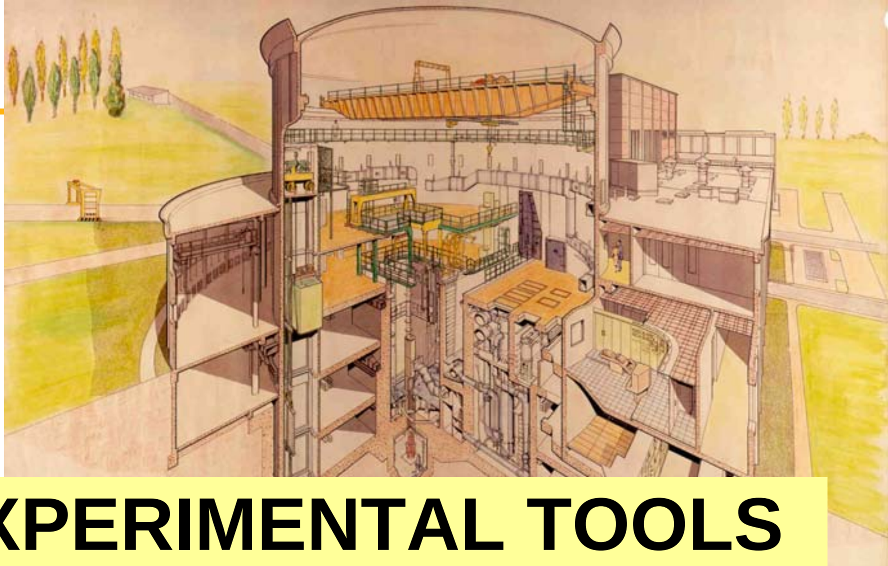

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MERCI – MOSAIC: EXPERIMENTAL TOOLS FOR RESIDUAL POWER MEASUREMENT IN THE OSIRIS REACTOR

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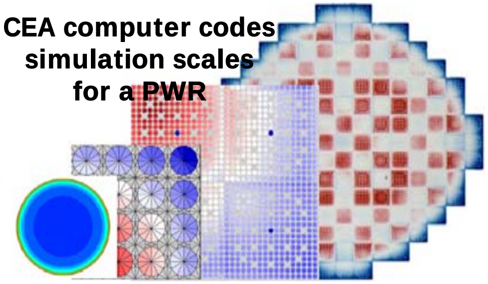
Introduction - objectives

- **Quantification of the decay heat induced by nuclear fission within nuclear power plants is an important factor :**
  - In the cooling system design of those reactors
  - For the post-irradiation handling of nuclear fuels
    - *Removal of fuel from reactors*
    - *Storage of spent fuel*
    - *Transport of spent fuel*
    - *Reprocessing of spent fuel*

Spent fuel storage (La Hague, AREVA-NC)

- **The total decay heat as a function of cooling time → significant impact on the safe operations and costs**
- **A drastic reduction of uncertainty in the decay heat at <u>short cooling times</u> → important implication on the operation costs**

- **Objectives:**
  - To decrease decay heat uncertainties
  - To qualify FAKIR and DARWIN/PEPIN CEA inventory codes,
  - To identify anomalies in basic nuclear data (cross-sections, decay data,…) evaluations



CEA computer codes simulation scales for a PWR

Experimental program in OSIRIS reactor

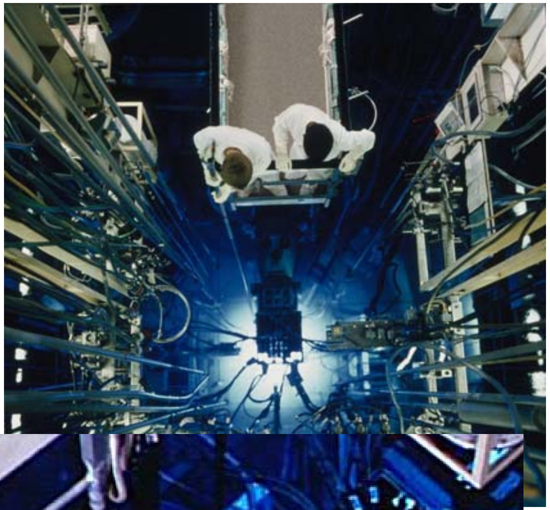
- **Experimental needs in order to reduce those uncertainties:**

