MERCI – MOSAIC: EXPERIMENTAL TOOLS FOR RESIDUAL POWER MEASUREMENT IN THE OSIRIS REACTOR

Ch. BLANDIN, S. LOUBIERE, D. GALLO-LEPAGE
CEA/Saclay –DEN/DANS/DRSN/SIREN - 91191 Gif-sur-Yvette Cedex – France

S. BOURGANEL, JC. NIMAL
CEA/Saclay –DEN/DANS/DM2S/SERMA - 91191 Gif-sur-Yvette Cedex – France

L. GROS D'AILLON, Ph. CLEMENT
CEA/Grenoble –DEN/DTN/SE2T – 38054 Grenoble – France

R. ESCHBACH
CEA/Cadarache –DEN/DER – 13108 St Paul Lez Durance – France

ABSTRACT

MERCI and MOSAÏC are two devices, dedicated to the accurate characterization of the residual power of a shortened PWR fuel rod immediately after its irradiation. This energy, produced after reactor shutdown, is mainly generated by the decay of unstable nuclei created during reactor operation. The knowledge of this physical quantity is of major importance for safety evaluation of a nuclear power plant including thermal aspects (residual heat) and radioprotection aspects (radiations spectra). This residual power is involved in the design of the cooling circuits of the core (normal or accidental operations) and of the pool (spent fuel storage). Transportation and reprocessing are also concerned.
Today, according to the consequences for safety, engineers are brought to add uncertainties to the calculated residual power in proportion with the severity of the accident. They can reach 1, 2 or even 3σ. The economic consequences of such margins are strong enough to motivate efforts for improvement.
This experiment, funded by CEA, EDF and GDF-SUEZ, aims at:

- Decreasing decay heat uncertainties ;
- Qualifying FAKIR and DARWIN/PEPIN CEA inventory codes ;
- Identifying anomalies in basic nuclear data (cross-sections, decay data,…) evaluations if any.

MERCI and MOSAÏC devices are successively used during the experiment including three phases:

- First phase: irradiation during 55 EFPD of a shortened PWR fuel rod in the reflector of the OSIRIS reactor core ; there, the mean linear power reached was about 300 W/cm and the burn-up achieved at the end of irradiation was about 4 GWd/t;
- Second phase : transfer of the experimental load after a scheduled shutdown of the reactor from its irradiation location to the hot cell for its introduction inside MOSAÏC calorimeter ; this transfer was performed in a 26 minutes period;
- Third phase: real time measurements of the decay heat released by the fuel using the MOSAÏC device during 50 days; over this period the power decreases from about 200 W to 4 W.

1 Introduction.

Quantification of the decay heat induced by nuclear fission within nuclear power reactors is an important factor in the design of those reactors and for the post-irradiation handling of nuclear fuels (fuel discharge, storage, transport, reprocessing and waste handling). The total decay heat as a function of cooling time has a significant impact on the safe operation and costs of nuclear power generation. A drastic reduction of uncertainty in the decay heat at short cooling times has an important implication on the operation costs.

The reduction of those uncertainties induces experimental needs. Then, two specific devices have been developed by CEA:

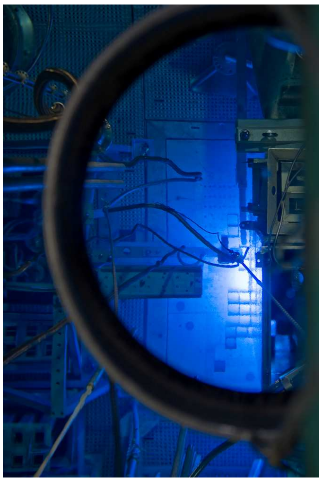
- An irradiation device to carry out the irradiation of a fresh UO_2 pin in the periphery of the OSIRIS reactor core [1],
- A calorimeter (so called MOSAIC) to measure the residual power with a target precision of 1% [2].

