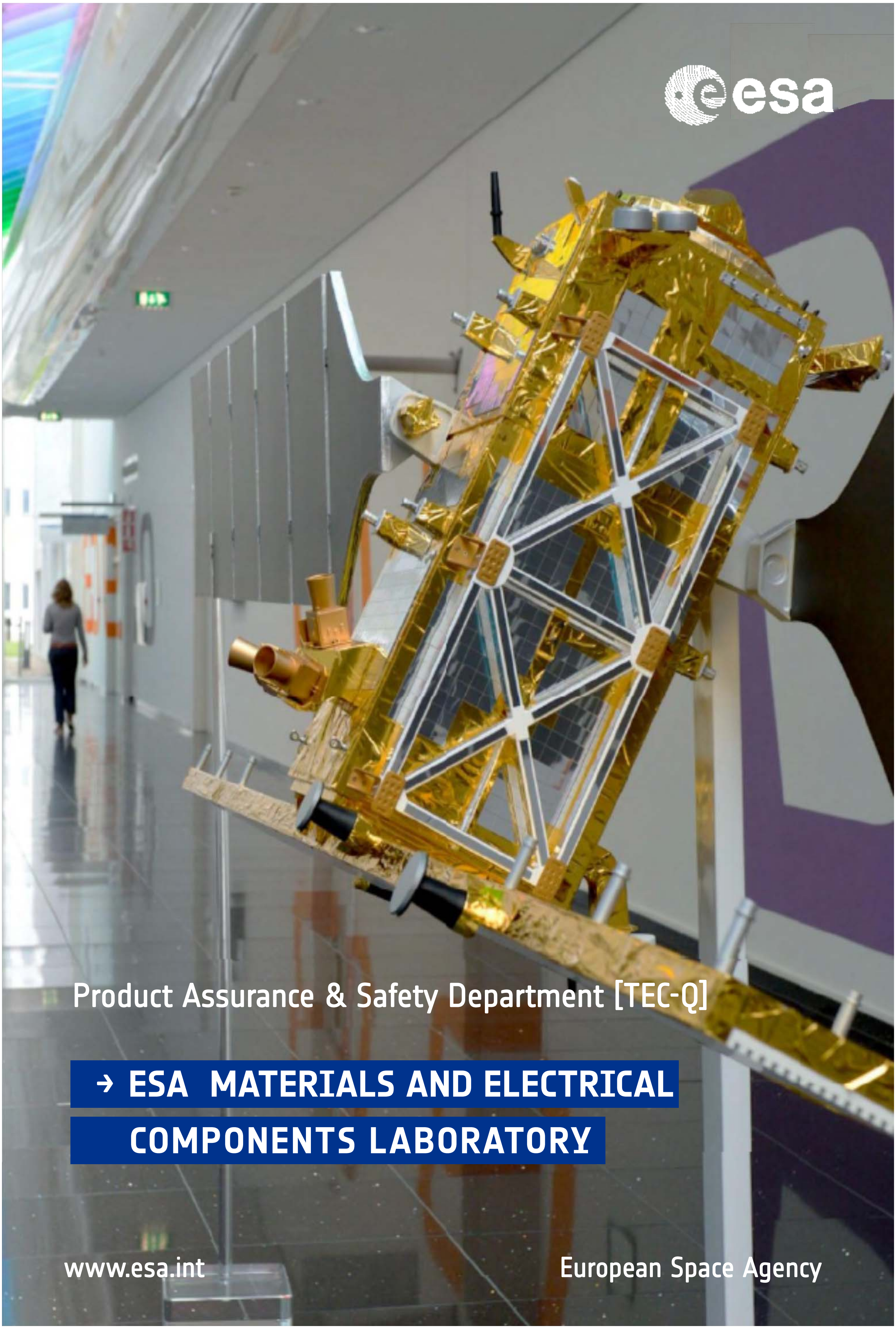

Product Assurance & Safety Department [TEC-Q]

→ ESA MATERIALS AND ELECTRICAL COMPONENTS LABORATORY

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1.To independently and impartially **support ESA projects** and **technology programmes** by ensuring the overall adequacy and suitability of space materials, processes and EEE components to meet the performance requirements on schedule. The support for schedule-critical activities is a key aspect.

2.To support the introduction of **innovative technologies and products** (R&D) while maintaining and enhancing the **engineering competence.**

3.To maintain and improve the efficiency, effectiveness and validity of (new) **test methods and relevant standards.** To act as a reference laboratory for space activities in Europe.

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→ ESA MATERIALS AND ELECTRICAL COMPONENTS LABORATORY

WHAT IS ITS ROLE?

Made up of more than 20 dedicated experimental facilities and hundreds of instruments overall, ESA's Materials & Electrical Components Laboratory guarantees an optimal choice of electrical components, materials and processes for ESA missions and external projects. As well as considering the unique environmental challenges involved in building for space, it additionally investigates test or operational failures to ensure similar issues do not recur on forthcoming missions.

The Laboratory provides expertise to investigate the effects of the environment on electrical components, materials and processes in support of advanced research and development, evaluation and qualification programmes and direct project support. In the materials domain, support is provided on various topics as well as their associated manufacturing processes, such as curing, bonding, coatings, welding, surface mount techniques along with cleanliness and contamination effects. In the electrical components domain this encompasses all aspects of reliability analysis, failure analysis and radiation effects characterisation.

WHAT SERVICES DOES IT OFFER?

Services on offer include

- **Hardware testing in simulated space environments** in particular vacuum, temperature and radiation testing covering infrared (IR), ultra violet (UV) solar, x-ray, ionising, non-ionising, electron and proton
- **Inhabited environment testing** (such as toxicity, flammability)
- **Ground environment testing** (such as corrosion, sterilisation, long duration storage effects)
- **Cleanliness and contamination control**
- **Thermo-mechanical testing** including fatigue and fracture mechanics
- Comprehensive characterisation of **component electrical parameters** and functionality **Destructive physical analysis** and **Constructional Analysis** of electrical components **Non-destructive evaluation** (e.g. 3D x-ray tomography, Acoustic Scanning Microscopy) **Development and comparison of tools and standards**
- **A certification dye penetrant authority** for space Materials & Processes in Europe
- **In-orbit experiments and post-flight investigations**
- Technical **knowledge exchanges and networking** with external centres
- **Independent support for failure investigations** (on-ground and in-orbit anomalies)
- **Quantification of materials properties, assessment/validation of processes** including electronic materials
- **Corrosion testing**
- **Thermo-mechanical testing**
- **Fatigue and fracture mechanics characterisation** of materials **Residual stresses measurements** (destructive and non-destructive) Non-contact **3D strain/stress measurements**
- Non-contact **3D displacment analysis** (including speed and acceleration)
- **Tribology (fretting and wear) testing** of materials
- **Verification of Surface Mounting Technologies** for space applications
- **Qualification of Printed Circuit Boards**

"Developing a mission to Mercury is not an easy undertaking. Having this internal access to a state- of-the-art laboratory with many excellent specialists and facilities is a key asset for our team, planning for a mission facing unprecedented challenges."

Mr. Uli Reininghaus (Project Manager of ESA's BepiColombo Mission)

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→ UNIQUE TOOLS, UNIQUE TESTS

HOW IS IT EQUIPPED ?

TEC-Q laboratory is a unique collection of specially-designed facilities, including:

- **Gas Chromatography/Mass Spectroscopy** – Determination of Molecular Organic Contamination with Fourier Transform Infrared Spectroscopy and Gas Chromatography/Mass Spectrometry
- **Photospectroscopy: Portable Thermo-Optical Device** – Optical investigation of materials at ambient temperatures across UV-VIS-NIR-IR wavelengths
- **Electron Spin Resonance Spectroscopy** – Absorption spectroscopy applied to
- paramagnetic species which yields information both on their concentration and structure
- **Optical Microscopy and Scanning Electron Microscopy** – down to 2 nm
- **Raman Microscopy** – Fast and localised chemical analyses of samples with chemical concentrations less than one monolayer to identify substances or defect regions
- **X-ray Photoelectron Spectroscopy & Atomic Force Microscopy** – XPS provides information on the top 5 nm of a sample surface; AFM produces atomic-scale 3D images of surfaces down to 0.1 nm
- **Contact Angle System** – Measurement of various substrates and surface free energy of liquids
- **Thermal Analysis** – Thermo-Gravimetric Analysis, Coupled TGA Analysis with MS/ FTIR analysis of evolved gases, Differential Scanning Calorimeter; Thermo-Mechanical Analysis; Dynamic Mechanical Analysis , Dilatometer, Laser Flash Analyser and Hot Disc for thermal conductivity, diffusivity and specific heat capacity testing, Dynamic Dielectric Spectroscopy
- **Broadband Dielectric Spectroscopy** – Characterising material electrical properties. **3D X-ray tomography** – building 3D models of components and materials from radiographic scanning techniques
- **Confocal Microscopy** - The 3D Confocal Microscope (compared to the traditionally used 2D equipment) allows the instrument to be used in a much more efficient and precise way for performing surface coating analysis and surface topography
- **Scanning Electron Microscopy** – Revealing fine surface detail and coupled with Energy Dispersive Spectroscopy of X-rays (EDX) and Wavelength Dispersive X-ray Spectroscopy (WDX) to map and quantify elemental distribution

Other equipment employed in electrical component reliability analysis – Bond pull tester, die shear, Particle Impact Noise Detection (PIND), shock, vibration, constant acceleration, gross and fine leak tester, test chambers for temperature cycling, humidity, endurance testing.

