

# Cleanliness and contamination control strategy for optical payloads of the ANSER-AT mission: a New Space approach

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## ABSTRACT

The ANSER program is an internal Research and Development initiative of INTA (National Institute for Aerospace Technology) aimed at developing and demonstrating enabling technologies for efficient Earth Observation (EO) missions. It explores concepts such as nanosatellite constellations, formation flying, fractionated instruments, and miniaturised optical technologies.

The program is aligned with the emerging New Space paradigm, which promotes cost-effective and rapid access to orbit through smaller platforms and agile development approaches. However, these constraints in schedule and budget challenge traditional space engineering practices, as well as the classical Product Assurance (PA) and Quality Assurance (QA) philosophies defined in ECSS standards.

Among the missions under development is ANSER-AT, dedicated to air quality monitoring. It is based on a fractional spectrometer distributed across a cluster of four CubeSats, designed to measure multiple atmospheric compounds of chemical and climatic relevance. Each payload operates within a specific spectral range (ultraviolet, visible, near-infrared and short-wave infrared) and includes two main optical subsystems: a telescope and a spectrometer.

For optical instruments operating across any spectral domain, contamination (particulate or molecular) is a critical concern, as deposition on sensitive surfaces can significantly degrade performance. A dedicated cleanliness and contamination control plan has therefore been developed for the ANSER-AT payloads, tailoring the ECSS approach to the needs of New Space technology-demonstration missions. Its objective is to ensure that contamination remain within acceptable limits, while enabling faster development cycles and cost-efficient implementation. The plan is applied from the early design through manufacturing, integration and testing, and pre-launch activities.

The paper presents the tailoring of ECSS Q-branch cleanliness and contamination control requirements, the adoption of risk-tolerant quality assurance strategies and the trade-off between innovation, technological complexity, and programmatic constraints within a New Space context.

**Keywords:** Contamination, New Space, Product Assurance, Optical payload

## 1. INTRODUCTION

ANSER (Advanced Nanosatellite System for future Earth observation Research) is an INTA-led Research and Development programme focused on advancing and validating innovative technologies for Earth observation. The initiative explores distributed mission concepts based on nanosatellite clusters, fragmented payload architectures, and highly miniaturised optical systems.

The program began in 2018 with the ANSER-WQ (ANSER Water Quality) mission, a cluster of three 3U CubeSats (see Figure 1), currently operating nominally in orbit [1]. Its main scientific objective is the monitoring of inland water bodies using a distributed optical payload. The mission has also validated INTA's initial formation-flight strategies, demonstrated an inter-satellite communication link, and flight-tested an S-band patch-antenna demonstrator designed and developed at INTA.

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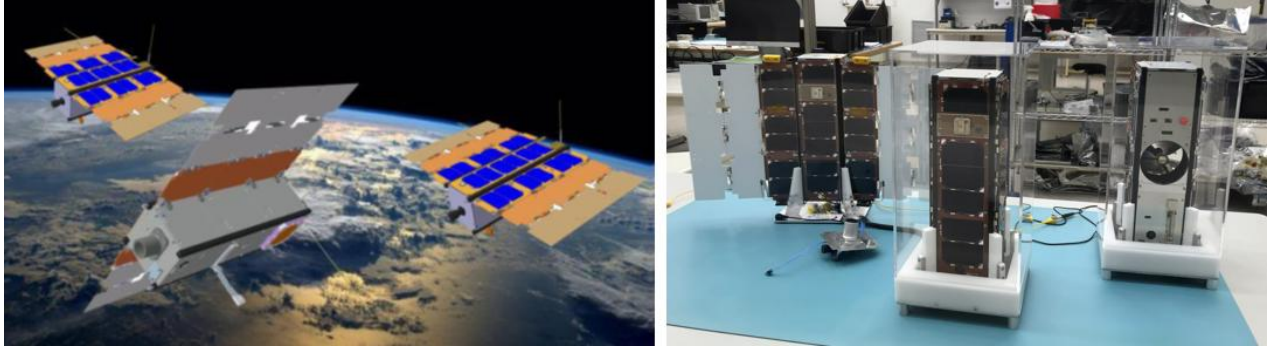


Figure 1. Left: ANSER-WQ cluster (conceptual image). Right: Flight models of the ANSER-WQ satellites.

Building on this success, INTA is developing a new and more demanding mission: ANSER-AT (ANSER Atmosphere). This mission has passed its Critical Design Review and is scheduled to be launched in 2028. ANSER-AT is dedicated to monitoring gases related to global warming and relies on a distributed payload composed of four optical spectrometers, each operating in a different spectral band and hosted on a cluster of four 6U CubeSats.

The payload is fully designed and developed by INTA, together with other on-board technologies such as the solar panel hold-on and release mechanism, and the S-band antenna. The remaining subsystems rely extensively on Commercial Off-The-Shelf (COTS), following a New Space-aligned strategy to reduce development cost and schedule. Additionally, INTA is responsible for the assembly, integration and testing of both platform and payloads, as well as the validation of the full constellation with the ground segment.

Given the presence of optical instruments, a rigorous contamination-control strategy is essential throughout development, integration, and verification. Maintaining the cleanliness of all optical and adjacent surfaces is critical to avoid performance degradation and ensure the scientific objectives of the mission.

## 2. ANSER-AT CONSTELLATION OVERVIEW

### 2.1 Platform overview

ANSER-AT is implemented using a cluster of four 6U CubeSats, representing an enhanced evolution of the ANSER-WQ service module. The platform retains the functionalities of the previous mission but significantly upgrades them. In addition to doubling the available volume (from 3U to 6U), the platform includes (see Figure 2 and Figure 3):

- Higher computational and power capacity.
- An upgraded communication system capable of operating in UHF or S-band.
- An Inter-Satellite Link functionality enabling communication between spacecrafts.
- A formation-flying concept based on aerodynamic flaps, now supported by an improved Flight Control Computer (FCC).
- An upgraded Attitude Determination and Control System (ADCS) providing enhanced pointing performance, complemented by a miniature colour camera for reference imaging and in-flight calibration.

As in ANSER-WQ, the service module makes extensive use of qualified, flight-proven COTS.

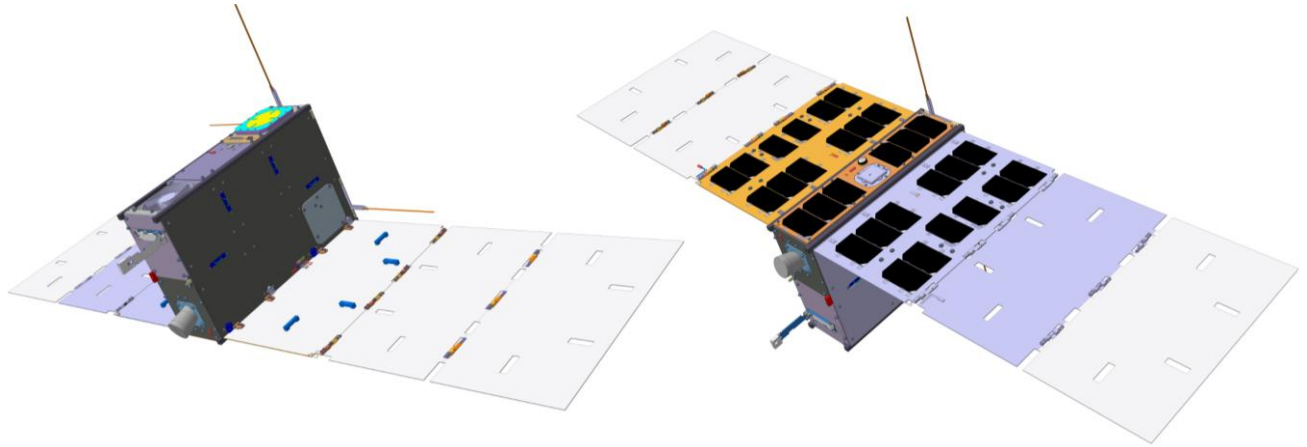


Figure 2. ANSER-AT satellite with deployed solar panels and aerodynamic flaps, shown from different viewing perspectives.