  → **two specific devices developed by CEA:**
  - An irradiation device (so called **MERCI**) to carry out the irradiation of a fresh UO2 pin in the periphery of the OSIRIS reactor core,
  - A calorimeter (so called **MOSAIC**) to measure the residual power with a target precision of 1%.

- **MERCI and MOSAIC devices 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.

Irradiation phase (1/5)

- **Main characteristics of OSIRIS research reactor :**
  - Open core pool type
  - Compact core : 57*57*60 cm3
  - Fuel
    - *38 standard elements*
    - *6 control elements with Hafnium as absorber*
    - *U3Si2Al plates (enriched to 19.75 %)*
  - Moderator, coolant et biological protection : H_2O
  - Thermal power : 70 MW
  - Maximum neutron flux
    - *fast (E>1 MeV) : 2.5 E14 n/cm²/s*
    - *thermal : 2.5 E14 n/cm²/s*



The main goal of OSIRIS reactor → to carry out irradiation tests of fuel and structural materials of nuclear power plants, and to produce radioisotopes

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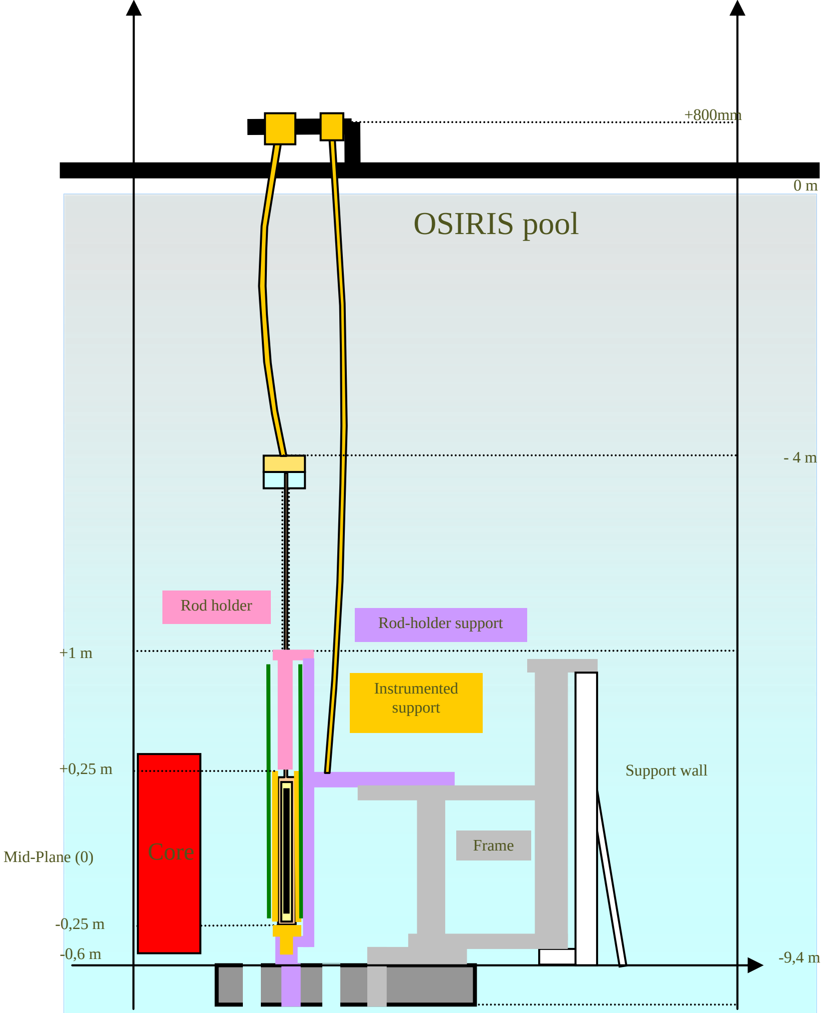
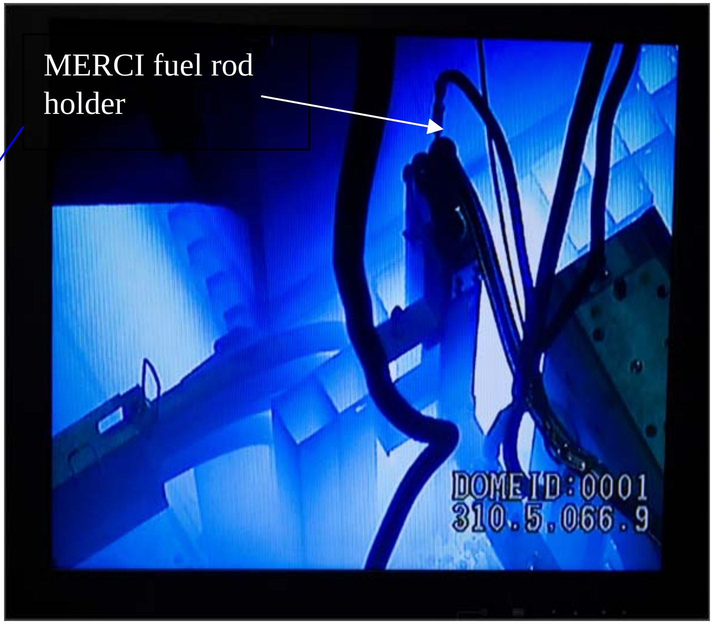
ce at the periphery of OSIRIS reactor core

