



**HAL**  
open science

## Characterization of thermal properties of ceramic foams by a numerically simulated Flash method

Morgan Sans-Laurent, Olivier Farges, Vincent Schick, Gilles Parent

### ► To cite this version:

Morgan Sans-Laurent, Olivier Farges, Vincent Schick, Gilles Parent. Characterization of thermal properties of ceramic foams by a numerically simulated Flash method. CTRMP VI, Apr 2018, Cascais, Portugal. hal-01974301

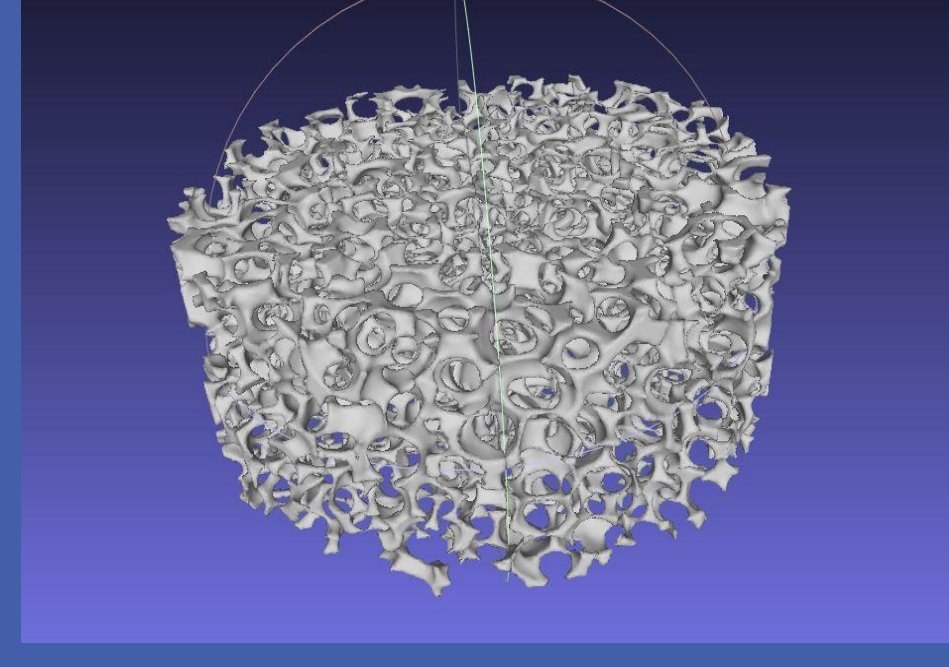
**HAL Id: hal-01974301**

**<https://hal.univ-lorraine.fr/hal-01974301>**

Submitted on 21 Mar 2019

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



## Introduction

- Interesting thermomechanical properties of **ceramic foams** for heat recovery / storage / transport at **high temperatures**
- Need for the most relevant **modeling** from the point of view of **coupled heat transfer** (conduction, convection and radiation) on complex geometries
- Better understanding and quantification of the physics involved
- Support for the **geometric, textural and thermal optimization** of ceramic foams
- Determination of **thermal and radiative properties** by **Flash method**. Coupled model in **conduction and radiation** with equivalent properties on a representative elementary volume (**REV**)



### Practical experiment :

Thermogram obtained at high temperature from a flash method in **practical conditions**

### Numerical experiment :

Thermogram obtained at high temperature from a **numerical method** with Monte-Carlo Method (**MCM**)

## 1. Practical Experimental Flash Method

Measuring bench High Temperature :

Structured and stochastic foam :

Cooled windows : Pulsed by CO2 laser:

