Overview of Contamination Control for the James Webb Space Telescope Launch Campaign

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Systems Contamination: Prediction, Control, and Performance 2022

(Credit: ESA - S. Corjava)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

James Webb Space Telescope

- Large observatory designed to seek out knowledge of:
  - First Light
  - Formation of early galaxies
  - Birth of stars and planetary systems
  - The origins of life
- Major external optics include:
  - 6.5 m primary mirror (PM)
  - 0.7 m focusing secondary mirror (SM)
- Optics were exposed to numerous facilities for over a decade of integration and test (I&T) ending with the 3-month launch campaign at the Centre Spatial Guyanais (CSG) in French Guiana
- James Webb Space Telescope (JWST) consists of three major components:
  - Optical Telescope Element (OTE)
  - Integrated Science Instrument Module (ISIM)
  - Spacecraft Element (SCE)
- OTE and ISIM most critical with respect to launch site contamination control
  - Exposed PM and SM carrying very tight particulate cleanliness requirements for the telescope's high sensitivity and light throughput
  - Science instruments' vulnerability to fibers
  - These drivers would define the launch campaign contamination control program.

(Credit: ESA - S. Corjava)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Ariane 5

- European Space Agency (ESA) provided launch services using Ariane 5 Launch Vehicle (LV)
  - European heavy-lift LV developed and operated by Arianespace for ESA
  - Launches from Centre Spatial Guyanais (CSG) in French Guiana
  - Provides a variety of mission opportunities, ranging from the typical 10-ton payload in Geostationary Transfer Orbit to 20 tons in Low Earth Orbit
  - Capable of custom trajectories such as those required for Rosetta, Herschel, Plank, and JWST
- Unique nature of JWST led to various adaptations of the Ariane 5 system
  - Specially developed rolling maneuver to avoid exposure of any fixed position of the telescope to the Sun
  - Fairing fabricated with modified vents to prevent the risk of depressurization that could damage the payload during fairing jettison
  - Fairing equipped with custom seals to protect the inner environment for cleanliness
  - Multiple fairing cleanings and inspections throughout development
- JWST necessitated special provisions at CSG
  - Final Assembly Building Encapsulation Hall (BAF HE) deeply cleaned and equipped with dedicated portable High Efficiency Particulate Air (HEPA) filter walls
  - BAF Composite Hall (BAF HC) upgraded with a removable clean containment, dubbed the "Air Shower Curtain" (AShC), between its mobile platforms surrounding JWST
  - Dedicated air supply system equipped with HEPA and Airborne Molecular Contamination (AMC) filters in the umbilical mast
- JWST was integrated with the Ariane 5 and launched in December 2021

(Credit: ESA - S. Corjava)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Project Requirements and Implementation

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Launch Campaign Contamination Requirements

- Launch campaign contamination requirements defined as particulate and molecular allocations for the PM and the SM
  - Derived from overall mission systems and science objectives and the current cleanliness of the hardware nearing the campaign
  - Allocations encompassed the entire period from arrival at CSG until launch
  - Allocations budgeted by time spent in each facility
  - Particulate allocations presented in Percent Area Coverage (PAC) ← **Primary Concern**
  - Molecular allocations were presented as deposition thickness in angstroms (Å)

Phase	PM		SM	
	Part. (PAC)	Mol. (Å)	Part. (PAC)	Mol. (Å)
Launch Campaign Allocation	0.60	15	0.42	15
Mission EOL Requirement	1.50	300	0.50	300

- Additional requirement to prevent water deposition on JWST through temperature and relative humidity controls
  - Compatible temperature and relative humidity ranges and change rates specified to avoid hardware crossing any dew point and collecting water

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Implementation for I&T

- JWST's contamination control (CC) program focused on maintaining flight hardware as clean as possible
- CC team maintained a crew of engineers and technicians present in Integration & Test (I&T) facilities during all operations
- Special precautions implemented for inaccessible or delicate surfaces, such as the PM, SM, and science instrument pick-off mirrors
    - Certain cleaning procedures designed and executed for the exterior optics
    - Science instruments continuously purged with dry, clean, manufactured air
- I&T conducted in International Organization for Standardization (ISO) Class 7 or better clean areas
    - Facility cleanliness class requirement applied to all locations leading up to the launch campaign
    - Operations conducted outside of ISO Class 7 or better facilities required components to be protected
    - Upgrades necessary for processing JWST in CSG's ISO Class 8 facilities
- Continuous monitoring of I&T facilities and hardware surfaces verified compliance
- Flight hardware inspections were embedded in the I&T workflow
- Routine work area inspections were conducted with white and ultraviolet (UV) flashlights and the facility lights dimmed
- Material restrictions strictly enforced
- Facilities cleaned daily
- Proper gowning practices enforced
- All Ground Support Equipment (GSE) required to be at least as clean as nearby flight hardware
- Practices produced a successful I&T program and were brought to CSG to maintain that success

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Training Sessions

- CC training sessions conducted at CSG, Northrop Grumman, and virtually
- Sessions included:
    - Overview of JWST’s sensitive surfaces
    - Necessity for CC measures
    - Facilities planned for use and CC implementations
    - Personnel garmenting, with live or video demonstrations
    - Hardware ingress and egress
    - Material restrictions
    - Best practices
    - Unique CC equipment developed for the launch campaign
- Training mandatory for access to any CSG cleanroom having already passed a Pre-Entrance Acceptance Survey
- Cards issued to each trainee indicating their approval for entrance

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

OSTTARS

- JWST shipped to CSG in a custom transporter: Observatory Space Telescope Transporter for Air, Road, and Sea (OSTTARS)
  - 33.5 m x 5.5 m x 4.5 m
  - Mobile cleanroom capable of isolating sensitive cargo
- Upgrade of JWST's original STTARS
  - Retrofitted to accommodate the full Observatory
- Equipped with robust air conditioning and filtration
- Comprised of cleanable components
- Inner hard-shell chamber
- Built-in purge line provisions
- Interior surfaces cleaned and inspected with white and UV flashlights
- Movable by truck
- Traveled via ship from Los Angeles, CA to Kourou through the Panama Canal


