# Development of experimental platform for analysis and imaging of fuel pellets heated at high temperature

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Understanding the behavior of nuclear materials, regarding fission gas release in relation to the different thermal loads to which they can be subjected, requires appropriated annealing tests in order to measure both the absolute level and the time dependence of the released fission products together with the corresponding fuel micro-structural changes during representative thermal transients. In this context, we describe in this paper the development and qualification of an experimental platform coupling heat treatment, gases release analysis and optical systems, for the study of fuel pellets at high temperature. This system, which is mainly devoted to power transient and LOCA (Loss Of Coolant Accident) type simulation, is based on an induction furnace to heat the pellet at high temperatures (up to 2000°C with up to 50°C/s temperature ramps) in controlled atmosphere. The device is coupled with dedicated analysis loops that are designed to identify and quantify on line the gases and fission products released during the annealing test. The purpose of the optical system is the real time monitoring of the sample surface to provide additional information (for instance on the micro structure evolution kinetics and fuel fragmentation). It is coupled with non-contact temperature measurements by thermal radiation analysis to monitor and control the fuel temperature. Based on experiments conducted on Uranium dioxide samples, we demonstrate the performance of the system in the range 20-2000°C with 10 µm resolution on a field of 1cm, with simultaneous temperature measurements obtained by multispectral pyrometry. We also discuss the limitations of the system as well as further developments for integration in a hot cell for application to irradiated fuels.

## Context

### Nuclear fuel research

Understanding the behaviour of nuclear fuels will give us possibility to enhance nuclear reactor safety and to precisely define specific on-site emergency plans in an extreme event. To reveal different mechanisms of above mentioned interaction, Merarg (Moyen d'Etude pour Recuit et Analyse des Relâchements Gazeux - Study Method for Annealing and Gaseous Release Analysis) is used. It is a device that has been developed and patented by the CEA Cadarache [1] to simulate the thermal level seen by the fuel pellets in Pressurized Water Reactors (PWR) in the case of LOCA type accident, at the hot cell laboratory level.

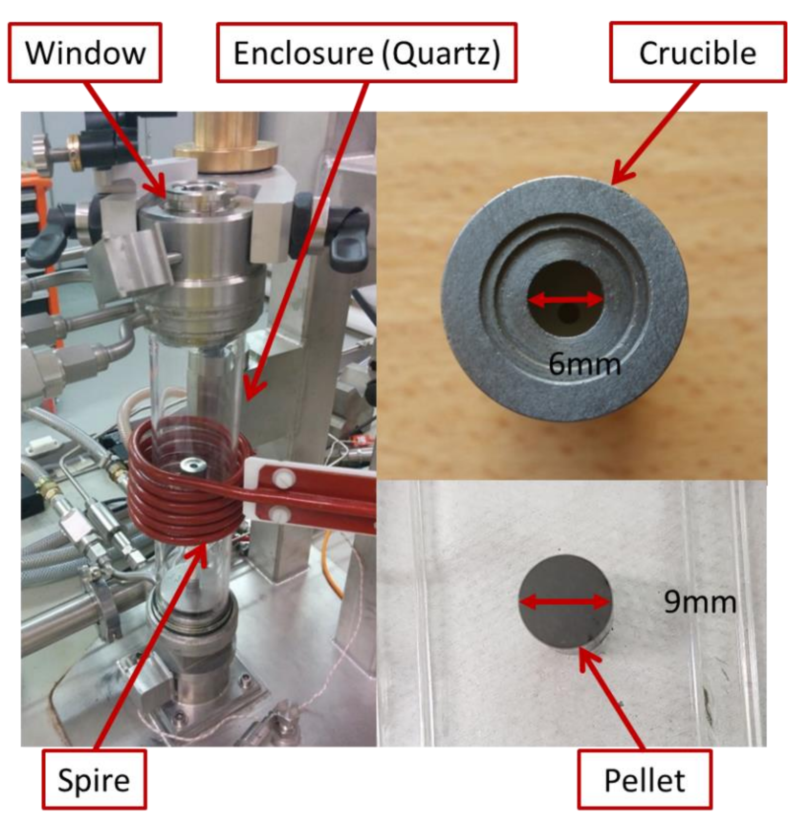
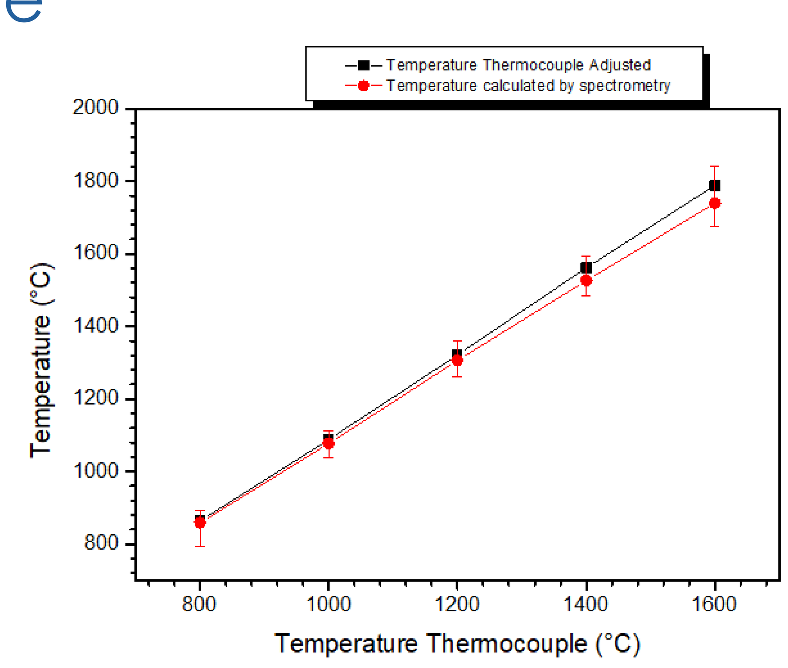