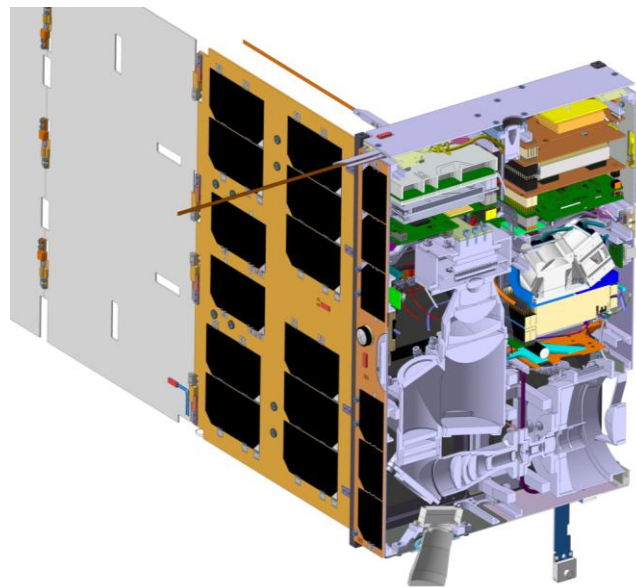


Figure 3. Detailed view of the different units and the payload assembled within the satellite structure.

## 2.2 Payload overview

The distributed payload consists of four spectrometers, each operating in a different spectral band to enable coordinated multi-band observations [2]:

- Ultraviolet range (UV): from 320 nm to 355 nm
- Visible range (VIS): from 355 nm to 420 nm
- Near infrared band (nIR): from 756 nm to 773 nm
- Shortwave infrared band (SWIR); from 1550 nm to 1680 nm

Each instrument includes two optical subsystems (see Figure 4 and Figure 5):

- A Telescope unit (TEL) that collects the scene radiance and directs it to the spectrometer entrance slit. It is identical for all satellites and is based on a compact two-mirror Cassegrain design, complemented by a lens barrel to correct residual aberrations and ensure adequate image quality.
- A Spectrometer (SP), composed of three main optical subsystems:
  - The Collimator that collimates the light from the entrance slit using a refractive lens set tailored to each spectral band.
  - The dispersive element is based on commercial diffraction grating, selected according to the operating spectral range, the efficiency and required spectral resolution.
  - The Collector that focuses the dispersed light onto the detector (a linear sensors for UV, VIS, and nIR channels and a two-dimensional sensor for SWIR) using a lens assembly optimized per each band.

Additional elements (such as folding mirrors, neutral-density and interferential filters, and a depolarizer) are incorporated into the design to ensure compactness, prevent saturation, and reduce polarization-dependent effects. UV and VIS payloads also include a Reference Module (RM) for direct-Sun measurements via a lens and fibre feed.

Beyond the optical subsystems, the payload includes:

- The Focal Plane Assembly (FPA), which supports the detector, and the Front-End Electronics (FEE), responsible for signal conditioning, digitisation, and data formatting.
- The Payload Computer Unit (PCU) provides the on-board processing and storage required for scientific data, implements the telecommand/telemetry interface with the platform's on-board computer, and manages power distribution to all payload subsystems.
- The Thermal Control Subsystem (TCS) ensures thermal stability through heaters for optical modules and a Thermoelectric Cooler (TEC) for detector cooling. A dual-branch thermal strap transfers the extracted heat to the external radiators for efficient radiative dissipation to space.

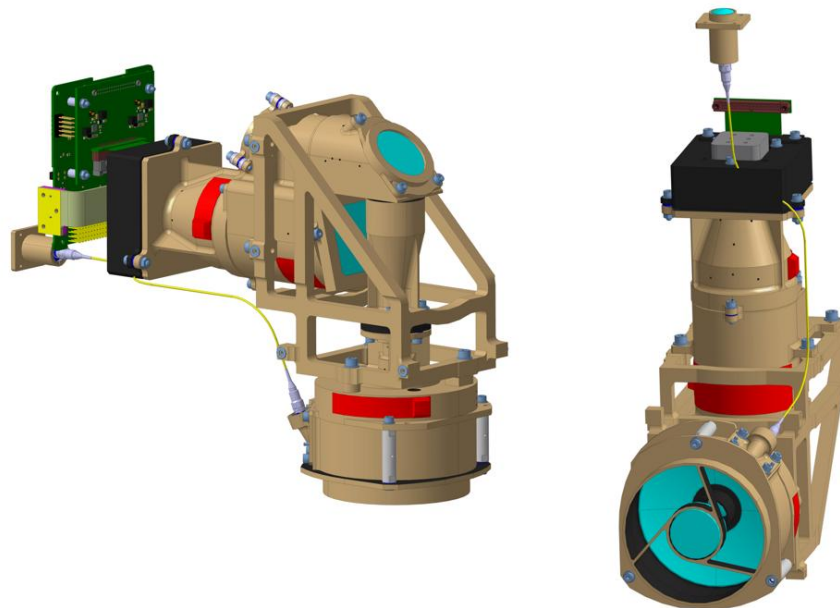


Figure 4. ANSER-AT payload, shown from different viewing perspectives.

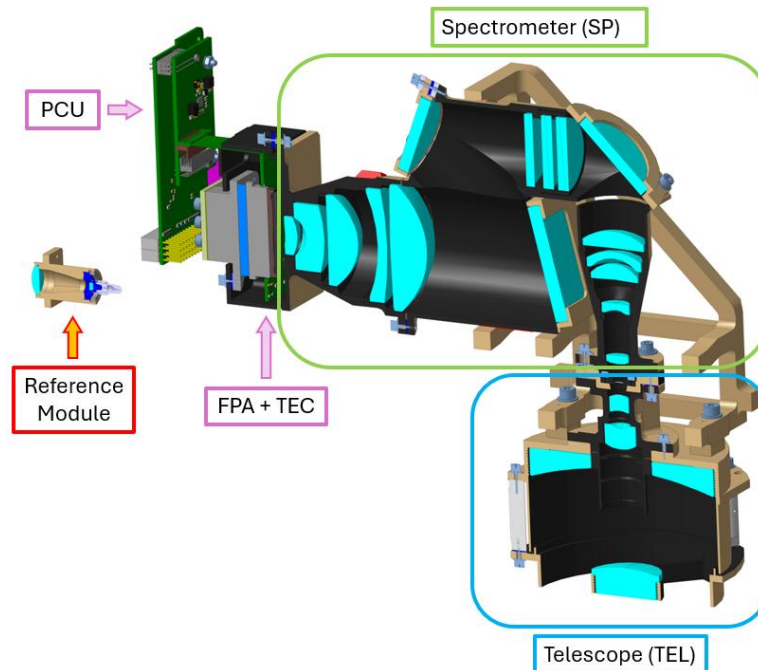


Figure 5. Detailed view of the different parts of the payload.

