# JULES HOROWITZ REACTOR PROJECT FUEL IRRADIATION DEVICE INNOVATIVE INSTRUMENTATION PROPOSAL FOR EXPERIMENTAL PHENOMENA REAL TIME MEASUREMENT.

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## ABSTRACT

To answer to the needs of the customers in terms of selection, qualification and behaviour of fuels and materials under neutron flux, Material Testing Reactors (MTR) types are used. These experimental reactors propose high performances in core in terms of fast neutron flux permitting to accelerate the irradiation processes on materials (as ageing phenomenon) but also permitting in the reflector to check, under pre-defined power scenarios, the behaviour (as Pellet-Clad Interaction (PCI) phenomenon) of fuel samples issued of nuclear power plants.

The irradiation devices used for the tests of fuel rods allow reproducing at small scales the conditions of the studied nuclear reactors (as LWR type). Exposed to the neutron flux of the reactor, they allow the test of samples under representative or more severe experimental conditions.

During the irradiation phase, the tested fuel rod can be stressed due to thermal, mechanical, nuclear effects which can modify its geometry (dilatation, swelling effects). After the test, the return to normal conditions can have as consequence the disappearance of the phenomenon or give access to partial information (final deformation).

In this case, the real-time measurement instrumentation constitutes an obvious interest (phenomenon kinetic measurement).

Generally, to follow the phenomena related to the irradiation phase, the experimental rod contained in the test device is instrumented with thermocouples & LVDT[1].As complement of this instrumentation, new sensors using innovative technologies are studied (deformation sensor integrating optical fibres).

On technological point of view, based on the use of an opto-mechanical sensor, the innovative instrumentation allows the on line follow up of the deformation phenomenon. The displacements are measured by an optical module integrated into the body of the sensor. The optical signal is transferred via fibre optics towards an acquisition and signal processing external systems (I&C). The body of the sensor provides a mechanical protection with respect to the conditions of the experimental environment (LWR conditions). The measurement is based on the optical principle of Michelson type interferometer with adapted amplitude of 1mm comparing to the phenomenon to observe (0,5mm range approximately). The optical fibres used have the advantage of a great compactness (low diameter). The implementation of an optical interferometer brings in an intrinsic way a high degree of accuracy for the measurement.

Through the example of a fuel irradiation device foreseen for the JHR, this paper aims to describe the present development of an innovative instrumentation with the objective to measure, in real time and under flux, the fuel rod deformation phenomena during a ramp test.

[1] LVDT : Linear Variable Differential Transformer

## 1. Introduction

In the industrial environment, some embedded components can be affected during their operation phases with various stressed as thermal, mechanical, nuclear which can lead to modify their geometry (deformation, dilatation, swelling) and to go until a degradation of their function even of their loss. The stress causes can be of various types (ex: heating, pressurization,wear). These working conditions can lead to deformation which one wishes to measure in real-time. The return to normal conditions can result in making disappear these phenomena of deformation (e.g. dilatation) or give only one total information of the phenomenon (e.g. wear). The access to the follow-up of the online information (in real-time) constitutes an obvious interest (measurement of the kinetics of the deformation for example).

To allow to solve this difficulty, a measurement "in situ", with close to the structure to be followed more proves to be necessary. Various solutions are possible, with in particular, the placement of integrated miniaturized sensors making it possible to follow on line the deformations.

## 2. The JHR facility [1]

The Jules Horowitz Reactor (JHR,Materials Testing Reactor) is under construction in the south of France (Cadarache, Bouches du Rhone). This Nuclear Facility is dedicated to perform irradiation of materials and fuels in support of actual (LWR) and futures power plants (Gen.IV, fusion).It allows also producing radioisotopes for medical applications, namely Mo-99. This facility will offer to the international community interesting irradiation capabilities (15 dpa/year at 100MWth) for core materials samples, high thermal neutron fluxes in the reflector for irradiation of fuels (corresponding to 8 times the neutron flux in a PWR). It will allow also a high flexibility in terms of experimental conditions, several irradiation locations in the core, in the reflector in fixed and also on movable locations (systems permitting to modify the distance between the sample and the core using pre-defined moving scenario).For different experimental issues, several thermal hydraulics conditions can be obtained (LWR (P&B), HTR, SFR...).