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

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Facilities at the Centre Spatial Guyanais

(Credit: CNES)

Centre Spatial Guyanais

- Located between the cities of Kourou and Sinnamary and covers an area as large as Paris
- Operational since 1968
- Provides state-of-the-art Spacecraft Preparation Facilities operated by Arianespace and Centre National d'Etudes Spatiales (CNES)
- Equipped to process several spacecraft from different customers simultaneously
  - JWST campaign, VA256, operated in parallel with three other campaigns on three different launchers
- Spacecraft arrives in French Guiana at the Port de Pariacabo in Kourou or Félix Eboué Airport in Cayenne and is brought to the Ensemble de Préparation des Charges Utile (EPCU)
- Campaigns begin in the Payload Preparation Facility (PPF) with fuel-free operations
  - Functional, electrical, mechanical, and fluidic checks
- Spacecraft fueled in a dedicated Hazardous Processing Facility (HPF)
- Then moved to the Final Assembly Building (BAF) for launcher integration and encapsulation
- Payloads moved within CSG inside a dedicated transporter, Conteneur Charge Utile (CCU)
- All facilities used for housing spacecraft nominally comply with ISO Class 8 parameters and maximum hydrocarbons deposition of 0.5 mg/m^2/week
- Monitoring, controls, and analysis of contamination and cleanliness are regularly performed
- Facilities selected for VA256 included:
  - S5C as the PPF
  - S5B as the HPF
  - CCU3 for transports
  - Both the BAF Encapsulation Hall (HE) and BAF Composite Hall (HC) for final integration with the LV

Site Survey – DDO presentation - © CNES

(Credit: CNES)

CSG – S5

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon and E. Prigent)

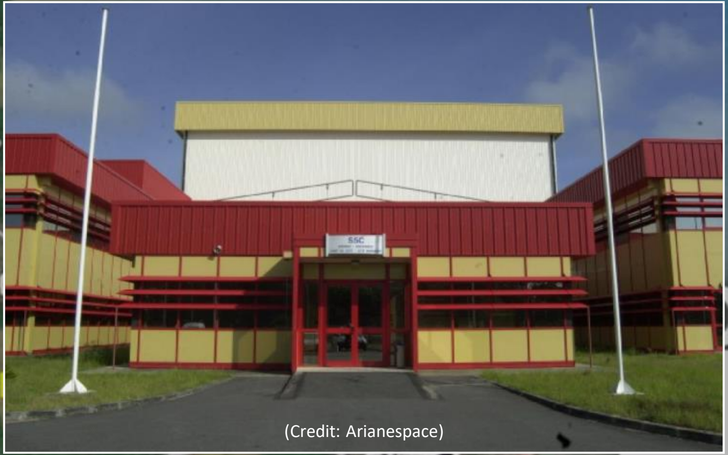
- Located close to Route de l’Espace, approximately 3 km northwest of the CSG main entrance and 10 km southeast of the Ariane Launch Sites (ELA)
  - Safe distance during launches
- Approximately 7000 m² large
- Primarily comprised of three main areas: S5A, S5B, and S5C, interlinked by two access corridors
- Also includes two disconnected buildings for decontamination, S5D, and Self-Contained Atmospheric Protection Ensemble (SCAPE) and Splash suit preparation, S5E

(Credit: CNES)

CSG – S5C PPF

- Located at the far west of the S5 complex and linked by clean corridors to S5A and S5B
- Includes two identical ISO Class 8 cleanrooms separated by a removable wall with a shared airlock, gowning rooms, office areas, meeting rooms, and electrical checkout rooms equipped with direct feeds into the cleanrooms
    - Two cleanrooms combined for VA256
- Major operations that occurred in the S5C PPF included:
    - Unloading from OSTTARS in the airlock
    - Rotating vertical
    - Mechanical preparations
    - Electrical checkouts
    - Functional acceptance testing
    - Mating with the LV adapter
    - Arming of the pyrotechnic separation system
    - Installation into the CCU3 for transport to the S5B HPF
- Contamination control preparations included:
    - Extensive cleaning and detailed inspections
    - Shielding of potential contamination sources
    - Assembly of portable High Efficiency Particulate Air (HEPA) filter walls
    - Configuration of a dedicated purge network


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)


(Credit: Arianespace)

Sinnamary

(Credit: CNES)

CSG – S5B HPF

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)

(Credit: Arianespace)

- Located at the far east of the S5 complex and linked by clean corridors to S5A and S5C
    - Clean corridors not usable for VA256 due to height
- Includes an ISO Class 8 cleanroom and airlock, a fuel tank transfer room, and a fueling preparation anteroom
- Major operations that occurred in the S5B HPF included:
    - Liquid propellant loading fuel tank pressurization
    - Removal from and installation into the CCU3 for transfer to the BAF
- Contamination control preparations included:
    - Repeat of S5C PPF preparations
    - Coordination of SCAPE suit cleaning process
    - Preparation of SCAPE suit room

