HAL open science

Using laser remote heating to simulate extreme thermal loads on nuclear fuels

Thierry Vidal, L. Gallais, J. Faucheux, H. Capdevila, Yves Pontillon

To cite this version:

Thierry Vidal, L. Gallais, J. Faucheux, H. Capdevila, Yves Pontillon. Using laser remote heating to simulate extreme thermal loads on nuclear fuels. Topfuel 2018, Sep 2018, Prague, Czech Republic. cea-02338471

HAL Id: cea-02338471

https://cea.hal.science/cea-02338471

Submitted on 28 Nov 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.

Using laser remote heating to simulate extreme thermal loads on nuclear fuels

Thibault VIDAL *, Laurent GALLAIS **

Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel UMR 7249, 13013 Marseille, France

**vidal@fresnel.fr, **laurent.gallais@fresnel.fr*

Jérémy FAUCHEUX, Hélène CAPDEVILA, Yves PONTILLON***

CEA, DEN/CAD/DEC/SA3E, Laboratoire d'Analyse de la Migration des Radioelements 13108 Saint-Paul-lez-Durance, France

****yves.pontillon@cea.fr*

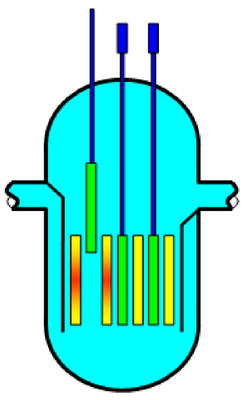
Understanding the behaviour of nuclear fuel materials in relation to the different thermal loads to which they can be subjected, i.e. from normal operation through severe conditions, is of critical importance in the nuclear field. Experimental studies can be performed with dedicated integral experiments conducted in-pile (i.e. in Materials Testing Reactor) with the corresponding cost and constraints, or at the laboratory scale with annealing tests that can produce representative thermal conditions.

In this context we are developing an experimental platform to perform annealing tests on irradiated nuclear fuel samples involving very high temperatures (up to 3000°C), with control of radial and axial thermal gradients and temporal dynamics, coupled with on line analysis of gas and fission product releases, microstructure evolution and fuel fragmentation kinetics. This experiment is based on a high power laser (1.5 kW) used to generate heat on the sample, implemented in an experimental chamber with controlled atmosphere, associated with different diagnostics. Based on the spatial beam profile and temporal power function of the laser, such a system allows producing complex spatiotemporal temperature gradients, relevant for addressing different research needs. It provides access to extreme thermal conditions that are very difficult to reach with other means. Particularly, one of the objectives of this work is to investigate conditions of Reactivity Initiated Accident (RIA).

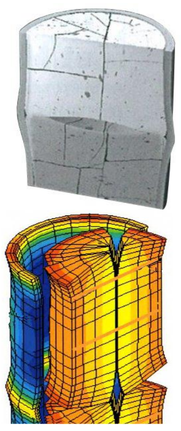
Context

Nuclear fuel research

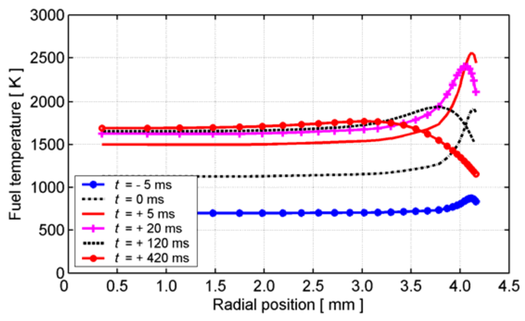
One of the main tasks of this work is the investigation on current and future nuclear fuels, particularly their behaviour and their interaction with the cladding under thermal loads representative **of RIA (Reactivity Initiated Accident)** type conditions in nuclear reactors. By understanding these mechanisms, it is possible to improve nuclear reactor safety and to precisely define specific on-site emergency plans in the event of an extreme event.



Schematic of a RIA event resulting from the ejection of a control rod.



