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Developing a new technique for measuring high temperature total emissivity based on laser flash

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- FASB operations
- FASB radiological control

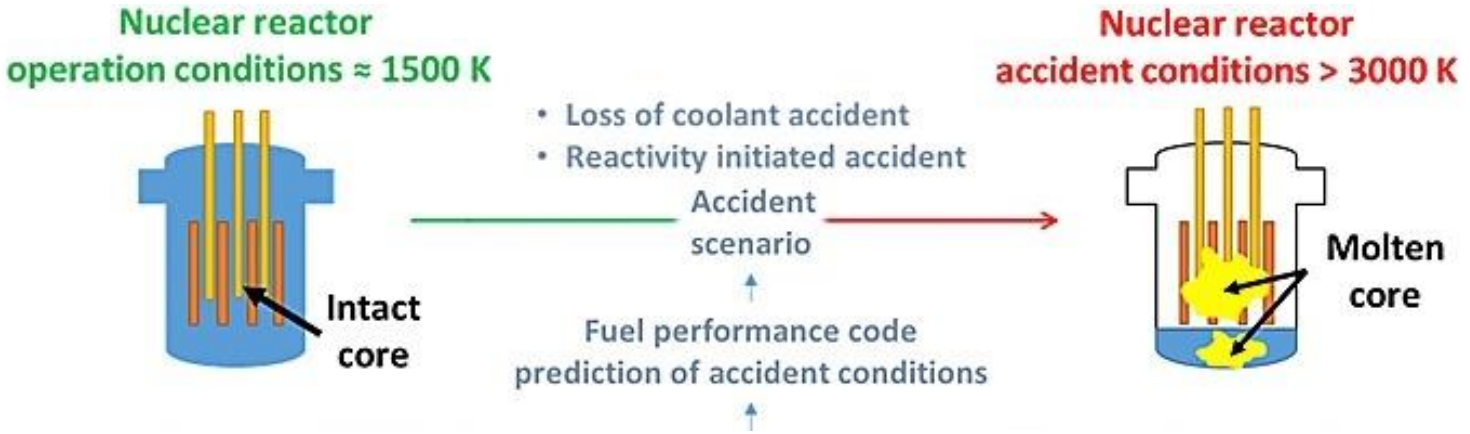


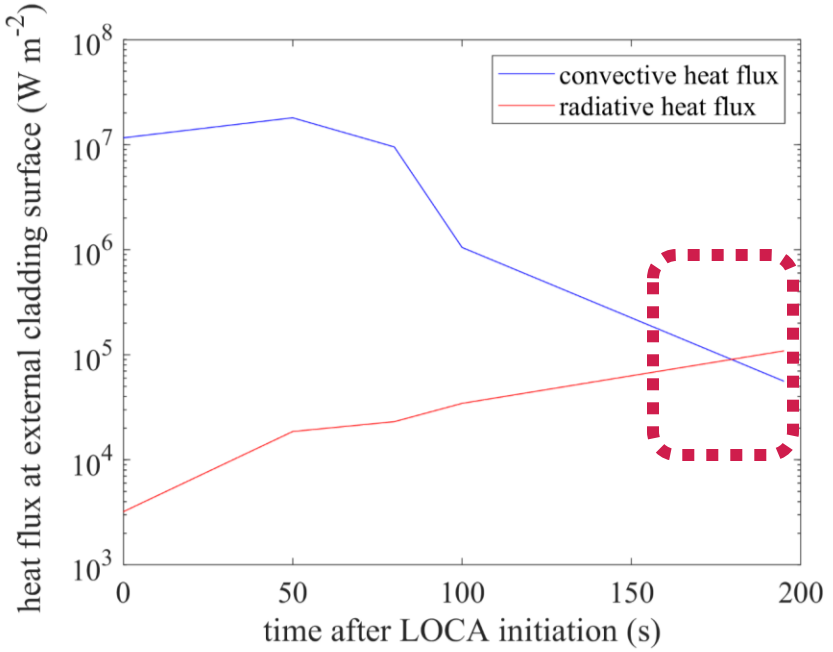
Overview

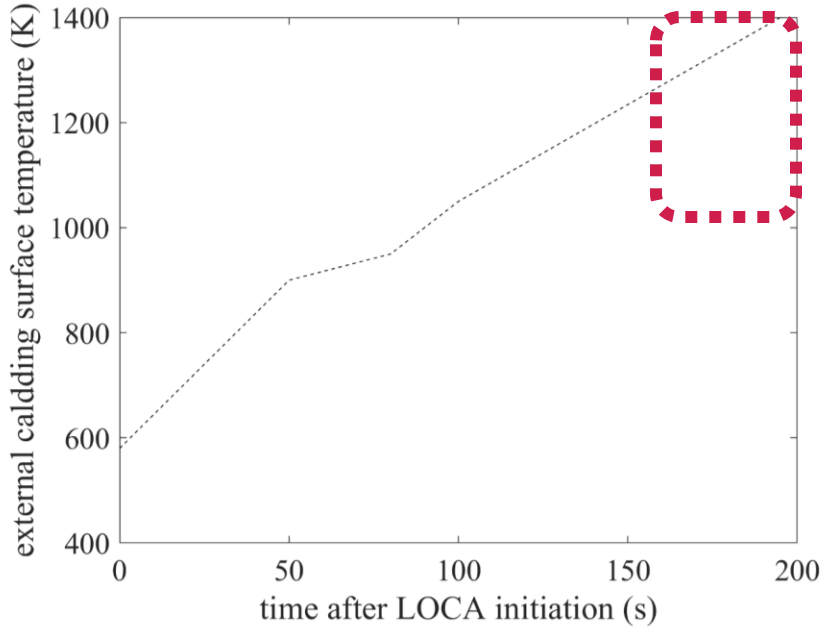
- Motivation
- Methodology
- Results
- Conclusion and future/ongoing work

Motivation

- Total emissivity governs the amount of thermal energy lost from the surface of a hot object