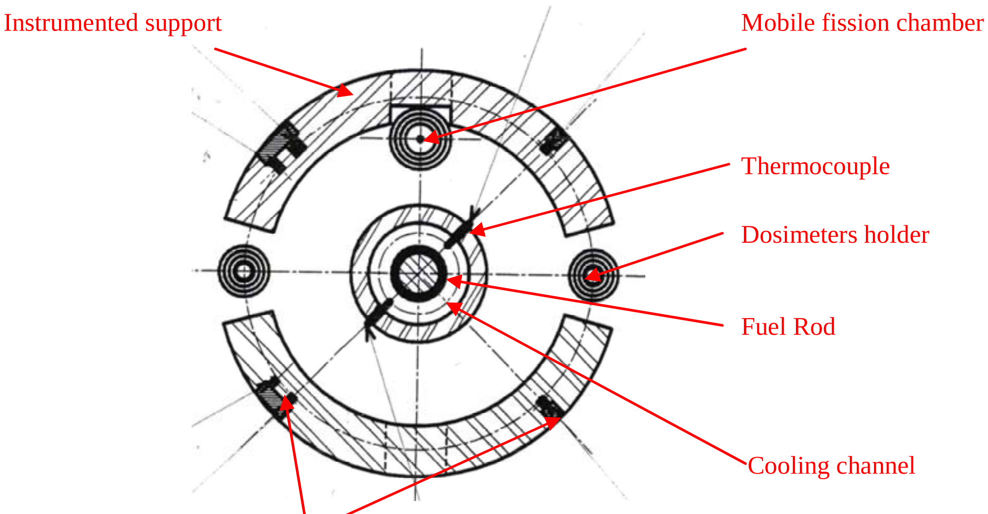




- **MERCI device → composed of two mechanical assemblies:**
  - the experimental load (mobile part intended to be transferred to the hot cell)
  - its support structure (part fixed to the reactor pool wall).