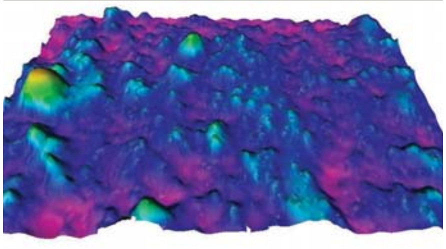
The Lab has more than 25 full-time staff with more than 300 years of experience, plus research fellows, young graduate trainees and stagiaires.

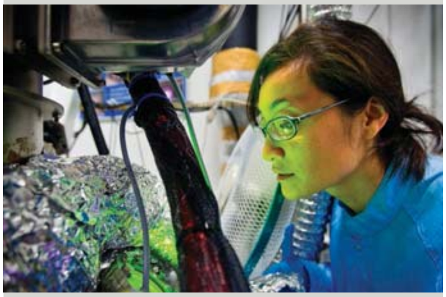
WHO ARE ITS CUSTOMERS?

The Lab's expertise is made available to all ESA missions and the wider European space community.

In preparation for ESA's Cosmic Visions missions, the Lab performed preparatory testing to decide on the types of
materials most suited to extreme environments ranging from Mercury to Jupiter.

The Lab's research findings have also led to an authoritative database of materials, hardware and processes qualified for space applications, as well as guiding the establishment of industrial production standards.





ESA-G. Schoonewille

HOW DO I FIND OUT MORE?

Visit:
www.esa.int/Our_Activities/Space_Engineering/Materials_Electrical_ Components_Laboratory

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Head of Materials Technology Section
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→ EFFECTS OF SPACE ON MATERIALS AND COMPONENTS

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Space is a tough place to stay: materials in orbits are subject to many degrading factors, including UV radiation , X-rays, charged particles and orbitals debris strikes. Frequent switching from scorching sunlight into bittercold shadow –thermal cycling- must be withstood, while atomic oxygen found at the top of atmosphere is inherently erosive/corrosive.

These factors can have a multiple of undesirable effects on exposed materials, including discoloration , cracking , embrittlement, mass loss and perforation. In some cases the factors combine with unpredictable consequences.

The Materials and Electrical Components Laboratories use many different test facilities to replicate on or more degrading components of space environment, including dedicated systems for synergistic testing. For long-duration missions lifetime testing may not be practical, so facilities are also set up for accelerated testing to extrapolate results.

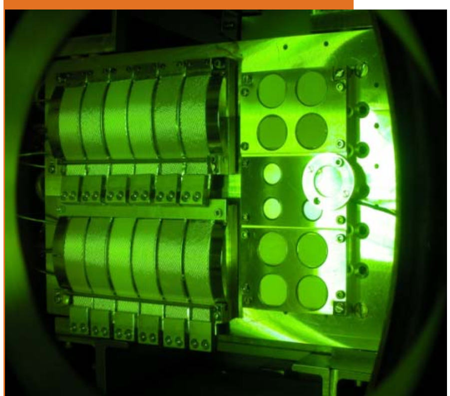
STAR I and II facilities offers possibility to expose multiple temperature controlled samples simultaneously to different radiation sources and to measure material properties in – situ by UV/VIS/NIR as well as by Raman spectroscopies without breaking the vacuum.

HOW IS IT EQUIPPED ?

TEC-Q laboratory is a unique collection of specially-designed facilities, including:

- **Atomic Oxygen Erosion Effects** (ATOX) **Facility** – Producing atomic oxygen with a laser to investigate its erosion effects on temperature-controlled external samples in vacuum
- **High Temperature Exposure System (HITES and XTES)** – exposure of samples to high temperatures in high vacuum furnaces, investigating effects of long-term thermal ageing
- **UV/VUV Chambers – (Cross1 , Cross2 and Cross3 , Mcross and BOF)** – for ultraviolet/vacuum ultraviolet (UV/VUV) exposure and thermal aging with in-situ thermal imaging of samples and residual gas analysis of contamination using a mass spectrometer and molecular condensed contamination using QCMs.
- **Synergistic Temperature Accelerated Radiation Facilities (STAR I and STAR II)** – allowing the simultaneous vacuum exposure of multiple temperature-controlled samples to different space radiation sources (electromagnetic and particle sources) and several in-situ measurement systems
- **ElectroStatic Discharge Facility (ESD)**– allowing the simultaneous (electron) irradiation of temperature controlled samples under high vacuum
- **Ground Storage – Humidity Test Facility** – subjecting samples to 5-95% humidity at temperatures up to 100°C
- ***Space radiation simulation*** *– using a Cobalt60 source and various other sources including Californium252*

Other equipment employed in electrical component reliability analysis – Bond pull tester, die shear, Particle Impact Noise Detection (PIND), shock, vibration, constant acceleration, gross and fine leak tester, test chambers for temperature cycling, humidity, endurance testing …



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→ CLEANLINESS AND CONTAMINATION CONTROL

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Space hardware must be kept rigorously clean: any contamination could endanger instrument performance or astronaut health .

Organic materials give off trace chemicals. In the vacuum of space this can cause molecular deposition, and even the very thinnest of layer may affect sensitive equipment such as telescope mirrors or laser lenses, solar array or thermal control surfaces.

In enclosed pressurised environments , airborne contamination is the concern, as astronauts must not be exposed to toxic substances.

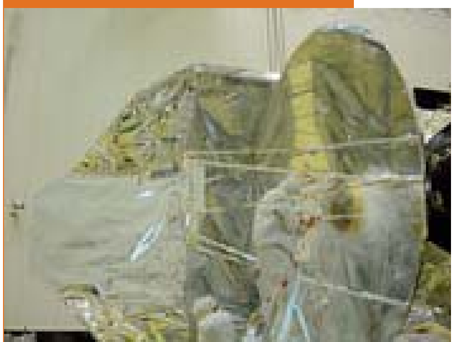
Contamination by dust and debris +- even sloughed-off skin cells- may cause beam scattering or affect the working of propulsion or mechanical devices.

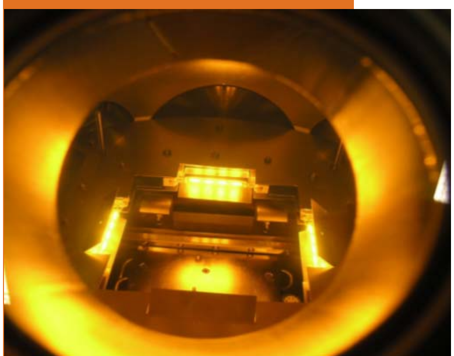
The Material and Electrical Components Laboratories offers expert advice on cleanliness and contamination control, quantify particulate and molecular contamination levels , audit cleanroom facilities and test materials and flight hardware for their contamination potential.

HOW IS IT EQUIPPED ?

TEC-Q laboratory is a unique collection of specially-designed facilities, including:

- **Dynamic Outgassing Facilities (VBQC 2 and VBQC3, DOK)** – Measuring the dynamic outgassing of materials or components by monitoring mass change as a function of time and temperature
- **Bake Out Facility (BOF 2)** – able to perform controlled bake outs in order to reach cleanliness requirements for contamination critical missions and payloads
- **Particle Contamination Measurements** – Including airborne particle counter, particle fall-out, optical and SEM particle counting, essential for cleanliness assessment
- **Gas Chromatography/Mass Spectroscopy**
- **Chemical Contamination Laboratory** - Determination of Molecular Organic Contamination with Fourier Transform Infrared





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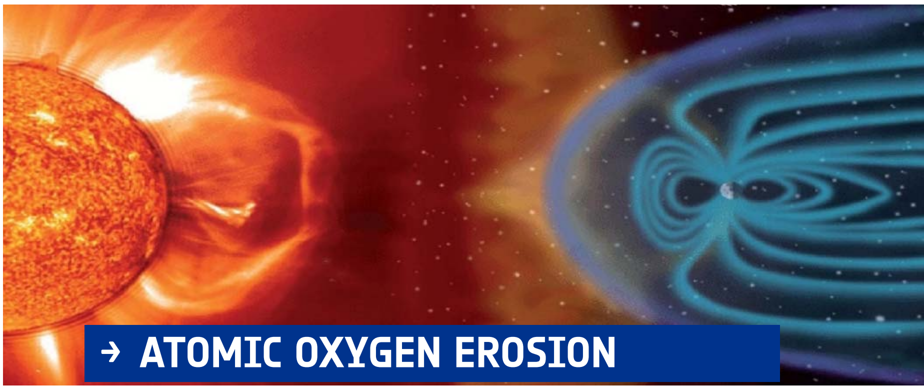

→ ATOMIC OXYGEN EROSION

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Atomic Oxygen [ATOX] facility produces atomic oxygen flux to evaluate erosion effects on materials

- Atomic oxygen produced by dissociation of molecular O_2 using pulsed CO_2 laser
- Atomic fluxes: around 1-10.10+19 atoms/cm^2 per day
- Typical atomic oxygen (AO) energy: 5.5eV
- AO beam angle with respect to samples: 0-70°
- Temperature controlled -150/+150°C
- Background pressure <10^{-5}mbar
- Dimension of samples: typically 2×2 cm^2 possibility of adaptation for bigger samples

