

Thermal and optical characterization of materials at high temperature

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(3) : Saint-Gobain Research Paris, Aubervilliers, France

Workshop TREE

14-16 Nov 2022, Noisy-le-Grand

Thermal and optical characterization platform

Experimental facilities

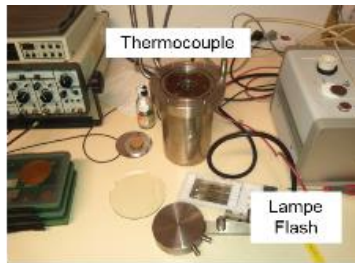
Multi-spectral pyrometry and infrared thermography

- **6 cameras :**
 - 3 InSb Broad-band ($1,5\mu\text{m}$ - $5,5\mu\text{m}$) of which 2 multi-spectral
 - 1 EM-CCD ($0,3\mu\text{m}$ - $1,1\mu\text{m}$)
 - 1 InGas ($0,8\mu\text{m}$ - $2,5\mu\text{m}$)
 - 1 HgCdTe ($8\mu\text{m}$ - $9,5\mu\text{m}$)
- **4 black bodies :**
 - Extended from -10°C to 100°C $10\times 10\text{cm}$
 - Extended from 20°C to 550°C $30\times 30\text{cm}$
 - With cavity from 20°C to 1600°C
 - With cavity from 500 to 2600°C
- **Spectrometry :**
 - 2 vari-spectra in visible and near IR
 - 2 mini-spectrometers covering the range of vari-spectra
 - Vacuum FT spectrometer, UV – Vis – IR ($\lambda \in [200\text{ nm} - 600\mu\text{m}]$)
 - Array spectrometers UV – Vis – NIR ($\lambda \in [200\text{ nm} - 2,5\ \mu\text{m}]$)
 - Integrating spheres Vis / IR
 - Bidirectional reflection/transmission measurement bench

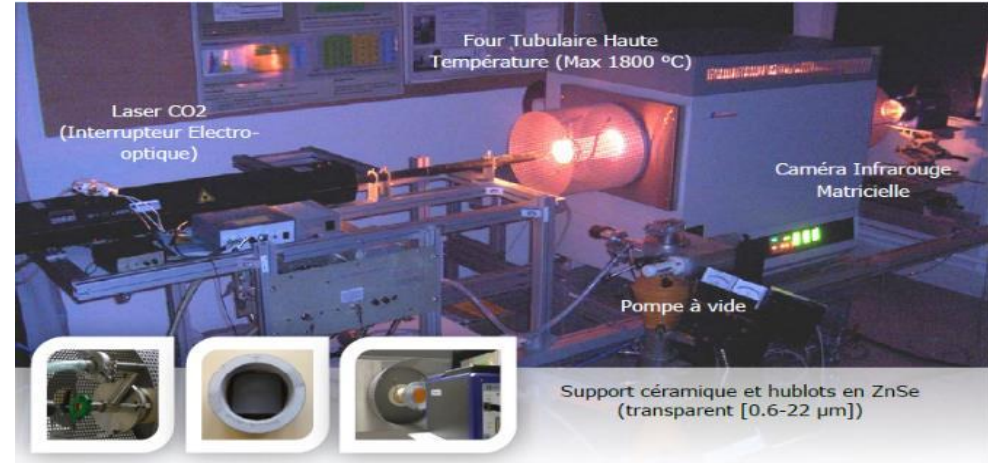


Characterization of thermal-physical properties

- 3D **thermal diffusivity** measurement (X,Y,Z) from 20°C to 1500°C under vacuum, N₂ or Air (sample from 0,1 to 10mm thickness)