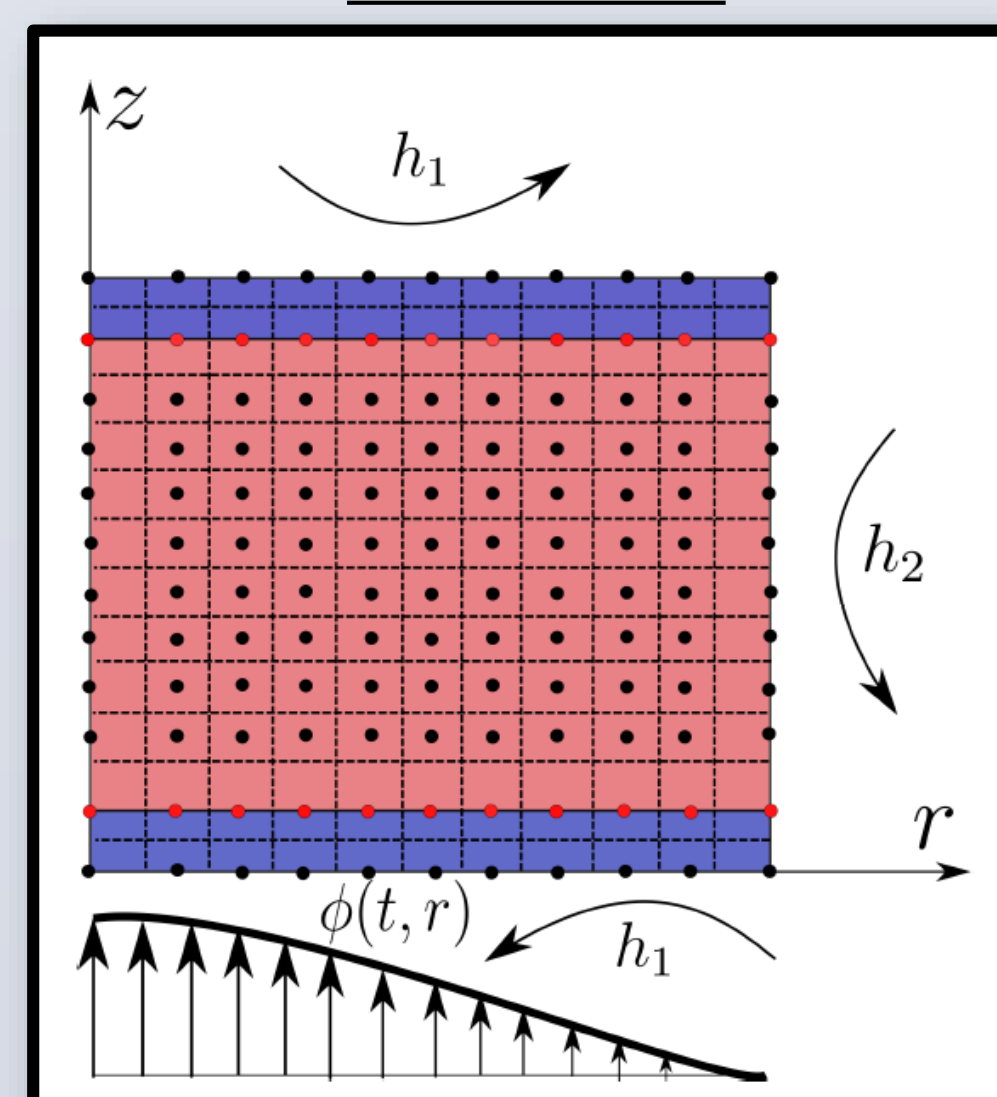
- Model 2D-axi-symmetric.
- Conduction : Finite Volume Method

$$\rho C \frac{\partial T}{\partial t} = \lambda \Delta T - \text{div}(\mathbf{q}_r)$$

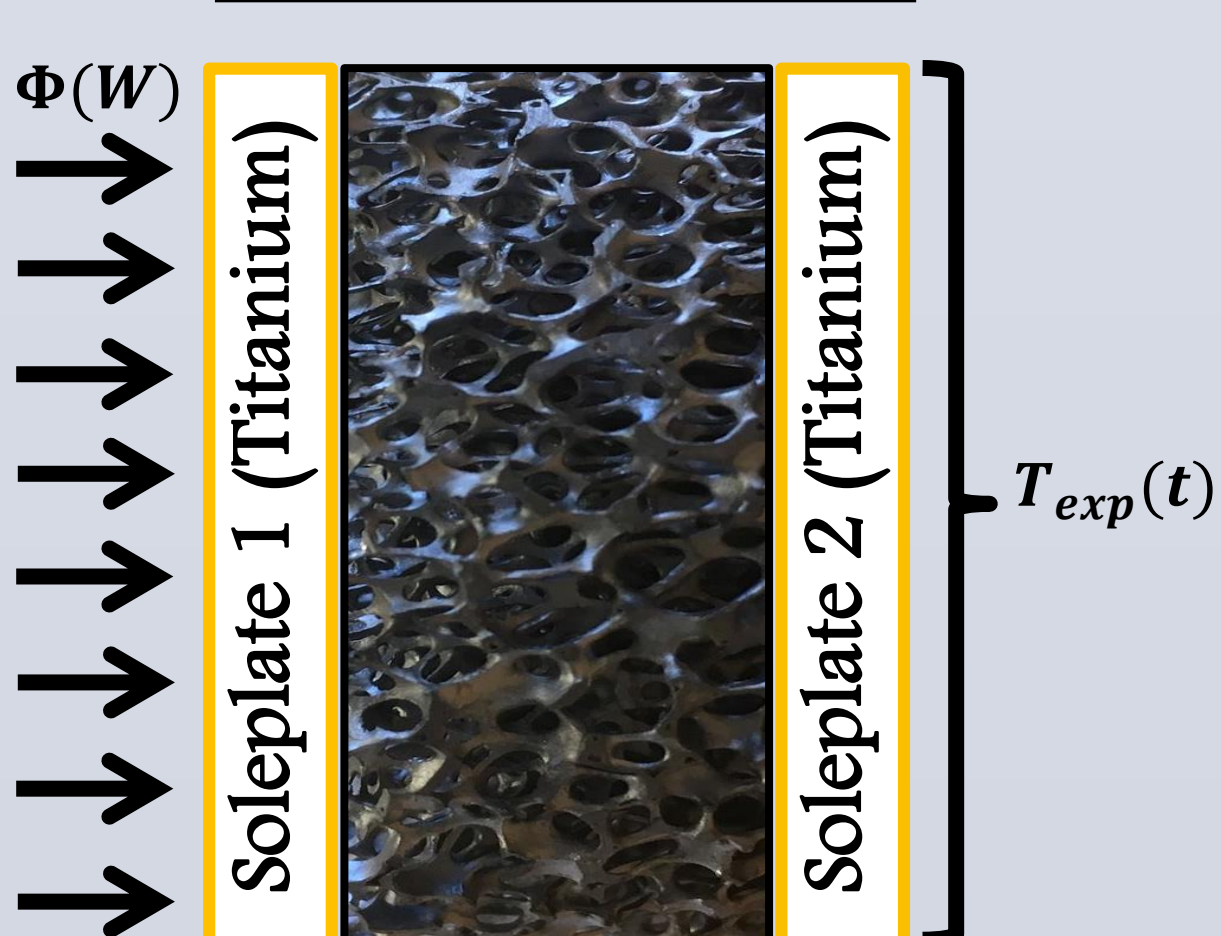
- Radiation : Optimized Reciprocity Monte-Carlo Method [1]