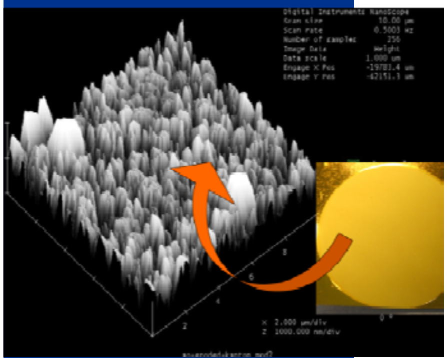
→ Associated characterisation techniques:

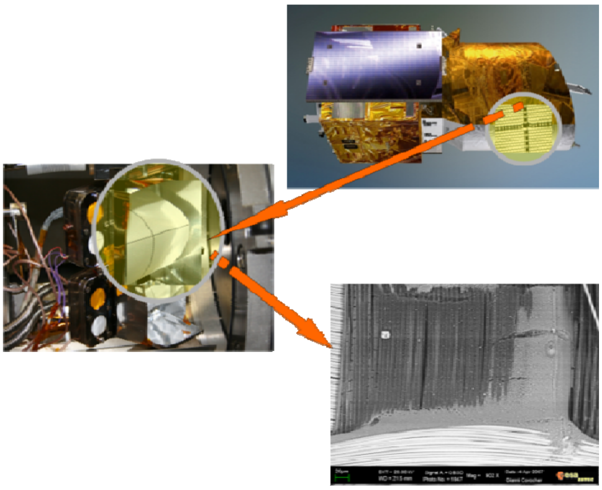
- Cleanliness and contamination control following ECSS-Q-70-01C
- Thermo optical measurement following ECSS-70-09C
- Surface and topography analysis (AFM, XPS, SEM, EDX)

External materials on LEO spacecraft such as ESA's Aeolus satellite must be resistant to atomic oxygen erosion

Testing the Aeolus Betacloth using the ATOX facility

Unprotected strands of carbon fibre were eroded





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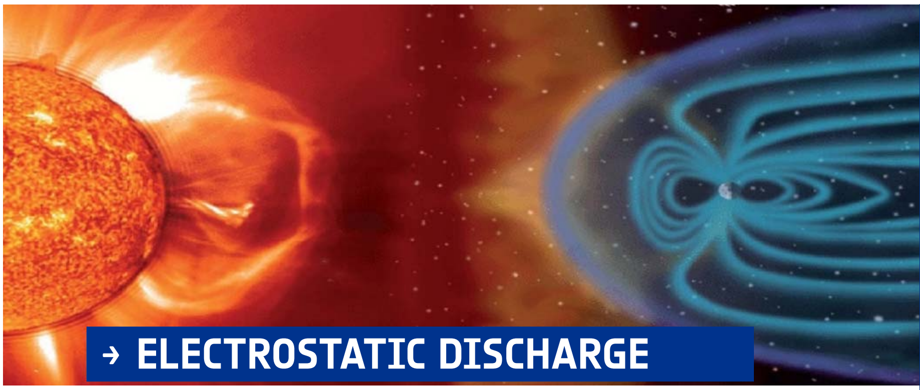

→ ELECTROSTATIC DISCHARGE

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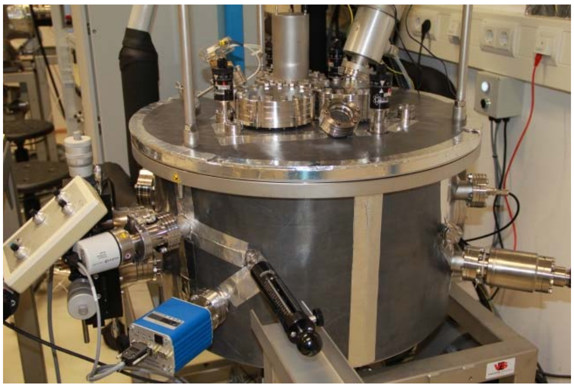
Monitoring of Electrostatic discharge effects on spacecraft materials with in-situ analysis capabilities of the materials' behaviour in the ESD facility

- Particle radiation: Electrons up to 30 keV, higher energy level possible upon request (100 keV / 1 meV)
- Extreme temperatures −240°C to +25°C
- Contact less in-situ temperature sample surface potential monitoring Pressure: vacuum < 10^{-6}mbar
- Dimension of samples: typically 20×20 mm² possibility of adaptation for bigger samples

→ **Associated characterisation techniques:**

- Cleanliness and contamination control following ECSS-Q-70-01C
- Surface and topography analysis (AFM, XPS, SEM, EDX..)
- Electrical resistivity- 4 point probe technique
- Surface and bulk resistivity following ASTM D257
- Impedance dielectric spectroscopy

ESD facility offers possibility to expose multiple temperature including cryogenic controlled samples simultaneously to electron source radiation (and strontium source) and to measure in – situ the surface potential without breaking the vacuum.



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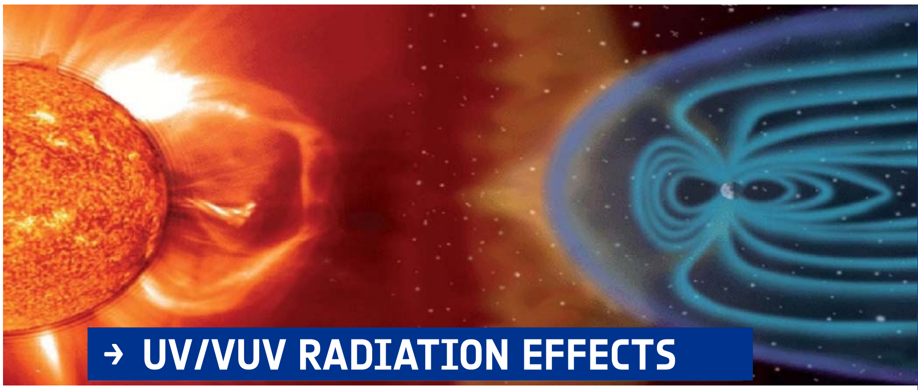

→ UV/VUV RADIATION EFFECTS

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UV-VUV testing can be performed on several facilities under high vacuum conditions in CROSS1,CROSS2, CROSS 3, BOF and MCROSS facilities

Cross facilities (1, 2, 3 and MCROSS)

- UV/VUV radiation from 115 nm to 400 nm up to 13 UV Solar Constants
- Thermal ageing up to +400°C
- Extreme thermal cycling from –150°C to +400°C (or higher in some cases)
- In-situ thermal imaging of samples
- Residual gas analysis of gas contamination (mass spectrometer)
- Pressure in the range of 10-5 - 5.10-7mBar
- Max size of the sample is 200x200 mm. Height is up to 150 mm
- Outgassing condensable contamination product monitoring via QCM
- Nominal samples size: 19x19 mm^2- changeable to fit sample plate dimension 140x160 mm^2

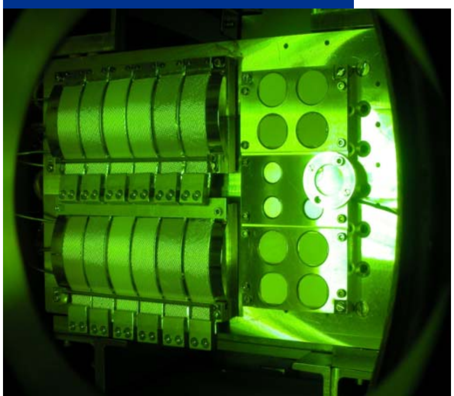
Accelerated UV exposure facility (BOF)

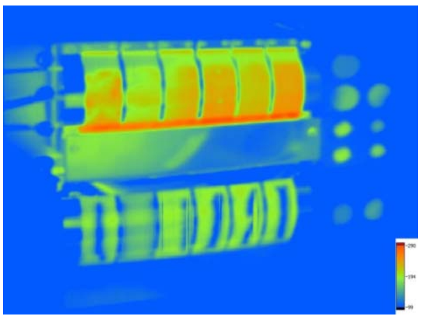
- UV/VUV radiation from 115 nm to 400 nm up to 20 Solar Constants
- Infrared registration of sample temperature –150°C to 500°C (patented 2D IR imaging)
- Residual gas analysis of gas contamination (mass spectrometer)
- Pressure in the range of 10^{-5} to $5x10^{-7}$ mbar
- Max size of the sample is 200x200 mm. Height is up to 150 mm

→ Associated characterisation techniques:

- Cleanliness and contamination control following ECSS-Q-70-01C
- Thermo optical measurement following ECSS-70-09C
- Surface and topography analysis (AFM, XPS, SEM, EDX..)
- Thermal mechanical analysis
- Tape test following ECSS-Q-70-13A

Thermal control material specimens and solar cells validation campaigns for Venus Express, Bepi Colombo and Solar Orbiter projects among others have been performed in the UV-VUV testing facilities