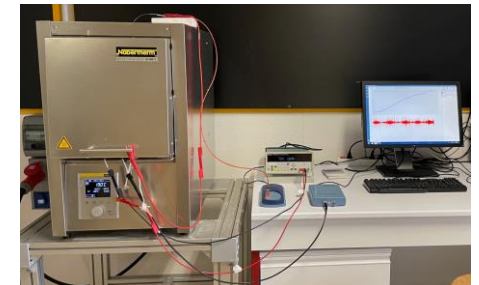
A. Degiovanni, B. Rémy



- **Heat capacity** measurements by DSC from 20°C to 1600°C



- **Thermal conductivity** measurement by hot wire method from 20°C to 1500°C



Realization of custom-made devices for the thermal characterization of materials

- Measurement with **variable hygrometry** (bio-sourced materials)
- **Thermal properties** measurements of :
 - Super-insulating material ($< 26 \text{ mW/m/K}$)
 - Liquids
 - Textile felts
 - Cosmetic products
 - Phase change materials ...
- Thermal properties measurements **under pressure**



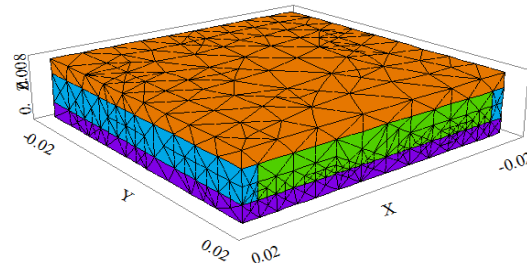
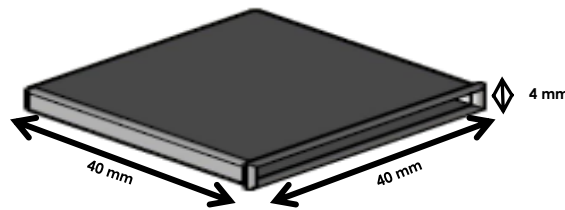
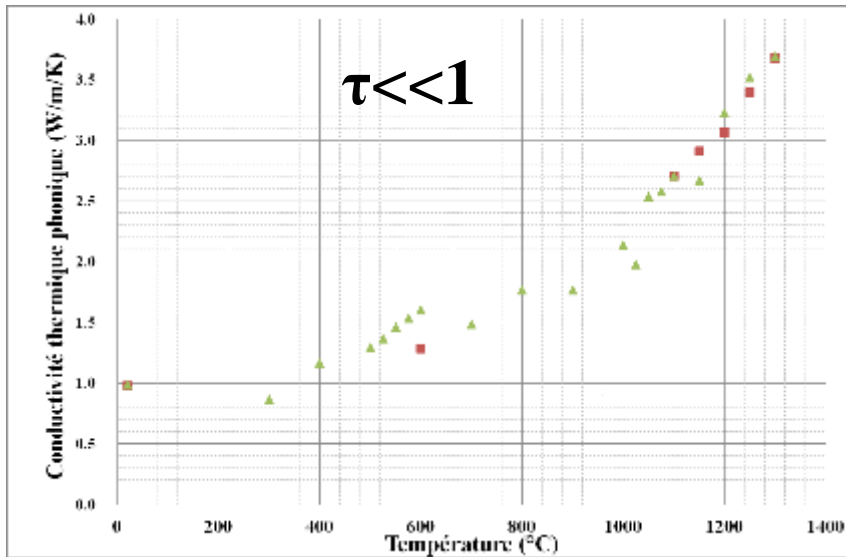
Thermal and optical characterization platform

Examples of realization

Thermal properties measurements at high temperature

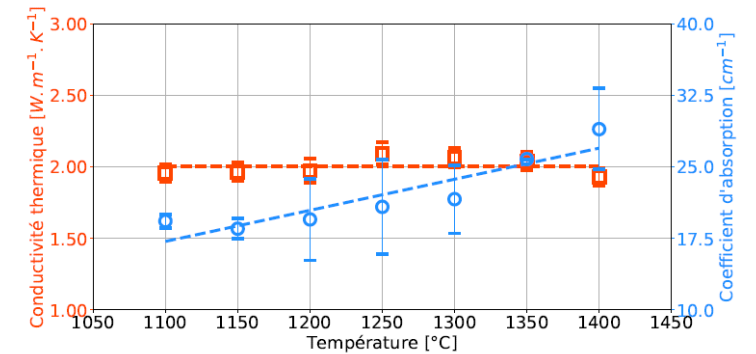
Thermal conductivity of SiO₂-based semi-transparent liquid with flash method + calorimetry
 Need for appropriate modeling of coupled heat transfer