In addition, some supports utilities (storage pools, hot cells, non-destructive equipments (X rays, gamma imaging systems)) are integrated in the facility in order to propose to the customers a complete offer in terms of irradiation services.

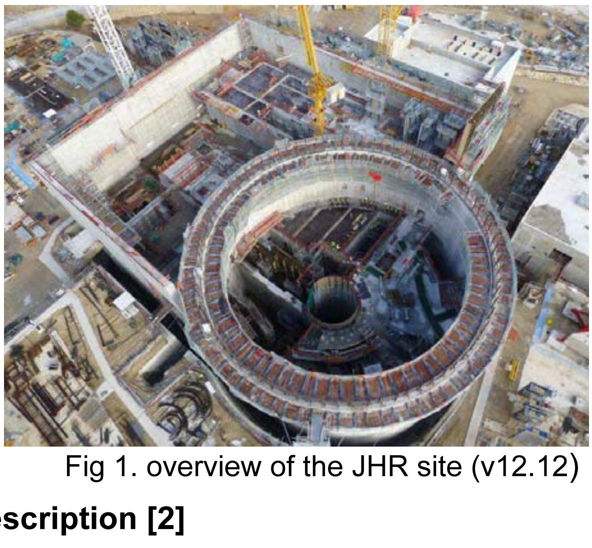

Fig 1. overview of the JHR site (v12.12)

## 3. Fuel test device description [2]

The sample considered for the fuel irradiation experiment will be a typical $UO_2$ or MOx single fuel rod with PWR geometry (diameter 9.5 mm), with a 200 to 600 mm long fissile stack and either being fresh or pre-irradiated up to 120GWd/t.

Current studies concern instrumentation and fluid tightness connectors allowing to load and unload the instrumented fuel sample in the hot cells of the facility.

In order to increase the flexibility of the device, studies are also performed on the internal structures design regarding the possibility to take into account BWR rods samples (diameter up to 12.3mm).

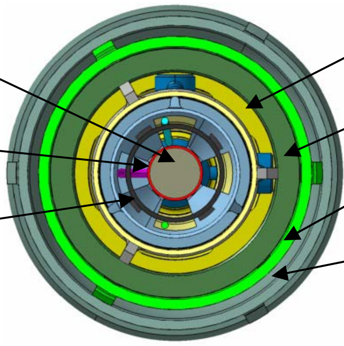


Fig 2. view of a sample holder and the test section (preliminary design)

The loop is composed of two parts: in one part, an in-pile section working under neutron and gamma fluxes, the low and high extensions, the instrumentation lines, the device head, the fluids and electrical lines, the pool experimental and the fission products penetrations (if required) (see Fig.3).

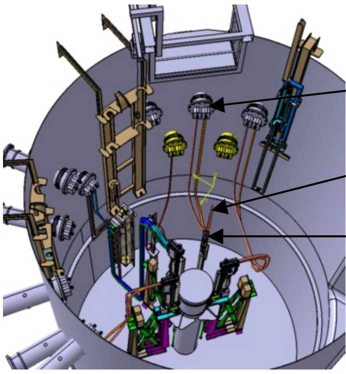


Fig 3. overview of the in pool part.

(in-pile section and flexible connections)

In other part, a grounded section include the fluid circuit and the connections to fixed parts of the facility.
During the experimental phase, the fluid circulating in the loop is regulated in temperature.
The fluid is injected from the out-of-pile section by circulation pumps operating simultaneously to obtain an overall flow rate of 50 g/s (called “inducing flow rate”).
The fluid flows through a flow rate injection module used to re-entrain part of the flow in the test line and thus amplify the inducing flow rate. The amplification factor is around 4 to 5, resulting in a “useful” flow rate in the test channel of 200 g/s.
The fluid exiting the device transits towards the out-of-pile section via an underwater flexible metallic line and a penetration through the pool (see Fig.3).