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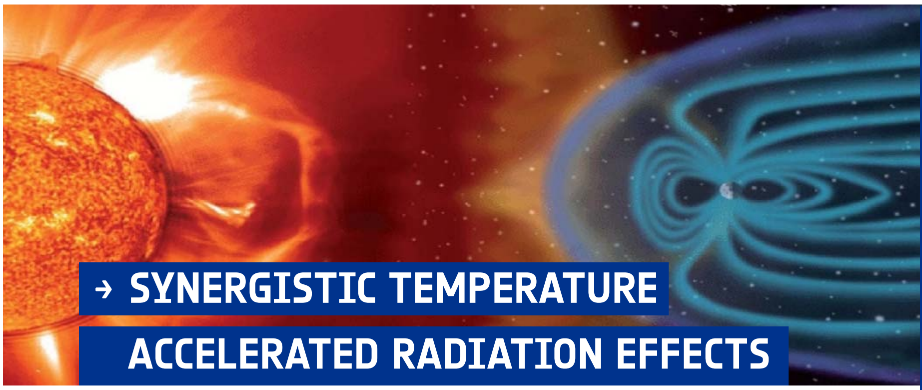

→ SYNERGISTIC TEMPERATURE ACCELERATED RADIATION EFFECTS

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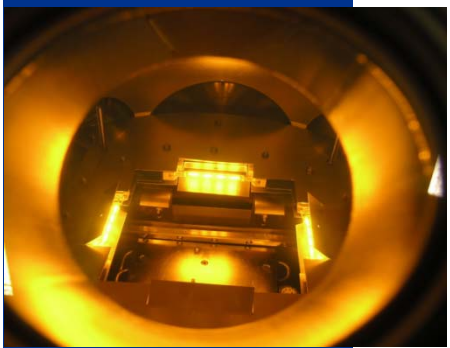
Synergistic exposure of spacecraft materials with in-situ analysis capabilities of the material's behaviour

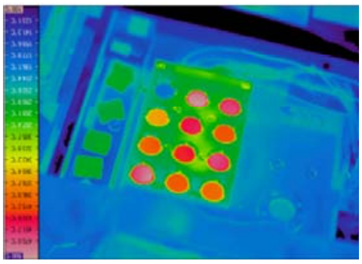
STAR I and II facilities offers possibility to expose multiple temperature controlled samples simultaneously to different radiation sources and to measure in – situ thermo-optical properties without breaking the vacuum.

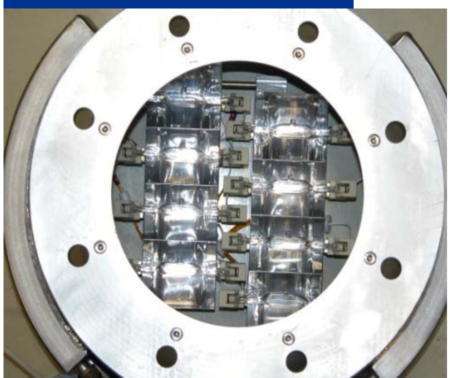
- Intense UV/VUV radiation (115-400 nm) up to 20 Solar constants
- Particle radiation: Electrons <100keV, Protons <100keV
- Extreme temperatures −180°C to +550°C
- Vacuum in-situ solar reflectance characterisation (integrating sphere)
- Vacuum in-situ Raman spectroscopy measurement
- Residual gas analysis using mass spectra up to 500amu
- Contact less in-situ temperature sample surface monitoring and regulating using pyrometer and 2D thermo-vision camera techniques
- Pressure: (guaranteed vacuum < 10^{-6}mbar) – typically 10^{-8}mbar
- Sample size: several samples can be tested simultaneously on a regulated temperature plate of 20 x20 cm^2.
- Dimension of samples: typically 20×20 mm^2 possibility of adaptation for bigger samples

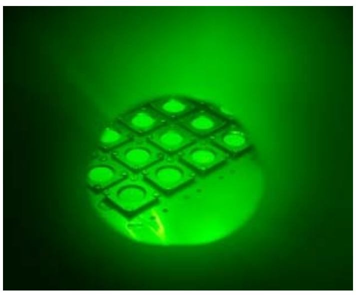
→ Associated characterisation techniques:

- Cleanliness and contamination control following ECSS-Q-70-01C
- Thermo optical measurement following ECSS-70-09C
- Surface and topography analysis (AFM, XPS, SEM, EDX..)
- Thermal mechanical analysis
- Tape test following ECSS-Q-70-13A









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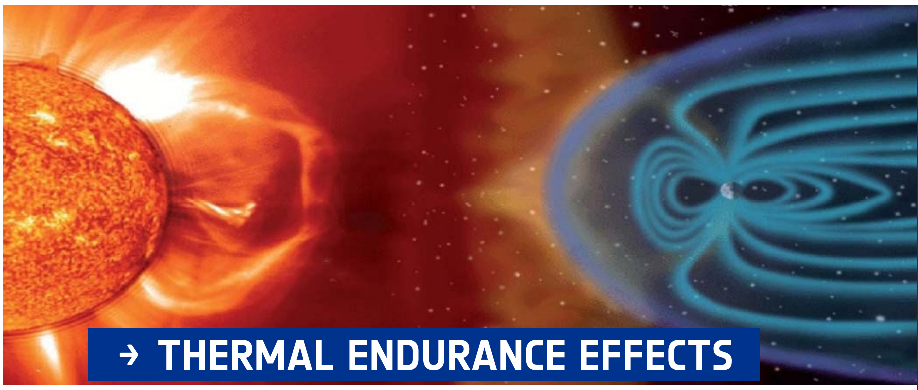


→ THERMAL ENDURANCE EFFECTS

Thermal ageing of spacecraft materials to extreme temperatures in High Temperature Exposure System [HITES and XTES facility and Ground storage facilities]

XTES facility

- External radiative heating
- Temperature: up to 1100°C
- Heating rate of the facility: up to 5°C/min
- Pressure: 10^{-7} mbar vacuum
- Samples: 2 sample holders of 78 cm length and 10 cm width

HITES facility

- External radiative heating
- Temperature: up to 400°C
- Heating rate of the facility : up to 20°C/min
- Pressure: 10-6 mbar vacuum
- Samples: 40 samples 30x30mm² and 400x80mm² area

High temperature furnace Entech

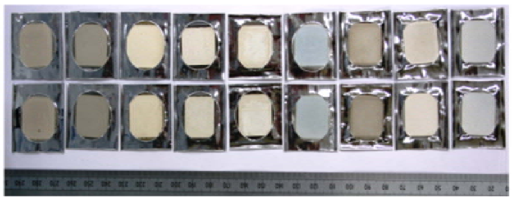
- Temperature up to +1600°C
- Ambient pressure (air or GN2)
- Samples: 10x10cm² - Height: 100mm

Ground storage – humidity test facility

- Humidity: 5-95%
- Temperature: ambient to +100°C
- Samples: 50x50x50 cm³ facility.

→ Associated characterisation techniques

- Cleanliness and contamination control following ECSS-Q-70-01C
- Thermo optical measurement following ECSS-70-09C
- Surface and topography analysis (AFM, XPS, SEM, EDX..)
- Thermal mechanical analysis
- Tape test following ECSS-Q-70-13A



Exposure of samples to high temperatures in High Vacuum Furnaces. The effects of long-term thermal ageing of sample materials: changes of thermo-optical properties, mass loss and thermo-mechanical properties.

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→ADDITIVE MANUFACTORING CAPABILITIES FUSED DEPOSITION MODELING (FDM)

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Modular (Open Source) filament extrusion 3D printing system specially design for processing high strength engineering thermoplastics

- Technical enhancements and high temperature control enable printing with largest range of thermoplastic polymers to date
- Thermally stable precision bowden extruder and hot-end
- Controlled printing temperature up to 420 °C
- Ability to process engineering polymer composites (fibres, CNTs, NPs)
- Heated printing platform
- Printing volume: 155x155x155 mm
- Layer resolution: 0.1 mm
- Nozzle diameter: 0.3 – 0.5 mm
- Compatible filament diameter: 1.75 mm
- Closed all-metal build chamber
- High torque 2.5 Ampère NEMA 17 motors
- Reduced weight of moving parts for high precision & speed
- Touch screen control via Raspberry Pi integration

3D printed PEEK test specimens
(Image courtesy of INDMATEC GmbH)

→ Associated characterisation techniques

- Tensile properties of plastics & composites - ASTM D638, ASTM D3039
- Flexural properties – ASTM D790
- Impact resistance – ASTM D256
- Thermal analyses:
- Differential Scanning Calorimetry – ASTM E1356, E2602
- Dynamic Mechanical Analysis – ASTM E1640
- Thermo-mechanical Analysis – ASTM E831
- Thermo-gravimetry – ASTM E2550
- Microscopy:
- Optical Microscopy, Scanning Electron Microscopy, Atomic Force Microscopy
- Computed tomography – ASTM E1570
- Broadband Dielectric Spectroscopy
- X-ray diffraction

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→ OUTGASSING BEHAVIOUR MONITORING

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Outgassing test and bake out facilities measure the dynamic outgassing of materials or components by monitoring the mass change as a function of time and temperature.