Sinnamary

EGA

EPCU S5

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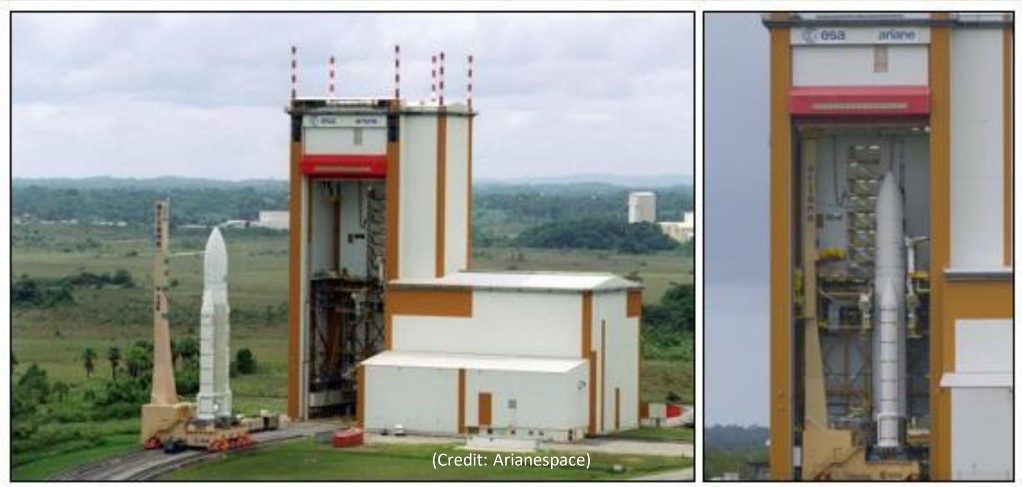
(Credit: CNES)

Sinnamary

CSG – BAF

- Located approximately 2.6 km south of the ELA
    - Railroad connecting facility with the ZL3 launchpad
- Approximately 4500 m^2 large with a total air-conditioned volume of 280,000 m^3
- Primarily comprised of two main areas: the BAF HE and BAF HC
- Fit for final preparation of the LV on the Ariane 5 Launch Table, integration of spacecraft onto the LV, and fairing encapsulation


(Credit: Arianespace)


(Credit: Arianespace)

Kourou

EPCU S5

(Credit: CNES)

Sinnamary

CSG – BAF HE

- Horizontal segment of the BAF
- Comprised of a 900 m^2 cleanroom and 570 m^2 airlock
- Linked to the BAF HC by a transfer chimney in the airlock for hoisting spacecraft and fairings to the LVs
- Major operations that occurred in the BAF HE included:
  - Assembly and mechanical, electrical, and cosmetic checks of Ariane 5 fairing
  - Final cleaning and inspections of fairing
  - Egress of JWST from the CCU3
  - Hoisting of JWST and fairing to the LV
- Contamination control preparations included:
  - Repeat of S5 preparations
  - Wrapping of Ariane 6 fairing scaffold
  - Bandaging of floor blemishes
  - Preparation of fairing transfer stand
  - Transfer of HEPA walls to airlock with JWST

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – J. Martin)

(Credit: CNES)

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CSG – BAF HC

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

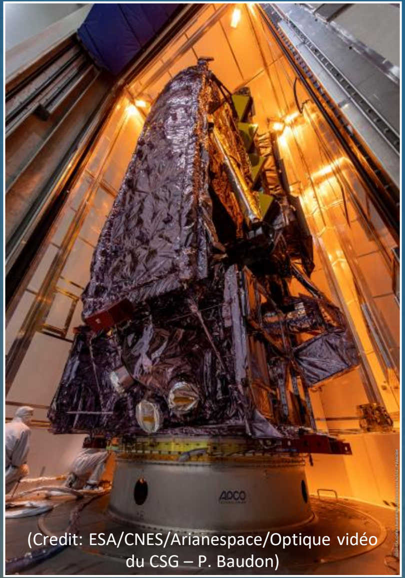
- Vertical segment of the BAF
- Houses the Launch Table and LVs
- Includes mobile ISO Class 8 work platforms: the lower Plate-Forme Elévatrice Inferieure (PFEI) and upper Plate-Forme Elévatrice Superieure (PFES)
  - Move vertically for access to various heights of spacecraft, fairings, and LVs
- Major operations that occurred in the BAF HC included:
  - JWST integration to LV
  - Final electrical checkouts
  - Final mechanical closeouts
  - Final surface sampling
  - Fairing encapsulation
- Contamination control preparations included:
  - Repeat of S5 preparations, except for HEPA walls
  - Cleaning and installation of the Air Shower Curtain (AShC)
  - Installation and removal of "Manhole Cover"
  - Configuration of air supply for AShC and fairing

(Credit: CNES)

CCU3

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

- Used to transfer spacecraft between various integration buildings across CSG
- Designed to protect spacecraft from shock and vibration and meet cleanliness, air conditioning, and overpressure requirements
- Equipped with inflatable seals to ensure airtightness
- JWST moved twice in the CCU3: from S5C to S5B and from S5B to the BAF
  - Utilized cable pass-through port to connect purge system
- Environmental parameters recorded and transmitted in real time via wireless connection to a radio receiver
- Contamination control preparations included:
  - Thorough cleanings and inspections prior to transports
  - Pre-characterization of cleanliness during empty container transport