$$\text{div}(\mathbf{q}_r)_i^{ARM} = \sum_{j=0}^{N_{elem}} \int_{\nu_{min}}^{\nu_{max}} P_{jt,i,\nu}^{ea} \left( \frac{I_{\nu}^0(T_i, n_i)}{I_{\nu}^0(T_j, n_j)} - 1 \right) d\nu$$

### Geometry :



### Three-Layer system.



- Inverse Method (Levenberg-Marquardt) : Characterization of equivalent diffusivity and optical thickness

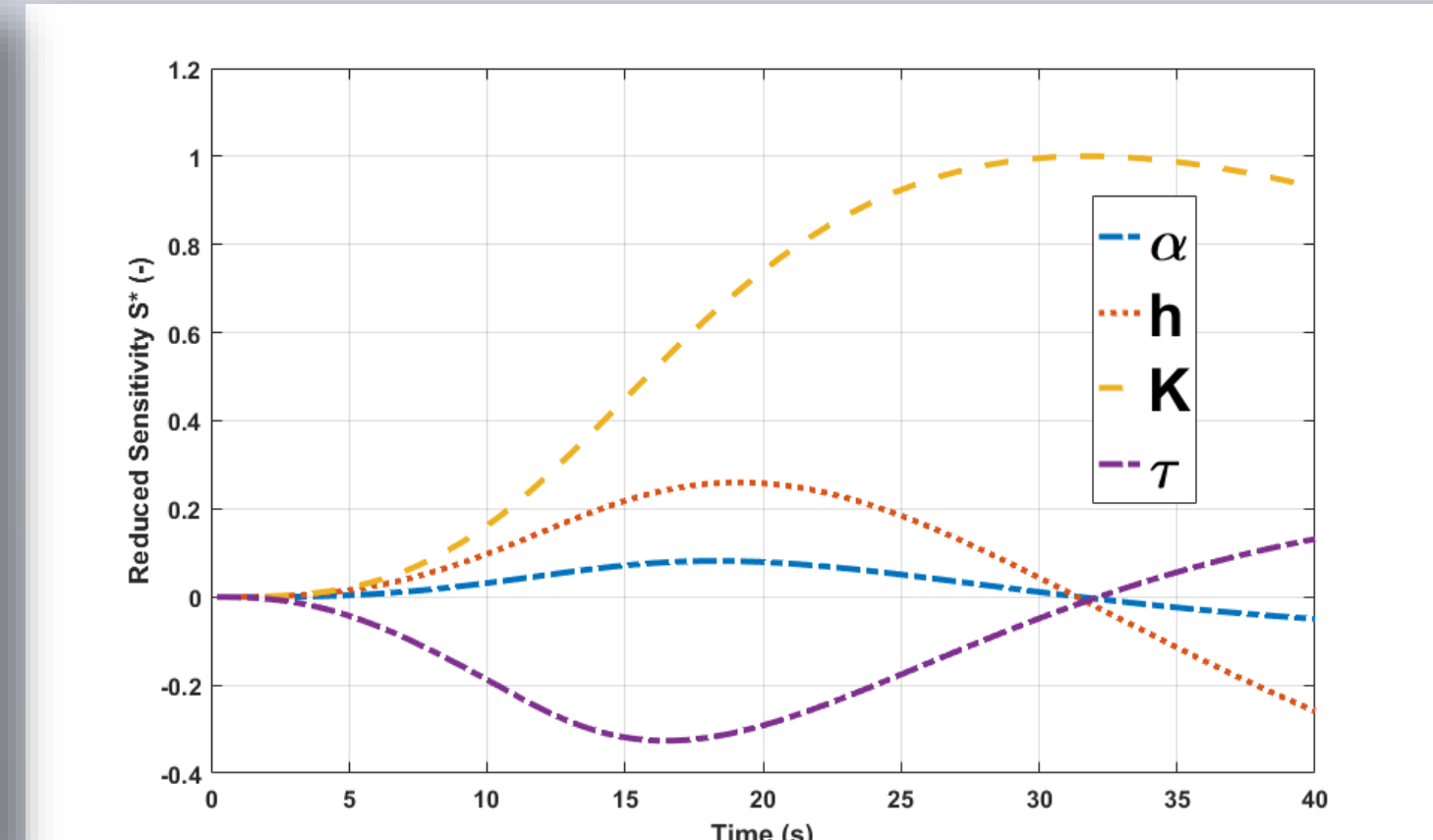
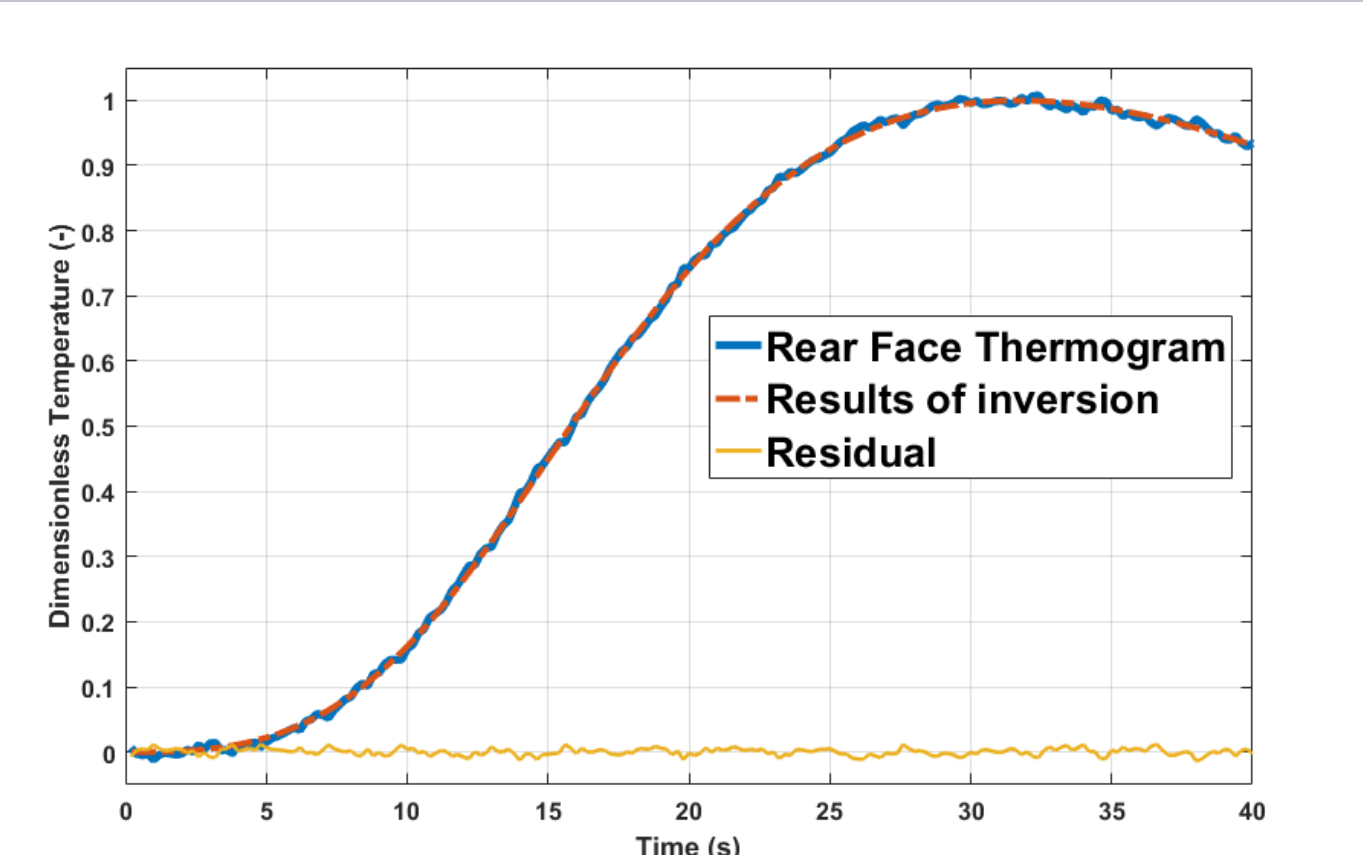
$$\beta = [\alpha \ h \ K \ \tau]$$

