ANNOUNCEMENT OF OPPORTUNITY

Atomic Oxygen Testing in the ESTEC Materials and Electrical Components Laboratory
Summary of this Opportunity

The ESTEC Materials’ Physics and Chemistry Section (TEC-QEE) of the European Space Agency announces an opportunity to perform testing using the atomic oxygen test facility “LEOX” in the Materials and Electrical Components Laboratory. This facility is unique within Europe, using a laser detonation source to provide a beam of hypervelocity oxygen atoms for ground based testing of spacecraft materials and assemblies.

The opportunity is a pilot project primarily aimed at raising awareness of the capabilities of the ESA test laboratories, especially amongst new or inexperienced players in the space business. Therefore it is restricted to SME, academia and national institutes.

The coordinator of the proposal shall be working in one of the ESA member or associated member states.

Test programmes shall be for peaceful purposes only and the results shall be of potential interest to on-going or future ESA space projects.

Analytical equipment within the Materials and Electrical Components Laboratory will also be available to investigators for sample analysis.

For this first pilot announcement, ESA shall cover the cost of facility operation (including certain preparatory steps) and routine sample analysis for selected proposals. All other costs are to be borne by the experimenters.

The test results shall be made freely available to ESA for its own activities and for inclusion in its materials databases (dissemination to scientific community).

The activities covered by this announcement also provide an opportunity for the TEC-QEE Materials and Electrical Components Laboratory to broaden awareness of the capabilities of the test facility and the laboratory in general within the European space community and beyond. Investigators of selected experiments are therefore encouraged to promote and communicate their results to a wider audience (e.g. general public, colleagues, students). However if this option is waived by the investigator, ESA reserves the right to publish data on its own.

Proposals shall be submitted in pdf format using the template provided in Annex C, to:

ESA Technical Officer (TEC-QEE Section), Adrian.Tighe@esa.int
ESA TEC-QE Laboratory Administrator, Laurence.tu-mai.levan@esa.int

Proposal deadline: 31st May 2019

Implementation schedule: Selected experiments will start in the third quarter 2019.
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1 INTRODUCTION

Atomic oxygen is the dominant residual species of the atmosphere in Low Earth Orbit, at altitudes from about 200 – 800 km. It collides with spacecraft surfaces at a relative velocity of about 8 km/s, and can cause erosion and degradation of exposed materials. In general, polymers are the most sensitive materials, although there are some important exceptions for metals (e.g. silver). The spacecraft geometry, the orbital parameters and the mission duration determine the total dose of atomic oxygen (or the so-called “fluence”) which a particular surface will encounter over the duration of a mission. The following general rules apply:

- fluence is higher in lower orbits and during periods of high solar activity
- fluence is higher for surfaces exposed perpendicular to the direction of spacecraft travel (the ram)
- fluence is proportional to the time of exposure
- surfaces can be shielded from atomic oxygen by surrounding parts of the spacecraft.

Atomic oxygen erosion is generally a surface phenomena. Degradation effects are very gradual, and cumulative i.e. the total erosion will be higher for longer exposure periods. However this is not always the case, as sometimes a self-protecting oxide layer can be formed on the surface of the material. Effects include surface erosion, modification of surface roughness, changes in thermo-optical properties, and changes in surface conductivity. Such effects are normally only a concern for thin coatings and foils, and they do not impact the structural properties of materials. However for severe erosion, when the integrity of the material is affected, generation of particulate contamination can also be a problem (e.g. if a thin foil is completely eroded).

The spacecraft sub-assemblies most often susceptible to atomic oxygen attack are the solar array, the passive thermal control system, optical surfaces and antennas. Typical materials which need to be assessed are Kapton based MLIs, Teflon radiators, polymer insulated cables, metallic interconnects on solar cells, coated cover glasses, optical coatings on lenses and telescope optics, thermal control paints and non-structural adhesives.

