Characterization of demisable materials in the VKI's Plasmatron

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Overview

- VKI Plasmatron facility presentation
- Specific testing methodology for demisable materials
  - Instrumented sample holder
  - Sample retention box
  - Measurement techniques
- Typical results from material demise tests
- Development perspectives
- Conclusions

Local Heat Transfer Simulation: LHTS

Locally similar BL equations

$$(lf'')' + ff'' + \frac{2s}{u_e}\frac{\partial u_e}{\partial s}\left(\frac{\rho_e}{\rho} - f'^2\right) = 0$$

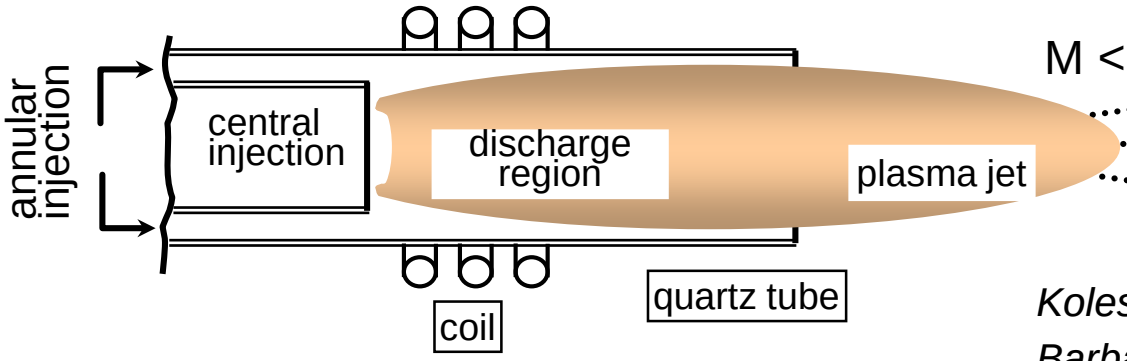
$$f\bar{g}' + \left(\frac{l}{\overline{\Pr}}\bar{g}'\right) + \frac{\mu_e^2}{2\bar{h}_{se}}\left(2l\left(1-\frac{1}{\overline{\Pr}}\right)ff''\right)' + \left(\frac{l}{\overline{\Pr}}Le\left(1-\frac{1}{\overline{Le}}\right)\sum\frac{c_{ie}}{h_{se}}h_i z_i'\right) = 0$$

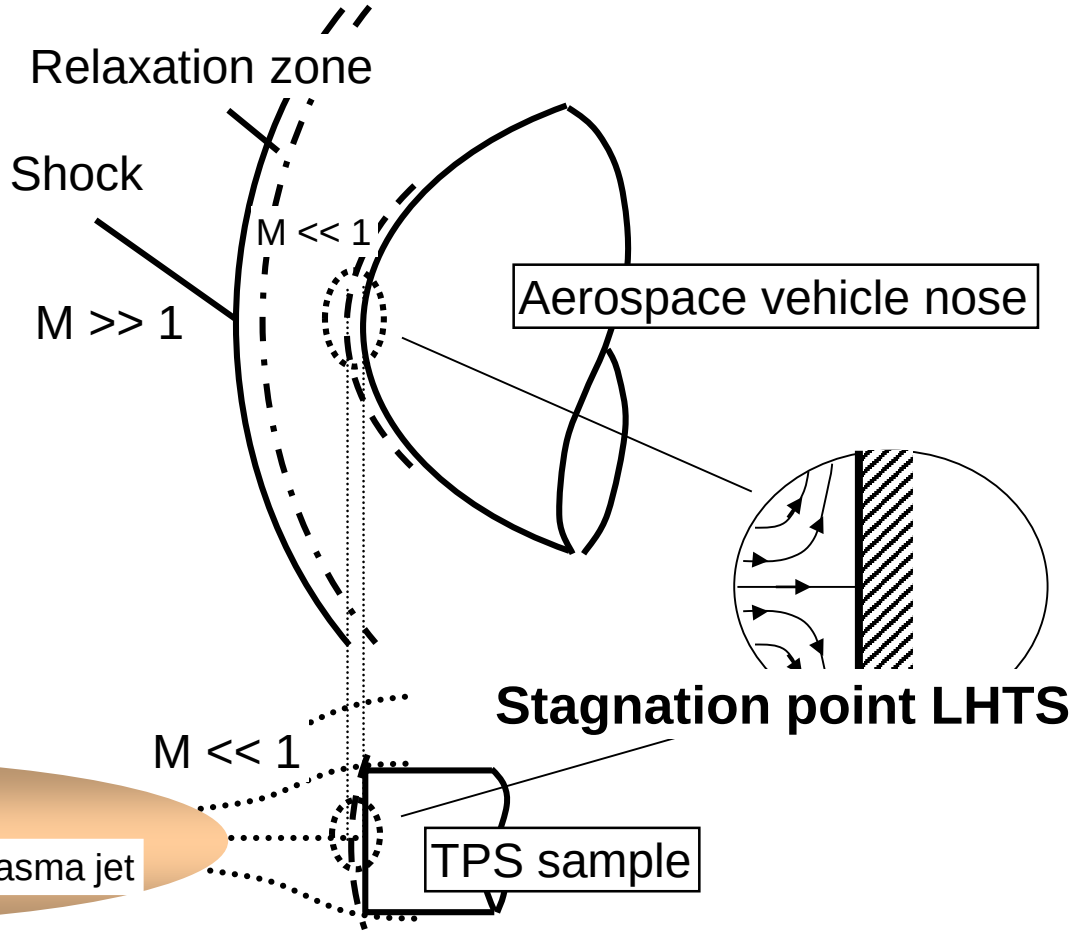
$$fz' + \left(\frac{l}{Sc}z'\right)' - 2\left(\frac{du_e}{dx}\right)^{-1}\frac{\omega_i}{\rho c_{is}} = 0$$

Real flight situation

H_e, P_e, β_e=du/dx, (LTE)