Sinnamary

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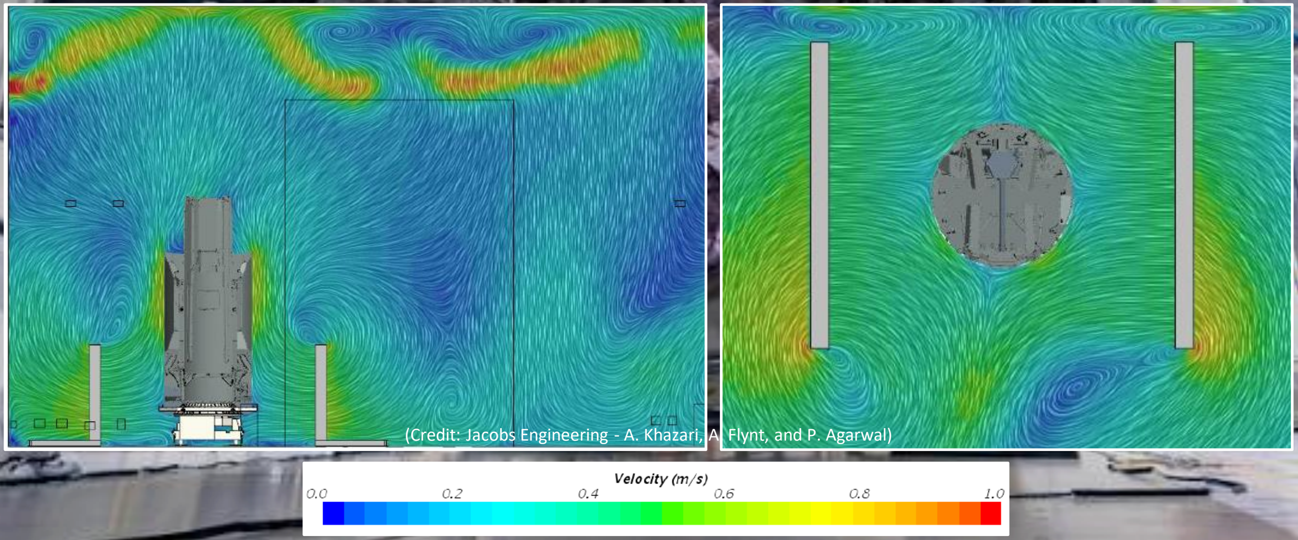
(Credit: CNES)

Operational and Facilities Upgrades

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Portable HEPA Walls

- Temporarily upgrade the CSG facilities' ISO Class 8 architecture to meet ISO Class 7
- 12 portable HEPA modules assembled as walls in configurations customized to each facility
  - Stacked 2 modules high on individual rolling dollies
  - Number of stacks per facility determined by available floorspace
- Collaborated with Jacobs Engineering to perform a series of Computational Fluid Dynamics (CFD) analyses to determine what compatible set-ups would maximize air cleanliness
- Simulations utilized existing S5C PPF and S5B HPF layouts and various arrangements of HEPA walls with JWST avatar
- CFD analyses demonstrated that push-push configurations in each facility allowed filtered air to reach the most of JWST's critical surfaces
  - Use of a return wall insufficient due to JWST's size



(Credit: Jacobs Engineering - A. Khazari, A. Flynt, and P. Agarwal)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Portable HEPA Walls (cont'd)

- Initially delivered to GSFC for verification check-outs and facility simulation testing
- Each module assembled, cleaned, and checked for hydrocarbon output, airflow velocity, filter leakage, and heat gain
  - First two modules also underwent 48-hour air particle and particle fallout testing
- HEPA stacks assembled and relocated to an uncontrolled high bay for testing
- Three tests executed representing the three CSG facilities:
  - S5C PPF layout included 3 HEPA stacks per wall
  - S5B HPF layout inside 1 stack per wall
  - BAF HE layout included 2 stacks per wall
  - Floor arrangements aligned with planned campaign layouts
- Included a mock-up of the Roman Space Telescope satellite as JWST surrogate
  - CFD analyses demonstrated that a large obstruction would significantly affect airflow
- Included continuous air particle counts, particle fallout wafers, and non-volatile residue (NVR) foils in between and outside of the HEPA walls
- Results exhibited improvements in:
  - Air particle counts: 83-99%
  - Particle fallout: 79-91%
  - NVR: 50-90%


(Credit: NASA – Z. Huang)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Portable HEPA Walls (cont’d)

- Assembled in planned arrangements at CSG
- Demonstrated same ability to reduce contamination shown during validation testing
- HEPA modules ran continuously in the S5C PPF and BAF HE but were shut off during Explosive Atmosphere (ATEX) restricted activities in the S5B HPF


(Credit: NASA – C. Gunn)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)

(Credit: ESA - M. Pedoussaut)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Pre-Entrance Acceptance Surveys

- Performed initial facility walkthroughs to identify and mitigate contamination threats
- Removed or bagged extra equipment
- Bagged needed items identified as potential contamination sources that did not conform to JWST materials restrictions
- Cleaned all surfaces
- Collected baseline air particle counts
- Required equipment that included lubricated surfaces, motors, chipping paint, sand, or unapproved insulation jacketing wrapped with either static-dissipative, polyethylene, or polyvinyl fluoride (PVF) bagging
  - PVF only approved bagging for use in ATEX-restricted areas

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG)

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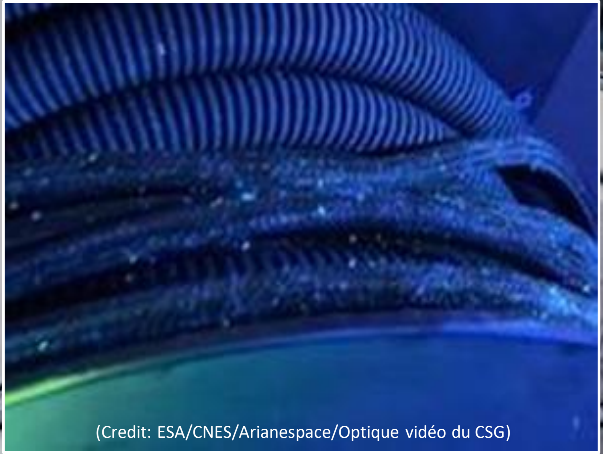
Pre-Entrance Acceptance Surveys (cont'd)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG)



(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG)

- Teams performed facility lights-out inspections using white and UV flashlights
- Further identified contamination accumulation areas, such as coiled cables and hoses
- Items cleaned and/or bagged
- Acceptance reports issued once all issues addressed