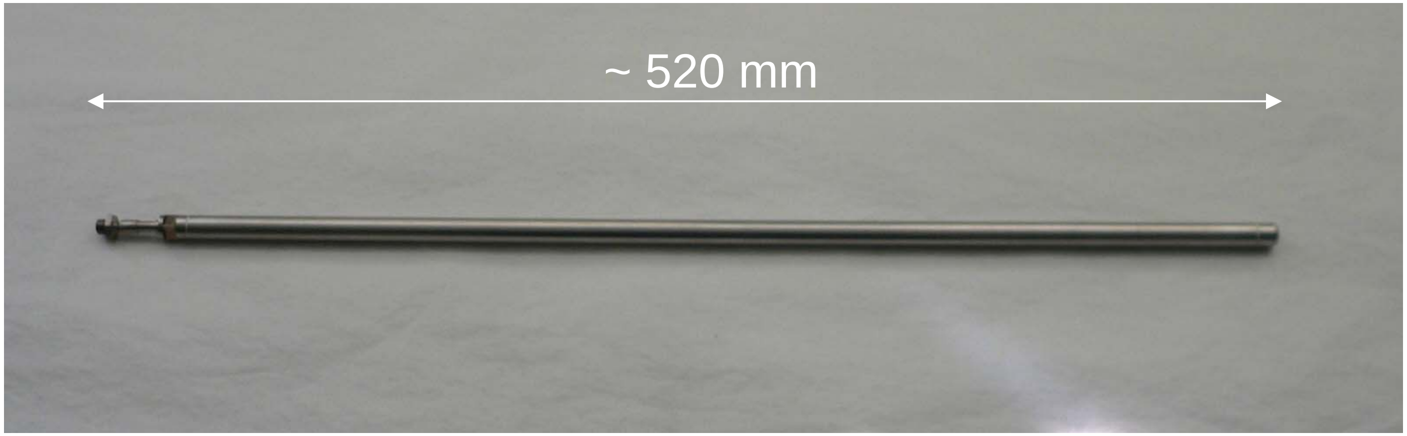
Irradiation phase (3/5)

- **The fuel rod → inside a channel equipped with 10 thermocouples and neutron detectors:**
  - 6 Rhodium Self Powered Neutron Detectors (SPND)
    - *Rh-SPND → accurate on-line assessment of the thermal neutron flux but with a delayed response time (about 12 minutes)*
  - A removable fission chamber
    - *Fast response time detector dedicated to the scheduled power transients follow-up (the scheduled reactor shutdowns) and the few days at the end of the MERCI irradiation* ***→ The quality of the experiment strongly depends on the knowledge of irradiation history***



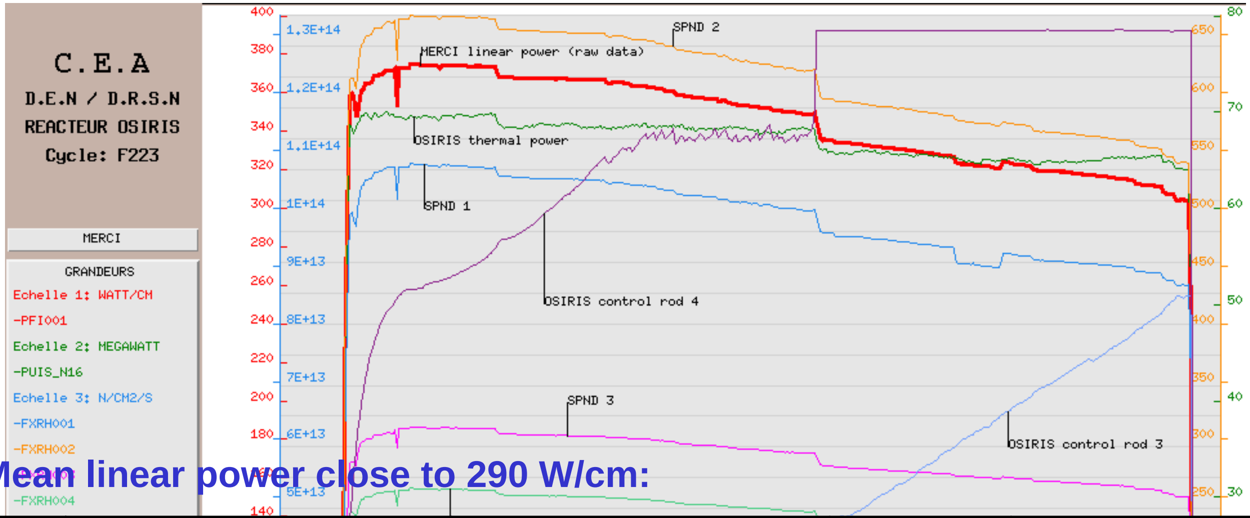
Irradiation phase (4/5)