- It is important for accurately predicting the operating temperature of components intended for high temperature applications (nuclear fuels, claddings, thermal barrier coatings, refractory materials, etc.)
- In pressurized water reactors total emissivity plays an important role during the “blowdown phase” of a LOss of Coolant Accident (LOCA).
- In the qualitative schematic (based on a Kernforschungszentrum Karlsruhe or KfK LOCA test), as the cladding approaches a peak temperature the radiative heat transfer (governed by total emissivity) becomes the dominant heat loss mechanism at the external cladding boundary

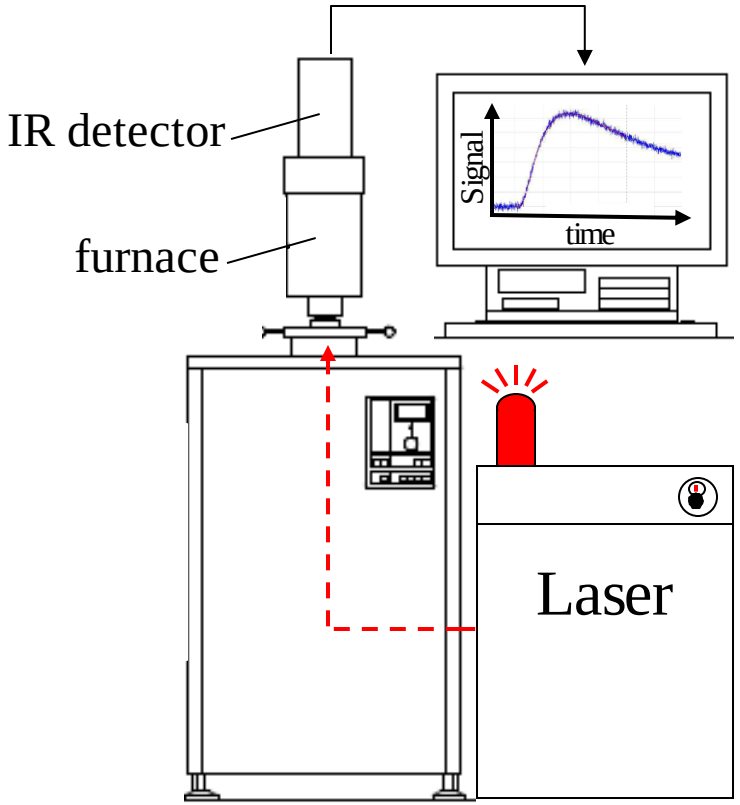




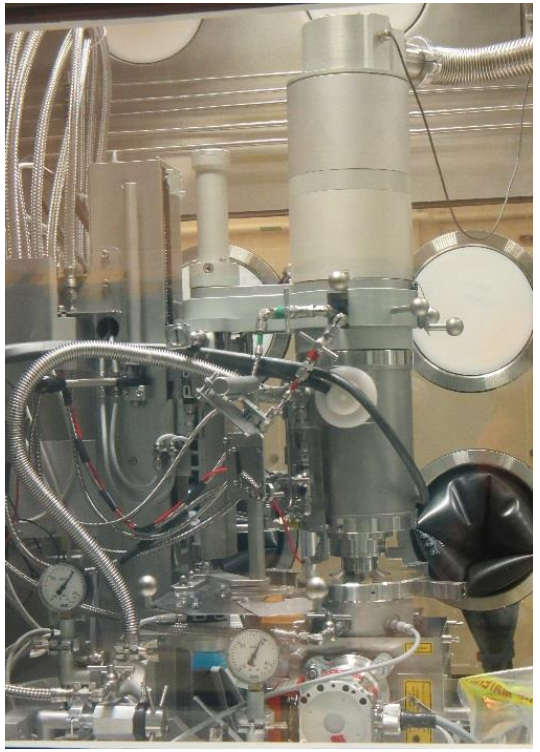


Methodology (experiment)