### 3. CONTAMINATION EFFECTS

In general, both particulate and molecular contamination can produce significant negative effects on space systems. Excessive contamination build-up may lead to:

- Programmatic and technical deviations.
- Reduction of the nominal performance of the affected subsystems.
- The generation of incidents or even functional failures.
- In severe cases, contamination can ultimately lead to complete mission loss

The following elements are typically the most sensitive to particulate and molecular contamination:

- The optical elements: Molecular contamination can alter transmittance and reflectance properties, degrading the radiometric performance. Particulate deposition (depending on particle size and concentration) may cause obscuration and increase straylight.
- Opto-electronic devices (such as CCDs, CMOS detectors and solar cells): Both particulate contamination and molecular deposition can produce surface darkening effects, reducing the efficiency of the devices.
- Optical sensors of guidance systems: Any particulate or molecular deposition on the optical surfaces can degrade their measurement accuracy. This directly affects the pointing performance of the spacecraft and may compromise attitude-control stability.
- Thermal control surfaces: Molecular films modify absorptance and emissivity, altering heat exchange and causing temperature drifts.

For this reason, it is essential to maintain strict control over the cleanliness levels of all systems, in order to reduce contamination-related risks and minimise their impact on functionality and performance.

#### 4. CLEANLINESS REQUIREMENTS AND ECSS TAILORING

As ANSER-AT is an INTA-owned mission, top-level requirements are defined by the INTA scientific team. The contamination-control baseline derives from the system's functional and optical cleanliness needs, complemented by the contamination limits and handling constraints imposed by the launch provider to ensure fairing cleanliness and minimise cross-contamination risks.

Within this framework, the first step is to specify the maximum allowable contamination levels throughout the mission life cycle. These limits derive from the performance assessment of the payload and other contamination-sensitive subsystems, ensuring that any contamination accumulated during manufacturing, integration, testing, launch, and operations does not degrade the system performance or compromise the mission objectives.

For ANSER-AT, the cleanliness requirement has been set to levels equivalent to visibly clean, according to [3]:

- Maximum particle concentration: 300 ppm
- Maximum molecular deposition:  $1 \times 10^{-6} \text{ g/cm}^2$

In addition to mission-specific requirements, the ECSS Q-branch standards define the general contamination-control practices for European space programmes. These standards are focused on the following key aspects:

- Evaluation of how contamination affects optical, thermal, and mechanical performance.
- Implementation of contamination-oriented design strategies.
- Appropriate selection of low-outgassing materials and processes.
- Planning of contamination control activities.
- The use of appropriated facilities, tools and handling procedures in order to guarantee the contamination control and monitoring

A key aspect for ANSER-AT is its alignment with the New Space philosophy, whose main objective is to enable faster access to space while reducing development time and cost. To achieve this, programmes often apply relaxed or tailored requirements, accepting higher levels of technical risk and relying extensively on COTS elements for many subsystems. Although many COTS items are already qualified or flight-proven, they pose challenges for contamination control:

- The information available is usually limited to datasheets and high-level qualification reports.
- Additionally, it is common that the information associated to materials and processes is incomplete, generic, or even unavailable. Since these components are not designed specifically for the mission, the level of control over materials, processes, and contamination-critical features is inherently reduced.

For this reason, the contamination requirements and the practices defined in the ECSS standards must be tailored and compensatory measures must be implemented to mitigate the lack of detailed information and control associated with COTS. For ANSER-AT, tailoring is defined as follows:

1. For elements specifically designed for ANSER-AT, materials and processes must be selected to minimise outgassing. As reference criteria, materials will comply with the following requirements:
  - Recovered Mass Loss (RML) < 1.0%
  - Collected Volatile Condensable Materials (CVCN) < 0.1%.

Outgassing control is not only essential to maintain acceptable contamination levels within the instrument and the whole system but also meet launch-provider constraints regarding cross-contamination.

2. A vacuum bake-out will be performed on all satellites prior to delivery, at the highest practicable temperature and for a minimum of 72 hours.
3. Compensatory measures for COTS may include:
  - Enhanced incoming inspections, focusing on initial cleanliness level provided by suppliers.

- Individualised bake-outs, when feasible, with a minimum of 72 hours at the item's maximum non-operational temperature minus 10 °C, assessed case-by-case.
- Additional cleanliness verification steps, stricter handling procedures, or dedicated contamination monitoring during Assembly, Integration and Testing (AIT).

## 5. CONTAMINATION CONTROL STRATEGY

Once the contamination requirements for ANSER-AT have been defined, the next step is to establish the Cleanliness and Contamination Control Plan (C&CCP). This plan specifies the strategy and methods to achieve and maintain the required cleanliness levels throughout the mission life cycle, from early design through manufacturing, assembly, integration, testing, and final launch-site activities.

A system-level assessment is performed to identify elements whose performance may be degraded by particulate or molecular contamination and to determine their susceptibility. For ANSER-AT, all sensitive items correspond to optical, electro-optical, and thermal control surfaces, including:

- The FPA hosting the detectors (see Figure 6).
- The payload optical elements and assemblies (see Figure 7). Specifically, the telescope region is the most critical part once integrated, as it remains exposed to external environment throughout the entire AIT phase, as well as during launch and operational phase. The remaining optical modules (of the spectrometer), once assembled, are encapsulated within their structural housings or optical barrels, which significantly reduces their exposure to external contamination sources. Nevertheless, potential contamination originating from internal sources within the system itself must also be considered.
- The solar panels (see Figure 8).
- The optical sensors of the ADCS, that includes Earth Horizon Sensors, the Coarse and Fine Sun Sensors and Star Trackers (see Figure 9).
- The auxiliar miniaturised camera (see Figure 10).
- The external radiator surface.

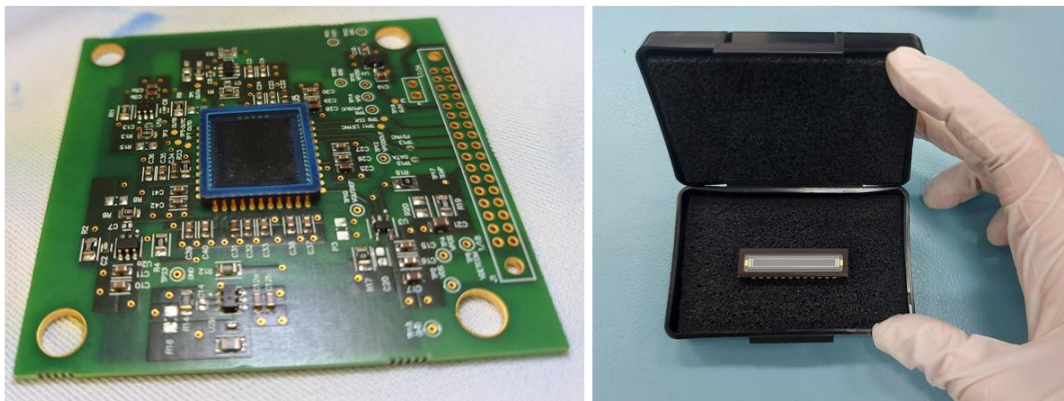


Figure 6. Left: SWIR detector integrated on FPA board (qualification model). Right: Linear detectors for VIS, UV and nIR payload (flight models).

