Inverse Method for Calculating the Tempeature-Dependent Thermal Conductivity of Nuclear Materials

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Introduction:

There is a great interest within the nuclear industry to accurately define thermo- physical properties of reactor materials. The precise determination of the thermal conductivity, especially at high temperatures, will help better predict and model the material's performance both during operation and accident conditions.

Methods:

- **Reverse engineering:** The proposed method will compare and fit theoretical thermograms (obtained via finite element analysis) to experimental thermograms (obtained from thermal camera imaging of a sample's surface) with finite element analysis. The reverse engineering method is described in in figure 1.

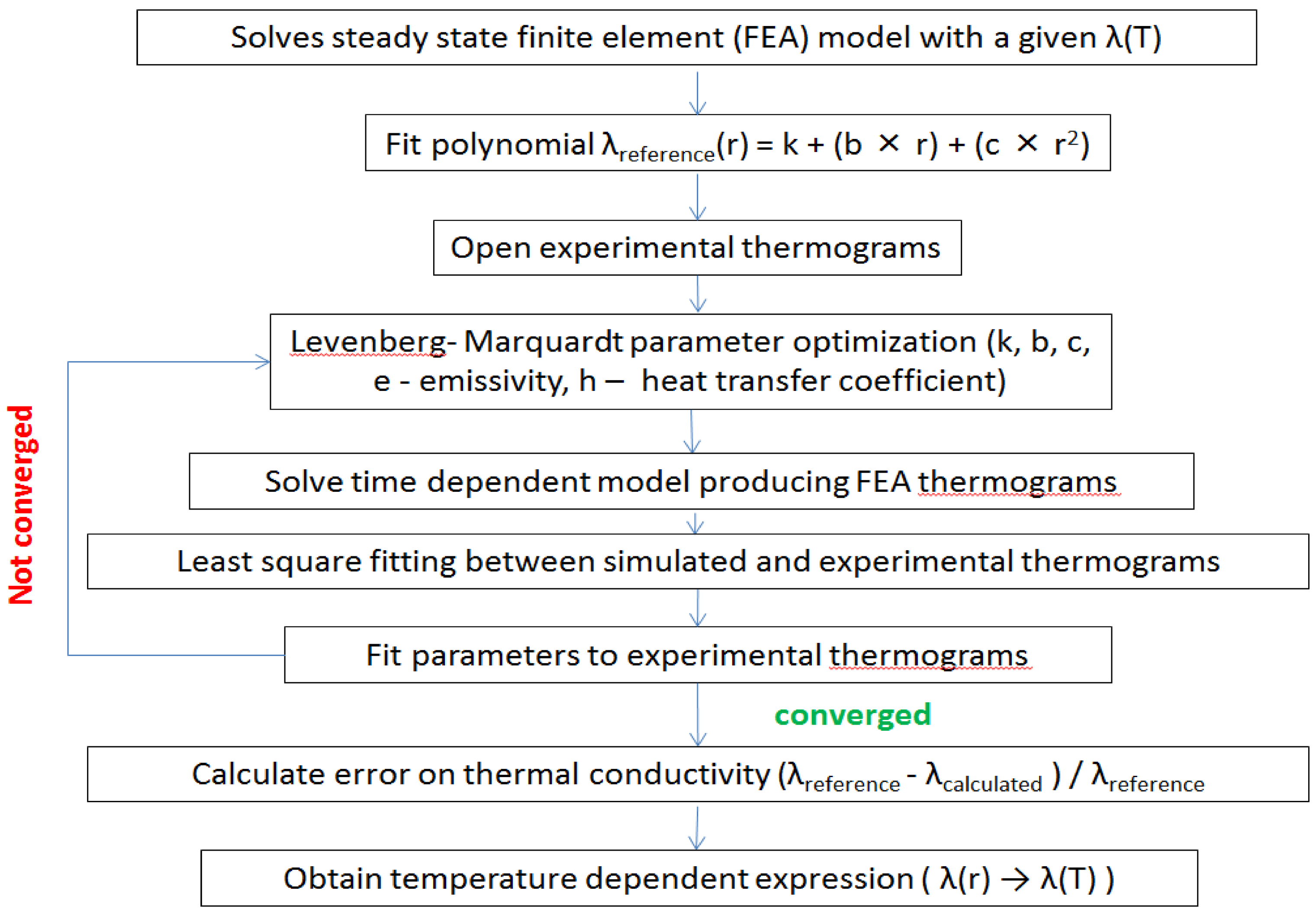


Figure 1 – Schematic of the method's logic.