$$J(\beta) = \|T_{exp} - T_{mod}(\beta)\|^2$$

$$J'(\beta_{opt}) = 0$$

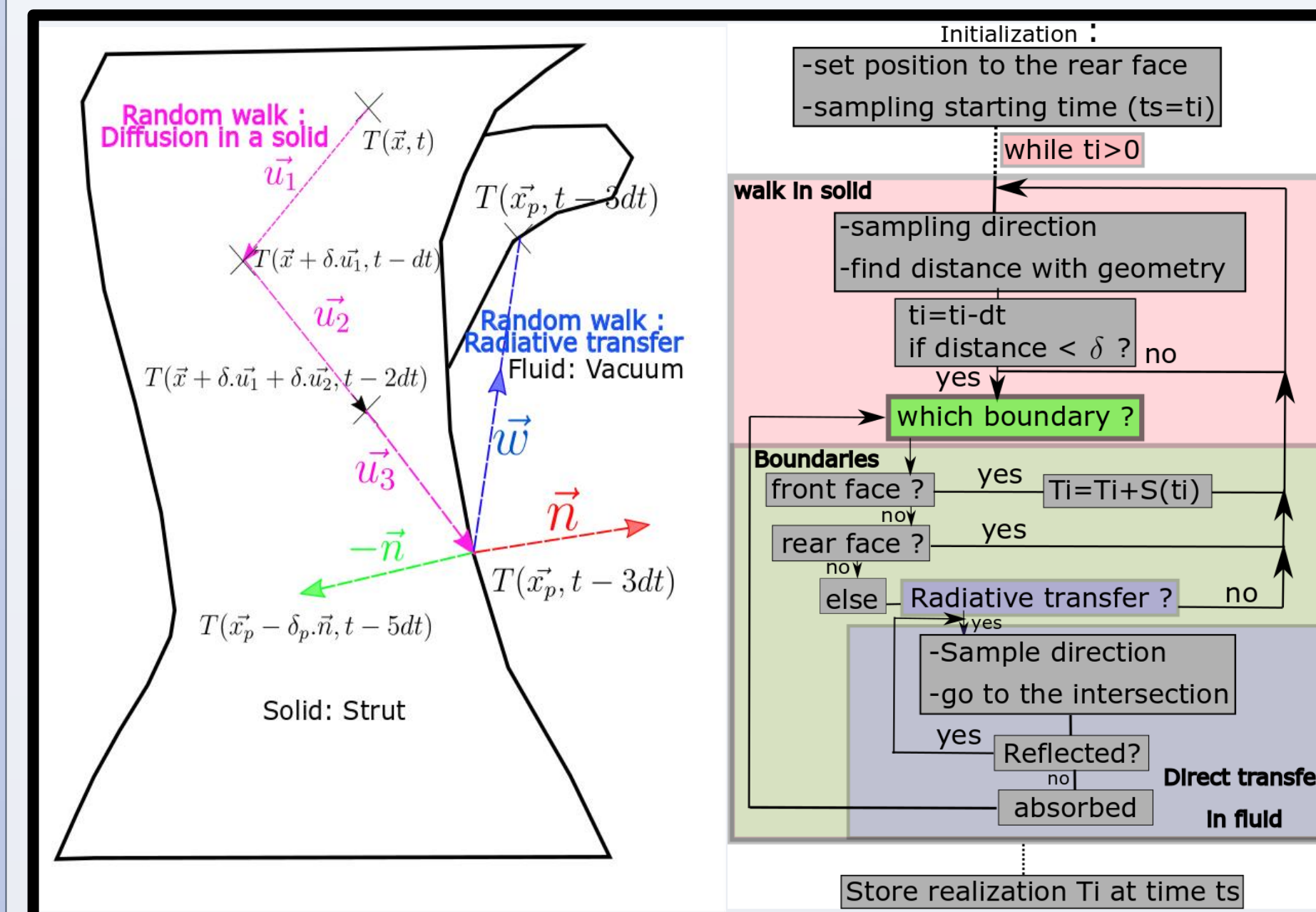
$$\beta^{(k+1)} = \beta^{(k)} + \underline{M} \cdot (y_{exp} - y_{mod}(\beta^{(k)}))$$

- Results** : structured foam (Kelvin-Cell pore diameter 7.5mm 800°C SiSiC) Characterization: **flat residual** Sensibility Analysis: **no correlation**