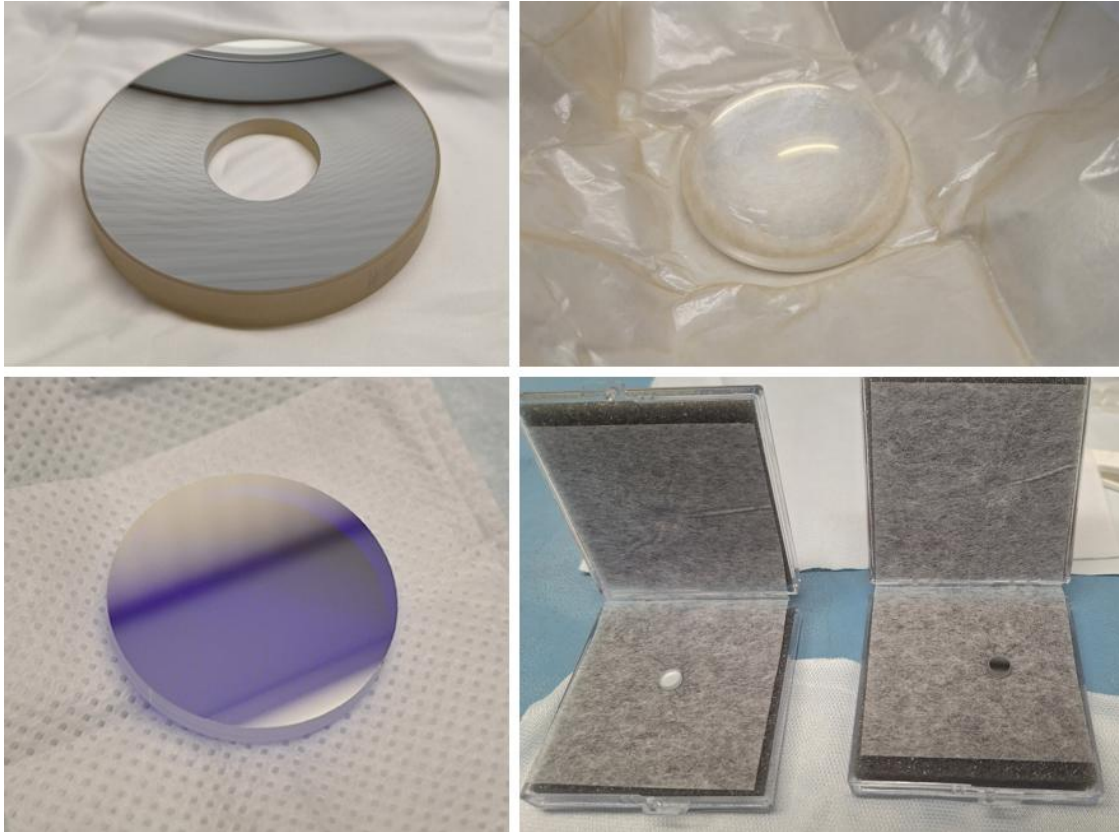


Figure 7. Some optical elements of the payload.

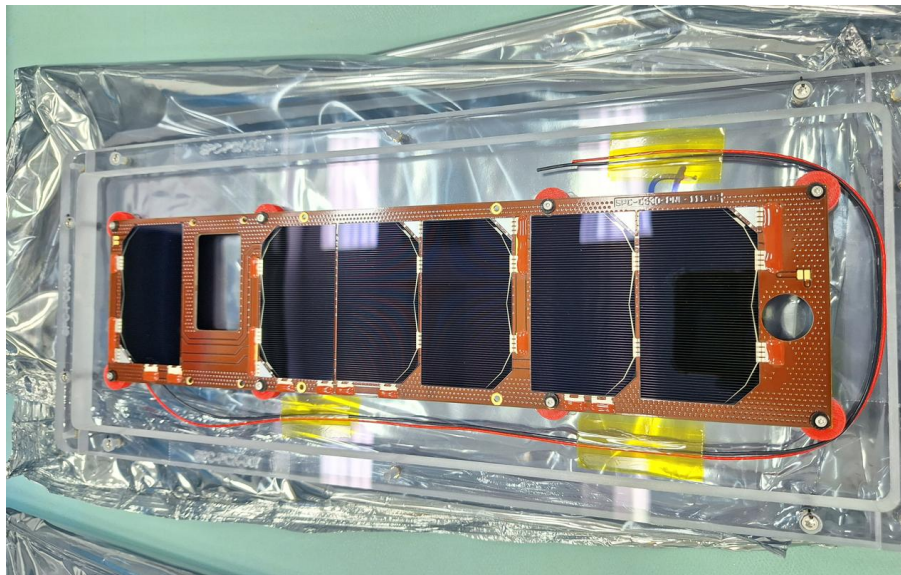


Figure 8. The image shows the fixed solar panel of one of the ANSER-AT satellites. Its design is similar to that of ANSER-WQ, which is presently undergoing manufacturing.



Figure 9. Left: Earth Horizon Sensor. Center: Star Tracker. Right: Fine Solar Sensor.



Figure 10. The auxiliary miniaturised camera.

The cleanliness and contamination-control approach for ANSER-AT builds on the methodology successfully applied in the previous ANSER mission [4] and other ESA collaborative projects [5], while being tailored to the specific characteristics of the new mission. The strategy combines preventive design, controlled integration processes, and continuous monitoring throughout all on-ground activities up to the integration with the launch vehicle.

### 5.1 Molecular and particulate contamination budget

To define the contamination-control strategy for the payload and the complete satellites, it is necessary to estimate the molecular and particulate contamination that the hardware may accumulate during each ground activity. Performing this estimation requires identifying the following parameters for each phase:

- Contamination-sensitive surfaces.
- Determination of the initial molecular and particle contamination levels of each item (after completion of the initial cleaning process and prior to the start of assembly activities). These levels can be estimated through surface rinsing with isopropyl alcohol (IPA) followed by infrared spectroscopy of the collected residues, and through tape-lift sampling when feasible.
- Exposure environment, including airborne particulate concentration, molecular deposition, and activity-specific contamination sources.
- Duration and conditions of exposure (e.g., direct exposition of the surfaces, absence of direct line-of-sight to the contamination source).
- Potential protective means, such as covers, purging strategies, temporary barriers that can be applied to reduce contamination.

Close cooperation with the AIT team is essential to map the complete activity flow. Based on this information, contamination accumulation is estimated for each step, considering both particulate and molecular contributions.