Ground based atomic oxygen testing of materials for space applications is challenging for a number of reasons:
- atomic oxygen readily recombines under normal atmospheric conditions
- orbital collision velocities are relatively high

The so-called atomic oxygen beam generator sources are generally the best way to most accurately reproduce the in-orbit conditions required for this testing. The thermal energy within a high density oxygen plasma is converted into kinetic energy, which accelerates the oxygen atoms to hypervelocity within a diverging beam. The beam is directed into a vacuum chamber and onto the samples under test.

The ESTEC TEC-QEE Section operates such an atomic oxygen beam source in the Materials and Electrical Components Laboratory, the only one of its kind in Europe. The atomic beam
source is a so-called laser detonation source, using a high power CO2 laser to create the high density oxygen plasma (further information can be found in Annex A).

Due to the complexity of the facility and the relatively high operating cost, access to the facility is usually only affordable for the larger industrial primes and national agencies. In many cases, the test results are often considered as proprietary and as such are of limited use to the broader space community. Furthermore, it is not cost effective for an organisation to commission a test for just one or two material samples.

2 OBJECTIVES OF THE ANNOUNCEMENT

The announcement of opportunity has the following specific objectives:

- to broaden access to the atomic oxygen facility
- to promote awareness of the atomic oxygen environment and its effects, including the requirements driving the selection and test of materials and assemblies, especially amongst new players in the space business
- to promote research and development into new study areas within this field (e.g. sensors, new materials)
- to provide testing opportunities for smaller institutes (e.g. SME, academia), who may not have the knowledge or resources to commission a dedicated atomic oxygen test campaign
- to provide test data which can be accessed by the wider space community, with limited restriction on confidentiality
- to increase efficiency of testing by co-ordinating combined test programmes

The opportunity is not intended to conflict with or replace the dedicated atomic oxygen test campaigns commissioned by the larger projects, national agencies or the industrial primes. The results from such dedicated test campaigns remain bound by the confidentiality requested by these customers.

3 PROPOSAL PREPARATION

3.1 Proposal format and content

Proposals shall be prepared using the form in Annex C.
Detailed information about the materials and processes used for the test items shall be provided. Proprietary information shall be identified. This will not necessarily exclude the proposal, as long as “reasonable” transparency is provided. For example, it would not be necessary to specify in detail the design for a multilayer optical coating, but the constituent materials should be identified.

Collaborative proposals are welcomed

The required sample analysis shall be indicated on the proposal form

In-situ monitoring of test items is possible during the exposure (electrical feedthroughs and viewports are available), but all of the required hardware shall be provided by the experimenters.

The total required atomic oxygen fluence for the testing shall be indicated if known. However this requirement is often not well established for technology development activities or in the early phases of a satellite project. In this case, the experimenter can opt for a standardised fluence which shall be proposed by the Laboratory.

### 3.2 Eligibility

The opportunity is restricted to SME, academia and national institutes and the coordinator of the proposal must be working in one of the ESA member or associated member states.

Test programmes shall be for peaceful purposes only and the results shall be applicable to on-going or future ESA space projects (clear evidence shall be provided in the proposal).

A representative of the organisation is required to visit the Laboratory at least once during the test campaign (e.g for the mounting and/or dismounting of the samples from the facility, or for the sample analysis).

Proposals not meeting these criteria will not be accepted for the scientific merit review.

### 3.3 Submission and Schedule

Proposals shall be submitted in pdf format using the template provided in Annex C, to: 
**ESA Technical Officer, Adrian.Tighe@esa.int**  
**ESA TEC-QE Laboratory Administrator, Laurence.tu-mai.levan@esa.int**

Proposal deadline: **31st May 2019**

Implementation schedule: Selected experiments will start in the 3rd quarter 2019
3.4 Review

Eligible proposals submitted in response to this AO will undergo a scientific merit review by ESA experts. The following criteria will be used to determine the scientific merit score:

**Relevance**: Is this study of relevance for on-going or future ESA space projects? Does this study address an important problem? If the aims of the application are achieved, how will scientific knowledge or technology be advanced? What will be the effect of these studies on the concepts, methods, or products that drive this field?