*Photo of Merarg (left), of the crucible (top right) and of a UO2 pellet (bottom right)*

## Results

### Measurement example

Starting point for measurements was 800°C (pellet begins to radiate sufficiently to obtain a usable spectrum) and , afterwards, every next 200°C. The last data was collected at 1600°C. Above this temperature, (1700°C), the spectrometer saturated .Experimental data are in reasonable agreement with qualification phase and suggest a temperature determination with an uncertainty of ±50°C at high temperature. This range could be refined after further work on the calibration, which would require access to a black body at very high temperature.




*Temperature of the sample from the qualification phase and ,as determined , by multispectral pyrometry*

### Visualization

The system allows us, to capture transient events such as the observations of cracking of the pellet during a rapid cooling sequence. At high temperature (>1500°C), the pellet acts as its own source of light by radiation. When the condition is reached( T>1500°C), the observation channel used on the camera is temperature.

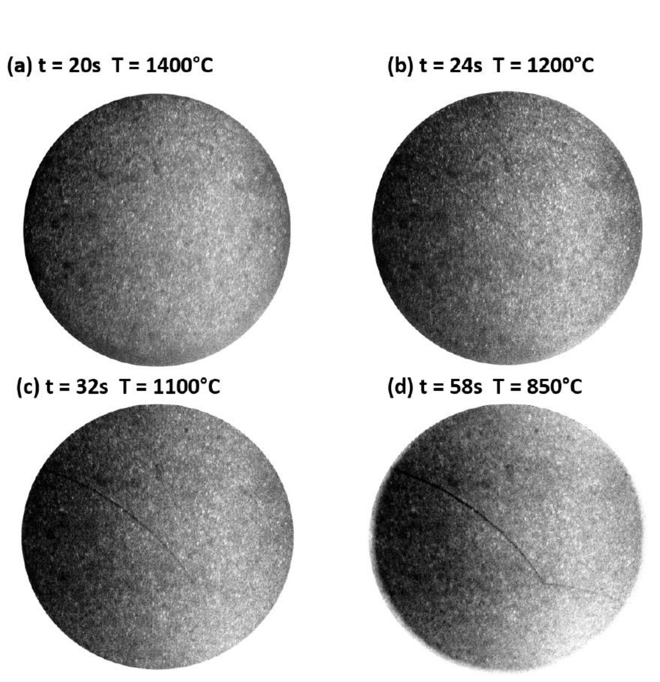
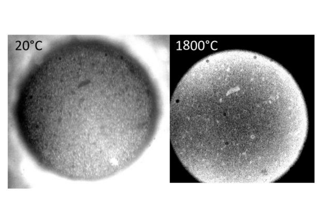