- **Fuel Rod**
  - Experimental fuel load = fresh UO_2 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*



Irradiation phase (5/5)

- **Result:**
  - **Irradiation of the MERCI fuel rod carried out during 55.3 EFPD (between 2007/12/20 and 2008/03/17):**
    - ***Burn-up at the end of the irradiation → ~ 4 GWd/t in order to ensure a sufficient build-up of the actinides***
  - **On-line linear power assessment with the on-line thermal neutron flux measurement (Rh-SPND) and a TRIPOLI-4 modelling**

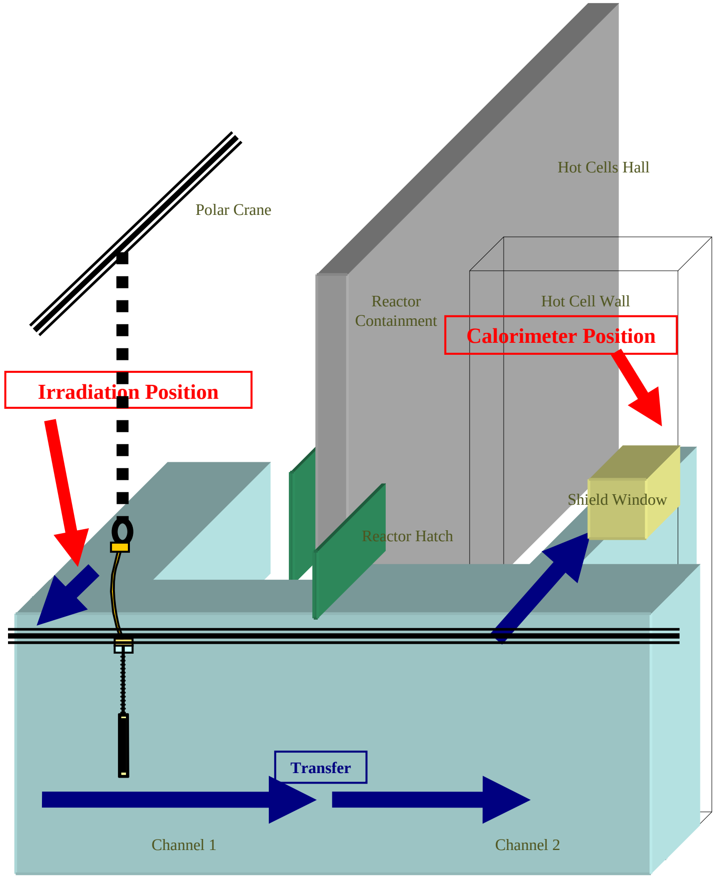


  - **Mean linear power close to 290 W/cm:**

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	

Transfer phase (1/2)

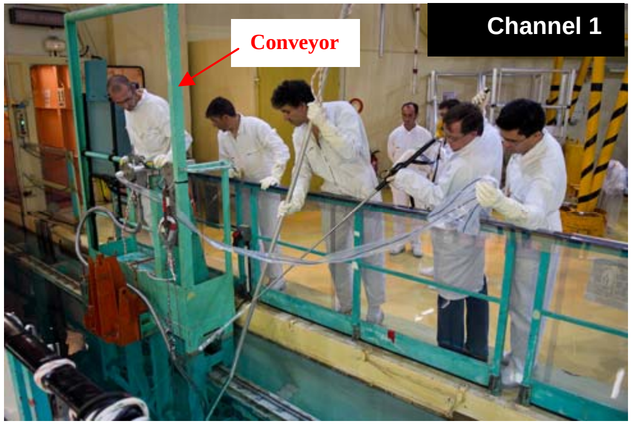
- **The transfer sub-phases of the experimental load :**
  - Scheduled reactor shutdown
  - Removal from its irradiation location
  - Transfer in the MOSAIC calorimeter inside the hot cell