- The main components are furnace, laser and infrared detector.
- The furnace heats up the sample to a desired temperature
- The laser send a short intense pulse to the bottom surface of the sample.
- The detector registers the temperature response.
- RT to 2000°C in controlled atmosphere (Ar, He or **vacuum**)
- A diagram of the laser flash analyzer housed in shielded glovebox (TPC)
- All testing was performed with a nearly identical benchtop system in FASB.



LFA in Thermophysical Properties Cell (TPC)



Methodology (FEA model – total emissivity)

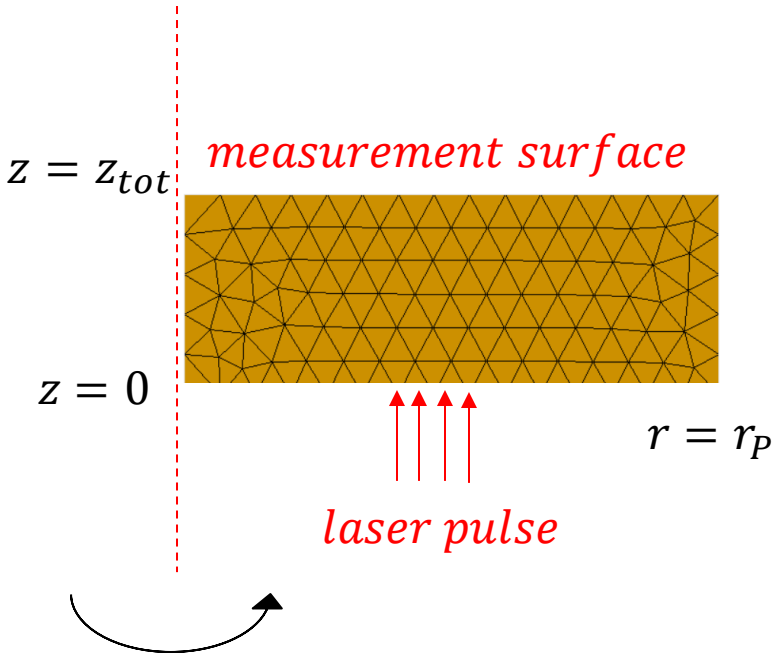
- Axisymmetric model with the following mathematical formulation:

$$-\nabla \cdot (k(T_0)\nabla T) = \rho(T_0)C_p(T_0)\frac{dT}{dt} \qquad T = \tilde{T}(t,r,z) + T_0(0,r,z)$$

$$-\left(k(T_0)\nabla\tilde{T}\right)\Big|_{r,\,z=0} = -\sigma\boldsymbol{\varepsilon_{tot}}\left(\left(\tilde{T}+T_0\right)^4 - {T_0}^4\right) - h\tilde{T} + P(r,z,t)$$

$$-\left(k(T_0)\nabla\tilde{T}\right)\Big|_{r,\,z=z_{tot}} = -\sigma\boldsymbol{\varepsilon_{tot}}\left(\left(\tilde{T}+T_0\right)^4 - {T_0}^4\right) - h\tilde{T}$$