*Image sequence illustrating the cracking of the pellet during a cooling phase*

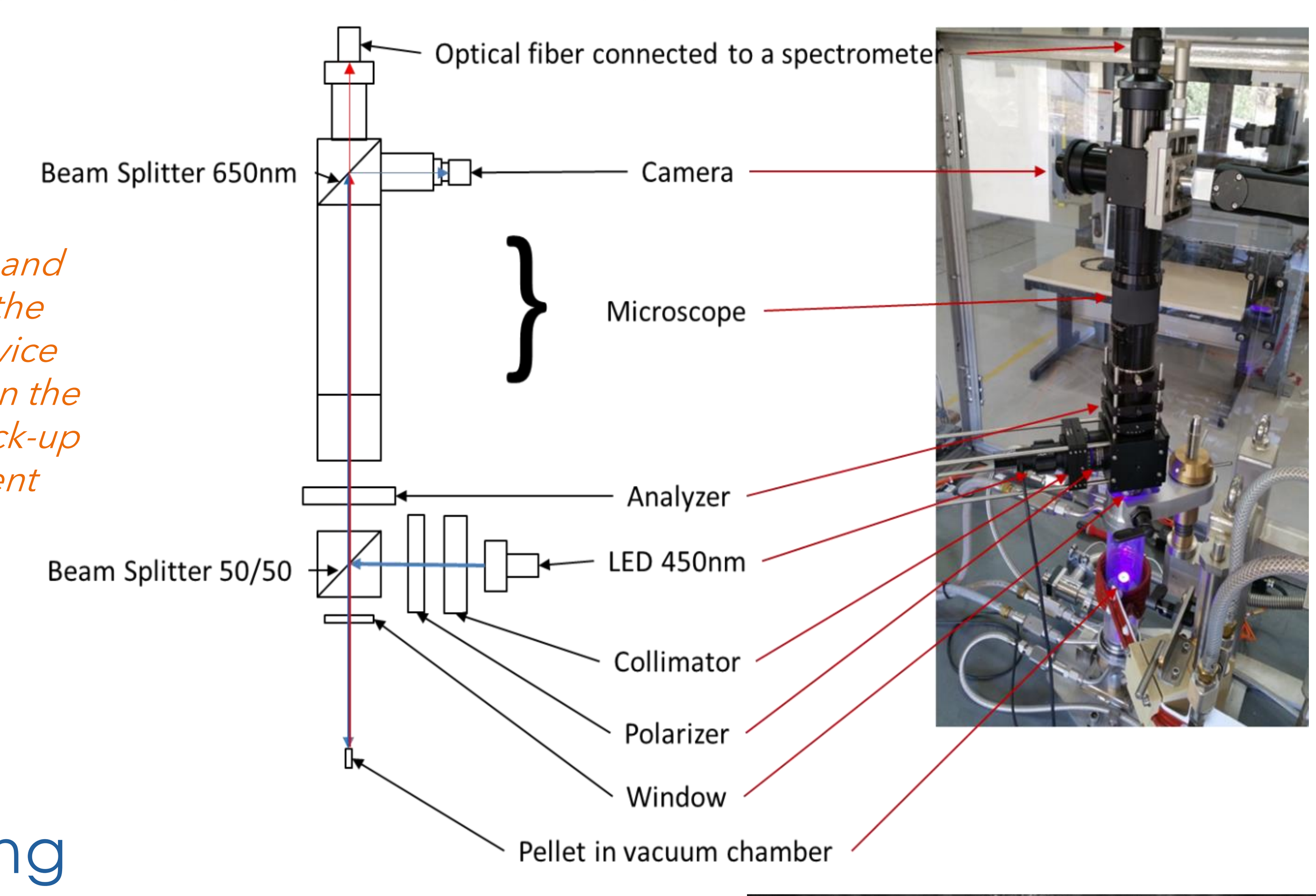


*Observation of a $UO_2$ sample at ambient temperature and at 1800°C*

## The optical device

### Concept

The optical system has been developed to allow the visualization and the measurement of the fuel pellet in real-time, during thermal annealing conducted on MERARG. It can provide additional information, for instance, on the micro structure evolution kinetics and fuel fragmentation. It is intended to operate in a hot laboratory environment, although at this point we report only on the implementation in a mock-up experiment of MERARG.