MERCI and MOSAIC devices are successively used during the experiment including three phases:

- First phase: irradiation during 56 EFPD of a shortened fuel rod within MERCI device in the reflector of the OSIRIS reactor core ;
- Second phase: transfer of the experimental load after a scheduled shutdown of the reactor from its irradiation location to the hot cell for its introduction inside the MOSAIC calorimeter ;
- Third phase: real time measurements of the decay heat released by the fuel rod using the MOSAIC device during 50 days.

2 Irradiation Phase.

2.1 OSIRIS reactor.



OSIRIS is a research reactor with a thermal power of 70 MW. It is a light-water reactor, open-core pool type, the main aim of which is to carry out tests and irradiate the fuel elements and structural materials of nuclear power plants under a high flux of neutrons, and to produce radioisotopes [3]. Located within the French Atomic Energy Commission (CEA) centre at Saclay, it is close to many research teams and inspection laboratories and has a large-scale technological infrastructure.

2.2 MERCI experimental device.

In order to reach the required irradiation conditions, the MERCI device has been implanted in the periphery of the OSIRIS reactor core (Figure 1).

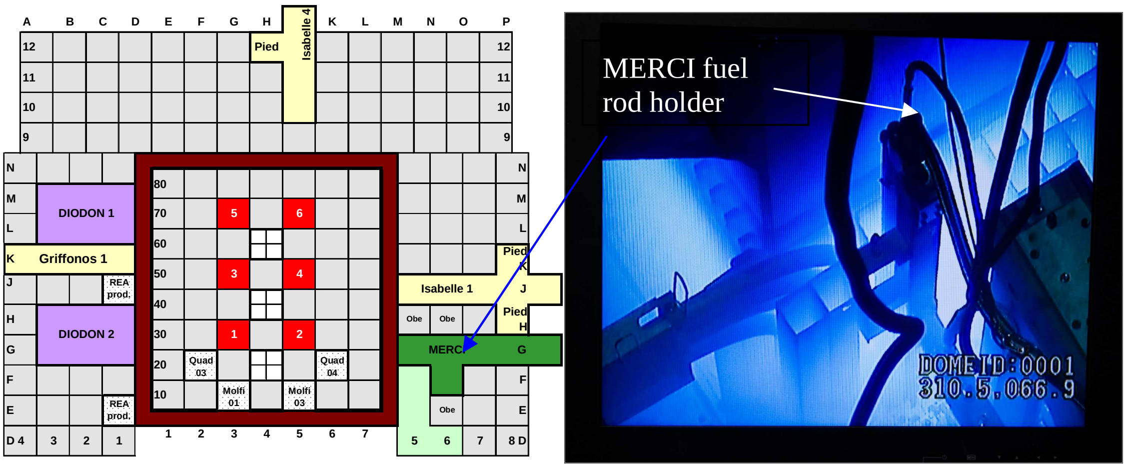


Figure 1 : Layout of the MERCI device in the reflector of the OSIRIS reactor core.

MERCI device is composed of two mechanical assemblies (Figure 2): the experimental load (mobile part intended to be transferred to the hot cell) and its support structure (part fixed to the reactor pool wall).

