical or sensitive hardware shall be documented. Such documentation is essential to ensure only contamination-free hardware is used in Camera assembly. Such documentation also serves to ensure any contamination “events” can be rapidly contained and corrected by providing traceability and activity history.

All contamination-critical or sensitive hardware shall be accompanied during their fabrication and assembly sequence by a process traveler.

Such process travelers provide information on:

- Defining and itemizing specific process tasks.
- Itemized assembly documentation, part lists & component serial numbers.
- Task event dates.
- Photograph history of set up and tooling configurations.

- Work station cleanliness requirements and traceability to monitoring records.
- Itemized required / accepted tool lists.
- Lists of all specialized tooling, fixtures or assembly jigs and serial numbers of such tooling used.
- Definition of worker gowning and ESD PPE requirements.
- Suggested support materials (lint free wipes, foil, etc.).
- Required storage or packaging at specific tasks completed.

In addition to process travelers, component and assembly pedigrees are established with the inclusion of such documentation as:

- Material certifications.
- Dimension, mechanical, chemical and electrical inspection data.
- Clean room history logs.
- Hardware cleaning process and history logs.
- Cleanliness testing results reports.
- Temperature and humidity records for clean room, transportation, and storage.

17.4. Record Keeping and Change Control

As change is most frequent and probable during the development phase good change control and change control documentation will be required part of the process.

Change history shall be maintained on all official process and test contamination-controlled hardware documentation (eLog)

17.5. Compliance Audit

Camera project managers, subsystem managers, contamination control engineers and responsible engineering staff shall reserve the right to audit hardware, processing, facilities and documentation for compliance to the requirements of this contamination control plan at a frequency of their choosing.