**Approach**: Is the theoretical framework, experimental design, data analysis and interpretation methods adequately developed, well integrated, and appropriate to the aims of the project? Is the proposed approach likely to yield the desired results? Does the applicant acknowledge potential problem areas?

**Innovation**: Does the project employ novel concepts, approaches, or methods? Are the aims original and innovative? Does the project challenge existing paradigms or develop new methodologies or technologies?

**Sample information**: Is sufficient sample information provided, to ensure that the results will be useful to the wider space community?

**Personnel**: Are the scientific personnel appropriately trained and well suited to carry out this work? Are the functions and responsibilities of the team members adequately described and appropriate? Does the project employ useful collaborative arrangements?

In the review, each proposal will receive a scientific merit score between 0 and 100 points. As a result of the scoring the proposals will receive one of the following marks:

- Outstanding 100 - 91 points
- Excellent 90 - 81 points
- Very Good 80 - 71 points
- Good to Fair 70 - 46 points
- Unacceptable 45 - 0 points

The highest scoring proposals will be given priority in the first available testing slot. Lower scoring proposals may still be accepted, but deferred to a later testing slot. Unacceptable proposals will be rejected.

On a best effort basis the selection board will seek clarifications as needed. However the decision of the ESA selection board is final and there is no right of appeal.
4 IMPLEMENTATION

After proposal selection, the highest scoring proposals will be offered a testing slot foreseen to start in the third quarter of 2019.

The specific details of the testing shall be organised between the proposal coordinator and the ESTEC laboratory.

ESA will cover the costs for any laboratory-specific training of the experimenter, for verifying the sample with a view to avoiding damage to the LEOX facility, for operating the LEOX facility during the testing of the sample and for routine sample analysis (see Annex B). All other costs are to be borne by the experimenter (e.g. travel, subsistence, specific sample analysis, detailed reporting of results).

Whilst every effort will be made to adhere to the agreed implementation schedule, investigators should be aware that delays may occur due to the operational constraints of the Laboratory. The Laboratory shall not accept any responsibility for impact to the project schedules of the investigators due to any such delay.

5 DATA RIGHTS

Final results of the testing shall be made available by the experimenter to ESA for non-commercial use, for the purpose of its activities and programmes, and to the scientific community through ESA's materials databases (access controlled), scientific conferences and peer reviewed journals.

Any publication of the results generated during the studies solicited in this Announcement of Opportunity must acknowledge the sponsorship of the study by ESA.

The activities covered in this AO provide an opportunity for ESA to enhance and broaden the public's understanding and appreciation of space environmental testing of materials and related research facilitated by ESA's Directorate of Technology, Engineering and Quality. Therefore, the investigators of selected experiments are expected to promote and communicate their experiments to a wide audience (e.g., general public, colleagues and involvement of students). In the event such reports or publications are copyrighted, ESA shall have a royalty-free right to reproduce, distribute, and use such copyrighted work for its purposes.

6 LIABILITY

ESA will not be liable for any damage to the items furnished by the experimenter, unless caused by gross negligence or wilful misconduct on the part of ESA.
The experimenter will only perform a limited set of tasks as part of the LEOX facility operations and will receive ESA training for those tasks. The experimenter will not be liable for damage to ESA equipment which may nevertheless arise, unless caused by gross negligence or wilful misconduct on the part of the experimenter.
ANNEX A OVERVIEW OF THE LEOX TEST FACILITY

The source concept of the LEOX facility is based on the Laser Pulse Induced Breakdown (LPIB) principle. First, molecular oxygen is forced through the throat of a nozzle, in the form of gas puffs generated by a fast-switching piezo actuated pulsed valve. After partial fill of the nozzle, a high power beam from a pulsed CO2 laser (wavelength 10.6 µm and 9.6 µm) synchronised with the valve is focused onto the injected gas. This produces breakdown and dissociation of the gas into a hot plasma, which emits light also in the VUV and UV wavelength region. The detonation creates a blast wave that propagates through the nozzle with a conversion of the plasma thermal energy into directed velocity. The cooling of the expansion allows the plasma to charge neutralise into oxygen atoms, but the expansion rate is kept sufficiently high, and the density sufficiently low, to prevent recombination of these atoms into molecules. A thermally cold (low spread in random velocity - meaning a couple of thousand Kelvin) AO beam with high directed energy finally exhausts the nozzle and propagates towards the samples (see Figure 1).