## 2. Numerical Experiment Flash Method

- Algorithm Monte-Carlo Conduction and radiative transfer [2]:



Value of the temperature at  $t_j$ :  $\bar{T}(\bar{x}, t_j) = \frac{1}{N} \sum_i T_i(\bar{x}, t_j)$

Fast computation of intersections between the paths and the surface mesh. Star-Engine library (<https://www.meso-star.com/projects/star-engine.html>)

- Problem Definition:

- Compute Temperature  $T(t)$  at the rear face
- Imposed moving step  $\delta$
- Recursive in time:  $dt = \frac{\delta}{6\alpha}$
- Surface source excitation at front face:  $S(t)$
- Probability of conductive or radiative path
- Probability of reflection/absorption:  $R_p < \rho$
- Transfer along  $\bar{z}$  direction
- Periodicity boundaries for  $\bar{x}$  and  $\bar{y}$

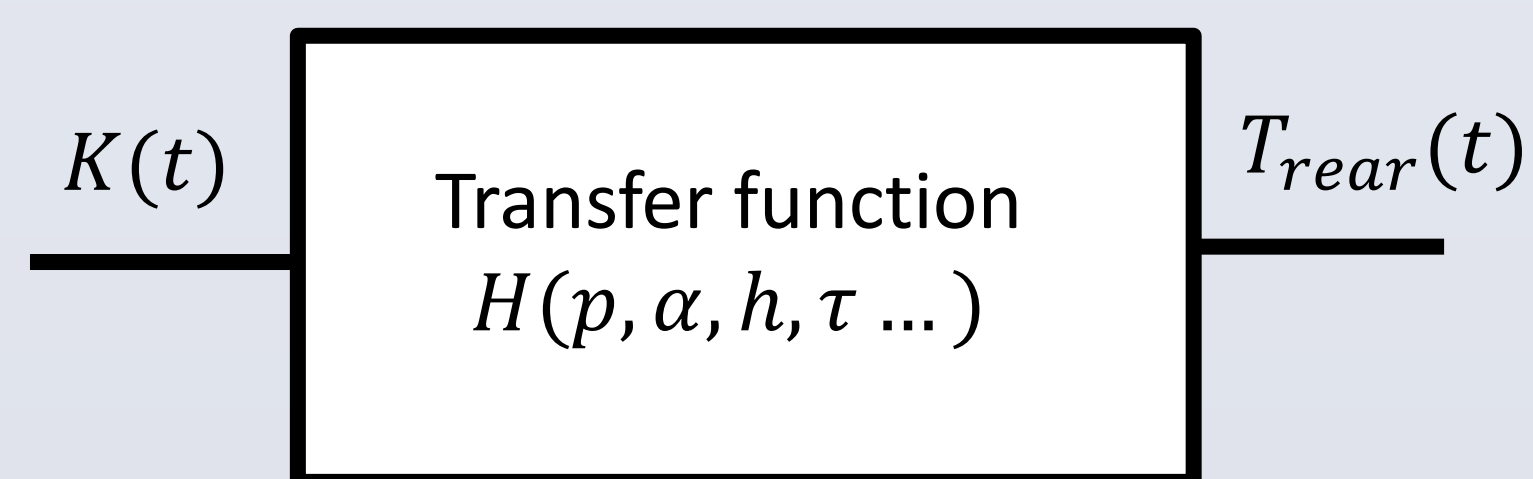
- Model: Quadrupole approach

- Geometry:

- Three-layer: 2 Pure conduction in soleplate, 1 absorbing-emitting media

- Model 1D semi-analytic (Laplace domain)

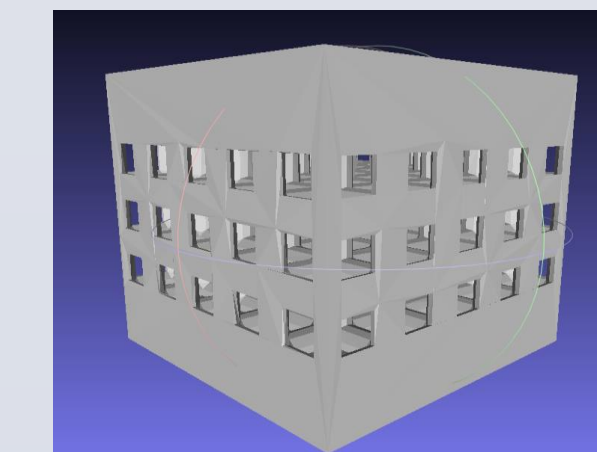
$$T_{rear}(t) = K(t) \cdot \mathcal{L}^{-1}[H(p, \beta)](t)$$