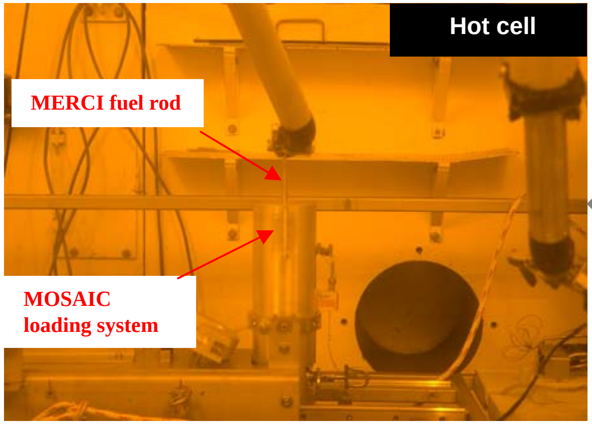


Result : transfer in 26 minutes (March 17, 2008)

- **Key parameters for this successful transfer, combining performance and safety :**
  - A trained team including more than 15 persons (operating and radiation protection staff and experimenters)
  - A human factor and ergonomic study.

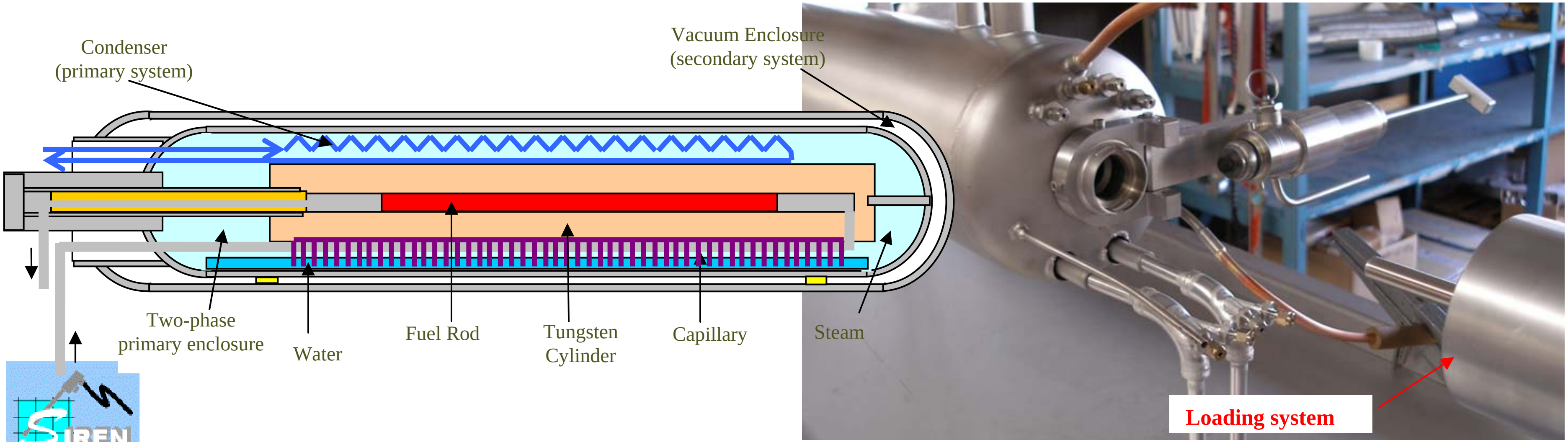
Transfer phase (2/2)