Semi-analytical approach



Deterministic approach (P₁)

$$\tau \approx 1$$

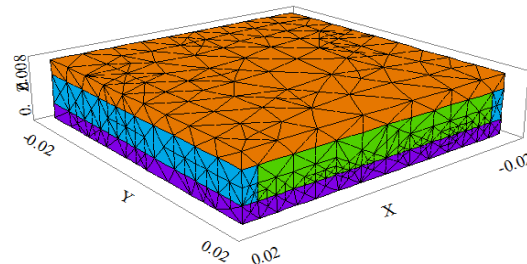
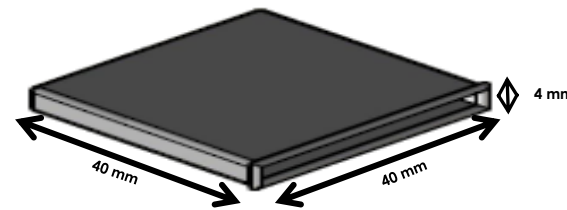
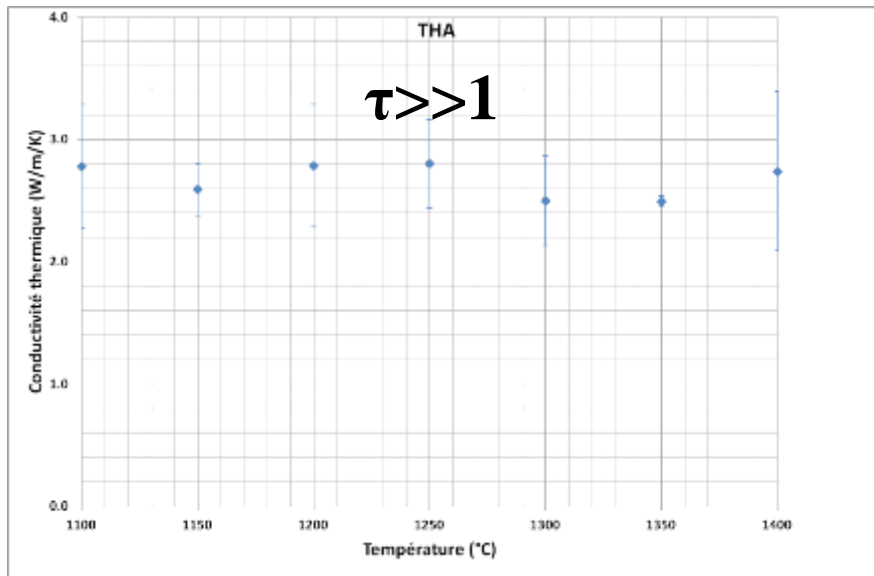


Thermal properties measurements at high temperature

Thermal conductivity of SiO₂-based semi-transparent liquid with flash method + calorimetry