Thermal vacuum outgassing test for the screening of space materials (μVCM facility)

Micro-VCM material screening outgassing test facility (μVCM)

- Quantitative gravimetric measurement:
- TML - Total Mass Loss
- CVCM - Collected Volatile Condensable Material
- RML - Recovered Mass Loss
- WVR – Water Vapor Regained

→Test standard: in accordance with ECSS-Q-ST-70-02C (isotherm test temperature range : 125°C to 250°C)

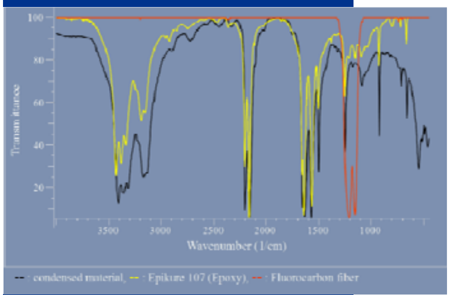
→ Condensable material collected on the collector plate is analyzed with infrared spectroscopy in accordance with ECSS-Q-ST-70-05C

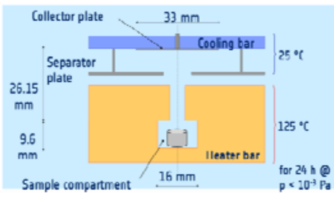
Sample cups:

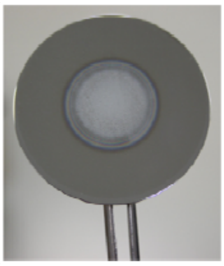
- three specimen cups per material are tested
- three empty specimen cups used for reference
- Weight range: 100-300 mg

→ Associated characterisation techniques:

- Cleanliness and contamination control following ECSS-Q-70-01C







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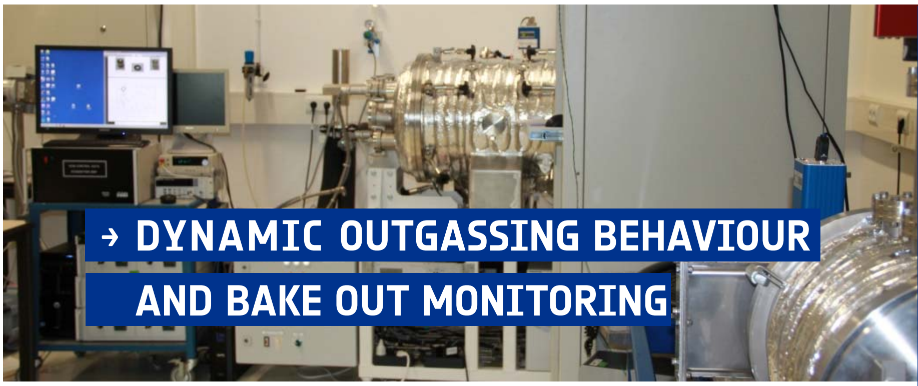

→ DYNAMIC OUTGASSING BEHAVIOUR AND BAKE OUT MONITORING

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High Temperature Dynamic Outgassing test facility KNUDSEN cell (DOK) and Vacuum Balance Quartz Crystal (VBQC)

Quantitative study of the kinetics - f(T,t) - of the outgassing phenomena, long term predictions (& modelling)

- TML - Total Mass Loss
- CVCM - Collected Volatile Condensable Material
- Acceleration factors
- Activation energies
- Residence time-temperature dependency
- Condensable material collected on QCM's (Quartz Crystal Microbalances) ASTME E 1559 compatible.

DOK thermal vacuum outgassing test at high temperature facility

- Temperature range: ambient to 500°C
- Sample size: Ø50 mm x 75 mm
- Working pressure: vacuum 10^{-7} mbar
- Resolution: 1 microgram
- Range: QCM needs to be re-evaporated every 100 mg TML

VBQC facilities

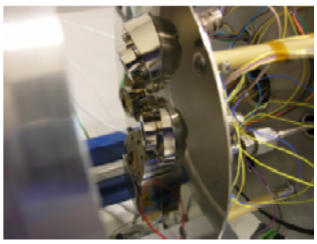
- Max loading mass: 20/2.54 gr / Size 100 mm
- Range/resolution: 18 g/1 microgram resolution (VBQC 3)
- Range/resolution: 40 g/1 microgram resolution (VBQC 2)
- Temperature range: ambient to 125°C (VBQC 3), to 225°C (VBQC 2)
- Vacuum pressure: 10^{-7} mbar

Bake out facility (BOF 2)

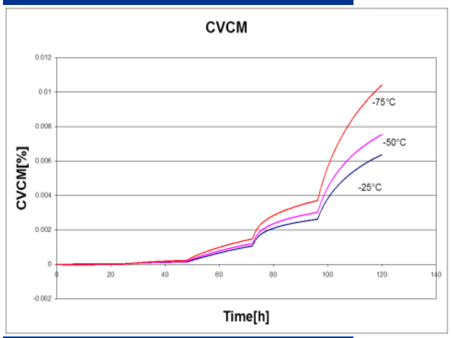
- Maximum sample size: 210x300 mm
- Temperature range: ambient to 175°C
- Vacuum pressure: 10^{-7} mbar
- RGA and QCM monitoring possible

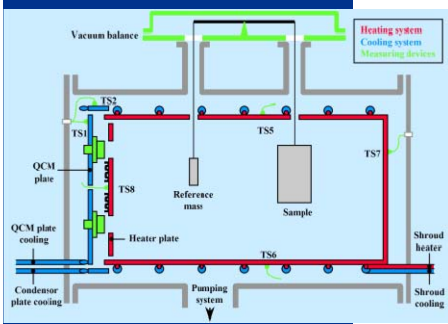
→ Associated characterisation techniques

- Cleanliness and contamination control following ECSS-Q-70-01C
- Detection of organic contamination of surfaces by infrared spectroscopy following ECSS-Q-70-05-C
- Gas Chromatography-Mass Spectrometry



Bake Out Facility (BOF 2) is able to perform controlled bake outs in order to reach cleanliness requirements for contamination critical missions and payloads





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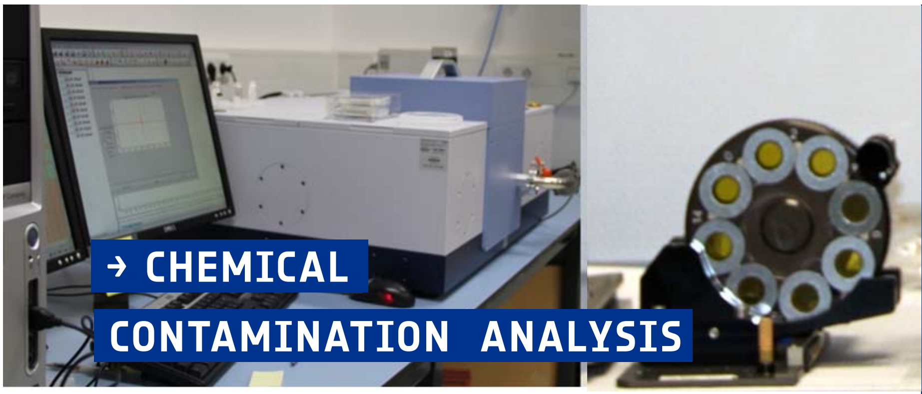

→ CHEMICAL CONTAMINATION ANALYSIS

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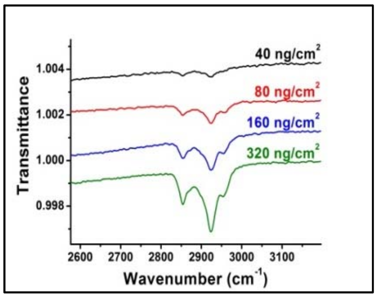
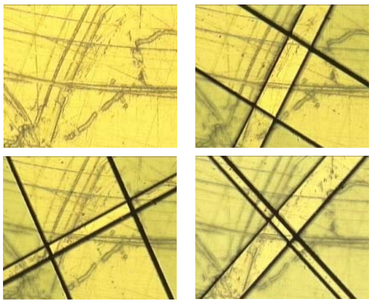
Molecular Organic Contamination (MOC) analysis

FTIR analysis of Molecular Organic Contamination (MOC)

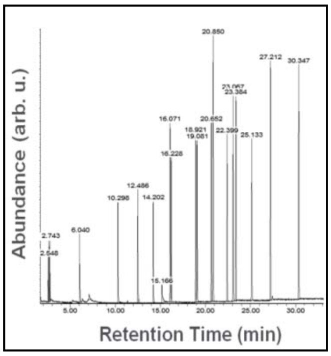


- FTIR: Fourier Transform Infrared transmission spectroscopy provides the possibility to determine levels & types of surface MOC, and thus enables to trace back sources of contaminants
- Available analysis range: 6500-10 cm^{-1}
- The absolute detection limits for surface contamination are around 0.2×10^{-7} g/cm^2
- Multiple surface contamination collection and test techniques in accordance with ECSS-Q-ST-70-05C are available. ISO 17025 ready.