Ground test simulation

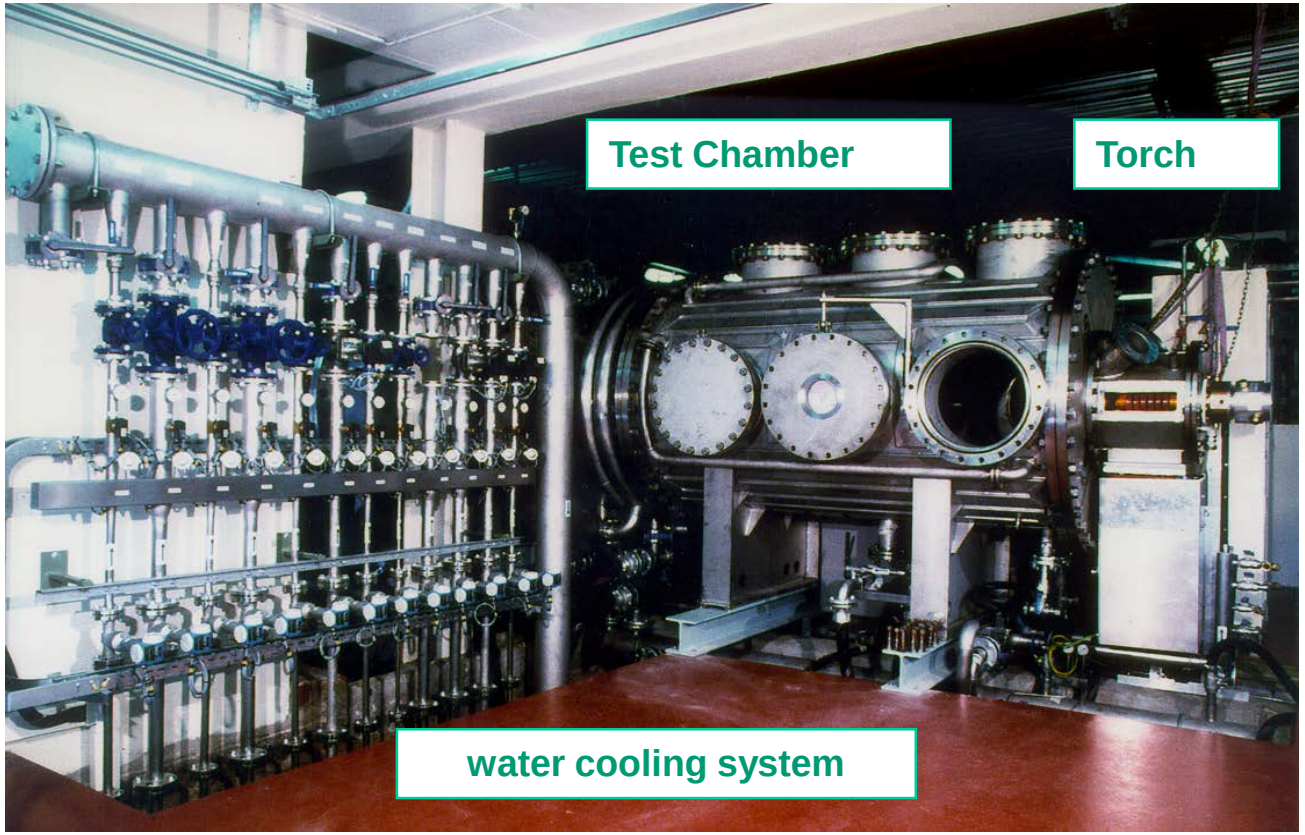


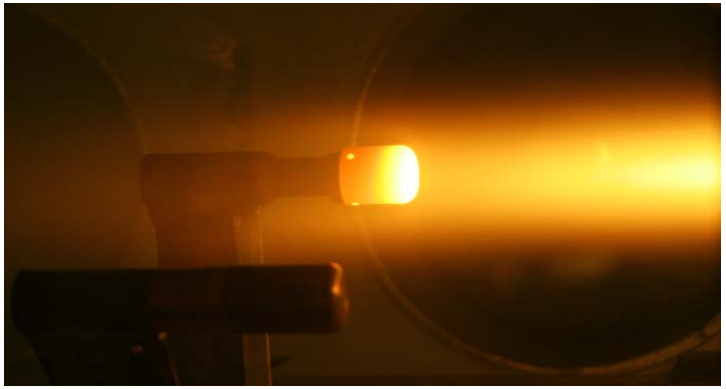


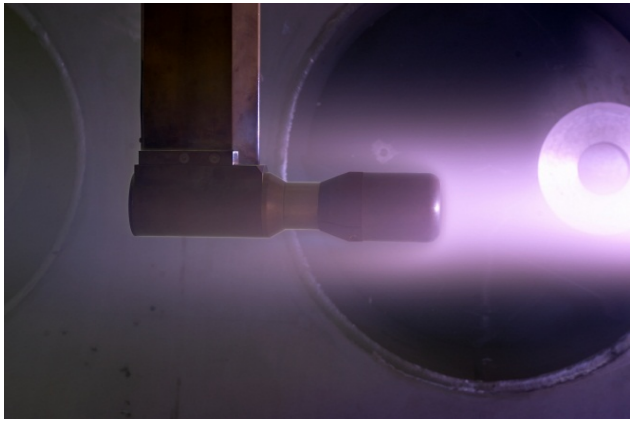
Kolesnikov, Fluid Dynamics 28 (1) (1993) 131-137

Barbante and Chazot, JTHT 20 (3) (2006) 493–499

VKI Plasmatron Facility





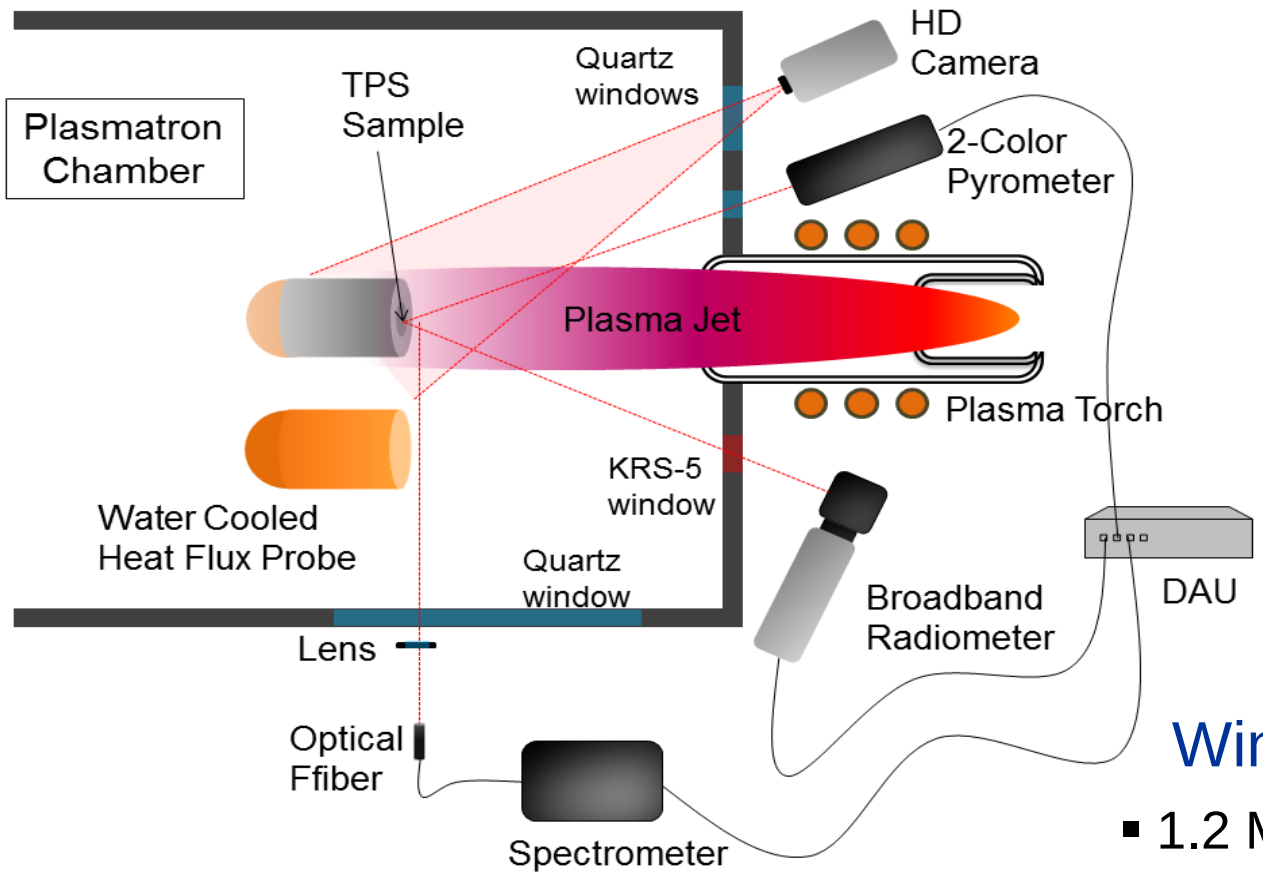


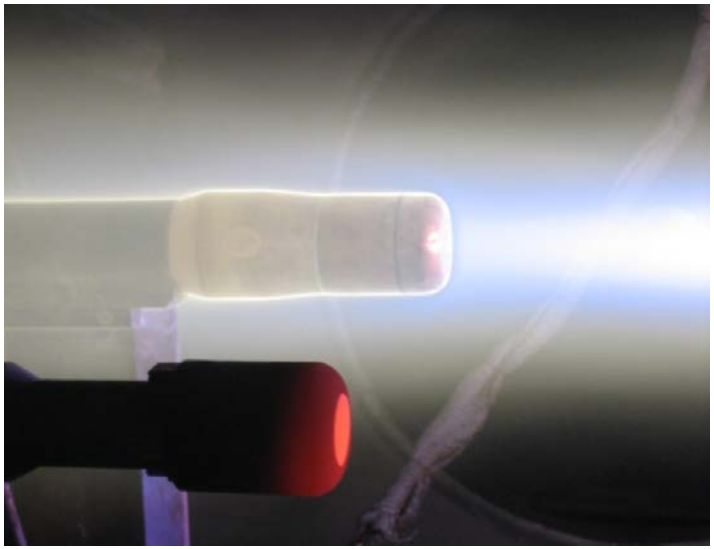
Power: 1.2 MW Gas: Air, CO_2, N_2, Ar Torch Diameter: 160 mm

(Heat flux / Sample holder)

Plasmatron facilities offer suitable conditions for aerothermochemistry ground testing