Coupling experiment and simulations to understand fuel behaviour



Evolution of the fuel temperature profile in rod REP-Na5, calculated with the SCANAIR-3.2 computer code. [3]

Objectives:

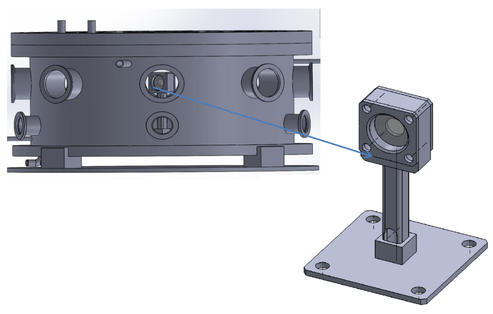
-Reveal more information about the behaviour of nuclear materials under different thermal loads, from nominal operation through extreme conditions

-provide experimental data as support of "PLEIADE", the calculation code developed at the CEA.

Experimental Platform « **CHAUCOLASE** »

The collaboration between Institut Fresnel and CEA Cadarache targets the development of a high power laser-based facility integrated in a hot laboratory environment that could address fuel R&D issues that cannot be achieved in current installations worldwide.

The first step in this direction is development of a pilot platform based at the Institut Fresnel operating on natural UO_2 or dummy samples, based on high power laser and optical instrumentation for the study of nuclear fuel samples or fuel pellets assemblies (fuel+cladding) under thermal transients.



Experimental chamber and RIA sample holder

Equipment:

-1500W CW Ytterbium fiber laser

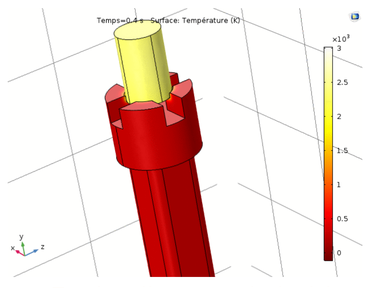
-Thermocouples type K (0-1200°C) and C (0-2200°C)

-IR camera (0- 2000°C)

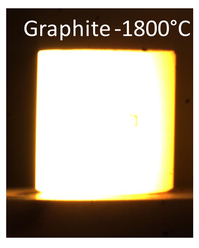
-High speed bichromatic pyrometers (400-1500°C, 1300-3000°C & 600-3500°C -80µs response time)

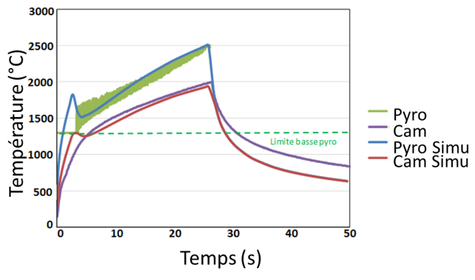
-PID regulator (pyrometers <-> Laser)

-High speed visible camera (1000fps)



Fuel pellet sample holder





Results of experiments conducted on graphite samples

Laser controlled RIA thermal transient

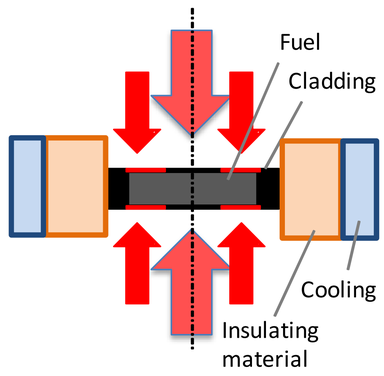
Concept

A **two-steps** laser experiment is proposed to reach RIA thermal conditions on a fuel sample:

1/ CW laser irradiation with gaussian beam intensity distribution to reach initial conditions;

2/ A pulsed irradiation with annular beam intensity distribution for the thermal transient on the edges of the sample.

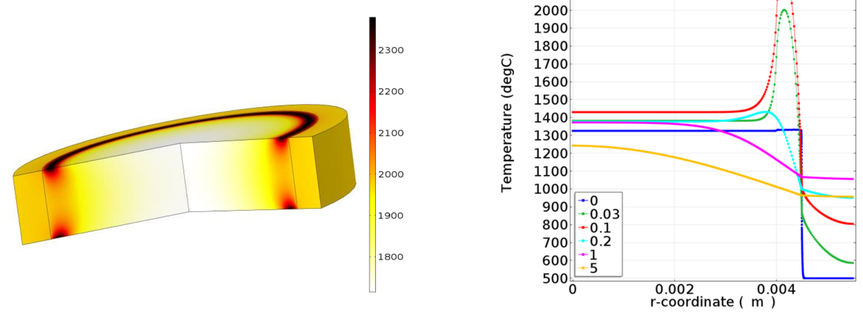
Thermal gradients can be controlled with the laser intensity distribution, outer insulating materials and potential active cooling.