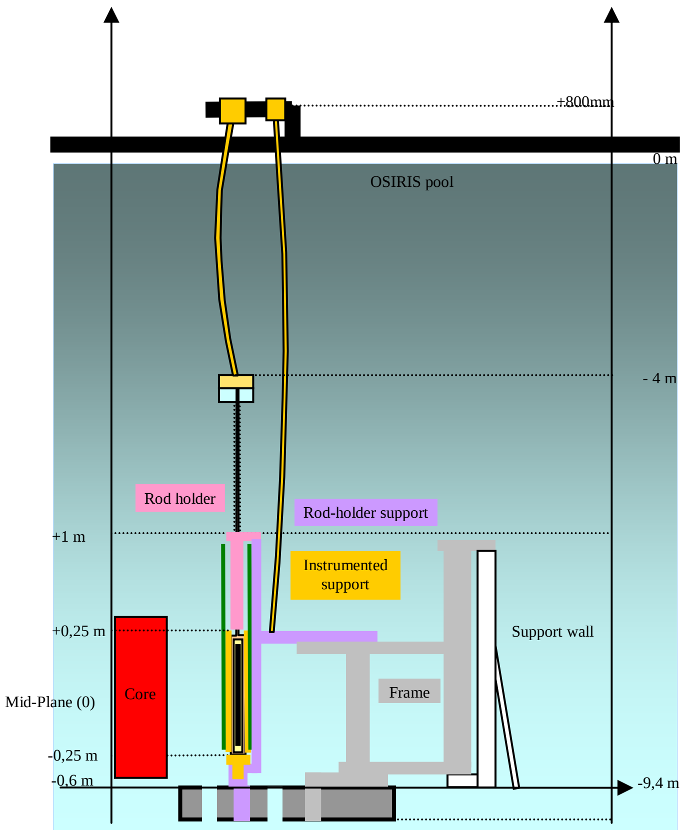


Figure 2 : Layout of the MERCI device in the OSIRIS pool.

The fuel rod is inserted inside a fully instrumented channel (so called "instrumented support" in the Figure 2) equipped with 10 thermocouples and 9 neutron detectors (Figure 5):

- 6 Rhodium Self Powered Neutron Detectors (SPND) and 2 Cobalt SPND; in particular 4 Rh-SPND are located in the fuel rod mid-plane. These Rh-SPND deliver an accurate on-line assessment of the thermal neutron flux but with a delayed response time (about 12 minutes).

Figure 3 : Rh-SPND (OD 1.5 mm)

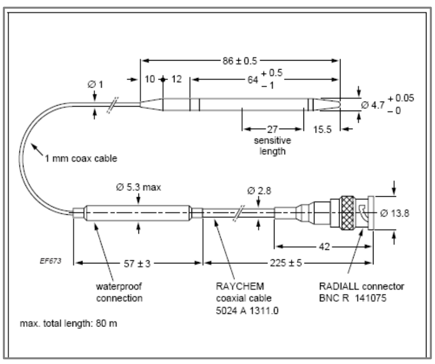


Figure 4 : CFUF 43 fission chamber

- A removable fission chamber (CFUF 43 type, manufactured by the PHOTONIS company); this fast response time detector is dedicated to the scheduled power transients follow-up, such as the scheduled reactor shutdowns and the few days at the end of the MERCI irradiation. Indeed, the quality of the experiment strongly depends on the knowledge of irradiation history.

Moreover two stacks of activation dosimeters are located at the front and at the rear side of the rod, in order to measure the axial neutron flux profile.