- FTIR microscopy allows for qualitative determination of surface contaminants by direct surface probing (reflection, transmission, ATR)
- Double glass blade aperture allows for easy separation of areas of interest
- Fast LN2 cooled MCT detector offers fast analysis runs on multiple surface regions

GC/MS: Gas Chromatography/Mass Spectrometry



- GC/MS: Gas Chromatography/Mass Spectrometry enables separation of complex component mixtures and acquisition of mass spectrum for each component
- Ionization and subsequent fragmentation allow for identification of organic compounds by comparison with established MS libraries
- Three independent GC/MS systems are optimized for variety of analyses including liquid injection and thermal desorption
- Available limits of detection are as low as a ng
- Easy and automated off-gassing toxicity analysis for manned spaceflight (ECSS-Q-ST-70-29C) is enabled by the use of a multi-sample thermal desorption unit
- GC/FID system dedicated to CO_2 detection allows for testing CO_2 concentrations down to <1 ppm levels

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→ CLEANLINESS AND CONTROL MONITORING

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Particle counting methods including airborne particle counter, PFO, optical and SEM particle counting

Airborne particle counter:

- Portable particle counter
- Flow rate 1ft³/min
- ISO Class certification: ISO class 5 - 8
- Particle distribution: from 0.3 to 20 µm
- Temperature and relative humidity monitoring
- *Example*: Class ISO 8 Maximum concentration limit per litre of air is Particles >0.5 µm: 3520 and Particles >5 µm: 29

Particle Fall Out (PFO) meter:

- PFO sample plates exposed in the vicinity of flight hardware
- PFO meter measures collected contamination and results are expressed in ppm (particle per million)
- Resolution: +/- 1 ppm
- *Example*: Class ISO 8 maximum 275 ppm/24 hours

Optical particle counting:

- automatic particle counting with shape and size
- minimum size of the particles: 5 µm

SEM/EDX particle counting:

- automatic particle counting with shape and size
- elemental composition (EDX)
- minimum size of the particles: 100 nm

- **Visual vacuum chamber and cleanroom inspection expertise**

Particle counting is an essential part of cleanliness assessment (ECSS-Q-ST-70-50) with particle airborne particle counter, PFO, optical and SEM particle counting methods.


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→ THERMO-MECHANICAL PROPERTY CHARACTERISATION TECHNIQUES

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Equipment able to characterise materials for spacecraft, re-entry devices and launchers

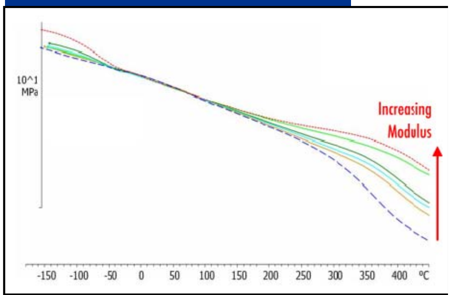
Thermal analysis applied for environmental and long term storage analysis campaign and Advance thermal analysis techniques (TTS/and AMFK) for lifetime modelling

TGA: Thermo Gravimetric Analysis (+25/+1600°C)
DSC: Differential Scanning Calorimeter (+25/+800°C)
TMA: Thermo Mechanical Analysis (-170/+800°C)
DMA: Dynamic Mechanical Analysis (-170/+500°C)

Coupled TGA-DSC-MS-FTIR and TGA-MS-DSC systems

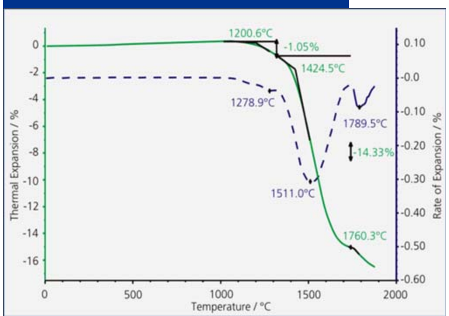
- used to predict the material behaviour subjected to high temperatures up to 1450°C and to know which products are released.
- Residual gas analysis of gas contamination (mass spectrometer) with mass range from 1 to 300 amu
- Very large sample range: liquid, solid, powder from 1 mg to 5 g

DMA1 environmental and long term storage analysis campaign
Advance technique : TTS/ AMFK



Dilatometer : linear thermal expansion in solids, liquids, powders, pastes, ceramic fibers

- Temperature range: -170°C /+2000°C
- Sample size: up to 50 mm
- Working pressure: ambient and vacuum at 10^{-2} mbar

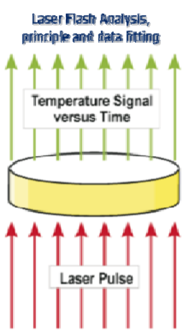


Laser Flash Analyser: Thermal diffusivity

- Measuring range: 0.01-1000 mm²/s
- Temperature range: -125°C/+500°C
- Sample size: up to 25 mm
- Working pressure: ambient and vacuum at 10^{-2} mbar

Hot disc : thermal conductivity, thermal diffusivity and specific heat capacity

- Measuring range thermal Conductivity: 0.005 to 1200 W/mK
- Sample Dimensions: 0.5mm High, 2mm Diameter (measurement of powder also possible)



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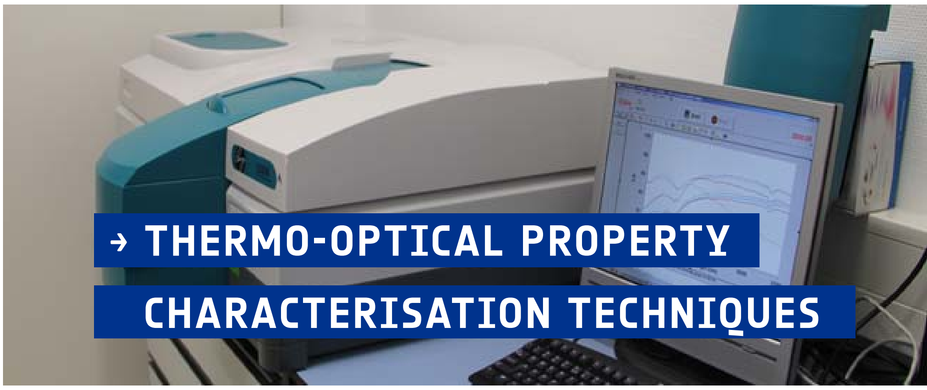

→ THERMO-OPTICAL PROPERTY CHARACTERISATION TECHNIQUES

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UV-VIS-NIR –IR Photo spectroscopy: several research instruments with various accessories for the thermo optical characterization of materials:

- Characterization of the reflectivity properties of macroscopic samples to be used in space application in order to determine the temperature dependence of the emissivity, in accordance with ECSS-Q-ST-70-09C
- Transmission properties with a collimated beam (190-3000nm)
- Hemispherical transmittance/reflectance properties (250-2500nm)
- Angle dependent reflectance measurements (190-3000nm)
- Temperature dependant reflectance with integrated spheres (250-2500nm). From room temperature to 250°C
- Emittance measurements at room temperature as function of temperature with a black body calculation over -230/+3000°C

Optical investigation of materials from the Ultra-Violet to the Near Infra-Red Wavelength band Handheld equipment used for optical characterization of materials at ambient temperature following ISO 17025 requirement.

Portable thermo-optical TEMP 2000A and TESA 2000

- Measure different types of surfaces :
- flat surfaces, specular or diffuse materials…
- Thermo-optical properties obtained:
- Near-normal IR emittance over the spectral range from 3μm to over 30μm (TEMP 2000 A and TESA 2000)
- Solar absorptance over the spectral range from 250 nm to 2500 nm (TESA 2000)

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→ ELECTRICAL PROPERTY CHARACTERISATION TECHNIQUES

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Electrical properties characterisation of materials using wide frequency and temperature ranges

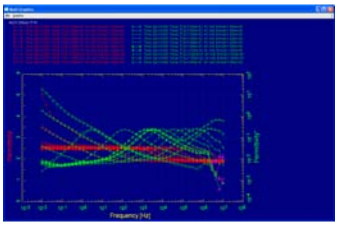
Electrical resistivity- 4 point probe technique 4 point probe:

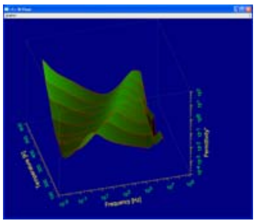
- Resistivity measurement range: 0-1000 ohm/square

Surface and bulk resistivity following ASTM D257

- Bulk (volume) resistivity: 10^{+3} - 10^{+18} ohm.m
- Surface resistivity: 10^{+3}-10^{+17} ohm

- Sample size: 90 x 90 mm2 with maximum thickness of 1 mm



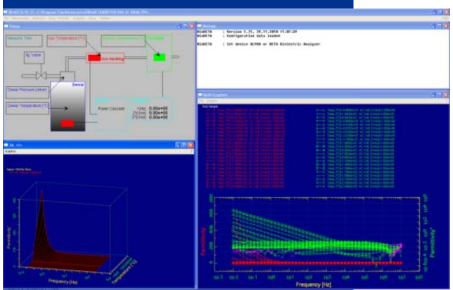


Impedance dielectric spectroscopy -BROADBAND DIELECTRIC SPECTROSCOPY (BDS)

Measures complex impedance Z *(w) and calculates dielectric parameters as complex permittivity ε*(w) and complex conductivity σ*(w) with:

- Broad frequency range from 3 μHz to 3 GHz
- Low frequency analyser : < 20 MHz
- High frequency analyser : > 1 MHz
- Optimized for broadband measurements of low loss dielectrics
- Wide temperature range from – 160°C to 400°C
- Sample prepared between additional external parallel gold-plated electrodes with diameters up to 30 mm to form a sandwich capacitor

ElectroStatic Discharge Facility (ESD)– allowing the simultaneous (electron) irradiation of temperature controlled samples under high vacuum