Concept of laser simulated RIA conditions

Numerical simulations

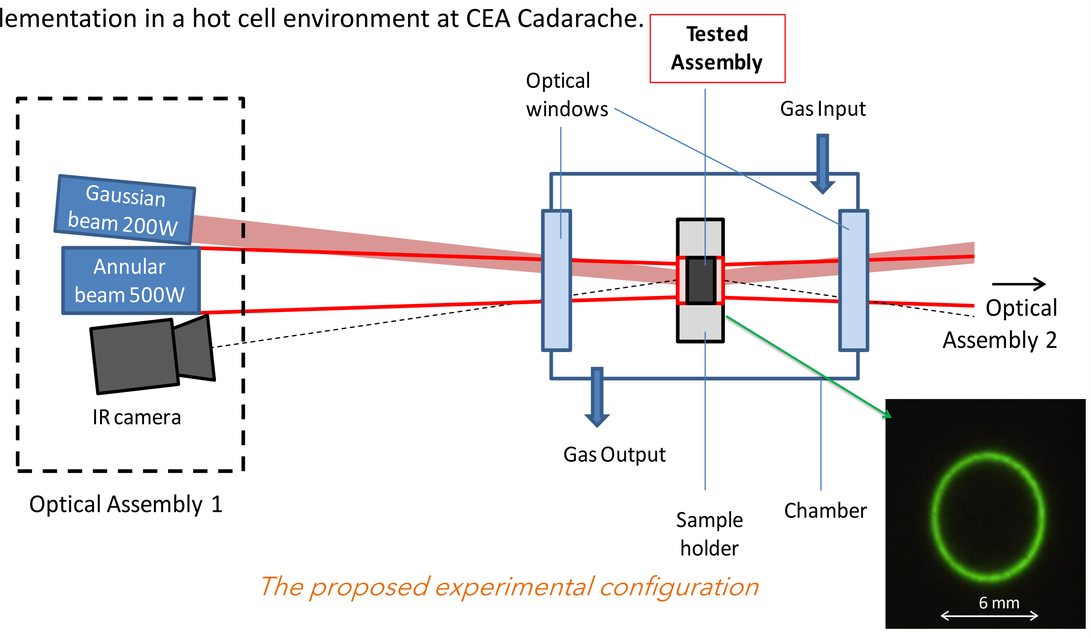
Based on the optical and thermal properties of UO_2 , RIA thermal transients conditions can be reached on a fuel disk of ~0.5mm thickness. Laser power of few hundreds of Watts are required for such experiment.



Numerical simulations of temperature distribution on a UO_2/Zircaloy cladding assembly illuminated by 150W annular laser beams

Experiments

A configuration based on high power laser beams and high speed optical instrumentation is currently under development at the Institut Fresnel, as a pilot experiment before implementation in a hot cell environment at CEA Cadarache.



The proposed experimental configuration

References

[1] I. Guénot-Delahaie, J. Sercombe, T. Helfer, P. Goldbronn, E. Federici, T. Le Jolu, A. Parrot, C. Delafoy, C. Bernaudat, '*Simulation of reactivity-initiated accident transients on UO2-M5® fuel rods with ALCYONE V1.4 fuel performance code*', **Nuclear Engineering and Technology** 50, 268 (2018)

[2] T. Vidal, L. Gallais, J. Faucheux, H. Capdevila, Y. Pontillon., '*Using laser remote heating to simulate extreme thermal loads on nuclear fuels during annealing tests*', **Top Fuel**, Prague, Czech Republic, 2018.

[3] « Nuclear Fuel Behaviour under Reactivity-Initiated Accident (RIA) Conditions » State-of-the-art Report. Nuclear Energy Agency. NEA N°6846 (2010) pp79-80

www.fresnel.fr