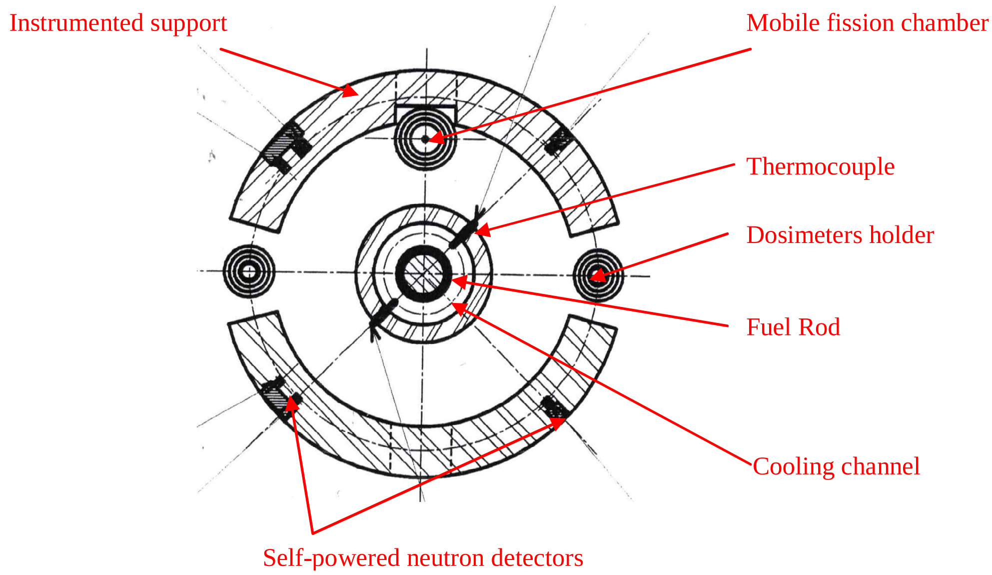


Figure 5 : Cross section of the MERCI instrumented support

2.3 Fuel Rod.

The experimental fuel load is composed a fresh UO2 pellets in a Zy-4 cladding and Stainless Steel (SS) containment:

Fuel	UO_2
^{235}U Enrichment	3.7%
Cladding material	Zircaloy-4
Fissile column height	~ 400 mm
Fuel rod height	~ 520 mm
Zy-4 cladding outside diameter	~ 9.5 mm
SS containment outside diameter	~10.8 mm

Table 1 : Main characteristics of the MERCI fuel load.

2.4 Linear power.

The irradiation of the MERCI fuel rod was carried out between 2007/12/20 and 2008/03/17. The on-line linear power was assessed with the on-line thermal neutron flux measurement (Rh-SPND) and a TRIPOLI-4 [4] modelling (Figure 6): then this mean linear power was close to 290 W/cm (Table 2).

In order to ensure a sufficient build-up of the actinides, the burn-up achieved at the end of the irradiation was about 4 GWd/t (obtained during 55.3 EFPD).

OSIRIS Cycle	Mean reactor power (MW)	Dates	EFPD (days)	Mean linear power in the MERCI rod (W/cm)
F223	66.7	2007/12/20-2008/01/07	17.3	312
F224	66.5	2008/01/21-2008/02/11	19.7	260
F225	68.1	2008/02/21-2008/03/17	18.3	291
			55.3	

Table 2 : Mean linear power for each OSIRIS cycle.

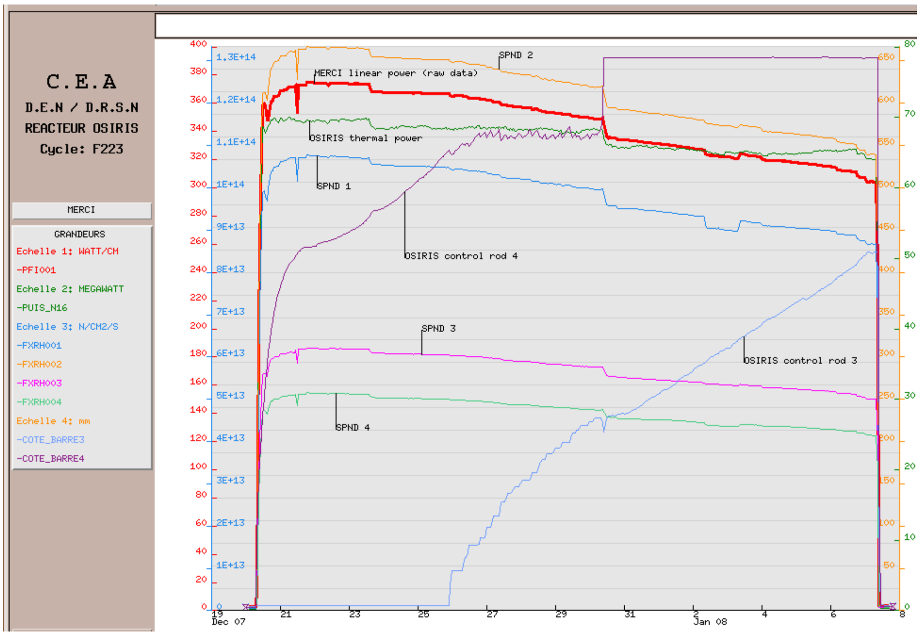


Figure 6 : MERCI experimental data during the cycle F223 of OSIRIS reactor.