- **Experimental methods:** The apparatus consists of a sample material (e.g. graphite) in the form of a disc screwed by three zirconium pins to a graphite sample holder, all of which encapsulated by a chamber. On both sides of the stainless steel chamber there are transparent glass windows which allow for two continuous-wave lasers to preheat each side of the specimen from around 323K to the conditioning temperature, respectively. The conditioning temperatures can vary between 1200K and 3000K. The rise in temperature on both the front and rear surface of the specimen are measured as a function of time by high-speed micro pyrometers and a thermal camera.

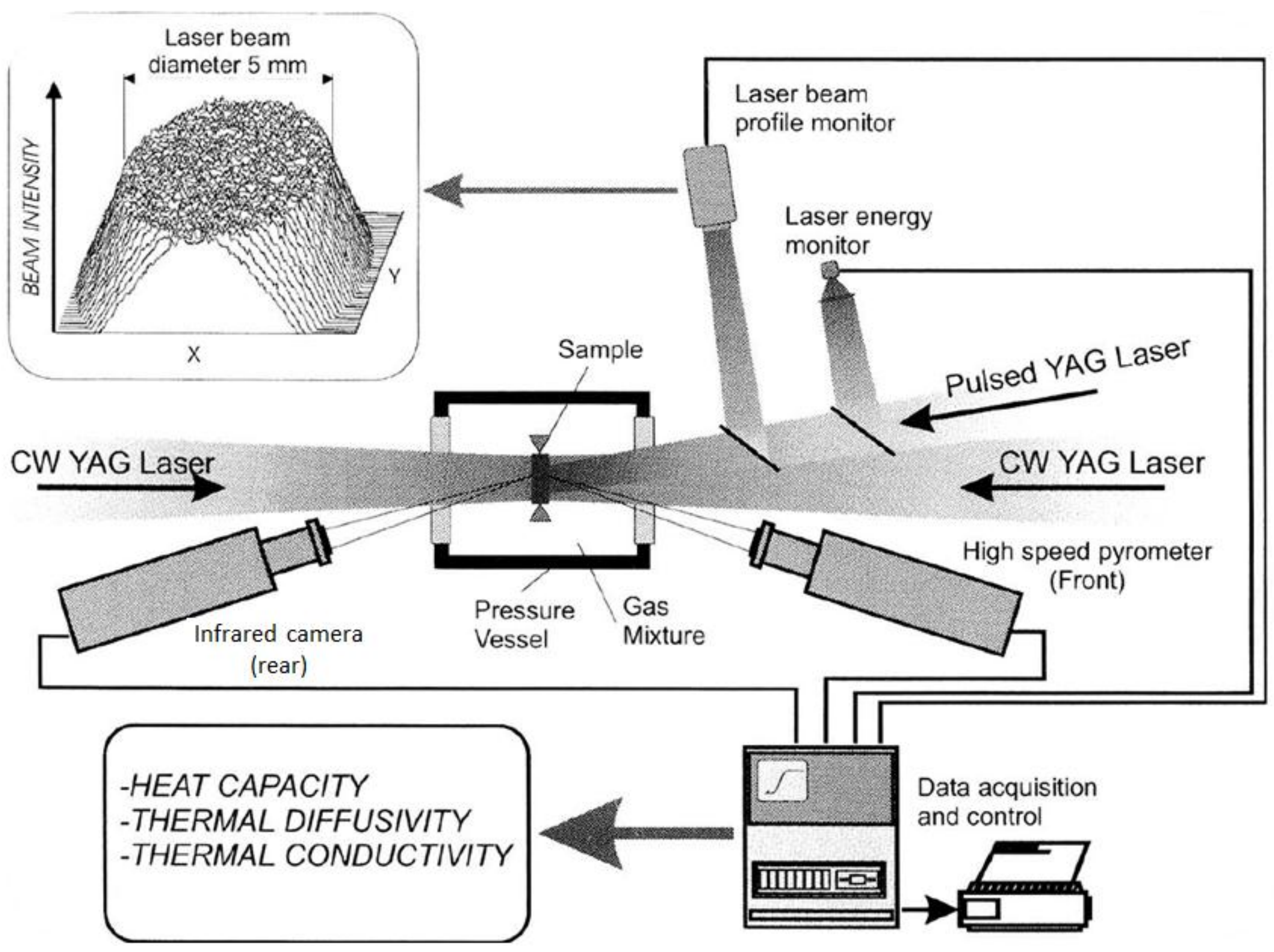
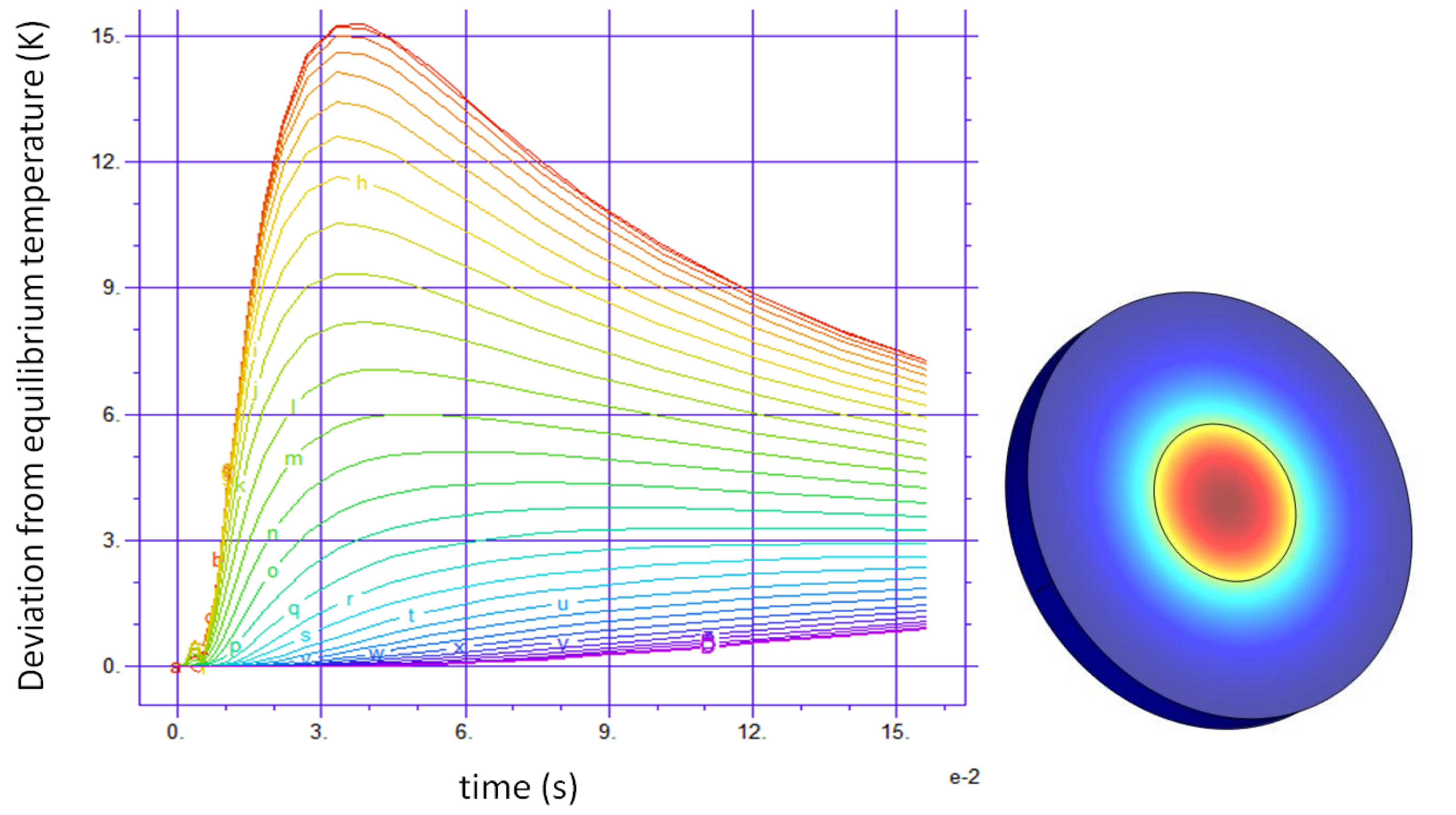