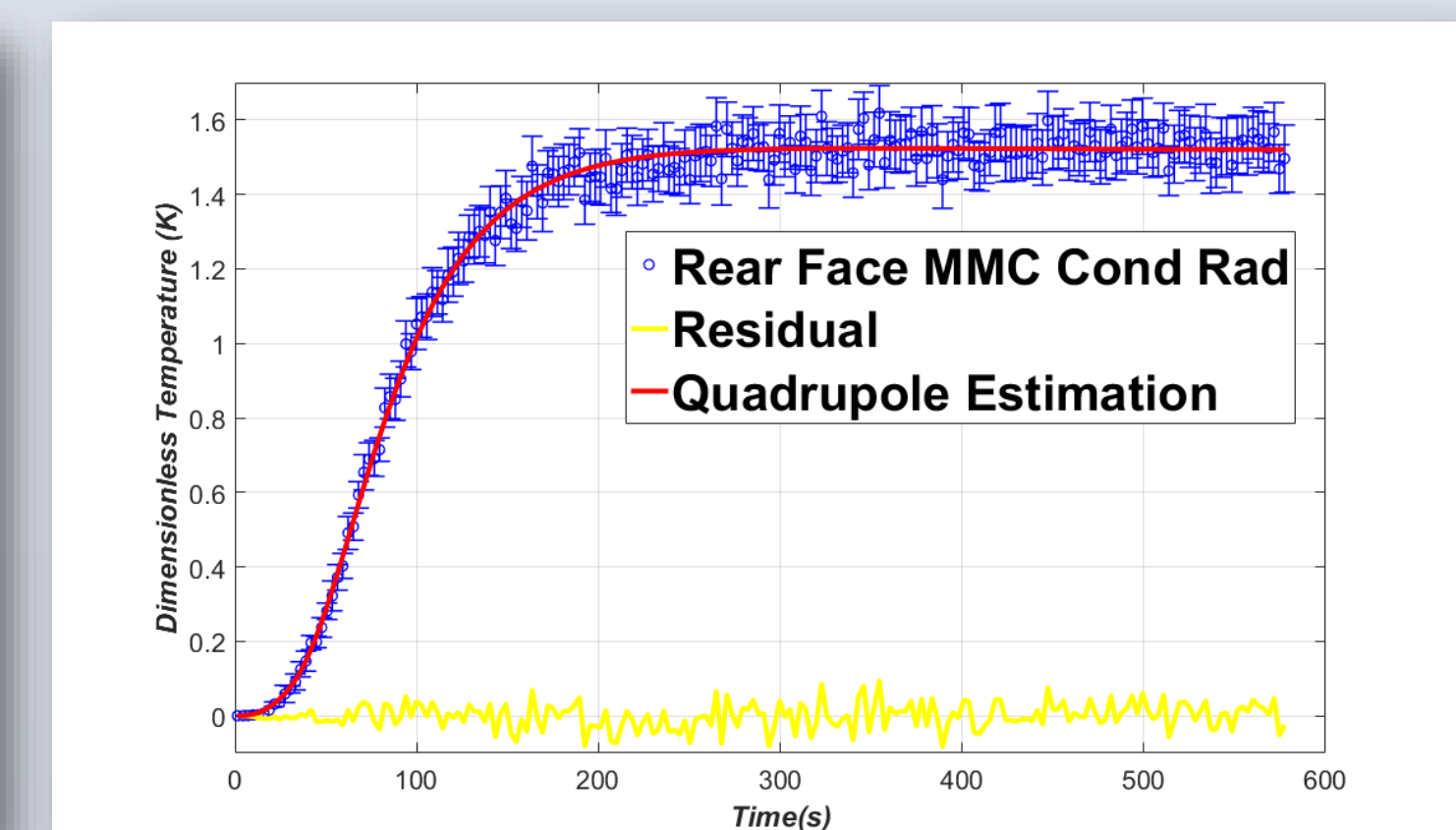
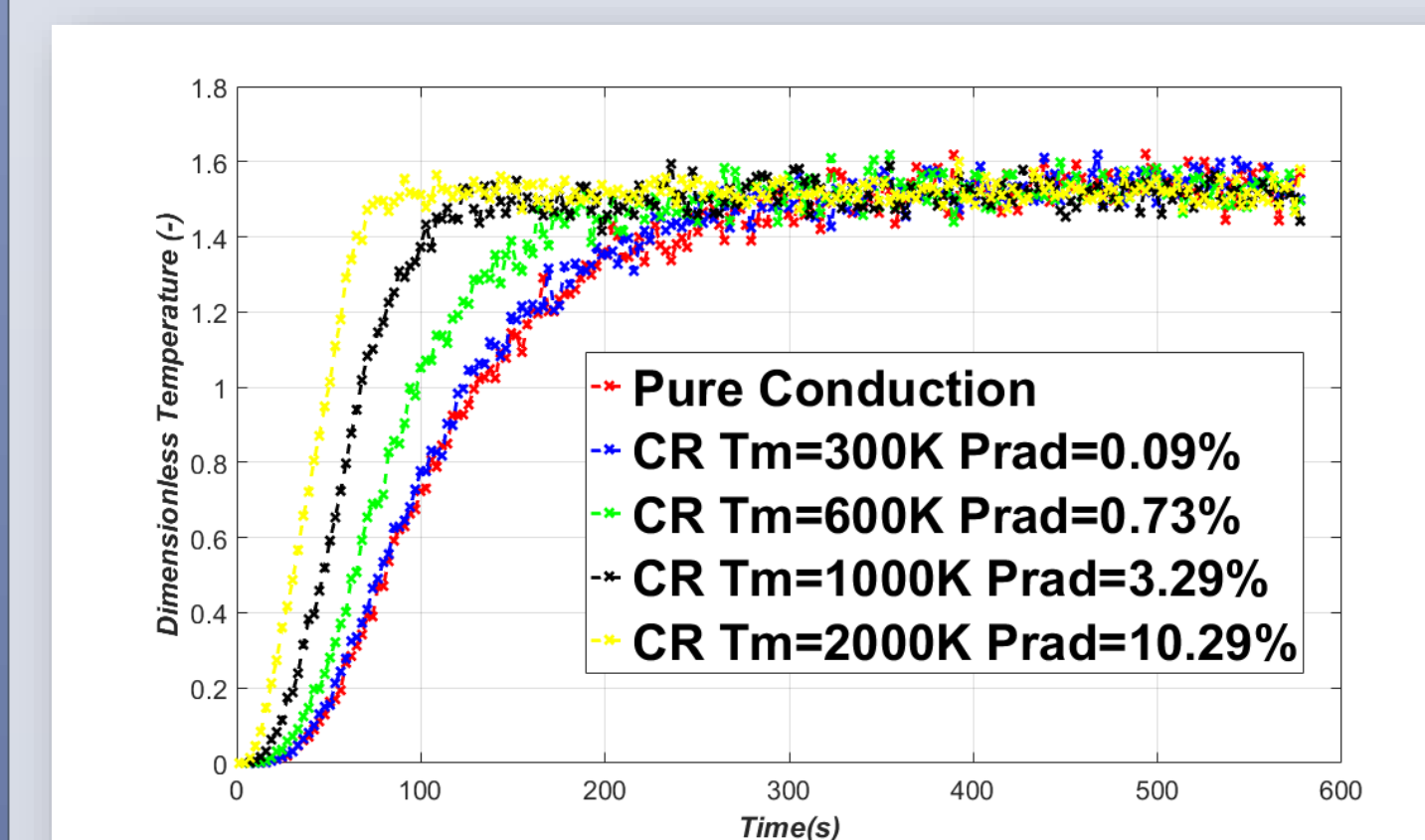
- Inverse method with  $\beta = [\alpha \ \tau \ K]$