3 Transfer Phase.

The transfer of the experimental load, after a scheduled shutdown of the reactor, from its irradiation location to MOSAIC calorimeter (inside the hot cell), was achieved in 26 minutes on March 17, 2008. This transfer is described in the Figure 7.

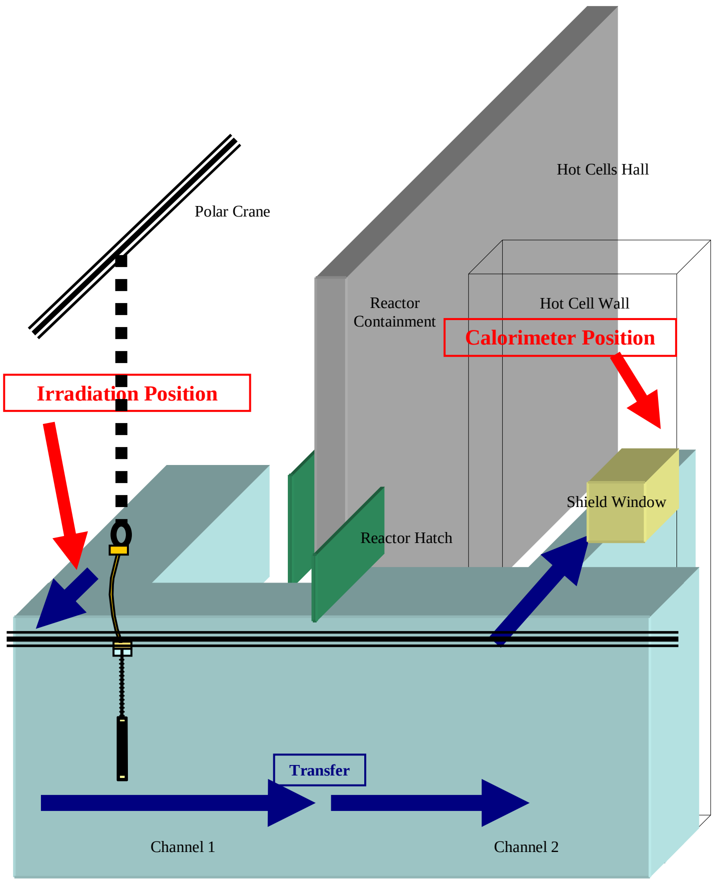


Figure 7 : Path of the fuel load from the reactor hall to calorimeter (in the hot cell).

A trained team including more than 15 persons (operating and radiation protection staff and experimenters) was involved for this operation (Figure 8 & Figure 9). Moreover a human factor and ergonomic study also contributed to combine performance and safety.

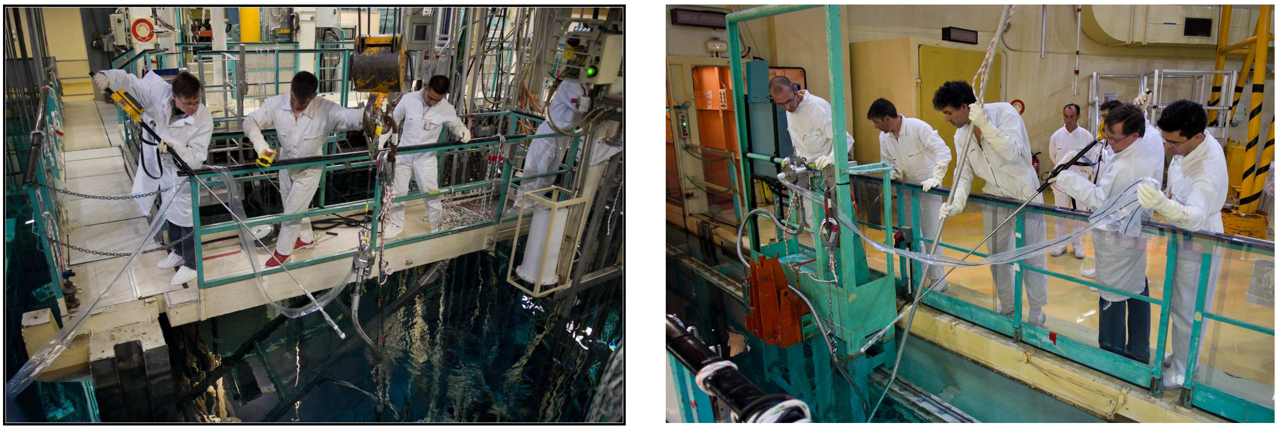


Figure 8 : The transfer phase of the MERCI experiment (views in the reactor hall).