Plasmatron Testing instrumentation

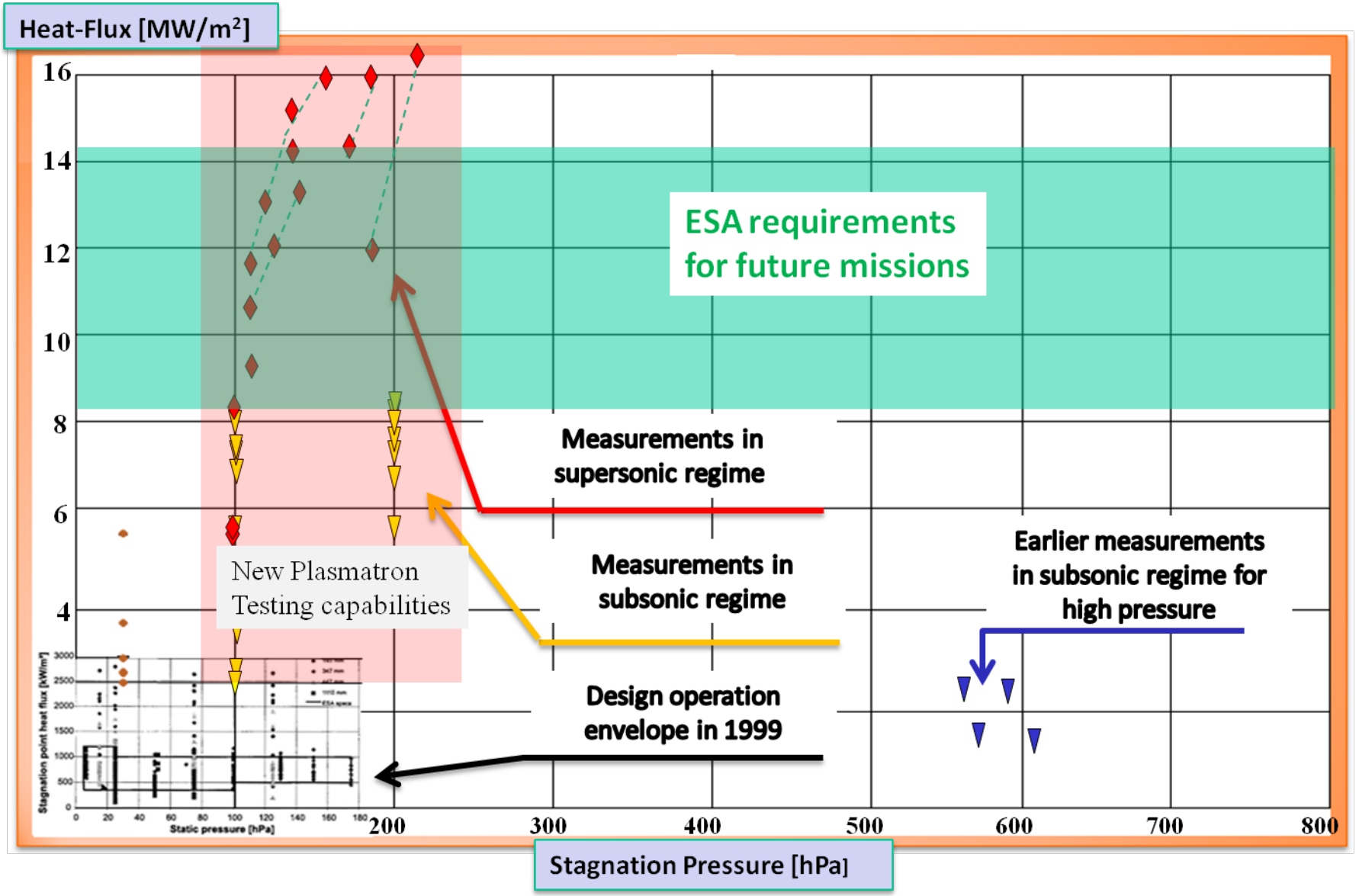




Wind tunnel characteristics:

- 1.2 MW ICP generator
- Gas: Air, N2, CO2, Ar
- Heat-flux: 90 kW/m2 - 16 MW/m^2
- Pressure: 10 mbar - 800 mbar

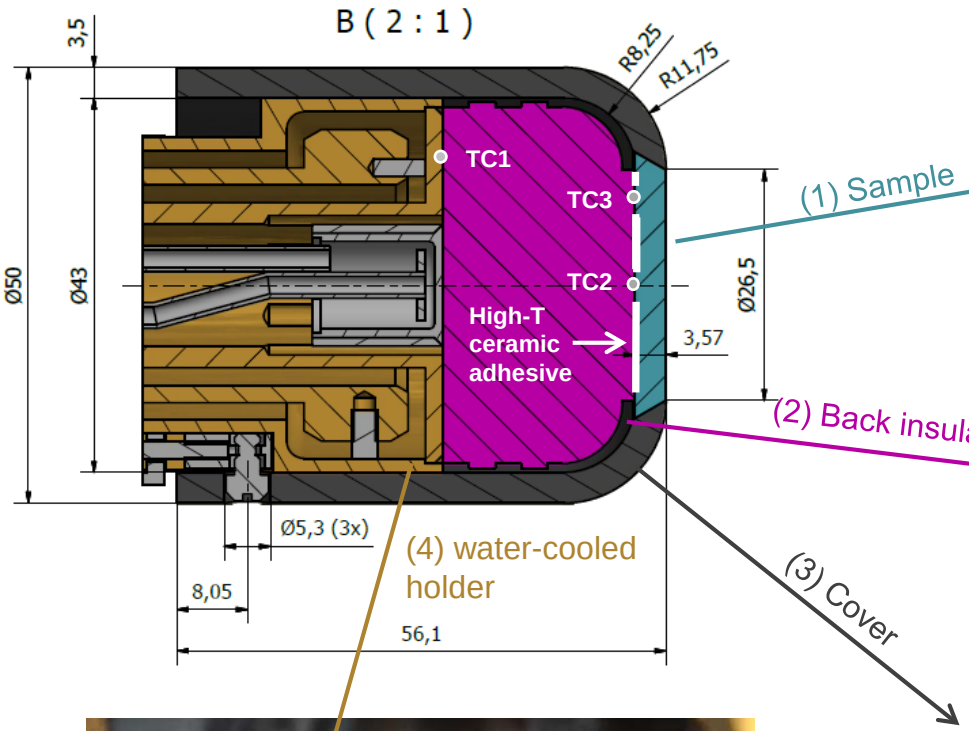
VKI Plasmatron performance envelope

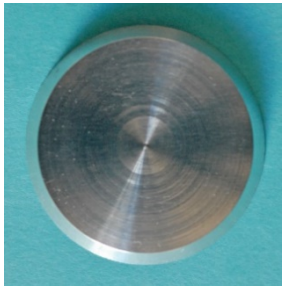


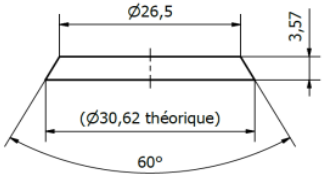
Demisable material testing

- Motivations
  - Uncontrolled destructive atmospheric re-entries may result in impacting debris over populated areas
  - Design for demise (vehicle layout, material selection…)
- Objectives
  - Develop a specific testing methodology to characterize demisable materials in the Plasmatron
  - Apply this methodology to different materials: stainless steel, aluminium alloys and GLARE
  - Provide PWT data to validate destructive re-entry codes (Fluid Gravity Engineering and Research Limited)
  - Read-across evaluation with other PWT tests (PWK1/RD5, IRS)

Instrumented sample holder (1/2)







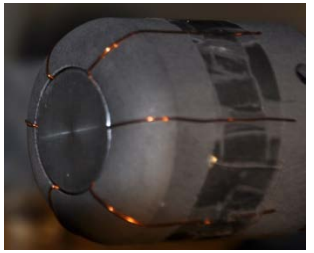
316L, Al2099, AL7075 and GLARE

Aged cork composite for moderate and high heat flux

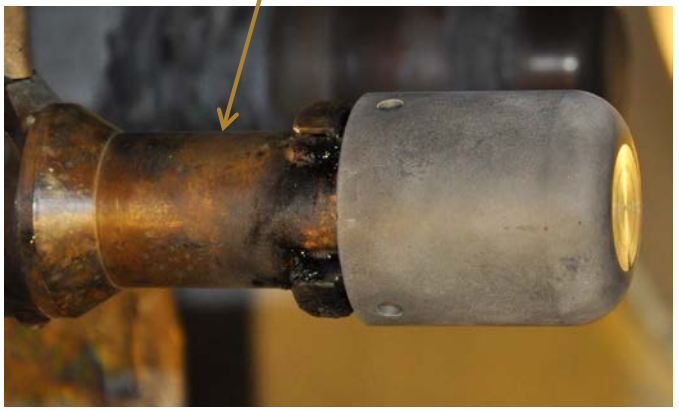
or

Virgin ceramic composite for low heat flux

<u>Preferred material</u>: SiC

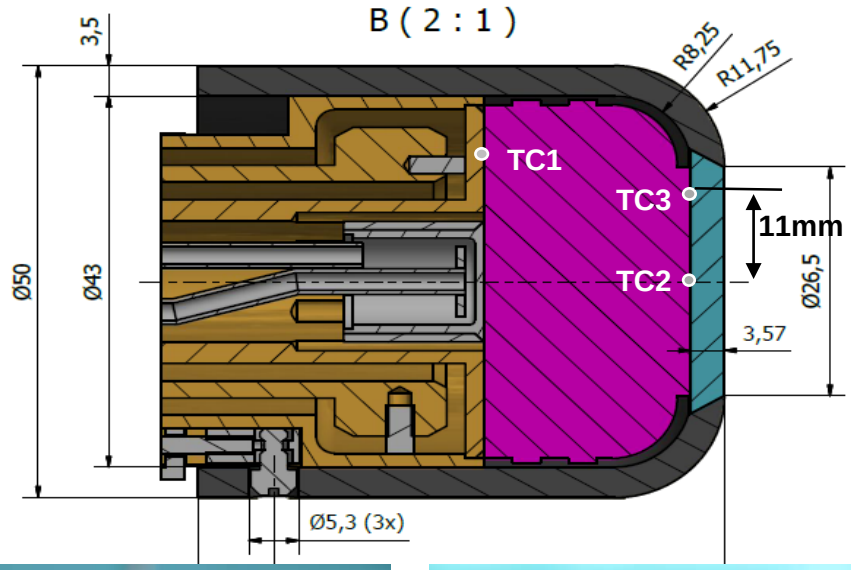


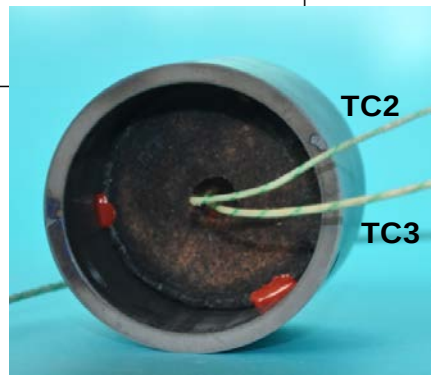
<u>Alternative at high heat flux</u>
Graphite w/ controlled air gap between cover and sample