Figure 2 – Schematic of the experimental equipment and it's layout[2].

- **Computational methods (Finite Element Analysis):** A transient step is used to model the initiation of the laser pulse. The transient carries the information about the fitted parameters λ (k,b,c), emmissivity (e) and heat transfer coefficient (h). Thus, when the least square difference between the experimental transients and the model counterparts is minimized the optimization has converged and the parameters are finalized.



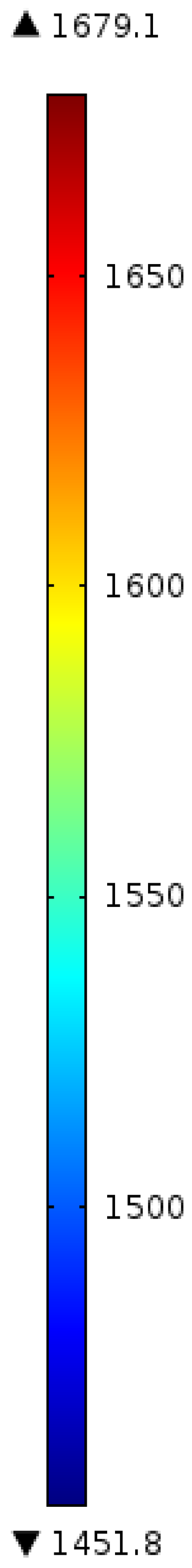


Figure 3 – Deviation from equilibrium temperature (rear side of pellet) after laser pulse initiation. The red thermograms represent the centre while the purple the edge of the sample. A 3-D COMSOL equilibrium model is shown on the right.