- Stochastic effect of Monte Carlo is considered as a **real experimental noise**
- Generated by GenMat© (LTEN): **Stochastic Kelvin-Cell structure** [3]

- Effect of radiative transfer on a cubic structured foam with cylindrical struts
- $d_{struts} = 0.1 \text{ mm}$   $\epsilon = 0,75\%$



- Result of the inversion. Estimation of both equivalent diffusivity and optical thickness
- $\frac{\alpha_{eq}}{\alpha_{bulk}} = 0,46$   $\tau_{eq} = 1.89$



- Acceleration of heat transfer when the radiation increases

- Good fit with flat residual

## Conclusion and prospect

- Possibility to characterize the equivalent conductive and radiative behavior at high temperature. Other experiments with different ceramics (ZrO2, Al2O3 ...) and different textural properties are planned.
- First encouraging results. Next step, influence of various parameters on the thermogram (possible bias, CPU-time, ...). Impact of the geometry on the equivalent parameter. Computation with stochastic foams generated by GenMat and with real tomographic mesh.

## References

- F. Dupoirieux, L. Tesse, S. Avila, J. Taine, *An optimized reciprocity Monte Carlo method for the calculation of radiative transfer in media of various optical thicknesses*, International Journal of Heat and Mass Transfer 49 (7-8) (2006) 1310-1319.
- R. Fournier, S. Blanco, V. Eymet, M. E. Hafi, C. Spiesser, *Radiative, conductive and convective heat-transfers in a single Monte Carlo algorithm*, Journal of Physics : Conference Series 676 (2016) 012007
- GUÉVELOU, Simon, ROUSSEAU, Benoit, DOMINGUES, Gilberto, *et al. Representative elementary volumes required to characterize the normal spectral emittance of silicon carbide foams used as volumetric solar absorbers*. International Journal of Heat and Mass Transfer, 2016, vol. 93, p. 118-129.