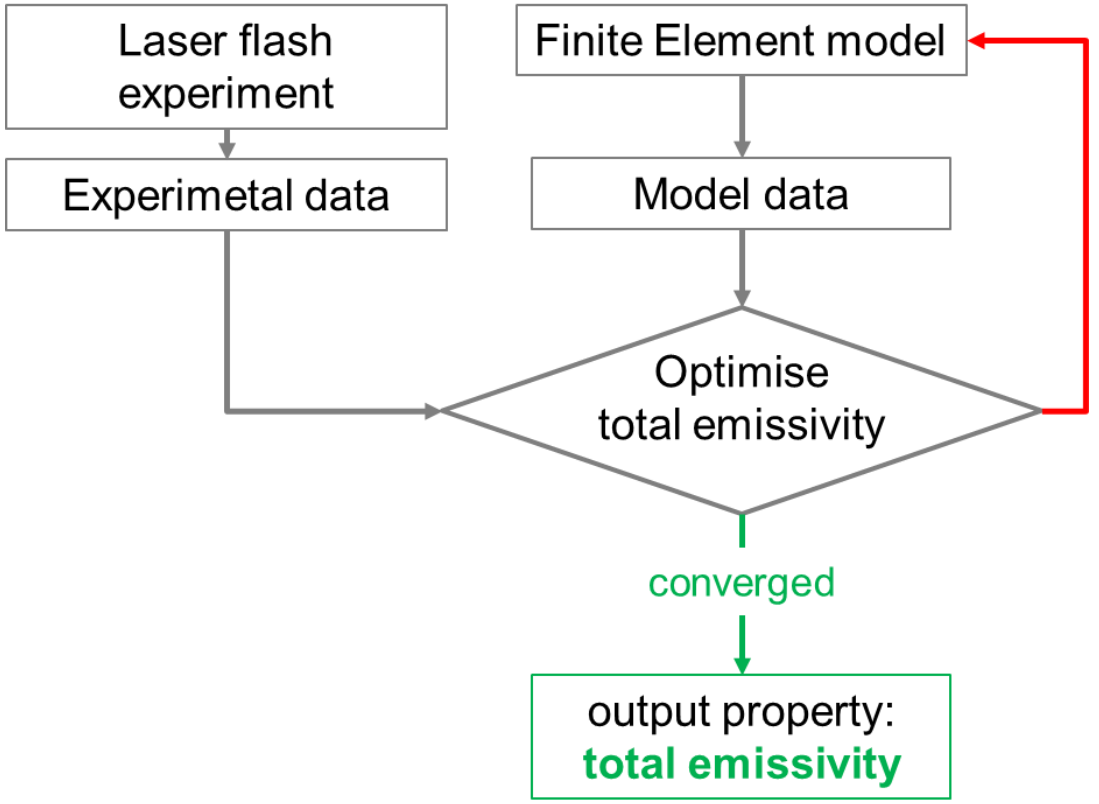
$$-\left(k(T_0)\nabla\tilde{T}\right)\Big|_{r=r_P,\,z} = -\sigma\boldsymbol{\varepsilon_{tot}}\left(\left(\tilde{T}+T_0\right)^4 - {T_0}^4\right) - h\tilde{T}$$



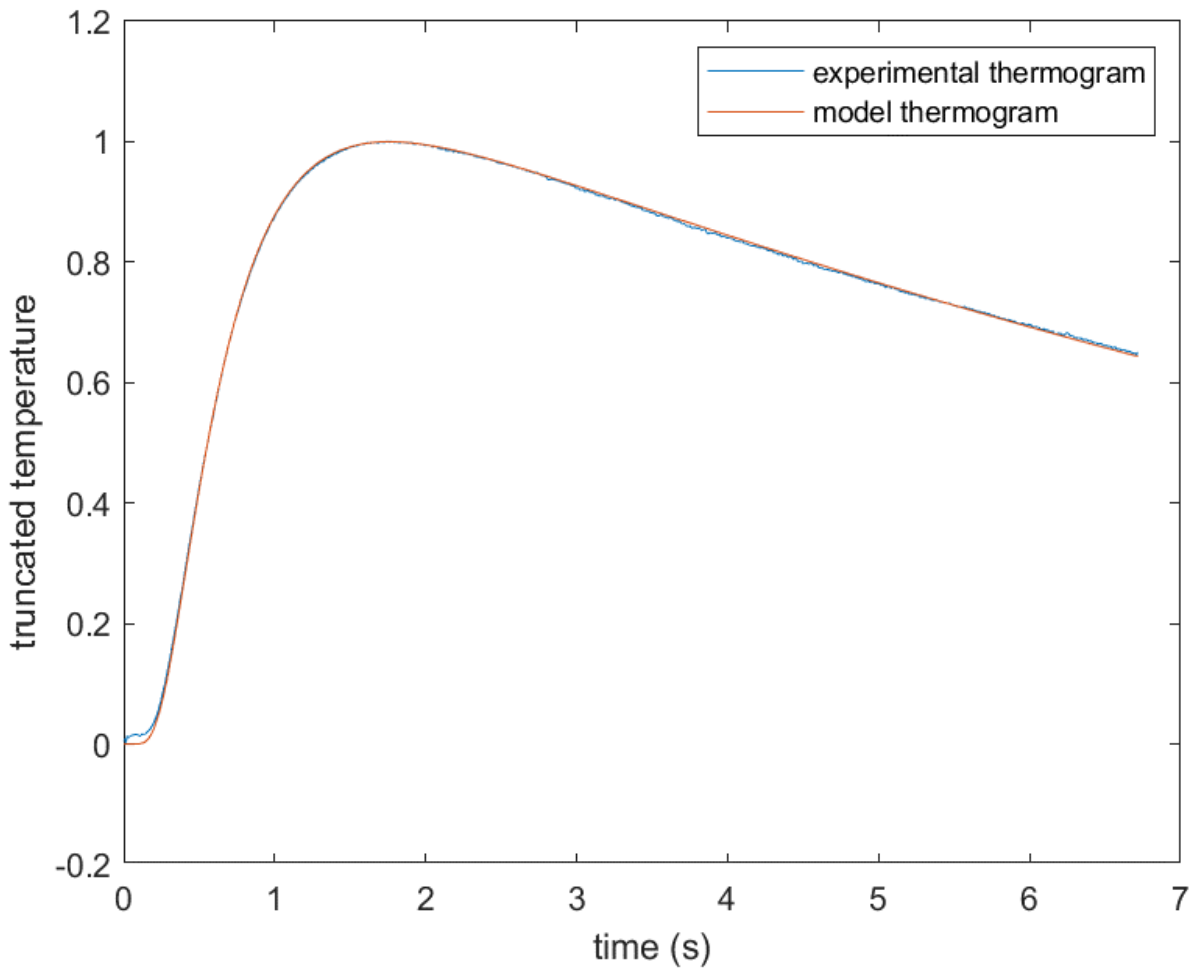
- Specific heat, thermal conductivity and density correlations are used as input.