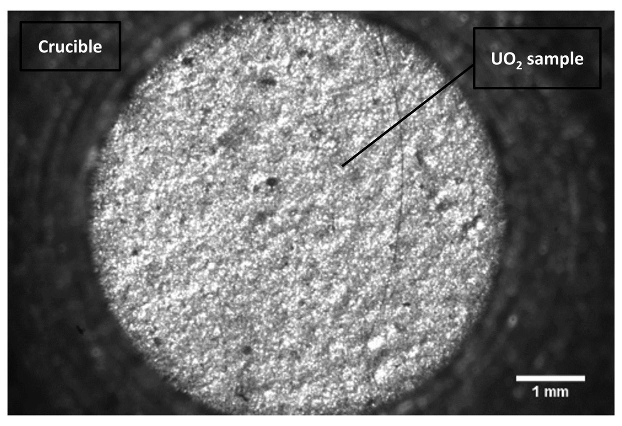



*Schematic and photo of the optical device operating on the Merarg mock-up experiment*

### Imaging

The optical device use a commercial colour camera (RGB) : that allow to operate simultaneously in different spectral bands, and take benefit for imaging in a large range of temperature, as it will be shown in the "Results – Visualization" part.

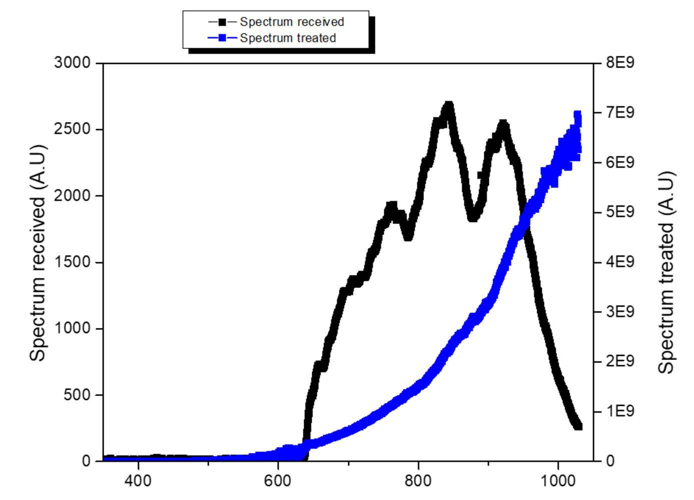
With 2048x2048 pixels on the camera, pictures obtained have a 10µm resolution on a 1cm². The use of a fast frame rate camera (>1000 images/s) to allow to capture transient events.



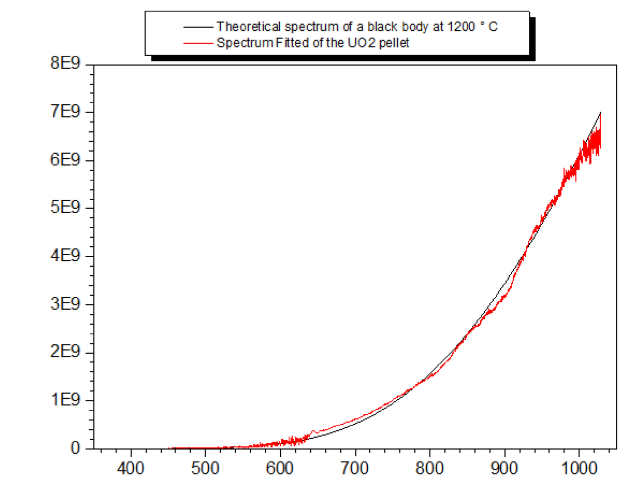

*Observation of a $UO_2$ pellet with the optical system*

### Multispectral pyrometric measurement

The system used multispectral pyrometric techniques. This technique requires only the wavelength dependence of the emissivity to retrieve the surface temperature and it is suitable for operation in extreme environments encountered in the nuclear field.




*Spectrum as received from the spectrometer of a $UO_2$ pellet heated at 1200°C (black) and after processing with the inverse transfer function (blue)*




*Measured spectrum of a heated $UO_2$ pellet (red) and fitted with Plank's law at 1200°C (black)*

## References

[1] S. Clement, Y. Pontillon, H. Capdevila, S. Bernard, V. Marty, M, Pontillon, G. Volle, H. Desmonts, F. Fiorito 2011 "*Note Technique : Qualification de l'instrumentation MERARG II*" (2011).

[2] T. Vidal, R.Burla, L. Gallais, F. Martin, H. Capdevila, Y. Pontillon., '*Development of experimental platform for analysis and imaging of fuel pellets heated at high temperature*', Top Fuel, Prague, Czech Republic, 2018.