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→ PARAMAGNETIC ANALYSIS (ESR)

CHARACTERISATION

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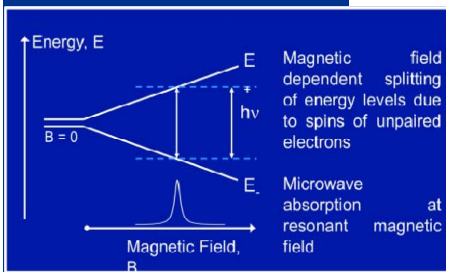
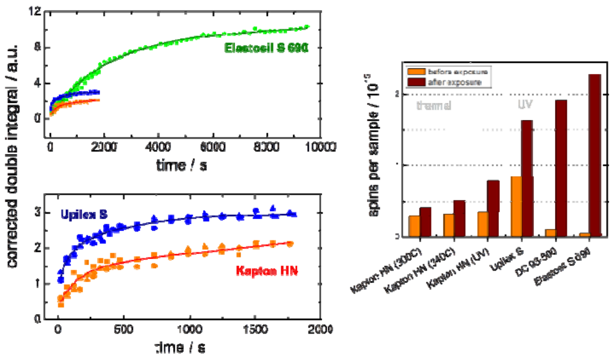
Electron Spin Resonance (ESR) spectroscopy is a magnetic resonance technique which specifically targets paramagnetic species

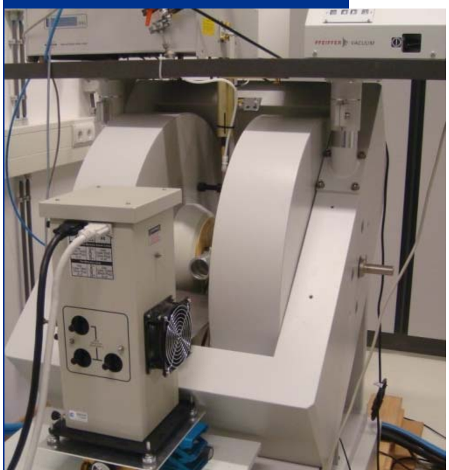
- Detects paramagnetic species (radicals, transition metal ions, colour centres) containing unpaired electrons and determines their concentrations
- Hyperfine interactions between the unpaired electrons and nuclei with non-zero spin (1H, 13C, 14N, etc.) provide formation about the structure of the material
- Experiments monitored in situ provide knowledge on degradation mechanisms
- Microwave resonator operating at X-band (approx. 9.5 GHz, 0.34 T)
- Custom built focusing system
- Simultaneous application of vacuum, UV irradiation and temperature control
- In-situ Thermal degradation: -150/+340°C
- In-situ UV degradation: 180–2500 nm
- Sample size: ø < 10 mm, l < 40 mm

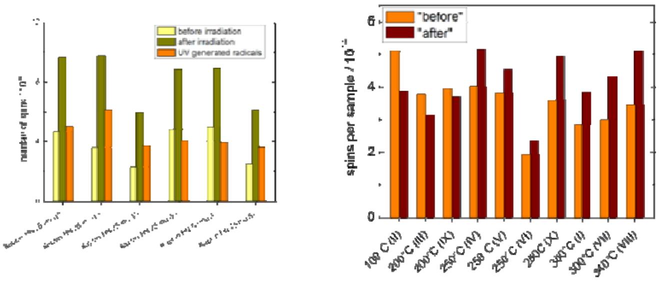
During the degradation of polymers, radical intermediates are very often present at some stage of the process. By monitoring these, information on the degradation process may be obtained and the stability of the investigated materials assessed.





Degradation of silicones and polyimide samples during UV irradiation





Thermal and UV degradation of polyimide samples

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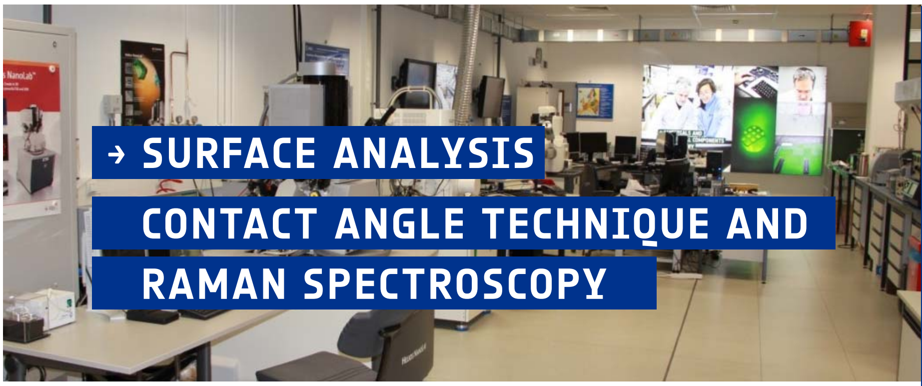

→ SURFACE ANALYSIS
CONTACT ANGLE TECHNIQUE AND RAMAN SPECTROSCOPY

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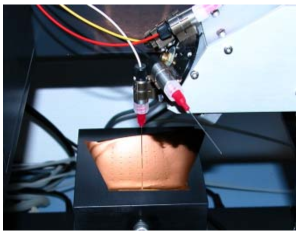
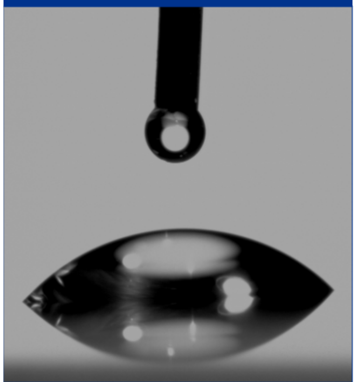
Measurement of the surface energy of various substrates and surface free energy of liquids



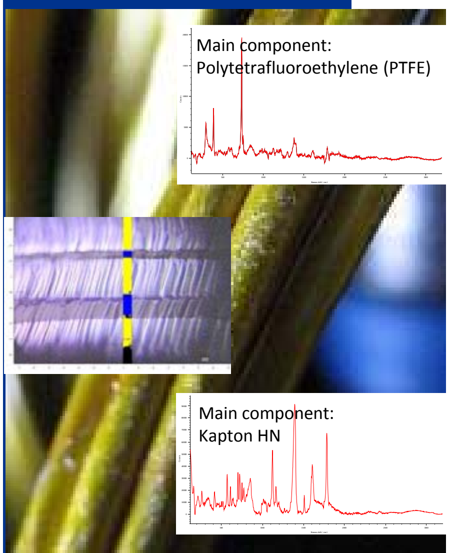
- Measure static and dynamic contact angle
- Measure surface free energy of solids
- Apply single or multi-dosing dispense system
- Measure advancing/receding contact angles
- Measure surface and interfacial tension of surfaces
- Sequential and surface mapping capabilities



The contact angle system features

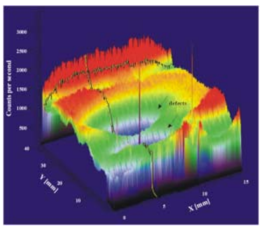
- High speed camera/ image acquisition 25 fps (up to 50 fps half resolution)
- Drop volumes of microliters (polar/non-polar liquids)
- X, y and z -axis stage movement
- Single/multi dosing syringe dosing droplet software system
- Automatic/manual drop shape analysis software
- Vacuum chuck accessory for thin film contact angle measurements
- Temperature/Peltier humidity controlled chamber options
- Sample size: up to 100x100 mm^2 (for solids)

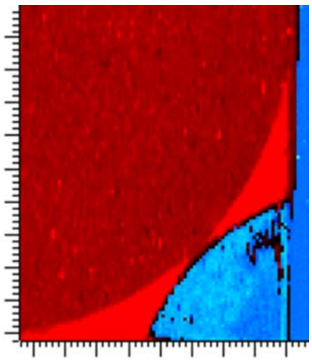
Analysis technique used during the for James Webb Space Telescope campaign to assess the degradation of the electrical cables



Raman spectroscopy for analysis of materials

- Express and localised chemical analyses of samples with surface concentration of substances less than one monolayer.
- Spectroscopic mapping based on Raman and luminescence signals from samples on areas up to several square centimeters with spatial lateral resolution below 1 µm
- Detecting locations of components or regions of defects by the high intensity areas in spectroscopic maps and the chemometrics pattern recognition
- Identification of substances and chemical imaging of samples based on their Raman signatures





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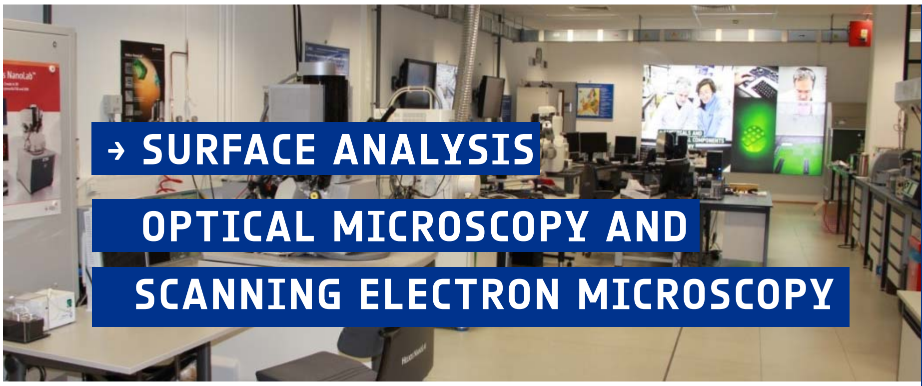