This approach enables determining whether the contamination-control strategy is adequate or requires revision. If the estimated contamination exceeds acceptable limits, alternative working environments, additional protective mechanisms, increased inspection or cleaning frequency, or modifications to critical activities may be implemented. Activities are considered critical when they generate excessive contamination, involve long exposure durations, or are incompatible with sensitive hardware or cleaning processes.

## 5.2 Hardware design for mitigating contamination

The contamination control is an activity that must not be limited to the phases in which hardware is physical present. Instead, it has to be initiated during the earliest stages of the system design. A design approach that neglects cleanliness considerations can lead to issues later in development or, worse, during operations, when corrective margins are minimal.

The contamination-control best practices implemented during the ANSER-AT design phase have focused on the following key aspects:

- Material and process selection.
- Use of protective means for contamination-sensitive items.

### 5.2.1 Selection of materials and processes

The selection of materials and processes for ANSER-AT is based on ensuring full compatibility with cleanliness requirements and outgassing constraints. All elements are carefully evaluated and selected to avoid becoming a source of molecular or particulate contamination for the system.

To prevent particle contamination, priority is given to non-flaky, non-shatterable, and non-dust-generating materials. When the use of materials with potential particle-generation risks is unavoidable, mitigation measures such as encapsulation or surface sealing are applied to keep particle release under control (see Figure 11).

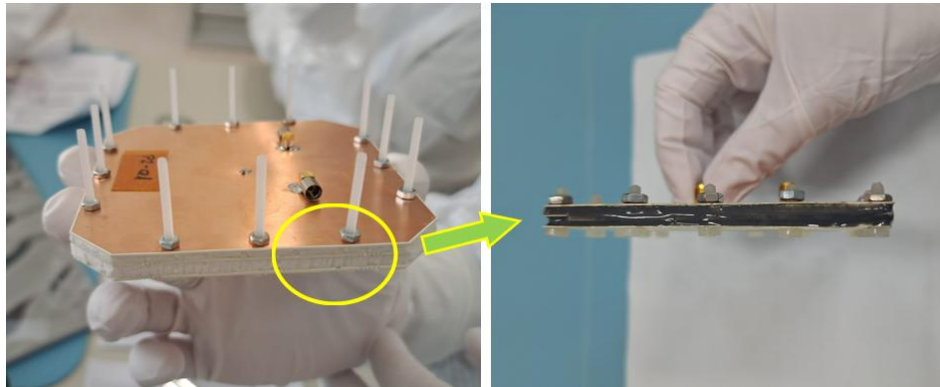


Figure 11. Example of encapsulation applied to the spacer sheets of the S-band patch to prevent the risk of particle release.

On the other hand, one of the main sources of molecular contamination is the outgassing of non-metallic materials. For this reason, significant effort has to be applied to ensure the extensive use of low-outgassing materials, within the limits established by ECSS standards. Particular attention is paid to materials located near the optical payload and other contamination-sensitive elements.

A specific challenge arises from the use of COST, which typically provide limited or non-existent information regarding the materials and processes used by suppliers.

To minimise the associated contamination risks, the following mitigation strategies will be followed:

1. Priority is given to materials and processes compliant with the ESCC outgassing limits indicated in Section 4 (RLM < 1% and CVCM < 0,1%). Special attention will be paid to non-metallic materials, adhesives and sealants (particularly those used to bond the optics or thermal control elements), coatings and paints (including solder masks, silkscreen materials and conformal coatings for electronic boards, internal coatings of the payload optical blocks for straylight suppression and thermal surfaces treatments).
2. For materials lacking outgassing data, and when feasible, a characterization according to ECSS-Q-ST-70-02C will be conducted at INTA, as an ESA-certified laboratory.
3. If testing is not feasible, or the measured outgassing exceeds the limits, a bake-out will be performed until compliance is achieved. In addition to the final bake-out at system level, unit-level bake-outs prior to assembly are preferred for effectiveness. It is also good practice to segregate elements according to their nature, avoiding the co-location of high-outgassing materials or COTS together with low-outgassing or contamination-sensitive items in order to prevent cross-contamination.
4. It is essential to assess the compatibility of the materials with the cleaning processes, their effectiveness, and up to which integration stage they can be applied.

### 5.2.2 Protection of sensitive items

All optical elements and contamination-sensitive surfaces that remain exposed to the environment during ground activities (such as the telescope, solar panels, ADCS optical sensors, and radiators) will be equipped with protective covers (see Figure 12). These covers must comply with the same cleanliness requirements as the items they protect, ensuring that no additional particulate or molecular contamination is introduced during handling, storage, or integration.

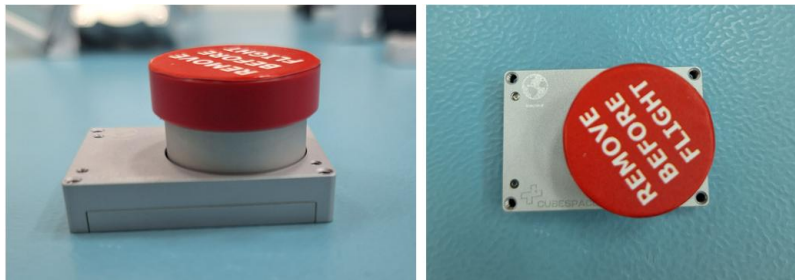


Figure 12. Cover to protect the optics of the Earth horizon Sensor.

In addition to physical protection:

- The relative position and line-of-sight exposure of contamination-sensitive elements with respect to potential contamination sources must be systematically assessed.
- Thermal gradients within the system has to be minimised to prevent sensitive elements from acting as cold traps and promoting the condensation or deposition of contaminants

## 5.3 Environments and facilities during integration and testing

### 5.3.1 Cleanrooms

The proper selection of clean areas plays a fundamental role in achieving cleanliness levels.

Since ANSER-AT includes elements that are critically sensitive to contamination, all assembly and integration activities involving flight hardware are planned to be performed within ISO 6 class cleanrooms or, when appropriate, inside ISO 5 laminar-flow cabinets.

Initially, all assembly, alignment, integration, and optical characterisation activities of the payload will be carried out in an ISO 6 cleanroom equipped with the required resources, optical benches, and metrology systems needed to perform these activities (see Figure 13).

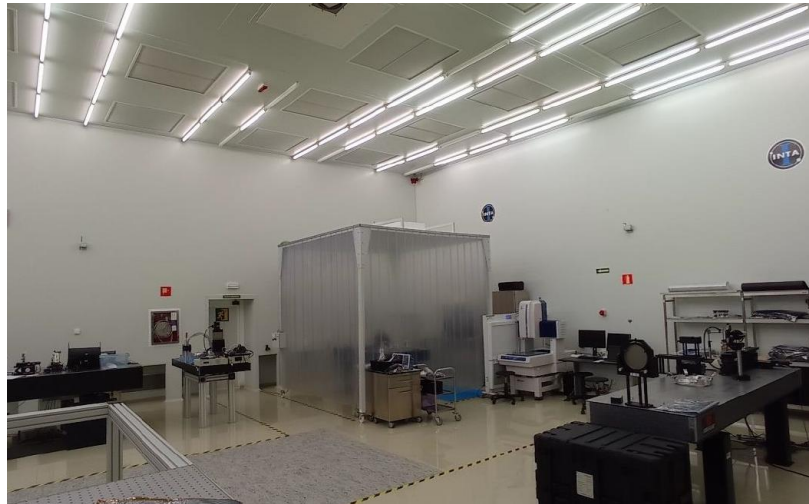


Figure 13. ISO 6 class cleanroom.