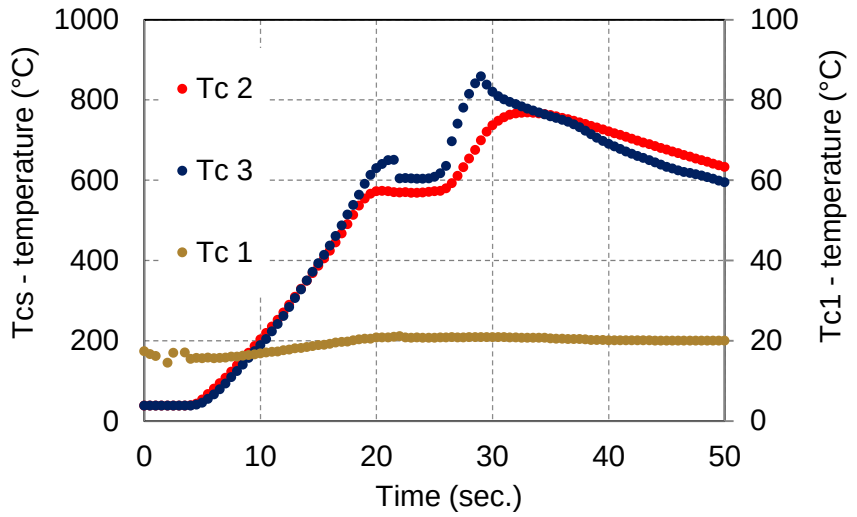


Instrumented sample holder (2/2)

- Type-K thermocouples (TC1, TC2 and TC3) to measure back temperature at different positions

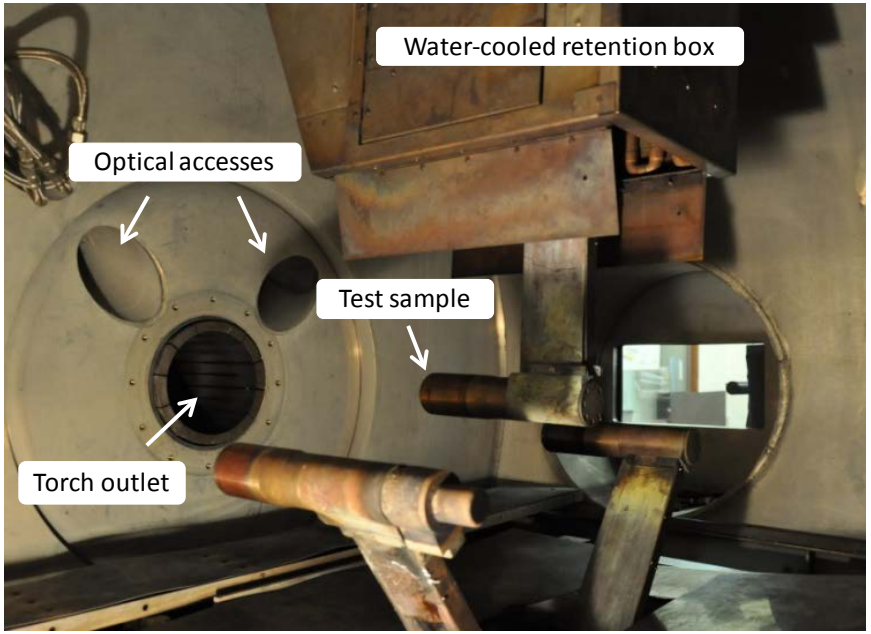


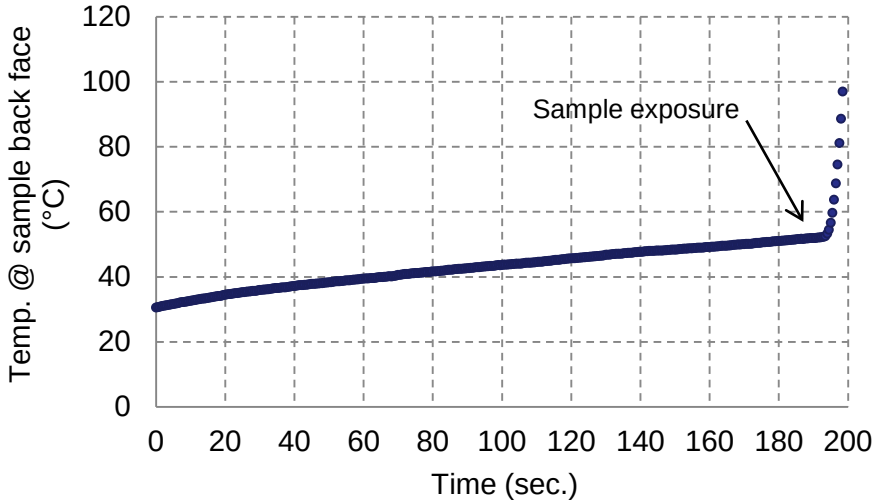




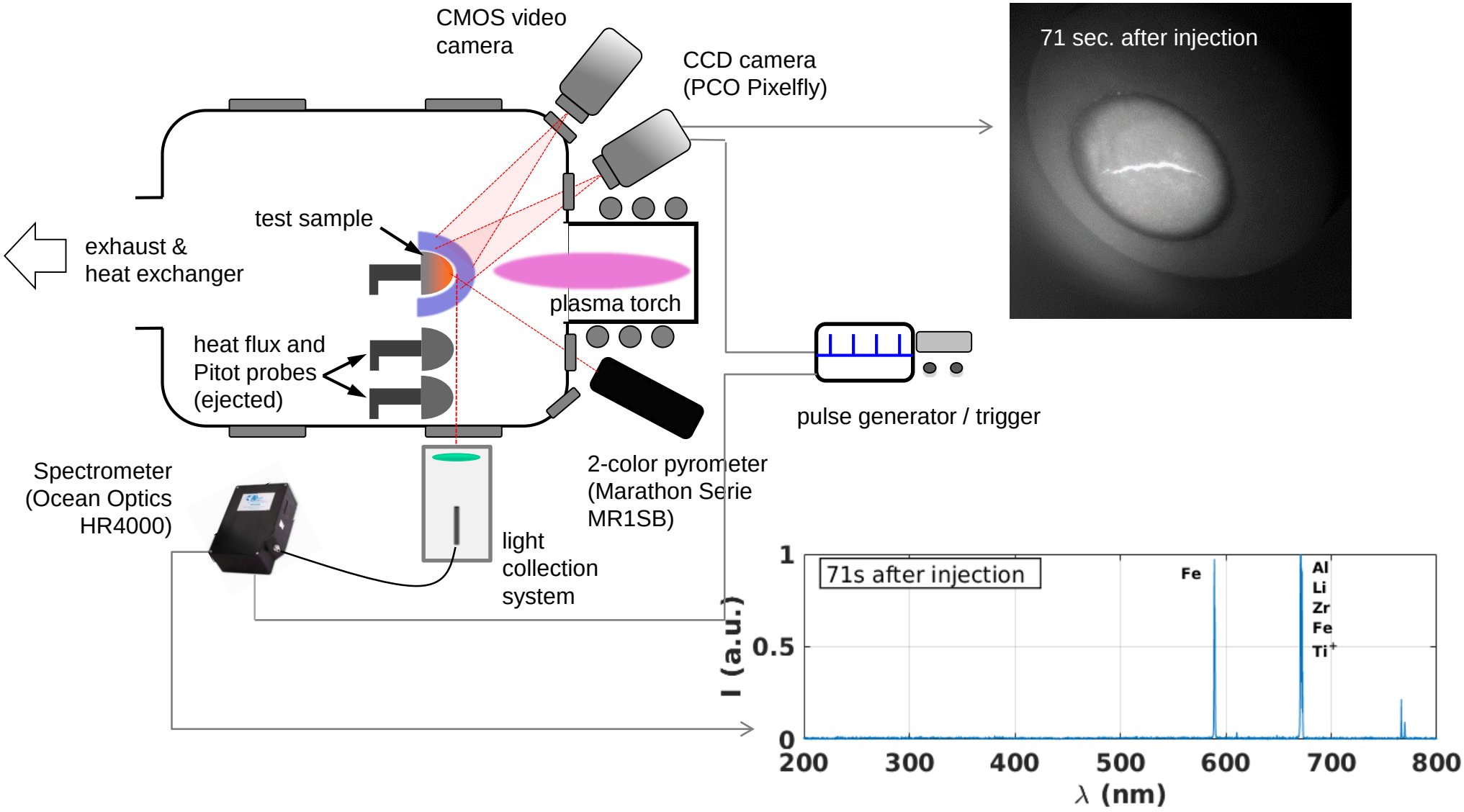
Sample retention box

- Water-cooled metallic box for sample retention
- Prevent material degradation during Plasmatron calibration (sample kept below 60°C after 3 min)