→ SURFACE ANALYSIS
OPTICAL MICROSCOPY AND SCANNING ELECTRON MICROSCOPY

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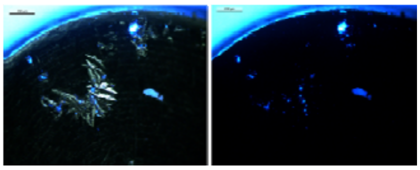
Macro/Microscopic Examination and Optical (fluorescence) Microscopy

Macroscopic Examination

- Optical Microscopy -DM6000M system-
- Objectives: x5, x10, x20, x50 and x100
- Choice of imaging options: Incident, Interference Contrast, Transmitted, Polarised
- Confocal Microscopy
- Optical Microscope Cooling and heating stage (-100 to +600C)
- Light/ Illumination Control

Scanning Electron Microscopy (EDX Analysis and EBSD)

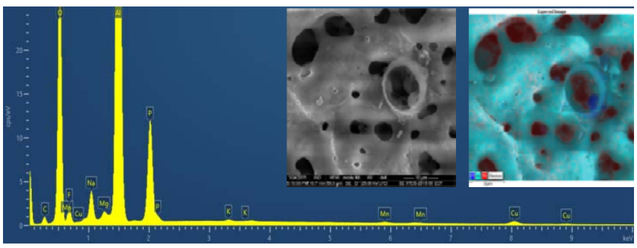
- X-Y-axis control (76mm x 50mm) Z-axis 25mm
- Variable light source including UV
- Fluorescence Imaging Options with optical filters (visible)



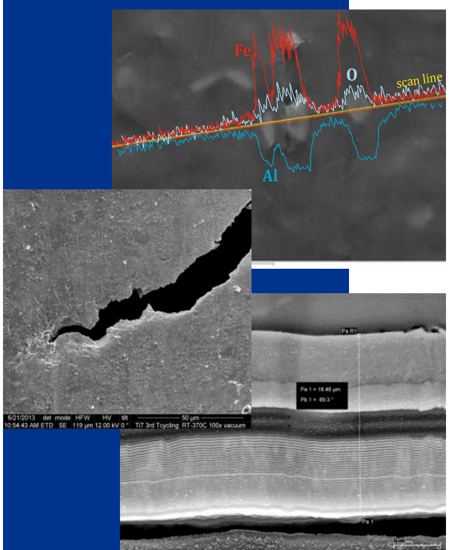
Electron Backscatter Diffraction camera can examine the crystallography orientation of many materials

Scanning Electron Microscopy (SEM) with Energy Dispersive X-Ray (EDX) Analysis

- Low voltage imaging of samples
- INCA- EDX elemental analysis
- 80mm^2 active area detection-large capture angle
- Working distance from 1 to 50mm
- X-Y-Z axis stage movement rotation and tilting options
- 330mm diameter inner chamber
- Sample size: XY: 20x20cm, height 9cm
- Working pressure: vacuum up to 10-7 mbar
- Raman in-situ measurement capability: spatial resolution 1μm, depth profile resolution 2μm
- High resolution imaging of samples to 1 nm@30kV
- Electron imaging of conductive and non-conductive materials
- High resolution energy dispersive spectrometer
- Particle counting and elemental quantitative/qualitative analysis
- Elemental composition maps



Electron imaging of conductive and non-conductive Carbon, Gold and Platinum coating of samples a possibility up to 900,000 Magnification



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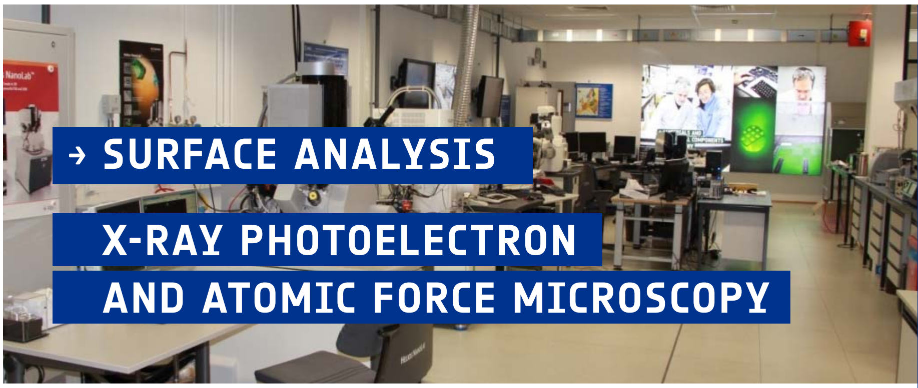

→ SURFACE ANALYSIS

X-RAY PHOTOELECTRON AND ATOMIC FORCE MICROSCOPY

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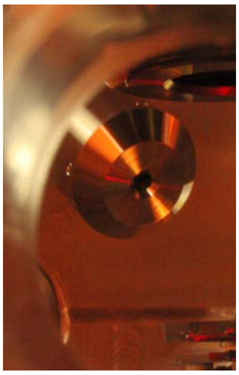
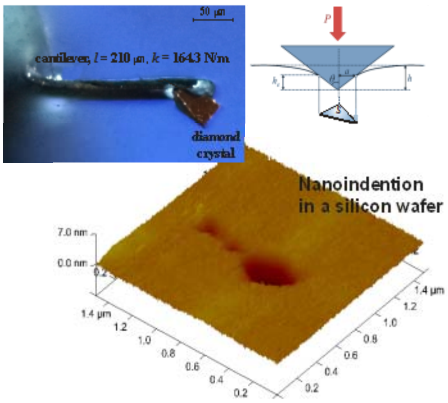
XPS provides information about chemical composition of the top 12 nm of a sample surface

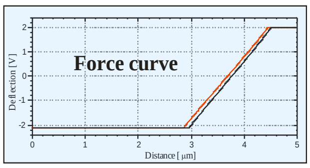


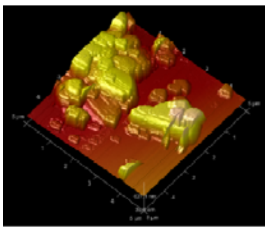
- Monochromatic X-ray source with an excitation energy of 1486.7.eV in a narrow band of 0.25 eV
- Energy resolution up to 280.meV
- Measuring of conductive and non-conductive materials
- Composition, depth profiling and interface analysis

AFM provides Scanning of sharp tip over sample surfaces with resolution in nanometer scale and produces atomic-scales 3D images of surfaces down to 0.1nm

- Atomic Force Microscopy (AFM): Resolution 2-5 nm (X,Y), 0.4 nm (Z)
- Nano Thermal Analysis (Nano-TA): Resolution ~ 30 nm (X,Y), 0.1°C.
- Force modulation microscopy and phase Imaging
- Nanoindentation and nanoscratching testing
- Nanomechanical analysis (few pN)







XPS is non-destructive technique . Thanks to its high surface sensitivity it can be applied for contamination control of surfaces down to one monolayer of contaminants; monitoring changes in surface chemistry caused by the space environment

AFM operating in the Electric Force Microscopy mode shows that electrical potential of the contamination differ from that of a conductive substrate indicating on absence of electrical conductivity. This is important to avoid short cuts in electrical circuits of the spacecraft

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→ SURFACE ANALYSIS
X-RAY TECHNIQUES

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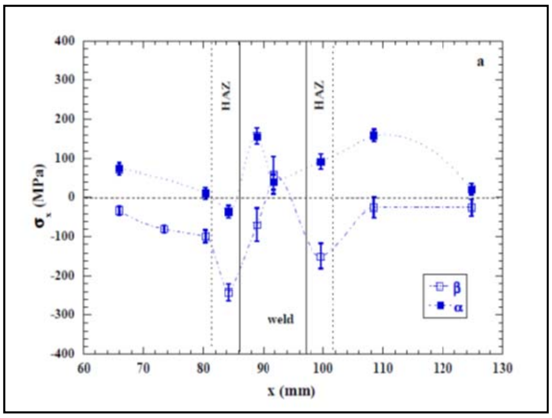
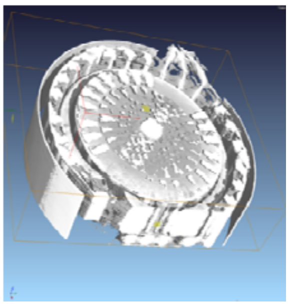
X-RAY Diffraction, X-RAY Fluorescence and X-RAY topography spectroscopies

- Phase analysis
- Degree of crystalline
- Detection of lattice strain differences
- Residual stresses measurements

Phoenix V/tome X-ray –micro focus XRT instrument

- Scanning Laser Acoustic Microscopy (SLAM)
- Scanning Acoustic Microscopy (SAM)
- Computer Tomography





Failed Water Pump
(corrosion visible in the 3D scan)

The X-ray photoelectron spectroscopy can identify a chemical composition of top view nanometers of a surface . Combination of this technique with ion sputtering allows one to do a depth chemical profiling of samples up to several micrometers.

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