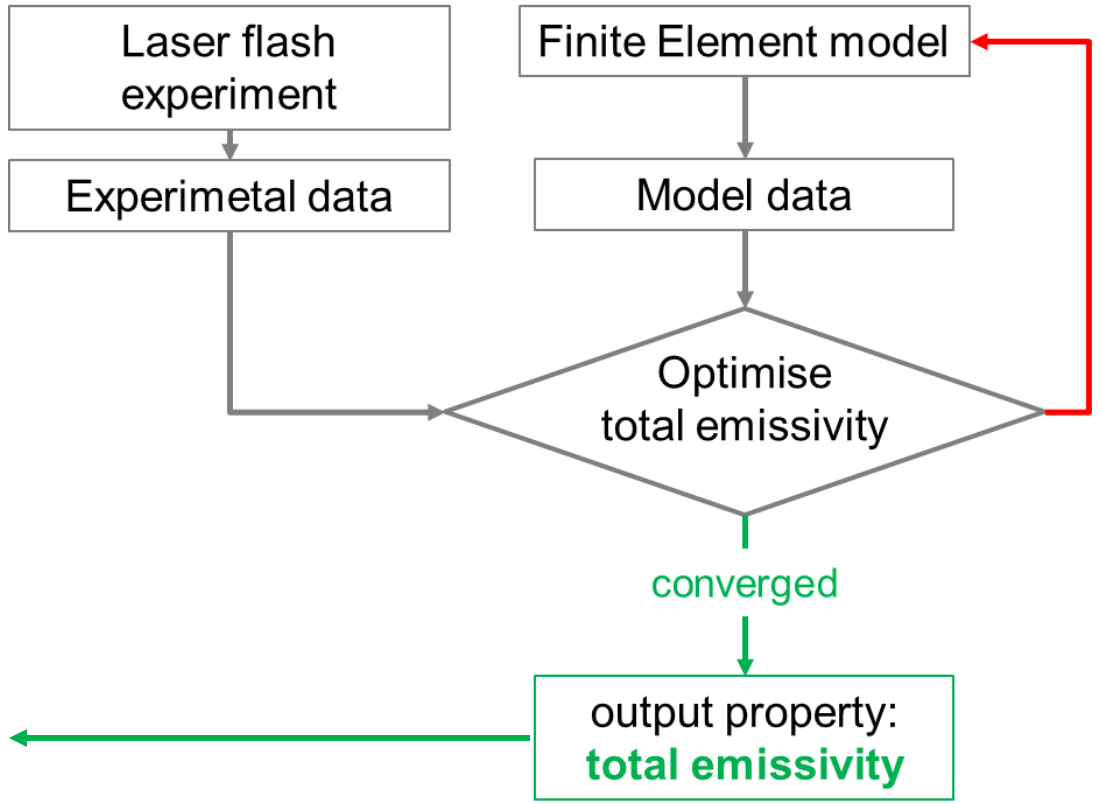
Methodology (logic scheme)

- A customized data analysis tool has been developed to extract emissivity based on:
  - Customized experimental design and procedures - focusing on the heat loss component of the temperature response under vacuum conditions.
  - Finite element analysis simulating the precise heat transfer mechanisms governing conduction and radiative heat losses from the surface
  - Multivariate optimization based on the Levenberg-Marquardt method (gradient descent-based minimization algorithm)