Conversely, the assembly activities of the platform, as well as the integration of all subsystems into the satellite structure, including the payload (once fully integrated and verified), will be conducted inside an ISO 5 laminar-flow cabinet located within an ISO 8 cleanroom (see Figure 14).



Figure 14. ISO 5 laminar-flow cabinet located within an ISO 8 cleanroom.

Despite working in clean areas (where airborne particle levels, temperature, and humidity are strictly controlled), it is essential to plan ground activities to minimise hardware exposure time. In addition, all items should remain protected (e.g., bagged) whenever they are not being actively processed, regardless of their contamination sensitivity. Optical elements and other contamination-sensitive components must remain covered at all times, except during operations that strictly require their exposure, such as specific tests or activities directly involving these surfaces.

Humans are the main source of contamination, so to prevent it, project team are trained on how to behave within clean areas and work facilities. Furthermore, access to the cleanroom will be restricted to the minimum number of essential personnel.

### 5.3.2 Thermal vacuum testing

During thermal-vacuum (TVAC) testing, it is essential to prevent cross-contamination from the vacuum chamber itself or from the mechanical and thermal ground support equipment (GSE) used during the test.

To minimise this risk, a blank test of the chamber (with all the GSE installed inside) must be conducted prior to the TVAC test. This process allows the reduction of molecular contamination and has to be monitored using MOC witness samples. To guarantee the effectiveness of the blank test, the chamber is maintained at temperatures at least above the maximum temperature defined for the TVAC test, for a minimum of 24 hours under vacuum conditions. The cleanliness status of thermal vacuum facilities has to be demonstrated by meeting the requirement of a total molecular contamination below  $10^{-7}$  g/cm<sup>2</sup> per vacuum cycle.

Furthermore, during the TVAC test, a cold trap is used to capture residual volatiles. If maintaining the cleanliness level of the vacuum chamber is critical, the vacuum recovery process becomes essential to avoid recontamination. This involves injecting dry nitrogen and maintaining the cold-trap temperature lower than all chamber surfaces to ensure efficient volatile capture.

The TVAC test itself must be also monitored using vacuum-compatible MOC and PAC witness samples, enabling verification of particulate and molecular deposition throughout the cycle.

This strategy to prevent and monitor contamination during TVAC testing has already been successfully applied to the ANSER-WQ satellites, as well as other ESA collaborative space projects, and its effectiveness has been demonstrated through consistent and compliant contamination results (see Figure 15).

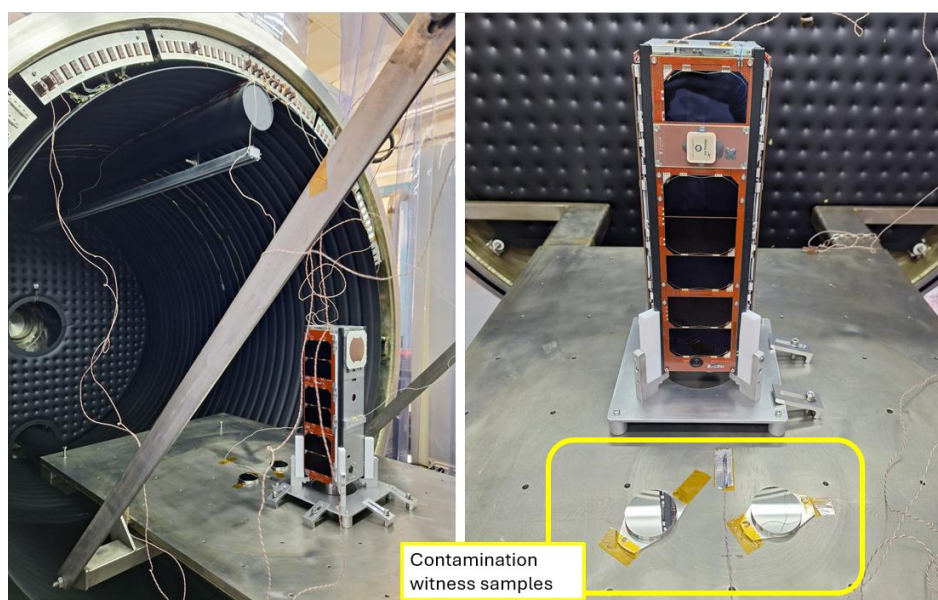


Figure 15. TVAC test of one satellite of ANSER-WQ constellation.

### 5.3.3 Vibration testing

Mechanical testing must be performed under controlled environmental and cleanliness conditions compatible with the requirements applicable to the specimen under test. In particular, vibration facilities can represent a significant contamination source, especially due to the slipping device of the shaker, which may generate oil droplets and vapours.

To conduct the mechanical test campaign for ANSER-AT, the test specimen has to be integrated inside its Poly-Picosatellite Orbital Deployer (P-POD), simulating the launch environment. In addition, appropriate contamination-control mechanisms are applied throughout the test to maintain the required cleanliness level and to avoid cross-contamination within the test environment.

INTA has mechanical vibration facilities within ISO 8 and ISO 5 controlled environments. Although it is possible to conduct the tests under the cleanliness requirements established for the project, the same philosophy applied to the predecessor ANSER-WQ satellites will be followed: the test specimen (the P-POD and satellite assembly) will be covered with an antistatic bag to prevent both molecular and particulate contamination (see Figure 16).

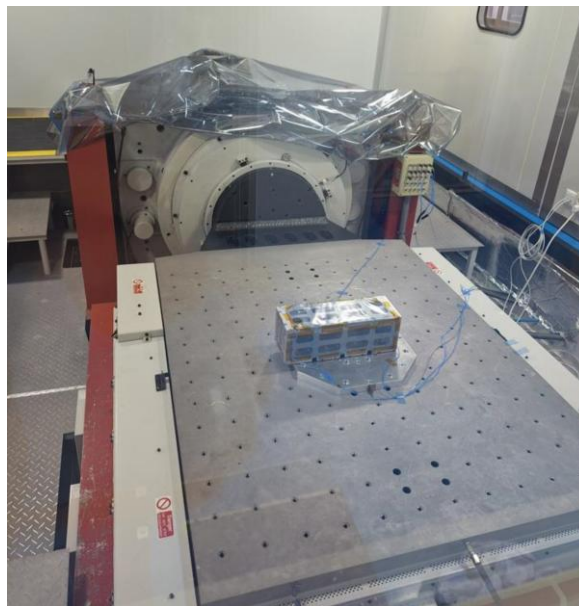


Figure 16. Vibration test during ANSER-WQ mechanical test campaign.

### 5.3.4 Ground Support Equipment during integration, testing, handling and storage

All Ground Support Equipment (GSE) that comes into direct contact with the flight hardware must meet the same cleanliness requirements as the payload and the satellite to avoid cross-contamination.

For the design of such GSE, appropriate material selection has to be considered to ensure compatibility with the proposed cleaning methods and to avoid introducing additional contamination sources.