Results:

The first results obtained from the code for thermal conductivity as a function of radius can be seen below. There is good agreement between the reference and calculated values with a maximum error of around 8% at 1500K.

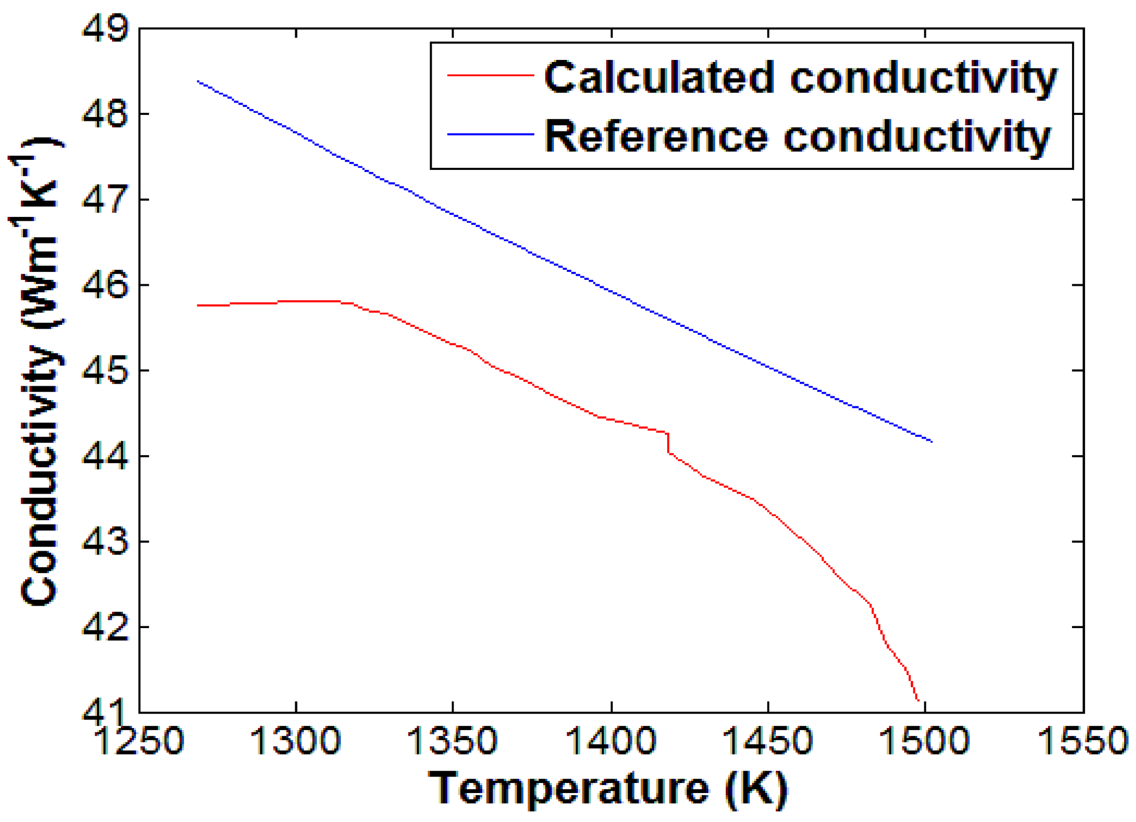


Figure 4 – Thermal conductivity vs. temperature (K) for a graphite sample.

Conclusions:

The proposed inverse method calculates thermal conductivity via optimization and least square fitting between experimental and model thermograms. The calculated thermal conductivity shows to be within a maximum error of 8% compared to the reference. This method will be applied to other nuclear materials (e.g. UO_2).

References:

1. Parker, W. J., Jenkins, R. J., Butler, C. P. & Abbott, G. L. Flash Method of Determining Thermal Diffusivity, Heat Capacity, and Thermal Conductivity. *J. Appl. Phys.* **32,** 1679 (1961).
2. Ronchi, C., Heinz, W., Musella, M., Selfslag, R. & Sheindlin, M. A Universal Laser-Pulse Apparatus for Thermophysical Measurements in Refractory Materials at Very High Temperatures 1. *Interantional J. Thermophys.* **20,** 987–987–996 (1999).

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