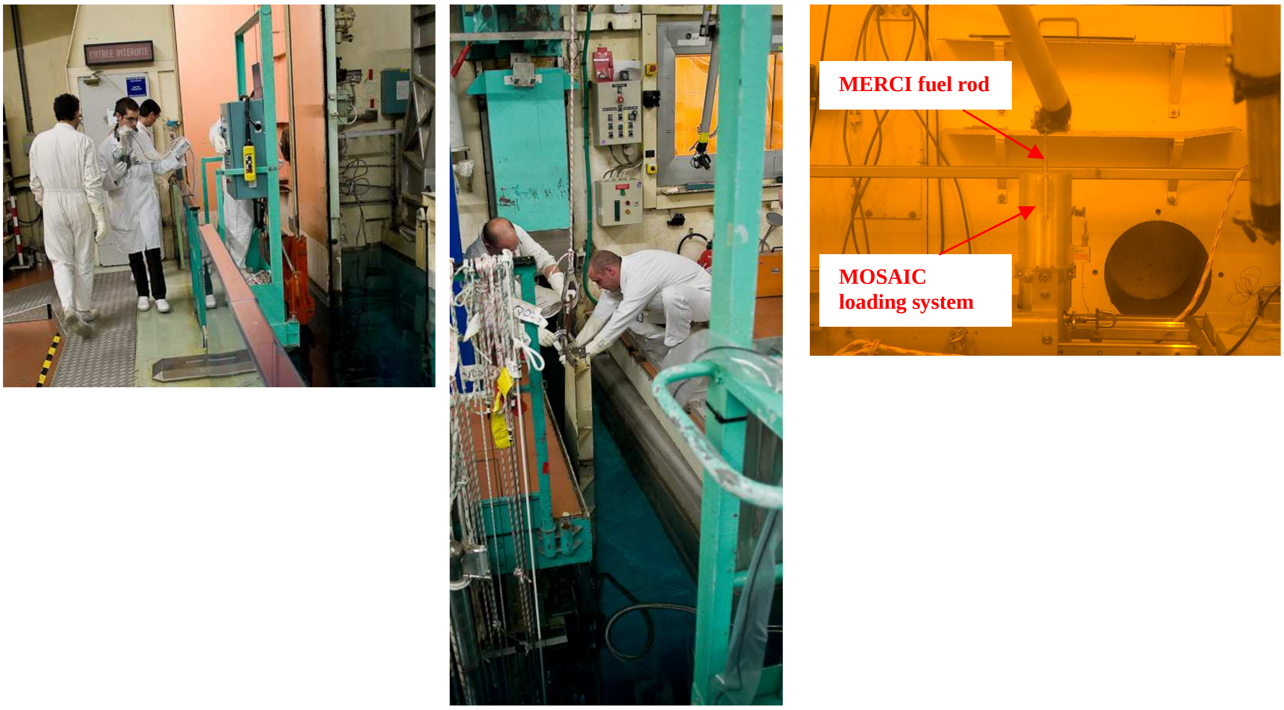


Figure 9 : The transfer phase of the MERCI experiment (views in the hot cells hall).

4 Residual power measurement.

4.1 MOSAIC calorimeter.

Developed and patented by CEA/Grenoble (DTN/SE2T) [2], the MOSAIC calorimeter design is based upon the heat pipe principle (Figure 10): the cold element is the condenser and the warm element is a tungsten cylinder. The tungsten with its high density (~18) reduces gamma leakage. MOSAIC was specially developed to reach an aimed precision of 1 % and then designed for a drastic reduction of heat losses.