In general, GSE is preferably manufactured from metallic and high-corrosion-resistance materials, such as aluminium. When non-metallic materials are required, they must exhibit dissipative behaviour to minimise electrostatic charge and particle attraction. Surface finishes should be smooth, with adequate radii and transitions to facilitate cleaning (see Figure 17).

All GSE (including mechanical and thermal equipment and harnesses used with electrical GSE) will undergo initial cleaning, consisting of IPA wipe-down and, when applicable, ultrasonic cleaning and individual bake-outs. During inspections, GSE cleanliness must be verified. If anomalies are detected, cleaning has to be repeated to restore compliance.

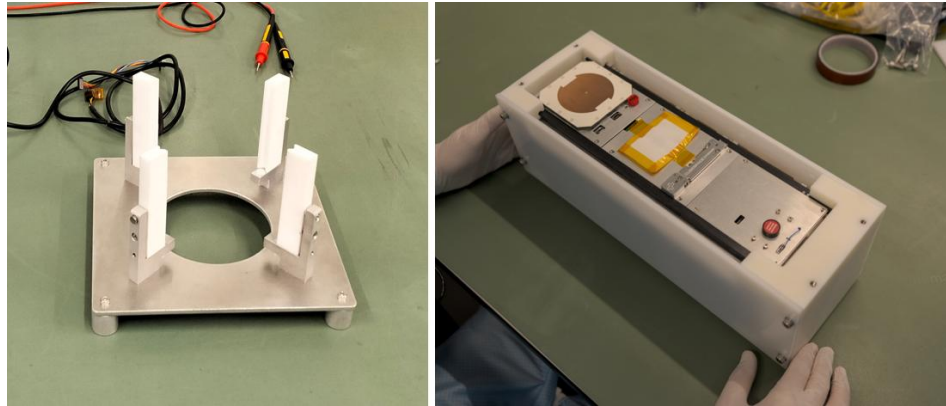


Figure 17. The image shows an example of mechanical ground support equipment designed for the ANSER-WQ satellites.

## 5.4 Cleaning methods

Before starting the manufacturing and AIT phase, all cleaning methods must be defined, including procedures, conditions of use, and compatibility with the specific elements to be cleaned. The selection of the appropriate cleaning technique depends on surface type, susceptibility to mechanical or chemical damage, accessibility, and component size, ensuring safe and effective cleaning without compromising hardware performance.

The cleaning processes foreseen for ANSER-AT include both molecular and particulate cleanliness methods:

- Molecular cleaning methods:
  - Solvent wiping using high purity (99.99%) IPA
  - Ultrasonic rinsing in IPA (99.99%)
  - Bake-out of at least 72 hours of duration under vacuum conditions, and typically at the item's maximum non-operational temperature minus 10 °C to remove volatiles while maintaining safe thermal margins (to be assessed case-by-case).
- Particle cleaning methods:
  - Solvent wiping and ultrasonic rising using high purity IPA (99.99%)
  - Filtered, high purity (class 4X) nitrogen gas flushing
  - Vacuuming with a vacuum cleaner

As a general rule:

- Mechanical parts undergo an initial IPA wiping followed by ultrasonic cleaning immediately upon reception, and always prior to any assembly activity. The same cleaning sequence is applied to all manufactured metallic parts with compatible and non-degradable surface finishes.
- Elements with non-compatible surface treatments (e.g., painted parts) can be cleaned by gentle nitrogen blowing to remove trapped particulates. If electrostatic adhesion persists, isolated particles may be removed using low-lint swabs, without solvent.
- Optical elements (such as lenses, mirrors and solar cells) are extremely contamination-sensitive and easy degraded items. Although cleaning processes are necessary, they are highly restricted. Therefore, the cleaning procedures recommended by the manufacturer must be applied whenever available.

If no manufacturer guidance exists, the following approach will be adopted:

- For particle removal, blow-off is recommended and mechanical contact must be avoided to prevent scratches.

- For molecular contamination, rinsing with fast-evaporating solvents (such as ether and acetone), followed by drying with filtered nitrogen gas, is recommended to prevent the formation of halos and water marks.
- Non-metallic parts (including encapsulated components, adhesives, harnesses, lacing cords, and COTS without outgassing data) must undergo vacuum bake-out before assembly to minimise contamination from outgassing.

## 5.5 Cleanliness monitoring

The tools selected to perform cleanliness verification throughout the Manufacturing, Assembly, Integration and Testing (MAIT) phase of ANSER-AT can be grouped into two main categories: contamination witness samples and visual inspection methods. These complementary approaches ensure continuous monitoring of both particulate and molecular contamination levels during integration, testing and activities at launcher site.

### 5.5.1 Cleanliness inspections

Periodic visual inspections will be performed on all relevant surfaces under dark-room conditions using both a UV lamp and a white-light lamp. The combined use of these illumination sources enables the detection of a broad range of contaminants: white-light lamp reveals metallic particles and non-fluorescing debris, while the UV light highlights organic fluorescing particles and residual organic films (see Figure 18 and Figure 19).

Inspection activities have to be applied to flight hardware, work areas and GSE.

Cleanliness checks are required before and after critical operations, after environmental tests, and prior to final satellite packaging for shipment. Additional inspections will be carried out whenever an incident occurs that could potentially affect the cleanliness levels of the hardware. This systematic approach ensures early identification of contamination events and enables prompt corrective actions to protect sensitive optical and mechanical surfaces.

In addition to visual inspection, a tape-lift analysis may be performed before final delivery, depending on launcher requirements. This technique consists of direct particle extraction from the surface using an adhesive tape, followed microscopic examination and particle counting. Tape-lift sampling provides a quantitative assessment of particulate contamination, including particle-size distribution and surface obscuration. Sampling will be performed on a surface that is not susceptible to damage, ensuring that the measured contamination level is representative of the overall system.



Figure 18. Visual inspections using white-light lamp during ANSER-WQ AIT campaign

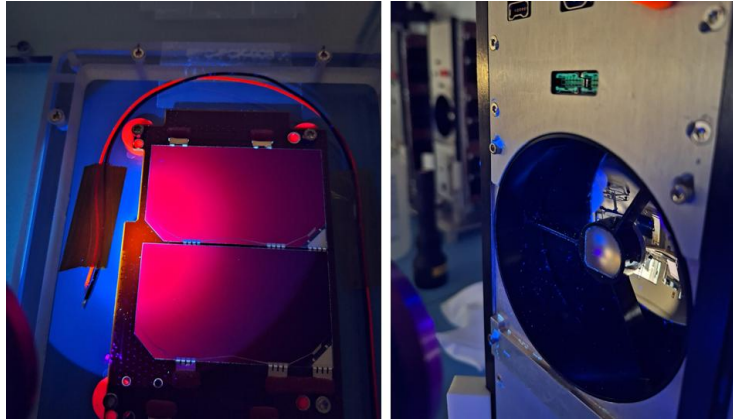


Figure 19. Visual inspections using UV-light lamp during ANSER-WQ AIT campaign

### 5.5.2 Contamination witness samples

In addition to visual inspections (which constitute a qualitative method inherently dependent on the operator, illumination conditions, viewing angle, distance, contamination type, and surface properties), the contamination monitoring strategy will be complemented with molecular and particulate witness samples. This combined approach provides a more robust assessment of the contamination environment throughout the AIT flow.