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Laundry Facility

- Typical JWST garment laundering occurred in regular cycling by a third-party launderer
    - Used garments shipped off site as clean garments returned
    - Adherence to strict techniques, including use of fragrance-free detergents, verified clean machines, controlled facilities, and vacuum sealing bags of cleaned garments
    - Drum testing to verify cleanliness of garments
- Regularly shipping garments from CSG to the US not compatible with campaign
    - Presented schedule and costs risks
    - Two loads shipped back for laundering in US
- Plan included bringing large sum of garments and upgrading CSG’s on-site laundry process in S5E
    - No drum testing for cleanliness verification available
    - Garments cleaned on site only used for non-flight-but-clean operations, such as facility preparation
    - Allowed project to reserve the verified clean garments for flight and critical operations
    - Upgrades included shielding contamination sources, wearing garments, visual inspections, and reviewing materials
- Upgrades also applied to laundering of Splash suits

(Credit: NASA)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

SCAPE Suits Cleaning

- Traditional fueling process begins with donning SCAPE suits in the S5E facility and transferring via shuttle to the S5B HPF
    - Boarding and exiting the shuttle included exposure of the SCAPE suits to the outside
- NASA and CNES teams agreed to dress technicians in a pre-cleaned S5B HPF anteroom
- Included touch-up cleaning of the SCAPE suits after their donning
- Anteroom prepared similarly to S5 cleanrooms with additional white and UV flashlight inspections
    - Daily cleanings and inspections added throughout fueling
- SCAPE suits cleaned by vacuuming and solvent wiping
- Suits inspected with white and UV lights and logged for traceability

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Piron)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Purge Adaptations

- Scientific instruments subject to irreversible stiction if the relative humidity exceeded 60%
- Only the pre-launch fairing interior compatible with humidity limit
- Dry purging was necessary to maintain humidity levels
- CSG facility and process adjustments included:
  - Installation of stationary purge networks in S5 and the BAF
  - Installation of mobile purge networks for the CCU3 and transfer from the BAF to ZL3
  - Provisions for purge disconnections during JWST integration with the LV and fairing encapsulation
  - Increase of fairing air temperature by 3°C during the transfer from the BAF to ZL3
- Purge system consisted of:
  - Dry air supply of portable racks of pressurized bottles kept outside of the cleanrooms
  - Control, filtration, and monitoring unit
  - Distribution network of flexible hoses fed through ports and leading to science instrument interfaces
    - BAF required approximately 250 m of hoses
- Two significant purge outages necessary:
  - Lift of JWST to the LV
    - Aerial work platform installed on the PFEI to meet safety regulations and minimize outage duration
  - Fairing encapsulation
  - Durations within allowable limits
  - Verification of humidity in the facility
- Final disconnection occurred once the fairing interior environment verified
  - Extendable diving board platform used on the PFEI and cranked into the fairing through a special access door

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Cleanroom Maintenance

- Critical for keeping JWST clean during all operations
- Initiation of daily cleaning activities after the pre-entrance acceptance surveys complete
- Maintenance program governed by a log listing each maintenance task with necessary frequencies
  - Technicians initialed tasks under the given shift and day
  - Log designed as a monthly schedule, allowing confirmation that task frequencies were being met

Facility:

Month/Year:		**1**	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Activity		**Per Shift**																													
Clean all Lifts	1st																														
	2nd																														
Charge Flashlights	1st																														
	2nd																														
Activity		**Daily**																													
Remove Trash																															
Check/Replace Tacky Mats																															
Wipe Work Surfaces																															
Clean Observatory Fixture																															
Vacuum & Mop Floor																															
Mop Gowning Area																															
Activity		**Weekly**																													
Remove Used Garments																															
Clean Garment Cabinets																															
Clean Cages																															

- Certain project activities occasionally necessitated frequency increases

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Pre-Cleaning Stations


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

- Cleaning stations operated to prepare flight hardware, tools, and GSE needed inside of cleanrooms
- Set up in both a built-in equipment airlock attached to the S5C PPF and portable, HEPA-filtered clean tents assembled in the airlocks of the S5C PPF and BAF HE
- Equipped with wipers, vacuums, white and UV lights, stainless steel tables and chairs, and an array of approved solvents, tapes, and bagging materials
- Offered a simple approach for teams to drop off items, fill out a form, and retrieve their cleaned, inspected, and bagged items
- "Customers" were ensured their items coming out of the cleaning stations were approved for use by JWST Contamination Control
- Employed consistent operating hours, aligning with flight hardware and facility preparation activities
  - Provided a hassle-free system for meeting contamination control impositions while minimizing schedule risk

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Air Shower Curtain

- Enclosure built between the PFEI and PFES to isolate the work area around JWST after integration with the LV
- Supplied with fairing air supply system
- Removable to prevent its own contamination when the BAF was opened to receive the LV
- Flexible to allow for up-and-down movement of the PFES with respect to the PFEI
- Required two cleaning events
  - First cleaning occurred prior to LV arrival
  - Second cleaning prior to JWST arrival
  - Initial cleaning reduced the amount of time needed for the second cleaning
  - Several previous cleanings also held ahead of the launch campaign to train personnel, rehearse the flow, and validate the process
  - Inspected with white and UV flashlights


(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – S. Martin)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Air Shower Curtain (cont’d)