The residual power is assessed by a precise heat balance measurement on the secondary system using an accurate instrumentation (platinum resistance thermometers and Coriolis flowmeters).

The main components of this device and the heat pipe itself were installed inside a hot cell. The acquisition and regulation system, coolant systems as well as electric and safety bays were outside (Figure 11).

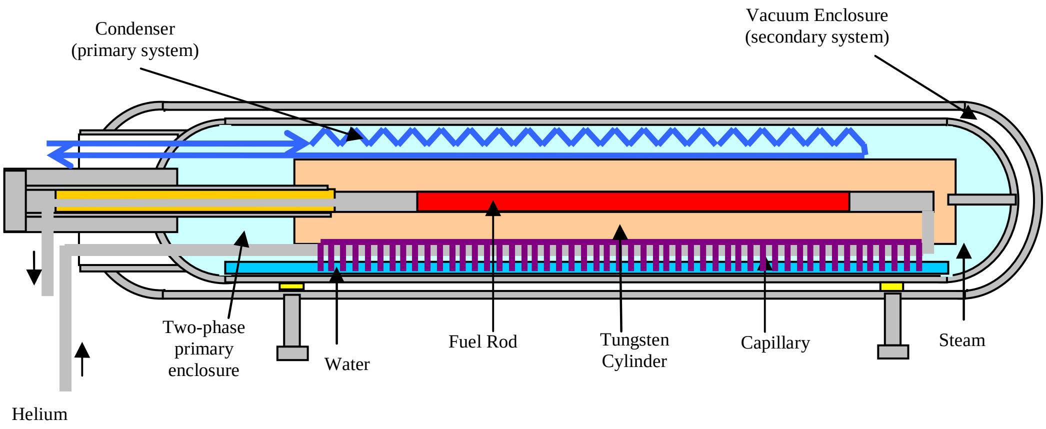


Figure 10 : Sketch of the MOSAIC calorimeter.

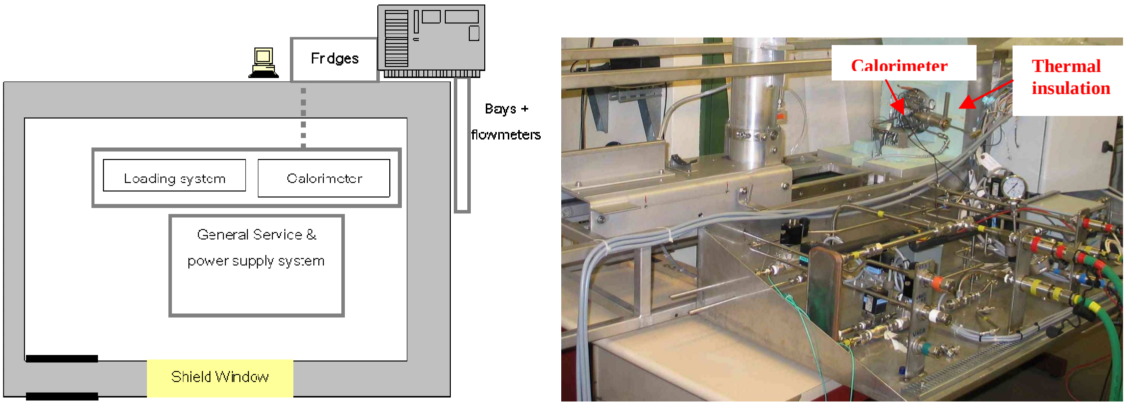


Figure 11 : Layout of the MOSAIC device in the hot cell area and its general service & power supply system (before setup within the hot cell)

4.2 Raw experimental result.

The decay heat released by the fuel using the MOSAÏC device was measured during 50 days, between 2008/03/17 (26 minutes after the end of the irradiation) and 2008/05/05.
Over this period the power decreased from about 200 W to 4 W (Figure 12).