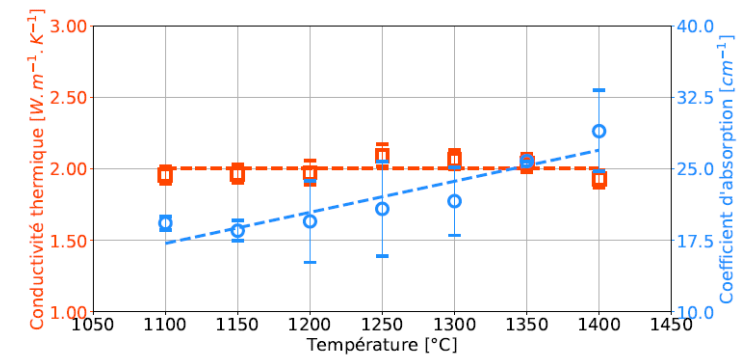
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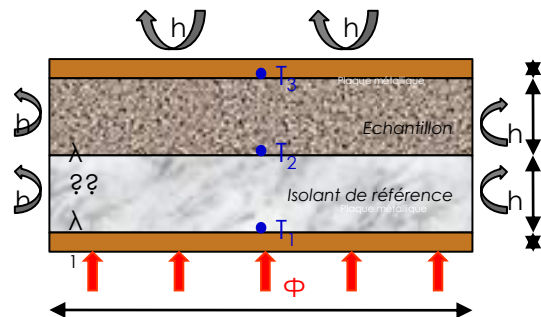
Technical insulating material → 1000°C

Thermal conductivity of small samples of 15 X 15cm

Difficulty : porous medium / heterogeneous / semi-transparency

2 developed methods

- **Steady state flux metric** method
- **Temperature / Temperature** method



Y. Jannot, J. Meulemanns

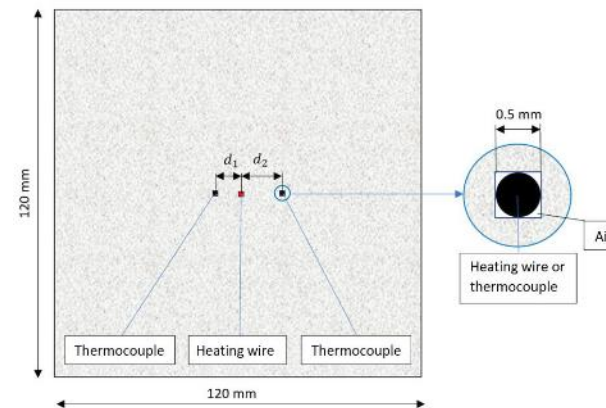
Hot wire method



High-temperature furnace [Saint-Gobain website]



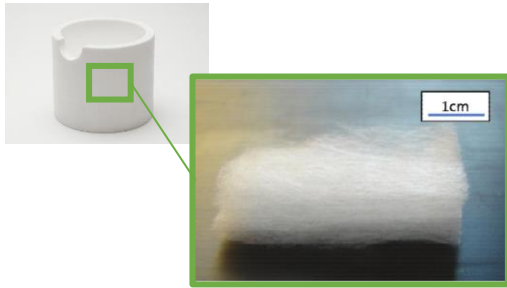
Insulating ceramic plates made of alumina (thickness : 100mm) [M. Schumann & L. San-Miguel, 2017]



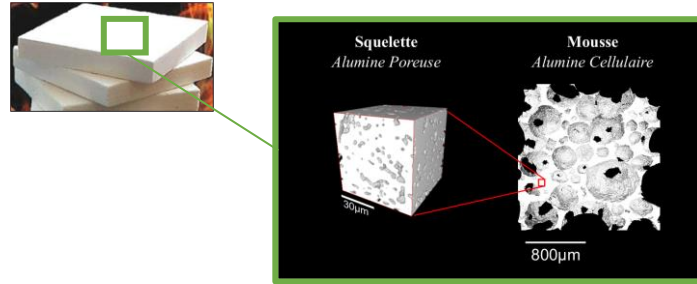
Technical insulating material → 1500°C

Difficulty : Modeling conductive-radiative heat transfer in heterogeneous media

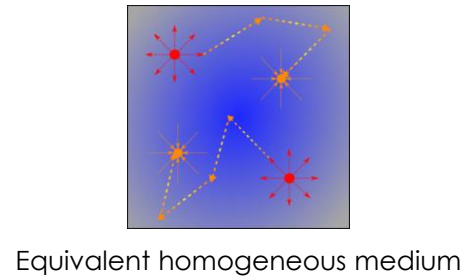
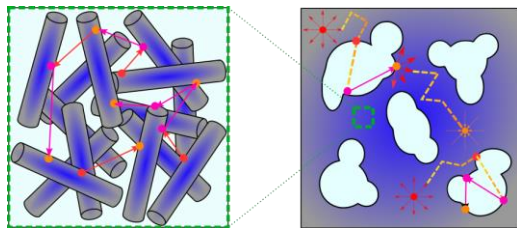
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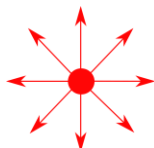
Silica foam
(Up to 1200°C)