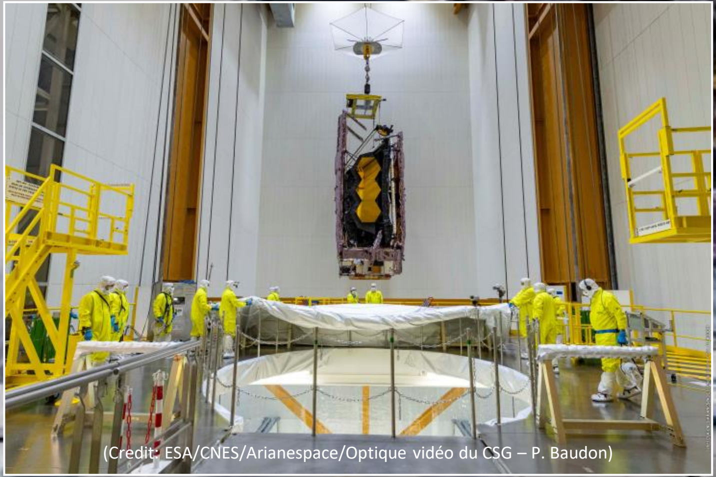
- Built in accordance with contamination control best practices
  - Completely sealed to pre-existing structures
  - Avoided uncleanable boxed volumes
- Constructed with transparent, urethane curtain material
  - Minimized particulate and molecular contamination
  - Provided visibility for security and safety cameras
- Curtains stowed prior to opening the BAF door for LV ingress
  - Accordion-like fashion inside a closable, metal basin around the perimeter
  - Folding pattern also allowed it to remain in place during PFES moves
  - As the PFES raised, the AShC unfolded with it
  - As the PFES lowered, the AShC stowed
- Portable, HEPA-filtered gowning room provided access inside the AShC where personnel changed from CSG garments to NASA garments prior to entrance
- Air supply upgrades included:
  - Additional ducting accommodated air from LV rollout control system that met humidity specifications
  - Power supply changes to LV rollout control system to avoid the diesel generator
  - Installation of air particle counters and Volatile Organic Compound (VOC) analyzers in the launch table mast downstream of the filters
  - Installation of VOC analyzers upstream of the AMC filters

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – S. Martin)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Manhole Cover

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)



(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

- Soft, clean cover atop PFES to protect the AShC interior cleanliness
- Consisted of a large, PVF tarp and four heavy duty sawhorses
- Sawhorses were padded with PVF to prevent tears in the tarp and equipped with hooks to secure corners of the tarp using reinforced holes
- PVF selected due to its electrostatic discharge and hypergolic compatibilities
- Guardrails positioned around PFES opening remained in place
- Process rehearsed at GSFC and CSG ahead of campaign
- Installed just after the AShC and working area was cleaned
    - Temporarily removed for the installation of JWST
    - Ultimately removed for encapsulation

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)

Ariane 5 Customizations

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Fairing Modifications

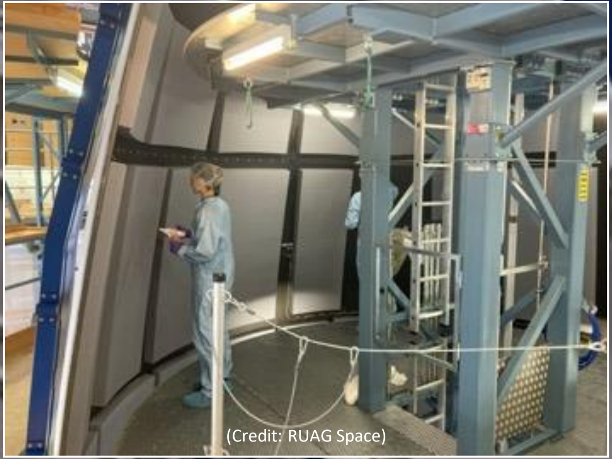
- Payload fairing manufactured by the Swiss company Rüstungs Unternehmen Aktiengesellschaft (RUAG) Space (now Beyond Gravity)
  - Nosecone used to protect a payload from the impact of dynamic pressure and aerodynamic heating during atmospheric ascent
  - Shroud jettisoned in two pieces, exposing payload to outer space and readying the payload to be separated from the LV
  - Nearly 17 m tall and 5.4 m in diameter
  - JWST folded to fit under the shroud
- ESA, Arianespace, and RUAG modified the design of vents to address depressurization concern
  - Residual air trapped in the sunshield could over-stress at fairing separation
  - Pistons placed near the purge vents to force their opening and maximally reduce pressure differential
  - Successfully tested on previous launches: VA252, VA253, and VA254
- Fairing cleanliness addressed
  - Clean fairing halves and extension module protected with polyethylene-aluminum-polyester blankets sealed with polyester tape
  - Small aluminum covers installed on handling points
    - Contained access doors to facilitate vacuuming
    - Fastened to the internal structure of the fairing
    - Protected against particles generated by the installation of lifting brackets or caps
  - Multiple cleaning and inspection points included in process

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Fairing Cleaning at RUAG

- Cleaning primarily performed at RUAG Space in Emmen, Switzerland
- Facility, scaffolding, and fairing all underwent initial cleaning prior to the NASA CC Lead arriving for inspections and a final cleaning
- Under UV, most of the Fairing Acoustic Protection (FAP) panels showed very few particles and fibers
  - Each cleaned with a wide-mouthed, HEPA-filtered vacuum
  - A few held a high density of particles and fibers that did not come clean with just vacuuming
  - RUAG Space began removing the particles and fibers with tape, but it became time consuming
  - RUAG Space then devised a solution using tape rollers that removed the remaining particles and fibers
- Molecular contamination samples were collected and analyzed prior to packaging

(Credit: RUAG Space)


(Credit: RUAG Space)


(Credit: RUAG Space)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Fairing Shipment


(Credit: RUAG Space)

(Credit: RUAG Space)

- Once passing results obtained, fairing halves transferred to shipping containers
  - Bagged and encased for transport to CSG
- Transported to CSG via ship
- Upon arrival, each half removed and unbagged in the BAF HE airlock
- Halves then transported to the BAF HE cleanroom and assembled on scaffolding
  - Scaffolding pre-cleaned in preparation

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Fairing Inspection at CSG

- Post-assembly inspection inside the fairing then performed with white and UV flashlights
  - Dark fairing interior provided a perfect inspection background
- Fairing mostly maintained cleanliness during shipment
  - Only touch-ups necessary.
- After compliance established, fairing hoisted from scaffolding and placed on temporary storage stand for approximately 3 weeks
  - Stand cleaned prior to installation
  - All openings sealed with static-dissipative bagging material to avoid ingress of insects or particles