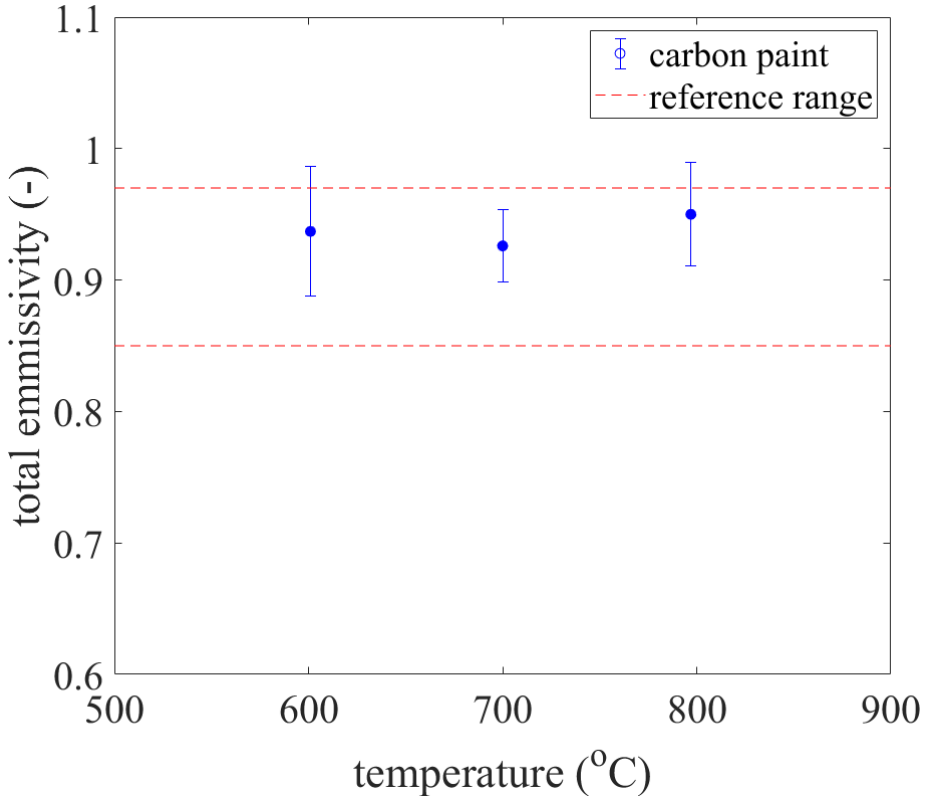
Methodology (logic scheme)

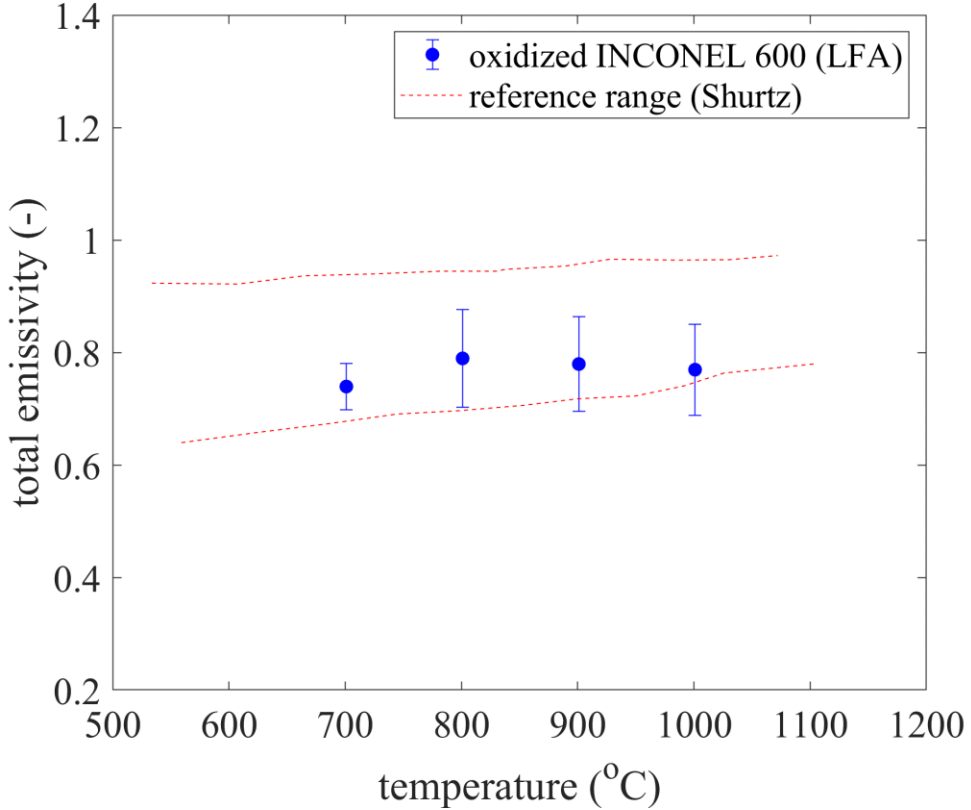




Results (Pyroceram 9606 and Inconel 600)