Measurement techniques

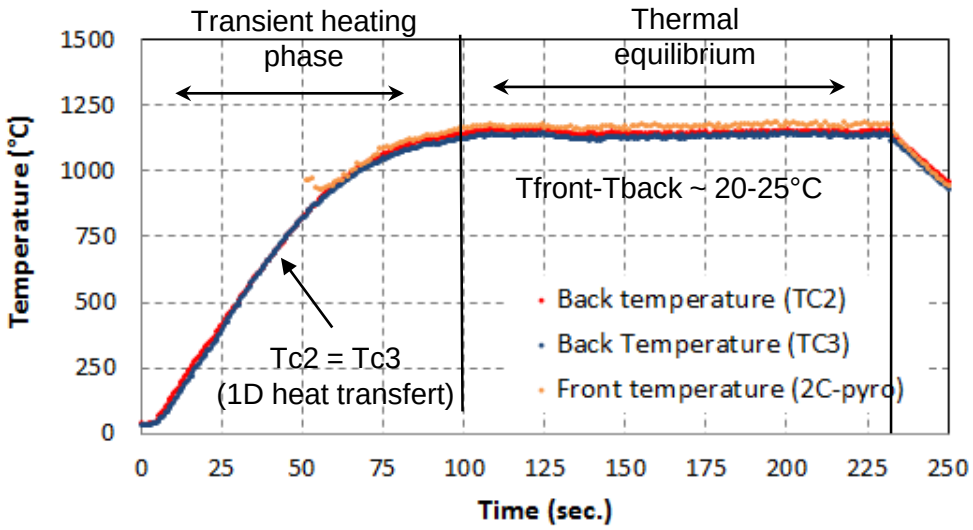


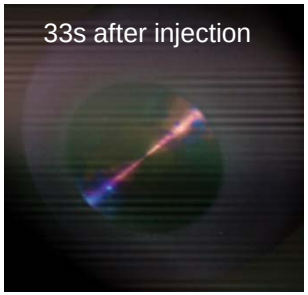
Stainless steel AISI 316L

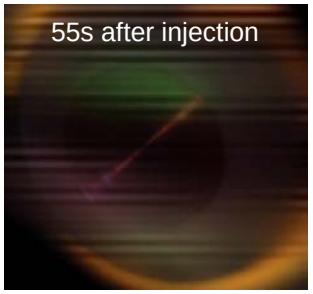
Constant heat flux of 260kW/m²

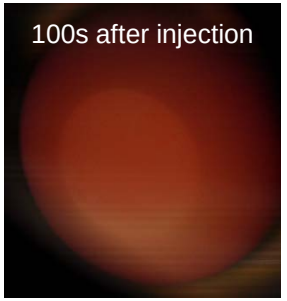
- No demise at 260kW/m² (complete demise at 520kW/m²)
- Quasi 1D heat transfer ($\frac{\delta T}{\delta r} \approx 0$)
- Visible oxidation of the exposed surface Detection of Cr and Ni species in the OES data

Evolution of the back and front temperature of a virgin 316L sample









Brown-red-blue colorization of the surface

Emission of intense green light (possible formation of Chromium and Nickel oxides)

Thermal equilibrium

No demise

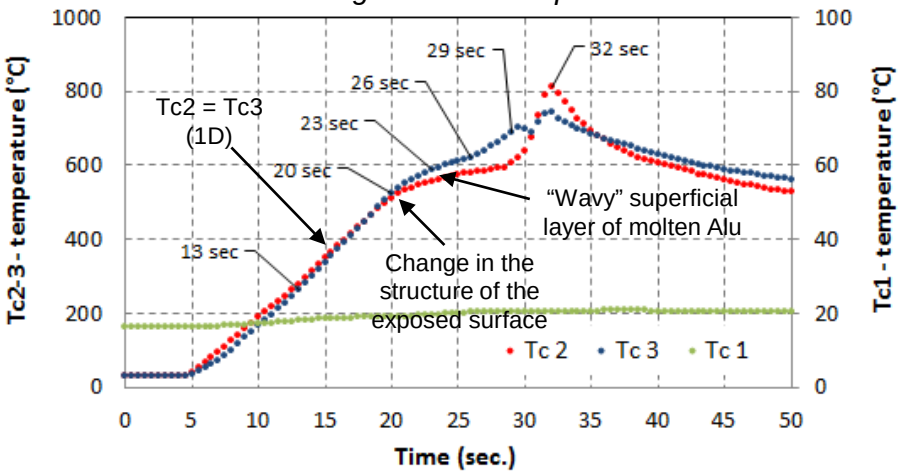
time

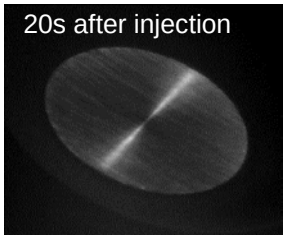
Aluminium alloy Al7075 (Al-Zn)

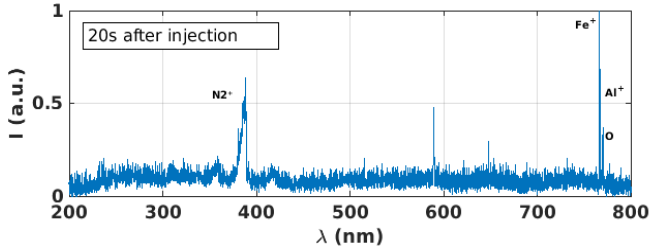
Constant heat flux of 260kW/m²

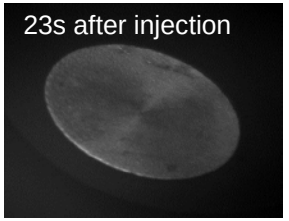
- Complete demise at 260kW/m² (and at 100kW/m²)
- Quasi 1D heat transfer before changes in the surface structure (Δt=20sec.)
- Detection of several species in the OES data: first, Fe+ and Al+ and then, Zn+, Si, Cr and Cu

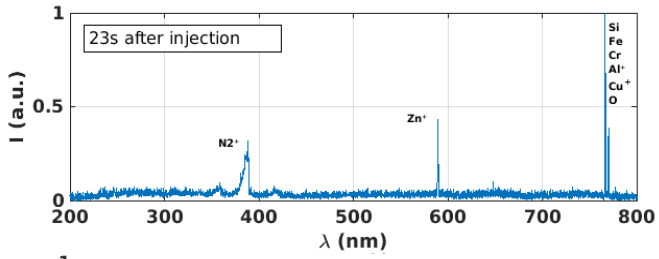
Evolution of the back and front temperature of a virgin Al7075 sample