The vacuum system consists of a main chamber, a differential pumping chamber and the RGA chamber. The pumping system includes a turbo pump located just below the main chamber backed by up to three dry scroll pumps. The vacuum reached in the vessel is about 10⁻⁷ mbar when no pulsed beam is introduced.

In the standard set-up twenty samples (about 2 x 2 cm²) are integrated into the sample holder. Non-standard configurations are also possible, with a maximum exposure area of 140 x 140 mm².

With this facility, the distance of the samples from the AO source can be modified in order to change the AO flux. Furthermore the sample holder can be rotated to any beam axis angle of attack, so from 0° up to 90°.

A digital delay pulse generator is used to synchronise the functioning of the facility. A pulse is sent first to the molecular beam valve driver which opens and closes the valve. The O₂ gas enters into the nozzle through this valve with a well-controlled pressure and mass flow rate. After a well-defined delay a pulse is sent to fire the laser. The CO₂ laser beam is focused into the nozzle throat. The AO velocity is obtained measuring the time of flight with a scientific grade mass spectrometer. The mass spectrometer is tuned to m/z = 16 in order to detect atomic oxygen continuously. The AO intensity is recorded versus time with a scaler, which integrates all signals as a function of delay relative to the 2 Hz trigger pulse. One small peak signal is induced by the photons, which are emitted from the hot plasma and the second peak is the actual pulsed atomic oxygen beam. With the mass spectrometer it is possible to monitor the quality and energy distribution of the produced pulsed beam.
ANNEX B SAMPLE ANALYSIS

B1 Routine analysis
The following routine sample analysis is typically performed on the exposed samples before and after an atomic oxygen test:

- Mass loss measurements using microbalance
- Thermo-optical measurement using spectrophotometer
- Visual inspection using digital camera and optical microscope (low resolution only)

B2 Additional analysis
The following analytical equipment is also available in the TEC-Q laboratories for potential additional analysis of the exposed samples:

- SEM/EDX
- AFM
- XPS
- Confocal microscopy
- Surface conductivity
- FTIR
- High resolution optical microscopy
ANNEX C PROPOSAL FORM

Proposal title:

Contact details
Provide full contact details (contact name/company/address/email)

Coordinator (primary point of contact):

Collaborator(s):

Background information
Provide background information about the proposed testing, including potential relevance of the data for on-going or future ESA space projects. Highlight any novel concepts, approaches, or methods.

Test items
Provide detailed information about the test items, including total number of items, materials & processes used, vacuum compatibility, handling & storage requirements. Highlight new materials and technologies.

Interface requirements
Provide preliminary information about the required mounting of the samples (including drawings if necessary).
**Exposure conditions**
*Provide as much information as possible about the required atomic oxygen exposure. Include atomic oxygen fluence (if known), intermediate inspection points, sample temperature, in-situ monitoring*

**Basic sample analysis**
*Indicate the basic sample analysis required*
- Visual inspection
- Mass loss
- Thermo-optical

**Additional sample analysis**
*Provide as much information as possible about additional sample analysis required. Use of analytical equipment in the TEC-Q Laboratory can only be negotiated after acceptance of the proposal.*

**Experimenters**
*Attach short CV of experimenters within the project team, including the personnel who will visit the Laboratory during the testing*

**Scheduling**
*Indicate the date by which the test items will arrive at the Laboratory
Please note that ESA cannot be held responsible for any delays which occur during the testing*