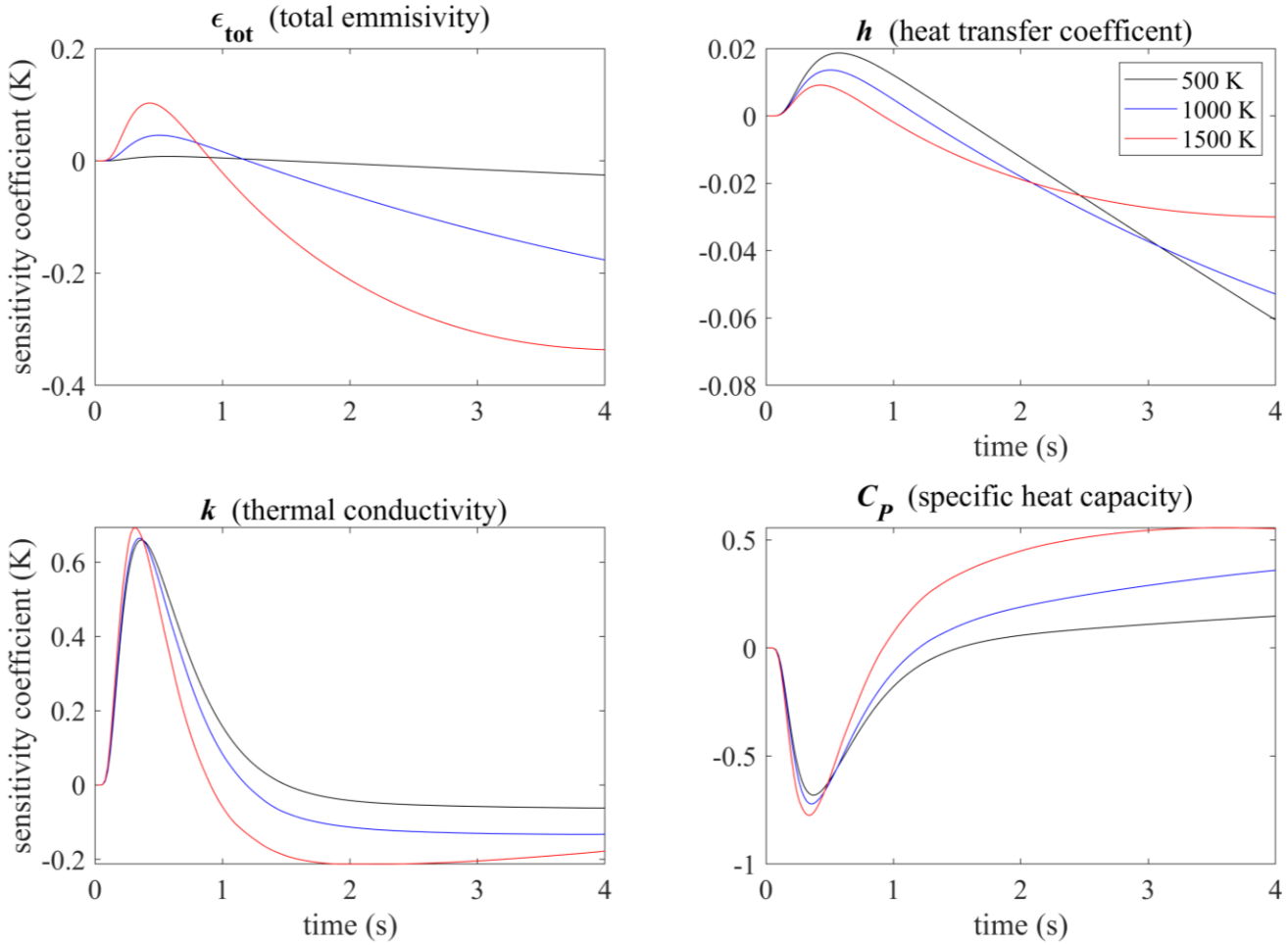
- First measurements obtained on:
  - carbon coated Pyroceram 9606 standard reference material
  - oxidized Inconel 600 standard reference material
- Good agreement between measured data and reference range for both materials