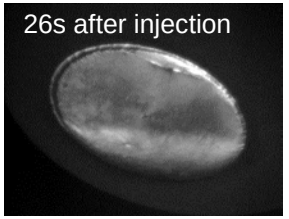


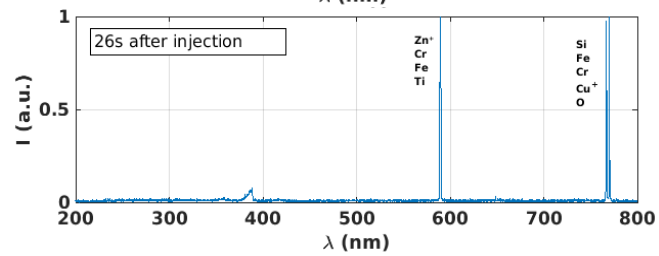


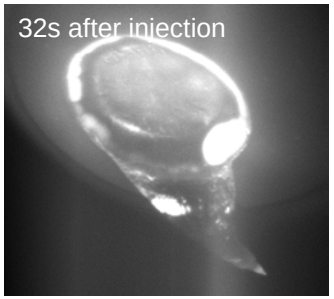


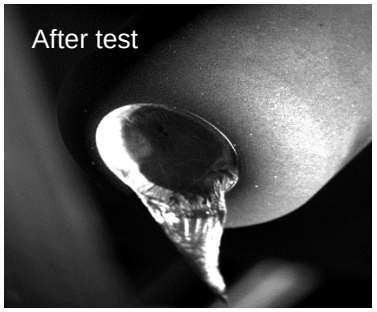








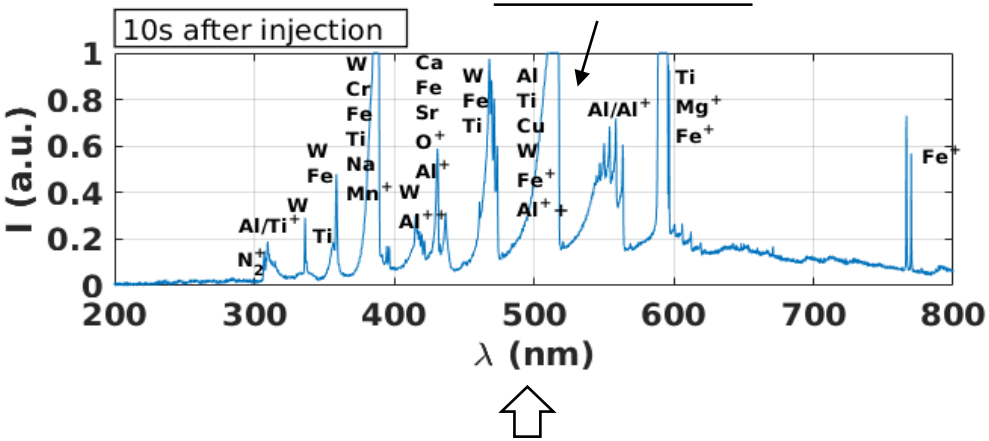




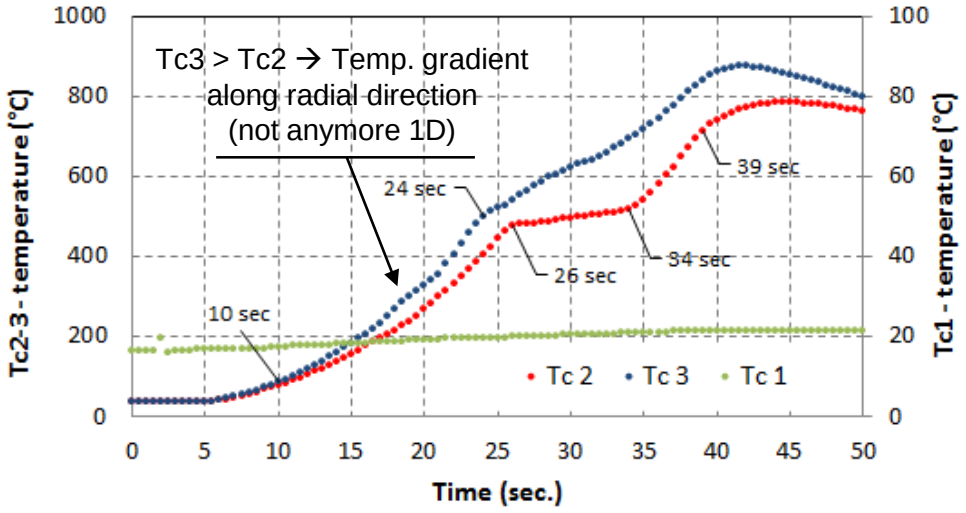
GLARE material

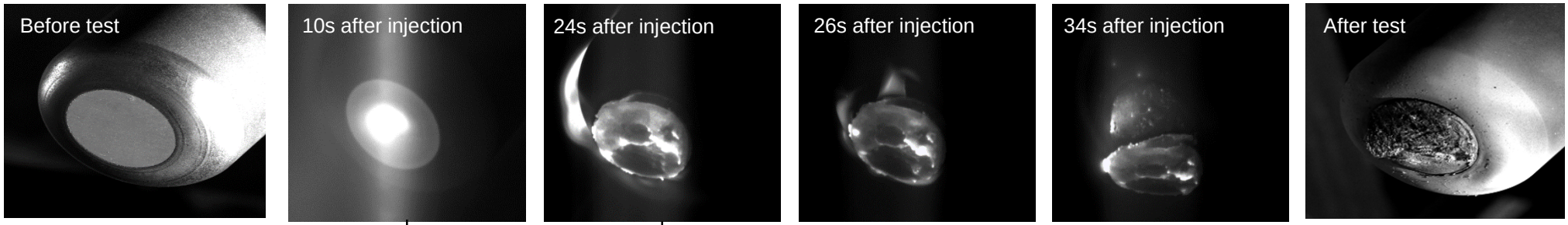
Constant heat flux of 260kW/m²

Signature of many different species
(wide peaks → difficulties to discriminate accurately the species)



Evolution of the back temperature of a virgin GLARE sample





Perforation of the first GF layer + emission of blue light (adhesive?)

First GF layer burns and ayers starts to release

Layers drops

Some more perspectives

Re-entry heat-transfer is a quite involved phenomena

- Rarefied effects
- Gas-Surface interaction
- Flow – material coupling
- …

Meteorites and re-entry vehicles

AIAA 68-670

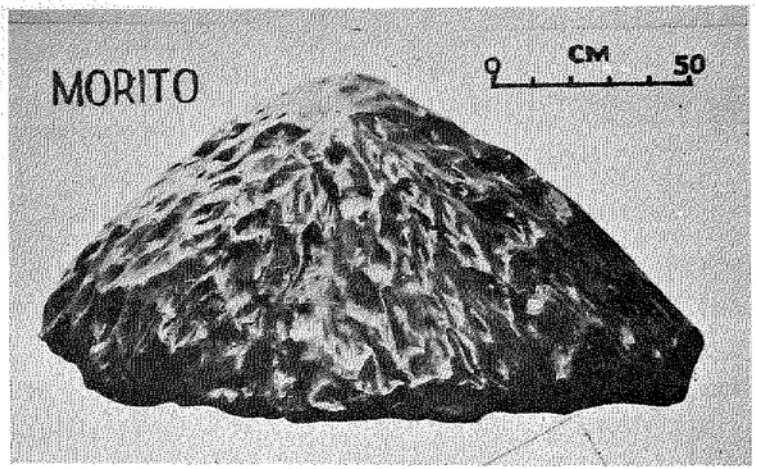
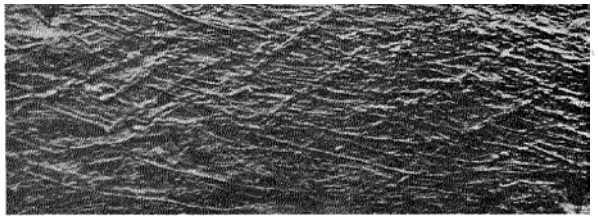
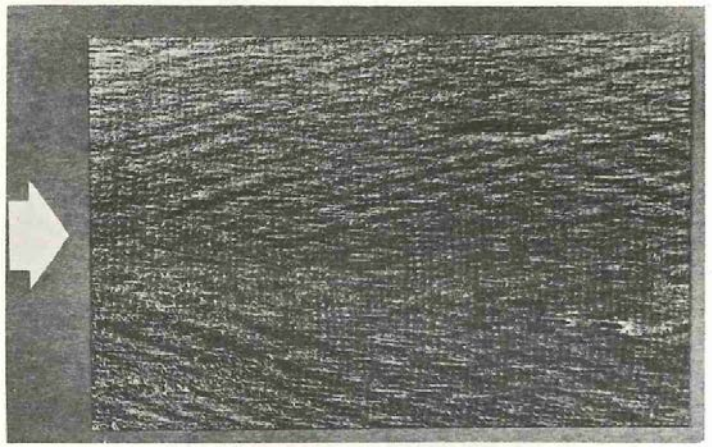


Fig. 19.- Meteorite Morito.



Surface of iron meteorite Repeev Khutor

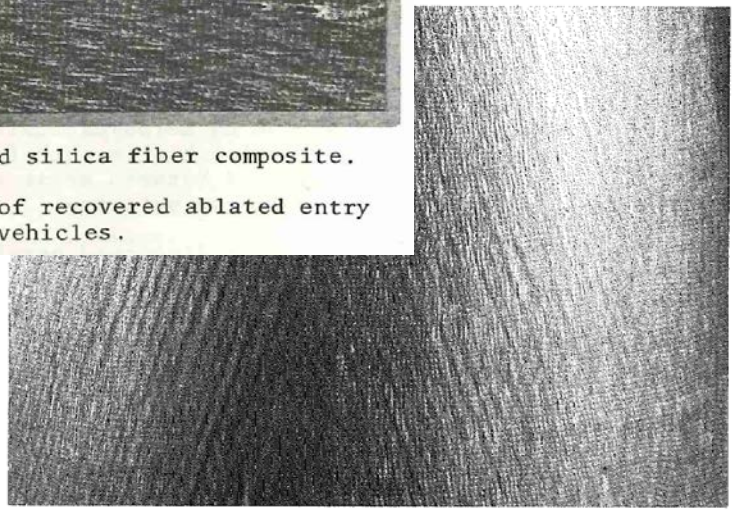


(b) Phenolic fused silica fiber composite.