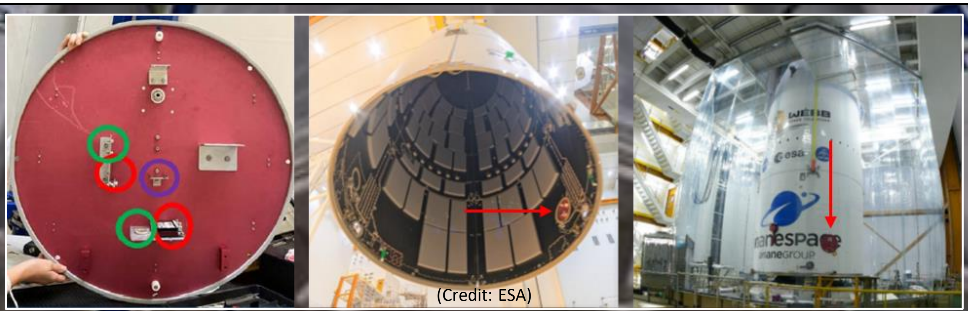
(Credit: ESA)

(Credit: ESA)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Fairing Monitoring

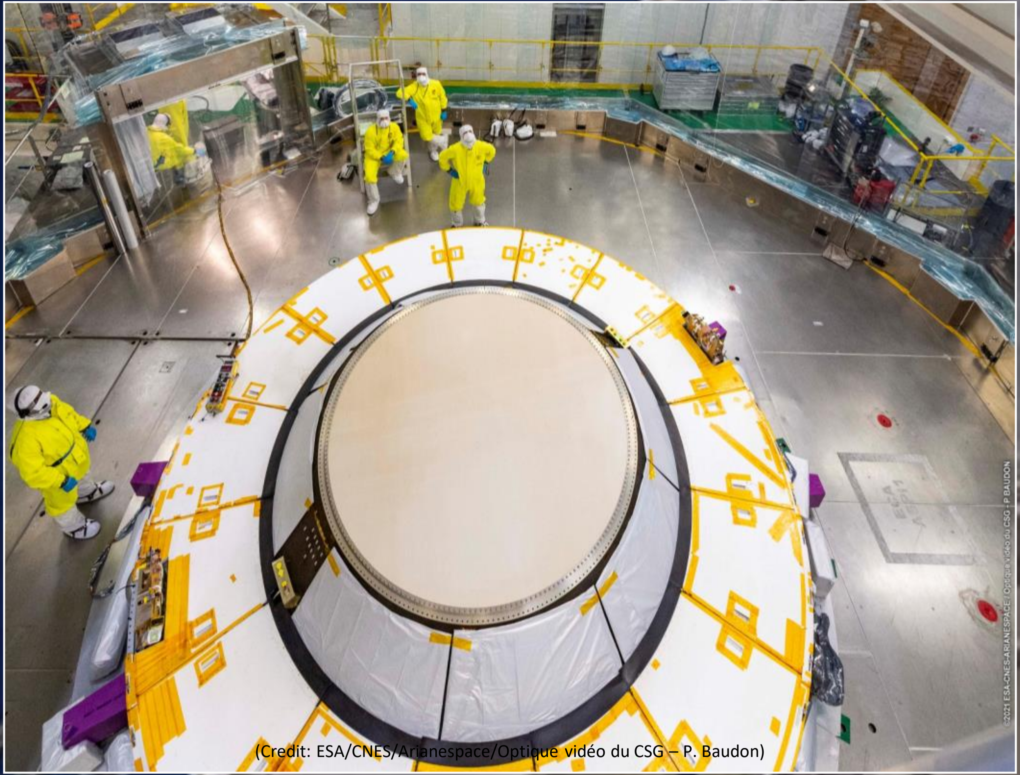
- While on the stand, particulate and molecular contamination sensors installed
  - Monitor the inner environment and provide notification of contamination build-up
  - Results could trigger another cleaning
  - No significant levels were detected
- To monitor after encapsulation, one fairing flight door temporarily replaced by a tooling door with contamination sensors:
  - Particle fallout plates
  - Metallic molecular plate
  - Calcium fluoride optical crystal
  - All measurements complied with allocations
  - Tooling door removed and replaced just prior to rollout


(Credit: ESA)

- Fairing ventilated with the same dry, HEPA and AMC-filtered air from the umbilical mast used with the AShC
  - Airflow set to 1 m^3/s
  - Air cleanliness monitored with:
    - Internal photoionization detector at the injection point
    - External airborne particle counter at a vent
    - VOC analyzers and airborne particle counters in mast
  - Temperature and relative humidity monitored at same vent as external particle counter
  - Air parameters verified with handheld devices just prior to installation of the duct
    - Also previously verified to minimize risk

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Vehicle Equipment Bay Cleaning



(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

- Vehicle Equipment Bay membranes, LV cone, and LV interface surface cleaned and inspected with white and UV flashlights multiple times
  - Collaboration with RUAG
  - Iterative cleanings reduced risk of schedule-halting findings and duration needed for final inspections
  - Leading up to JWST’s installation to the LV
  - Prior to fairing encapsulation
- LV interface surface and cone spot cleaned by delicate vacuuming
  - Cone protected from damage with clean pads wrapped in PVF
- Membranes cleaned by delicate, dry wiping
  - Protected with hard covers allowing personnel to safely crawl
  - Covers recleaned in place daily by vacuuming and solvent wiping
- Contamination could have migrated by airflow or contact transfer to sensitive JWST areas not cleanable on the LV

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG – P. Baudon)

Conclusions and Discussion

(Credit: NASA – B. Ingalls)