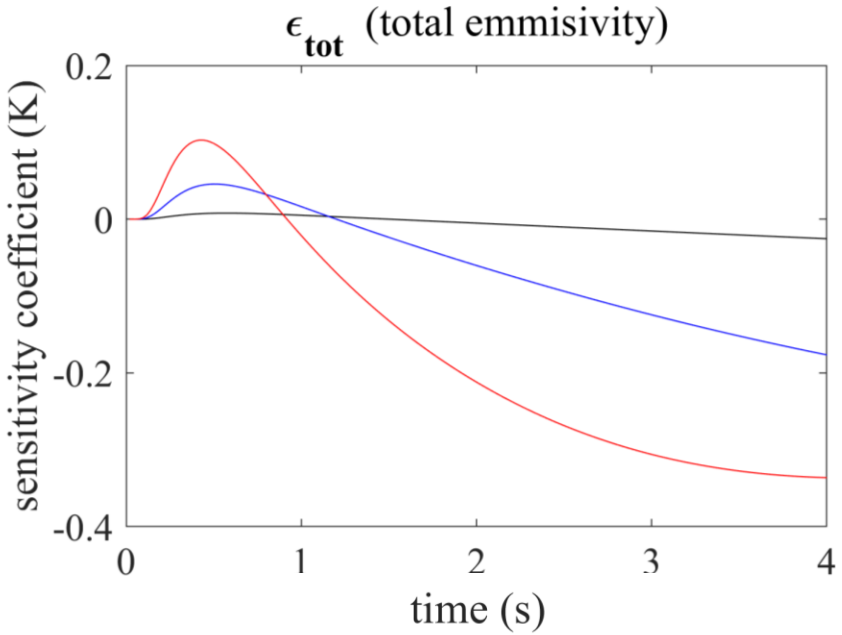
Results (statistical analysis)

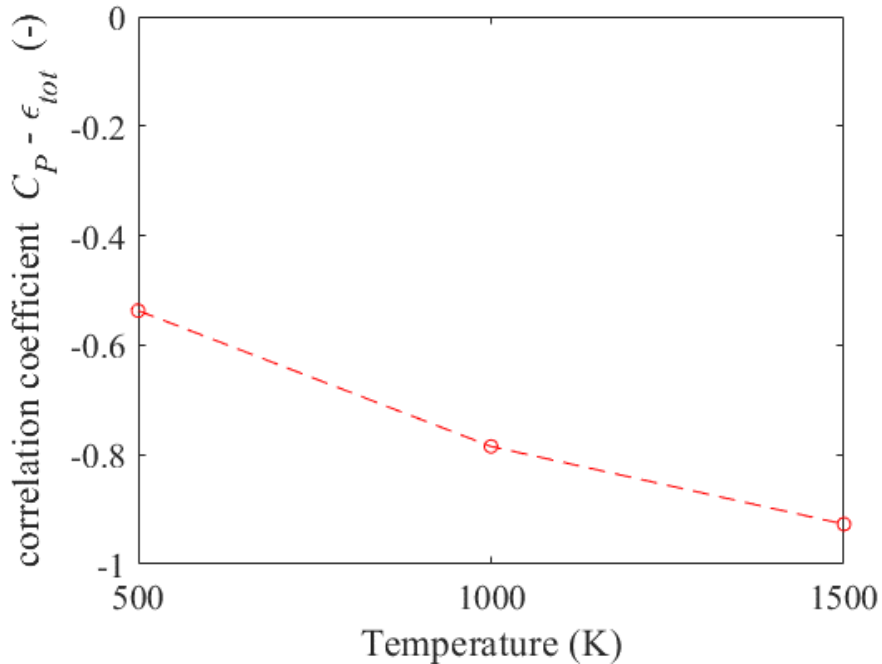
- The sensitivity coefficients are presented at three different temperatures for the following four properties:
  - Total emissivity
  - Heat transfer coefficient
  - Thermal conductivity
  - Specific heat capacity
- The model becomes significantly more sensitive to total emissivity as a function of higher temperatures



Results (statistical analysis)

- The sensitivity and correlation analysis allows to probe for potential weaknesses and limitations of the new inverse methodology
- Limitations include:
  - High equilibration time needed to reduce any errors associated with furnace temperature baseline drifts
  - Minimum temperature for accurate measurements of 600C due to lack of sensitivity.
  - High correlation with specific heat (ε_{tot}-C_P) and density (ε_{tot}-ρ) which requires accurate input for both properties.





Conclusion

- First measurements on carbon painted Pyroceram and oxidized INCONEL 600 are in good agreement with the reference range of the carbon paint
- The statistical analysis helps explain certain technique limitations such as a lower limit on the temperature range (~600°C) and the need for accurate input values for specific heat capacity and density

Ongoing work

- Identifying nuclear materials with unknown total emissivity values (U-10Zr, SiC, Zircaloy, etc.)
- Drafting publication

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