Fig. 4.- Surfaces of recovered ablated entry vehicles.

flow

AIAA 68-671



(b)
PHENOLIC REFRASIL

Figure 15. Typical Surfaces of Recovered Re-entry Vehicles

Ground testing studies

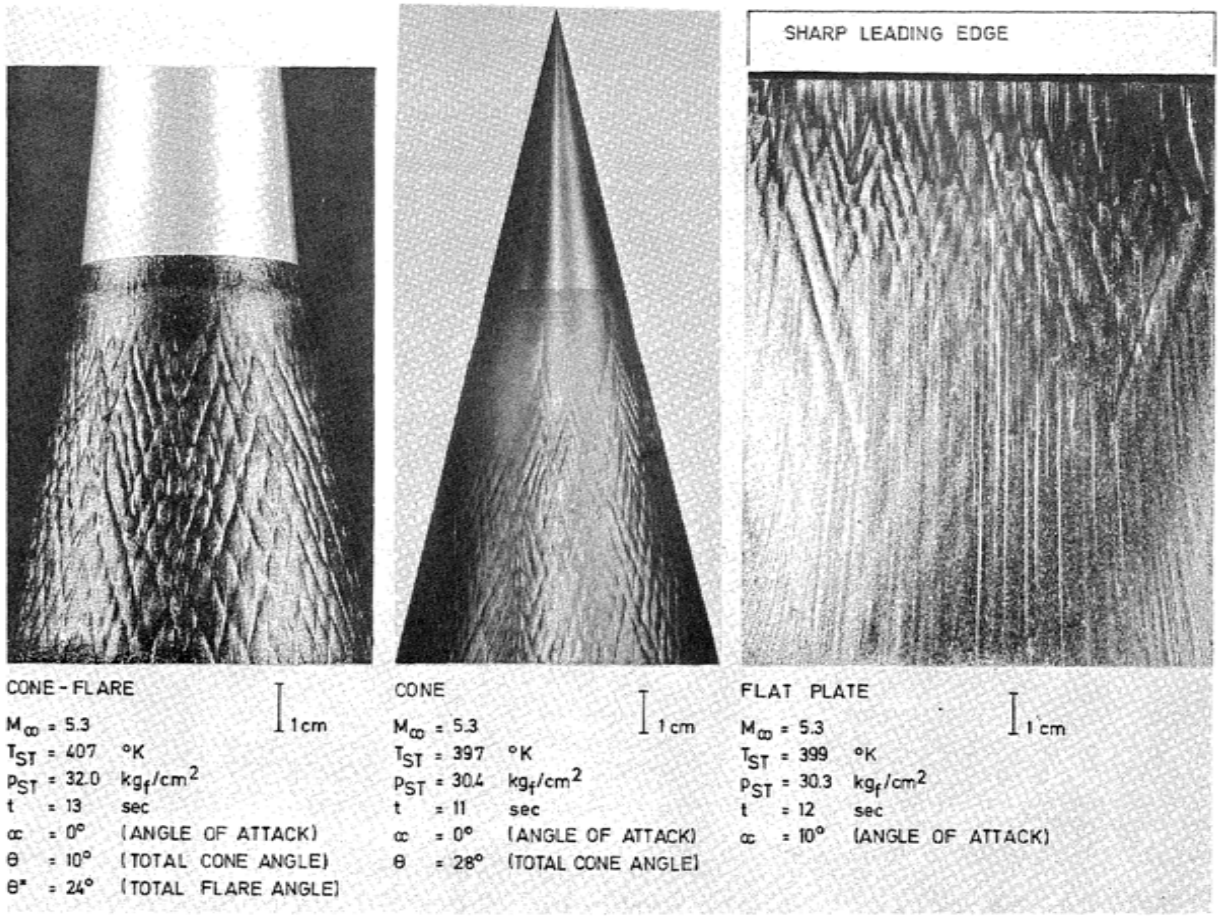


FIG.4. TYPICAL TEST RESUTS ON WAX MODELS

The flow regime has large influence on the heat-transfer phenomena.

VKI Tech. Note 64 Hypersonic low temperature ablation
An experimental study of Cross hatched surface patterns