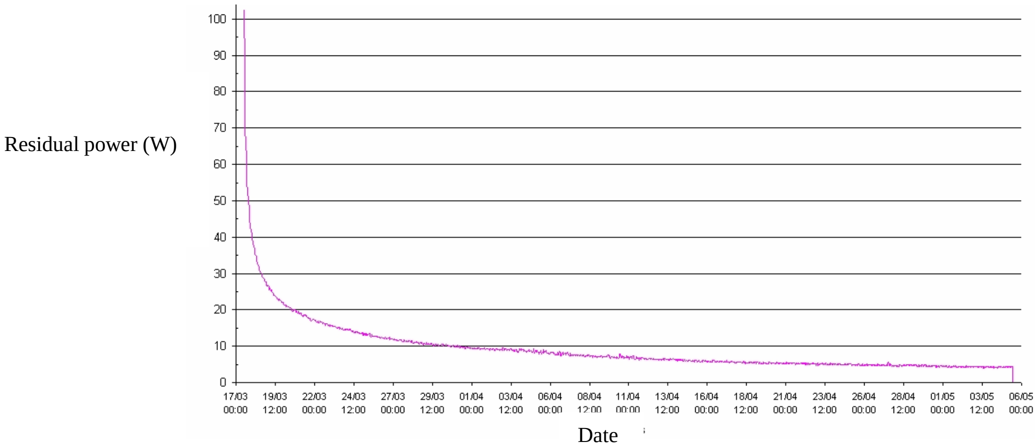


Figure 12 : Measured residual power (raw data).

5 Conclusions

In order to characterize accurately the residual power of a PWR fuel rod immediately after its irradiation, CEA has developed two specific experimental tools: the MERCI device to carry out the irradiation of a fresh UO_2 pin in the periphery of the OSIRIS reactor core and the MOSAIC calorimeter to measure the decay heat.

The MERCI short fuel rod was irradiated in the reflector of the OSIRIS reactor between 2007/12/20 and 2008/03/17. In order to ensure a sufficient build-up of the ^{239}U and ^{239}Np actinides, the burn-up achieved at the end of irradiation was about 4 GWd/t. The transfer of the MERCI rod from the irradiation device to the MOSAIC calorimeter, the key moment of the experiment, was achieved in a very short time (26 minutes). The measured raw residual power decreased from about 200 W to 4 W after a 50 day period.

Several non-destructive tests of the fuel rod (γ spectroscopy & neutron radiography) and the dissolution of one pellet were performed in the CEA labs. Using mass spectrometry techniques, the burn-up (Cs and Nd isotopes) and U/Pu & Nd/Pu ratios were quantified.

The detailed analysis of the experimental results is in progress at CEA/Grenoble (DTN/SE2T) for the thermal measurements and at CEA/Saclay (DM2S/SERMA) for the neutronic simulations using the Monte Carlo transport code TRIPOLI-4 [4] and the inventory code DARWIN/PEPIN2 [5].

After the full success of this first experiment with UO_2 fuel, the next irradiation with MOX fuel is planned in the OSIRIS reactor at the end of 2011.

References

[1] S. Bourganel – “Design of an experiment dedicated to the measurement of the decay heat released by an irradiated fuel: MERCI experiment” – Thesis (PhD), November 27, 2002.

[2] L. Gros d'Aillon - MOSAIC patent: "Ex-reactor two phase transient nuclear calorimeter" - Priority claim number & date: FR/2007/0058626, 2007, October 26 - International publication reference: WO/2009/053456.

[3] S. Loubière et al. - “OSIRIS reactor for fuel, material and other irradiations”- 12th International Group On Research Reactors (IGORR), 2009, October 28-30, Beijing.

[4] J.P. Both et al. - “User Manual for Version 4.3 of the TRIPOLI-4 Monte Carlo Method Particle Transport Computer Code”, CEA-R-6044 (2003).

[5] A. Tsilanizara, C.M. Diop et al. - “DARWIN: An Evolution code system for a large range of applications”, Journal of Nuclear Science and Technology, Suppl.1, p.845-849, March 2000.