For ANSER-AT, the same contamination monitoring strategy that was successfully implemented for ANSER-WQ will be followed. Witness samples will be placed near the hardware during handling, exposure, or any activity that may pose contamination risks. After exposure, contamination will be quantified using dedicated analytical techniques:

- Particle contamination (PAC): Particle deposition is measured indirectly using a Particle Fall-Out (PFO) photometric device, which provides the total obscuration factor caused by deposited particles. Although it does not discriminate particle type, number, or size, it complements visual inspection and tape-lift analysis.
- Molecular contamination (MOC): Contamination is assessed through an indirect method, in which the contaminants deposited on the witness surface are extracted via rinsing and subsequently analysed using infrared spectroscopy. Results for each molecular witness are reported in ng/cm<sup>2</sup> and classified into four groups:
  - Hydrocarbons (detection limit: 50 ng)
  - Esters (detection limit: 55 ng)
  - Methyl silicones (detection limit: 50 ng)
  - Phenyl silicones (detection limit: 70 ng)

The total molecular contamination is obtained by summing the contribution from all four groups.

Witness samples will remain in place throughout all activities performed on the hardware, starting from the initial assembly operations and the integration of subsystems into the spacecraft structure, through the execution of environmental tests, and up to the final packaging of the satellite (see Figure 20).

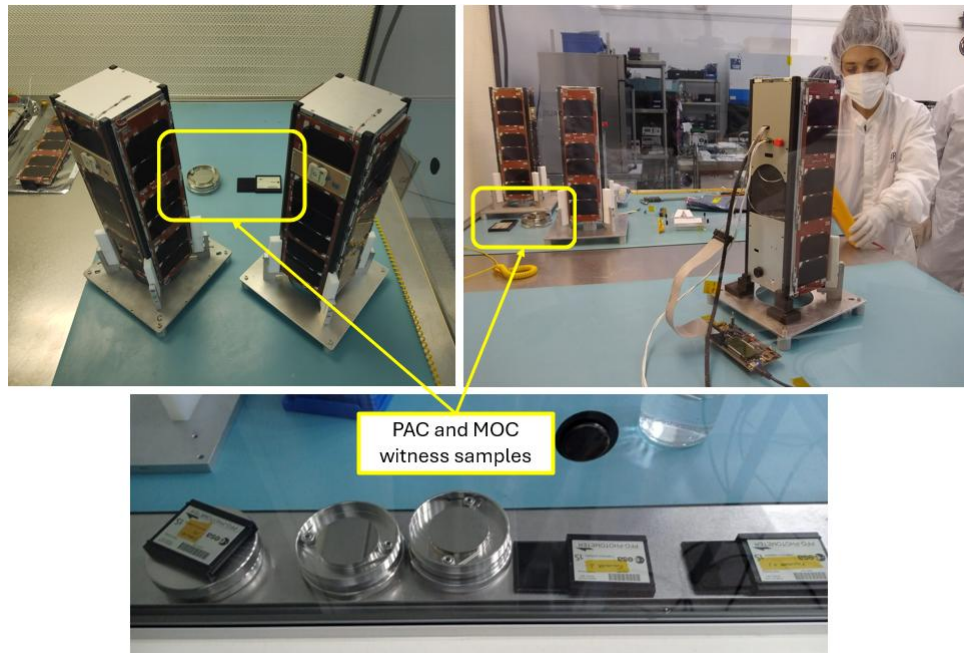


Figure 20. PAC and MOC monitorization during ANSER-WQ MAIT campaign

## 6. CURRENT STATUS OF PLAN IMPLEMENTATION

The model philosophy established for ANSER-AT is based on a hybrid approach:

1. Qualification Models (QM) will be produced for all newly designed elements (such as the payload, the hold-on and release mechanisms for the solar panels and the aerodynamic flaps). These units will undergo a complete functional, thermal, and mechanical qualification campaign.
2. One Flight Model (FM) will be manufactured for each satellite, each of which will undergo a full acceptance test campaign.

Based on this philosophy, the implementation of the C&CCP will be applied to both the qualification and flight models. Particular emphasis will be placed on monitoring all assembly and integration processes of the payload QM model, with the objective of fully characterising each step, identifying weak points, critical operations, or any non-compliance with contamination requirements. This will allow corrective actions to be defined for the FM, including minimising exposure times and identifying additional protection methods or barriers where required.

According to the ANSER-AT master schedule, the assembly activities of the payload QM (together with the start of the integration activities of the platform elements ready for FM) were expected to begin during Q2–Q3 of this year. However, due to unforeseen delays in the manufacturing of several mechanical components and in the procurement of certain COTS platform units, it has been necessary to reschedule these activities to Q4. For this reason, the effective implementation of the contamination control plan has not yet begun.

Nevertheless, several contamination-related pre-assembly activities have already been initiated:

- Inspection of received COTS units, with particular focus on their cleanliness status.
- Pre-cleaning of mechanical parts already manufactured, preparing them for subsequent steps (either assembly or surface-treatment processes).
- Detailed inspection of the QM optics, including a preliminary cleanliness assessment and rough pre-cleaning (particle-reduction blowing). See Figure 21.

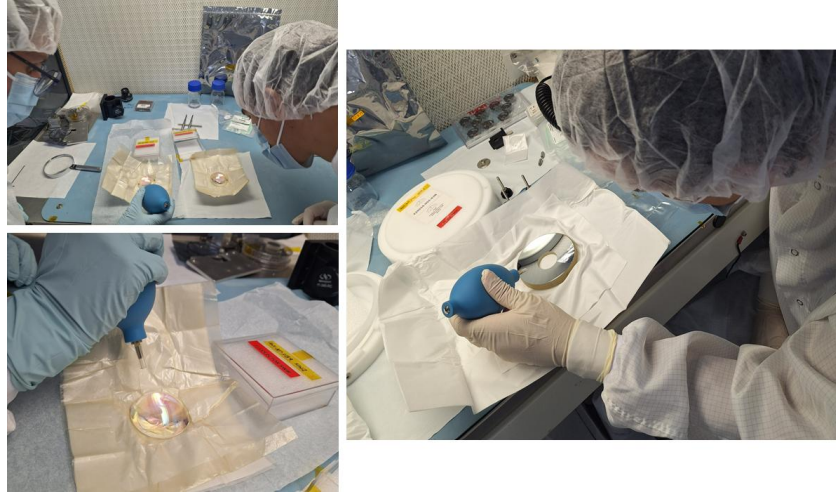


Figure 21. Inspection and pre-cleaning of payload optical parts (qualification model)

## 7. CONCLUSIONS

The C&CCP for ANSER-AT has been defined using, as baseline, the strategy successfully implemented for ANSER-WQ. This approach ensures continuity in the contamination-control philosophy across the ANSER constellation and makes use of the lessons learned from the previous mission.

Due to delays in the manufacturing of several mechanical components of the payload and platform units, the assembly activities for both the payload and the platform have been rescheduled to Q4 of this year. As a result, the effective implementation of the contamination control plan has not yet started.

Nevertheless, several pre-assembly activities related to contamination control have already begun. These early actions help reduce contamination risks once the full MAIT phase begins.

## ACKNOWLEDGEMENTS

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