VKI experiments on cross-hatched ablation

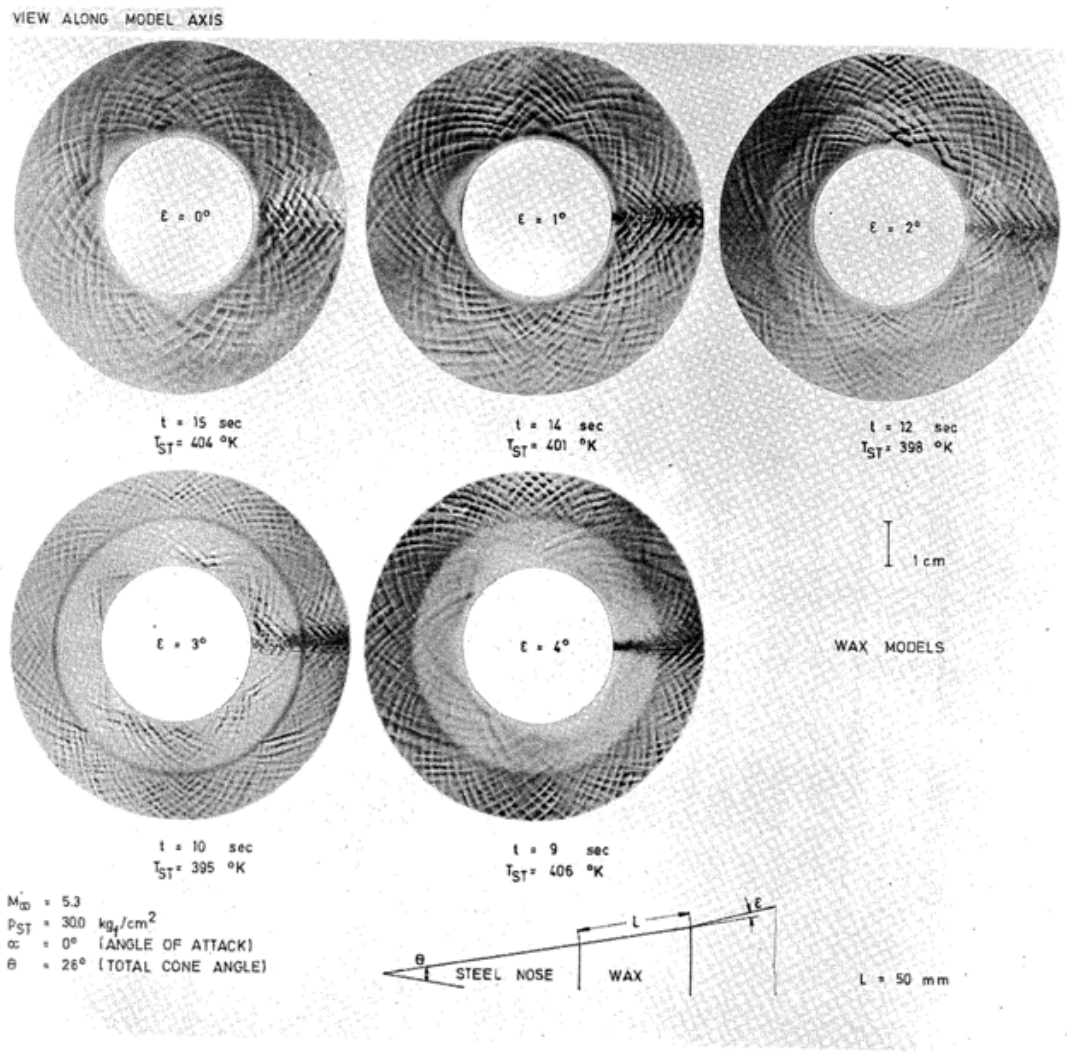


FIG.14. INFLUENCE OF FLOW COMPRESSION ON THE CROSS-HATCHING FORMATION

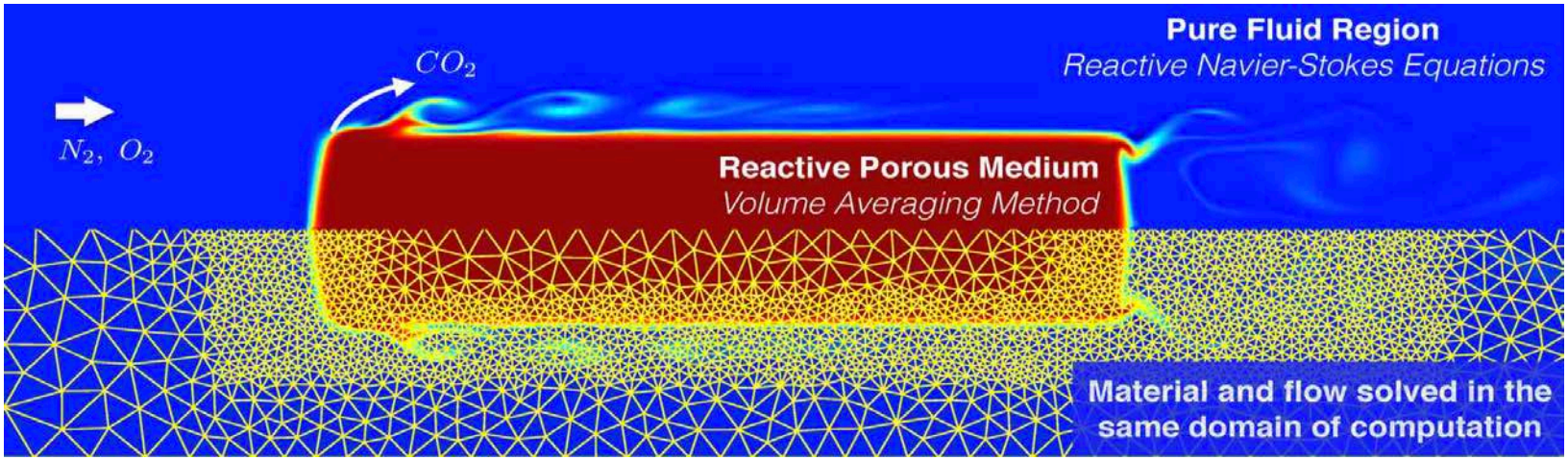
VKI Tech. Note 64
July 1971

Multiphysics CFD modeling

- Advanced CFD modeling will help investigations of flow regime and heat-transfer coupling

- Coupled CFD with multiphysics modeling should be run in parallel to the experimental testing

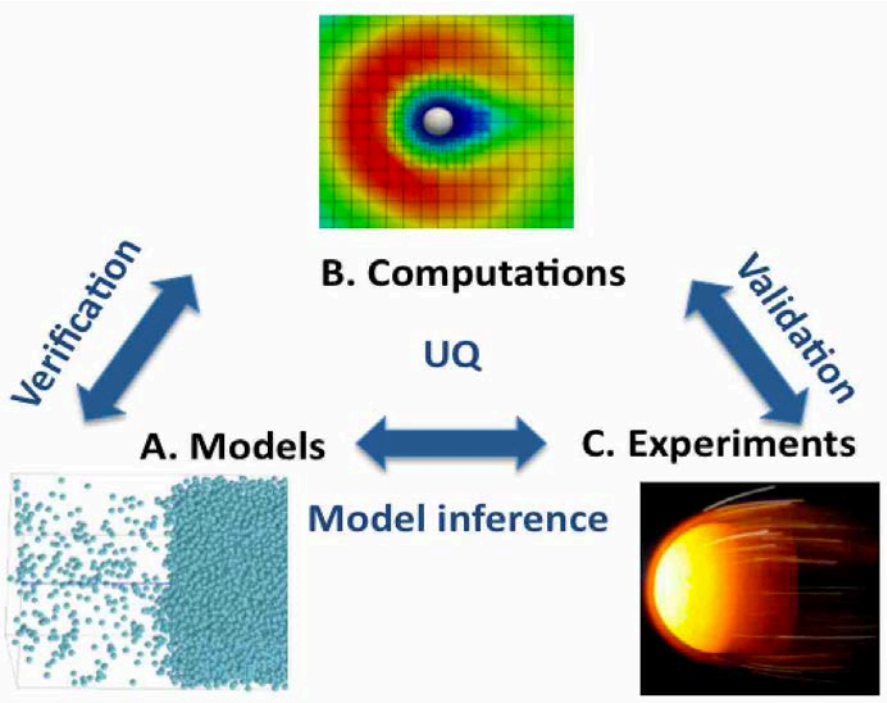
- Physical studies will allow to tailor wider Monte-Carlo approaches



ARGO computation (Cenaero/VKI): Ablation of a carbon preform sample by an air flow

Uncertainty Quantification tools

Engineering tools for prediction



UQ will serve for:

- Evaluating the most relevant parameter on heat-transfer phenomena

- Defining the uncertainty on the material properties

- Determining the design margins for demise

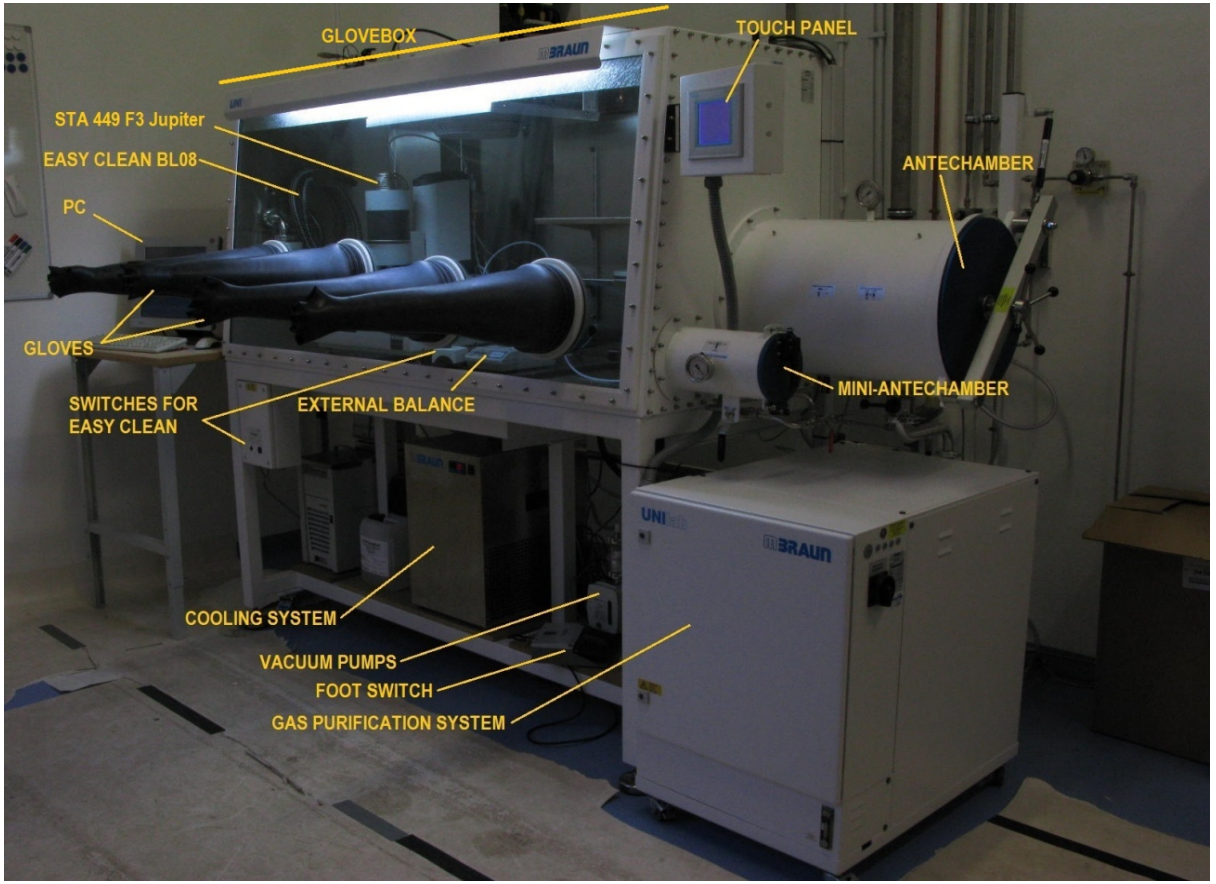
Conclusions

- Summary
  - New testing methodology in place at the Plasmatron to characterize demisable materials at constant heat flux
  - Successful application of this new methodology to several materials in the framework of the TRP demisable materials (CCN)
  - Generate database for material demise (design and code validation)
  - Thermal analysis upgrade for material properties (not presented)

- Future works
  - Adapt the testing methodology to simulate on the Plasmatron full heat flux trajectory
  - Surface temperature measurement – Emissivity determination

ACKNOWLEDGEMENTS: *Support from ESA through CCN on TRP demisable materials*

Facility for thermal analysis (TGA / DSC)



Thermal Analyzer STA 449 F3 Jupiter in its controlled environment at VKI