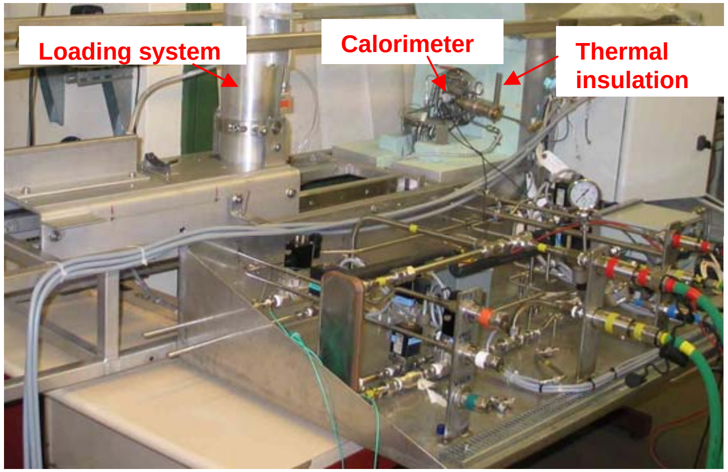
Residual power measurement (1/3)

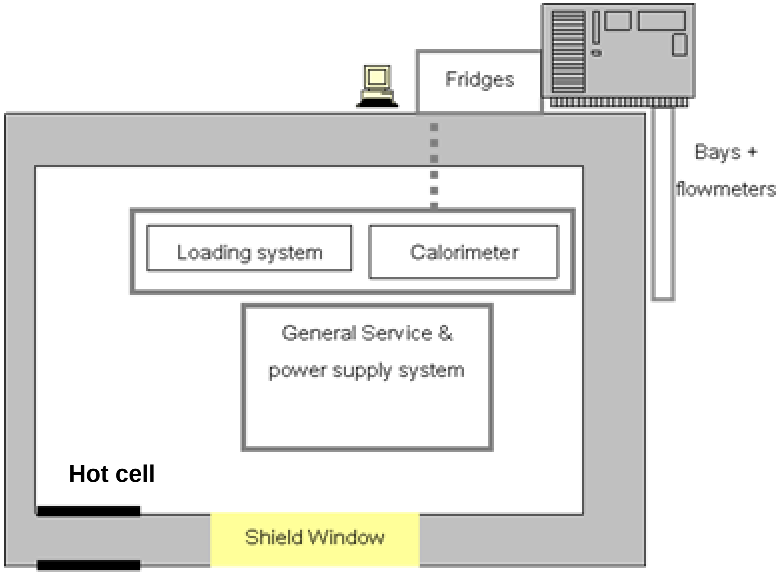
- **The MOSAIC calorimeter:**
  - Developed and patented by CEA/Grenoble (DTN/SE2T)
  - A design based upon the heat pipe principle:
    - *Cold element → the condenser*
    - *Warm element → tungsten cylinder (high density element in order to reduce gamma leakage).*
  - Specially developed to reach an aimed precision of 1 %
  - Designed for a reduction of heat losses
  - Residual power assessment → heat balance measurement on the secondary system



Residual power measurement (2/3)