Alumina foam
(Up to 1650°C-1800°C)



Equivalent homogeneous medium



Emission



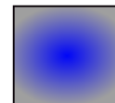
Absorption



Scattering

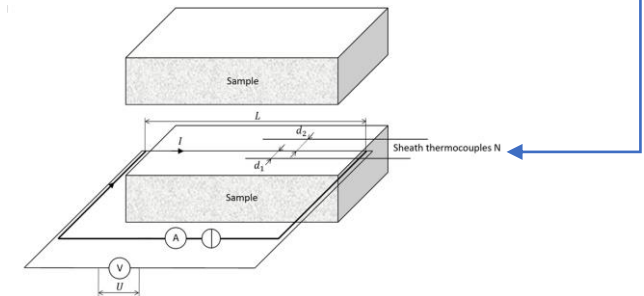
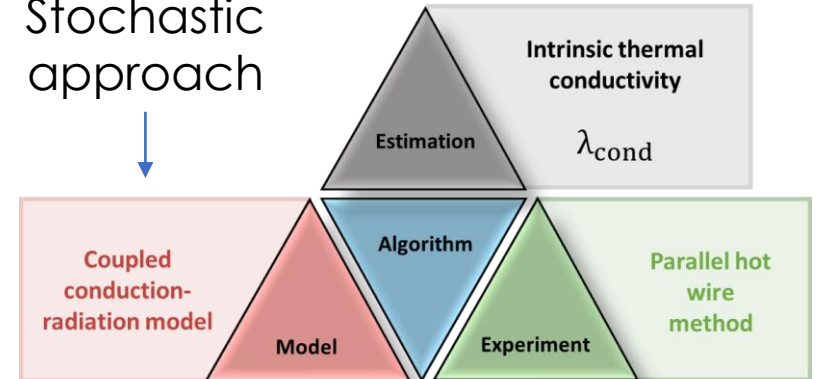


Reflection



Conduction

Stochastic approach



CANOPEE : Pyrometry

Temperature measurement by multi and hyperspectral methods on opaque and semi-transparent materials

PhD thesis K. ENNASS (2021 - 2024) - Labcom project CANOPEE

B. Remy / V. Schick / J. Meulemans (SGR)



Heat tempering of flat glass

More accurate measurement of temperatures and heat fluxes during these processes



Automotive windshield forming

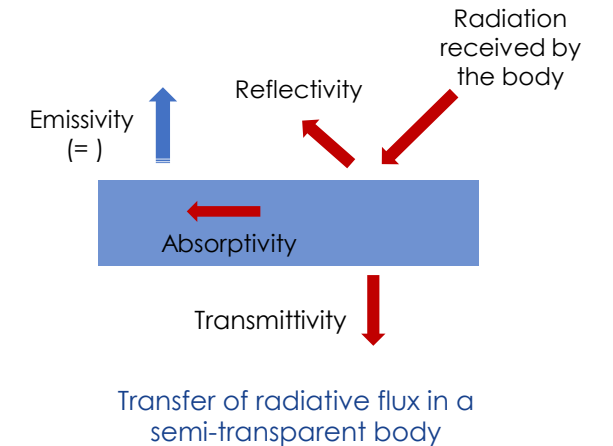
Reduction of energy consumption and associated carbon footprint



Mineral wool fiberization



Objective : Carbon neutrality by 2050



Emissivité ϵ_λ
($\epsilon_\lambda = \alpha_\lambda$)

Project : Measurement above 1500°C

European project ESFR-SMART (WP2.5) + SIMPLE project on the MOX properties.