Effectiveness Against Requirements

- Ahead of the launch campaign, the team predicted the amount of contamination JWST would accumulate at CSG
  - Scrutinized data from the few available sources:
    - Reports from the Herschel-Plank mission
    - Reports from the Automated Transfer Vehicle missions
    - Facility monitoring history provided by CSG
  - Initially predicted that JWST was at risk of not meeting its End of Life (EOL) particulate cleanliness requirements
- Predictions refined with additional data and testing:
  - On-site particle fallout tests
  - Protection from the portable HEPA modules
  - Surface orientation knockdown factors
  - Deposition rate uncertainty
  - Cleanroom activity levels
  - Indicated JWST would likely meet its EOL requirements

Phase	PM		SM	
	Particulate (PAC)	**Molecular (Å)**	**Particulate (PAC)**	**Molecular (Å)**
Launch Campaign Allocation	0.60	15	0.42	15
Launch Campaign Measurement	0.16	1	0.17	1
Mission EOL Requirement	1.50	300	0.50	300
Mission EOL Measurement	0.75	45	0.15	59

- Throughout the campaign, data collected showed that the processes, procedures, and special GSE were effective
  - Particle fallout results in the S5C PPF, S5B HPF, and BAF HE facilities showed substantially less accumulation than predicted
    - Largest improvement achieved in S5B
      - HEPA modules in use more than planned for
      - Maintenance efforts by the technician team
- Program at the launch site resulted in the PM particulate cleanliness being approximately 50% better and the SM approximately 70% better than their EOL requirements
  - Molecular measurements indicated an even greater achievement
- Data collected during the campaign showed that employing reasonable mitigations significantly decreased contamination levels in all facilities

(Credit: NASA – B. Ingalls)

Future CSG Campaigns

- Ariane 5 will soon be replaced by Ariane 6
  - BAF HC will no longer be used
- Launch campaign for Jupiter Icy Moons Explorer (JUICE) on Ariane 5 will impose similar operational constraints as JWST
  - Leverage some process upgrades:
    - Use of sealed-edge wipers
    - Cleanroom garment specifications
- Many environmental management systems and contamination control methodologies developed for VA256 now part of CSG standard operating procedures

(Credit: NASA – B. Ingalls)

Lessons Learned for Future Programs

- Drawn from experiences both successful and unsuccessful:
  - Technical achievements
  - Facility nuances
  - Logistics
  - Strengthening of team morale
- <u>Utilization of an experienced technician team</u>
  - Provided limited engineering staff flexibility to work other responsibilities
  - Technicians authorized to enforce cleanroom rules, approved or rejected GSE for cleanroom ingress, supported lab processing, and performed critical GSE cleanliness inspections
  - Technicians trained and empowered to both perform and take ownership of advanced tasks catered to their individual strengths:
    - Technician with previous lab experience trained to process particle fallout wafers through Image Analysis and ellipsometry
    - High energy technician spearheaded the laundry facility upgrades in collaboration with CNES
    - Technician demonstrating leadership potential built a positive working relationship with CNES in development and execution of the SCAPE suit cleaning procedure
    - Created sense of pride resulting in high quality work
- <u>Scheduling in support of I&T</u>
  - Scheduling shifts in accordance with the rest of the I&T teams initially resulted in midday lulls
  - Additional, small mid-shift team moved the overlaps to different parts of the day than the rest of I&T
    - Allowed the contamination control team to provide seamless support without burnout
    - Avoided interference between contamination control maintenance and restocking with other operations
  - Fostered positive working relationships with management
    - Contamination control team operated in the background
    - Influenced management to keep the contamination control team abreast of general issues, schedule updates, and technical challenges
- <u>Pre-characterization of facilities in advance with data can allow for proper planning</u>
  - Historical data may be limited
  - Unique sensitivities may be new to any given facility
  - Quantifying risk levied by environments in advance can allow for the development of custom GSE, corrective actions, and facility upgrades
  - Justifies consequential costs

(Credit: NASA – B. Ingalls)

Lessons Learned for Future Programs (cont'd)

- Supply chain issues
  - COVID-19 pandemic and remote geographical location
  - Stocking of extra supplies and consumables
    - Launch campaigns can be dynamic and running out of items due to an extended schedule in a remote area could be costly
    - May require purchasing supplies a year or more in advance and identifying long term storage options
  - Budgeting for a surplus worthwhile since plans evolve
    - Cleanroom consumables can quickly be used up by unexpected work
  - Increase of short-term costs hedges against risks arising as a program approaches launch
- Use of sealed-edge cleanroom wipers
  - Development of the Near Infrared Spectrograph (NIRSpec) revealed shedding of unsealed cleanroom wipers during UV inspections
    - Fibers liberated during nominal use
    - Wiper fibers were found inside of NIRSpec
  - Switch to sealed-edge wipers alleviated the issue
  - Along with regular darkened room UV inspections, should become standard procedure for any fiber-sensitive mission
- Use of portable HEPA modules
  - Allowed for creating and maintaining cleaner work areas inside and outside of cleanrooms
  - Significantly reduced contamination levels
  - Kept on a separate power source to reduce risk of losing all clean air during an outage
  - Became attractive supports for individuals to lean on
    - Future use should include stanchions or keep-out zones in front of the filter faces to prevent personnel from blocking airflow
- Insect control measures
  - Geographic areas supporting large hardware ingress and egress that have issues with insects
  - Operation of bug zappers in cleanrooms and airlocks during off-hours
  - Understanding of mating schedules for prominent species
  - When rollup doors opened, positive pressure can is quickly lost, and insects attracted to light coming from inside
  - Time will be needed after closure with the facility lights darkened for intruding bugs to be eliminated
  - Should be added to written work orders and procedures to ensure occurrence

(Credit: NASA – B. Ingalls)

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(Credit: R. Wooldridge)

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(Credit: ESA - S. Corjava)

(Credit: ESA/CNES/Arianespace/Optique vidéo du CSG - P. Piron)