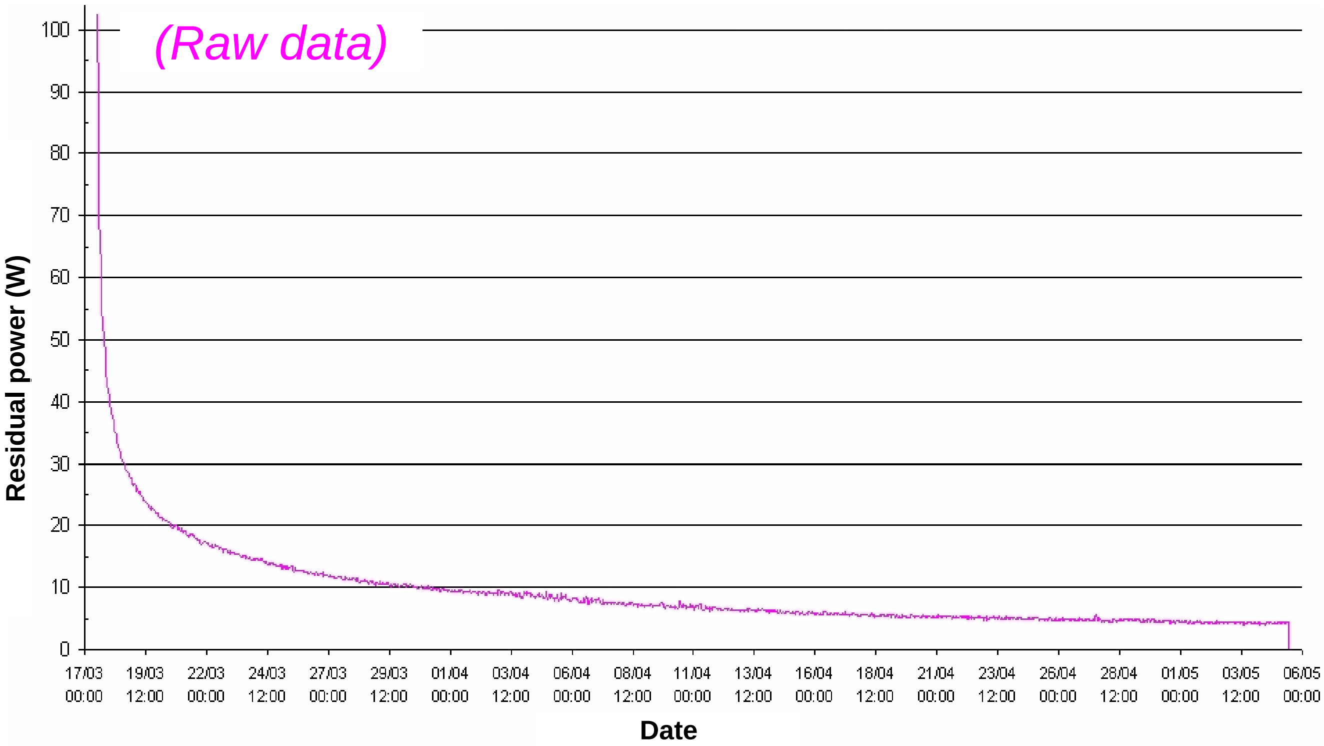
- **Layout of the MOSAIC device in the hot cell area:**
  - Main components (heat exchanger, …) → inside the hot cell
  - Acquisition and regulation system, coolant systems as well as electric and safety bays → outside the hot cell





Residual power measurement (3/3)

- **Result :**
  - Measurement of the decay heat during 50 days → between 2008/03/17 (26 minutes after the end of the irradiation) and 2008/05/05.
  - Decreasing of the power → from about 200 W to 4 W



Conclusion

- **Development by CEA of two specific experimental tools in order to characterize the residual power of a PWR fuel rod:**
  - MERCI device in the OSIRIS reactor → irradiation of a fresh UO2 pin
  - MOSAIC calorimeter in hot cell → measurement of the decay heat
- **Experimental results in OSIRIS reactor:**
  - Irradiation of the MERCI short fuel rod during 55 EFPD (burn-up ~ 4 GWd/t).
  - Transfer of the MERCI rod to the MOSAIC calorimeter in a very short time (26 minutes).
  - Measurement of the residual power → from about 200 W to 4 W after a 50 day period.
- **Post irradiation examinations:**
  - γ spectroscopy & neutron radiography
  - Dissolution of one pellet were performed in the CEA labs
  - Quantification of the burn-up (Cs and Nd isotopes) and U/Pu & Nd/Pu ratios using mass spectrometry techniques
- **Ongoing detailed analysis of the experimental results:**
  - CEA/Grenoble → thermal measurements in the calorimeter
  - CEA/Saclay → neutronic simulations using the Monte Carlo transport code TRIPOLI-4 and the inventory code DARWIN/PEPIN2.

→ Next irradiation with MOX fuel : at the end of 2011 in the OSIRIS reactor

Thank you for your attention !