B. Remy / V. Schick / N. Chauvin (CEA)

Thermal conductivity of (U,Pu)O₂ nuclear fuel: taking into account the composition and microstructure of the material and the burn rate in the reactor.

PhD thesis P. BONEV (2020 - 2023) - Projet européen ESFR SMART / SIMPLE (Oct. 2022)

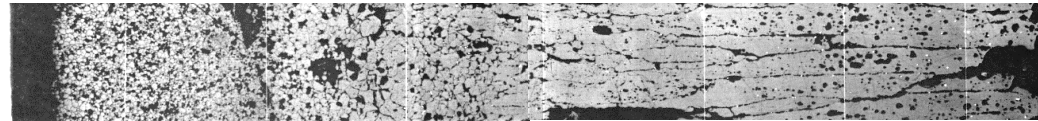
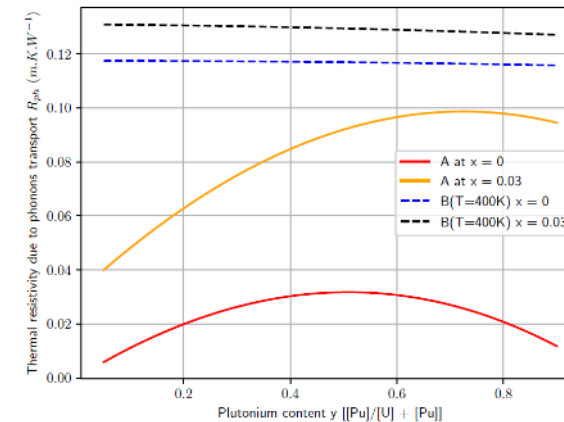
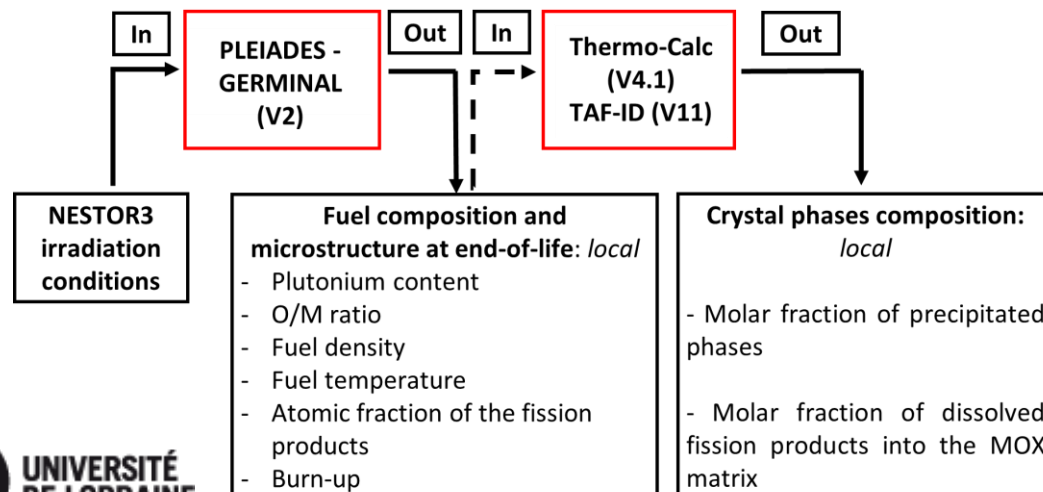


Figure 2 : Evolution radiale de la microstructure





Key points

Up to 1500°C :

- High temperature **metrology** and instrumentation
- Development of **coupled conductive-radiative models** → Estimation of intrinsic thermal properties of materials

Challenges to overcome beyond 1500°C :

- Specific **metrology and regulation** equipments
- Enhanced difficulties to model the **coupling between different physics** phenomena :
 - Convection heat losses
 - Radiation preponderant
 - Oxydation ...



Thank you for your attention, questions ?