## 4. Instrumentation equipment on fuel irradiation sample :

Depending of the test objectives, the sample holder (PE) can be equipped regarding different issues:

| test type | sample instrumentation request |
|---|---|
| “simplified” test | no request |
| standard ramp test | deformations rod sensor (mainly axial dilatation)<br>additive instrumentation (option) :<br>-fuel and clad temperatures,<br>-swelling measurement sensor. |

| test type | sample instrumentation request |
|---|---|
| ramp test & fissions products measurements | - fuel and clad thermocouples,<br>- elongation rod sensor,<br>- FP gas sweeping measurements connected to the Fission Products Laboratory.. |

In the case of standard ramp test, the sample can be instrumented with a fuel centreline thermocouple and a cladding thermocouple. At the bottom of the sample holder, a sensor as LVDT type is used in order to follow the dilation of the rod during the test.
For the fission product tests type, two capillary tubes connected to the top and the bottom free volumes of the rod will be used to sweep the gases (fission products) released by the fuel and to route them to the fission product laboratory in the JHR experimentation area. The instrumented sample is maintained in the test section through a sample holder (see Fig 4.).

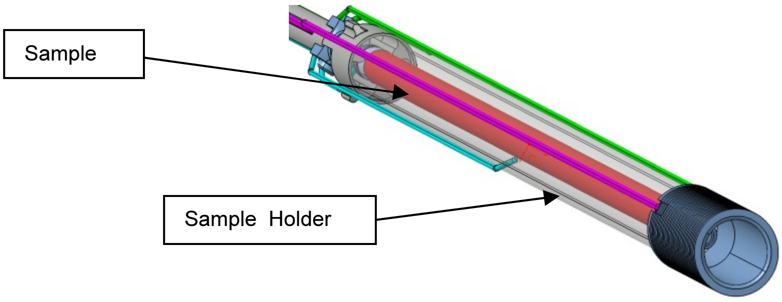


Fig 4. typical view of the instrumented sample holder

## 5. Proposal of innovative instrumentation

In the field of fuel irradiation programs, test devices are used, in particular, to study the phenomena of corrosion under flux or to characterize the thermal mechanical behavior of a fuel rod submitted to variations of power (ramp tests). In this last case, the rod can face during the test deformation (of the swelling type) up to 10% of its diameter. It is this deformation which one seeks to measure in real time.

### 5.1 Principle of measurement

The proposed measurement is based on Michelson type optical interferometry, with a beam light reflecting on one hand on fixed surface known as “of reference” and on the other hand on a “mobile” surface of measurement known as associated with the deformation of the sample (see.fig.5&6).These variations are measured by an optical module integrated into the body of the sensor. The optical signal is transferred via fibre optics towards an acquisition and signal processing external system (I&C).
The system offers a measurement range (about 1 mm) adapted to the phenomenon to observe (0,5mm range specified approximately). The optical fibers and the small components used to make the optical module have the advantage of a great compactness (low diameter). The implementation of beams of light brings in an intrinsic way a high degree of accuracy to measurement (less than 10 microns specified).
To note within this framework, the tests performed in nuclear reactors tested the optical fibers resistance to the irradiation (cf. INSNU program, COSI experiment carried out in OSIRIS reactor in March 2006 (French CEA DRSN/DPC & Belgium SCK-CEN institutes works)).[3]

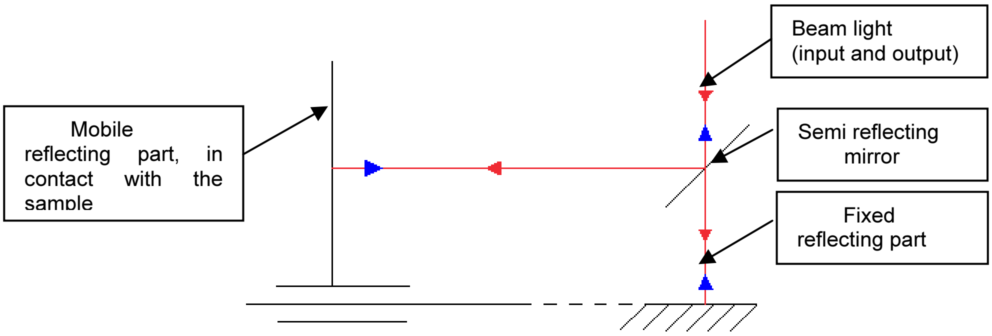

Fig 5. Principle of swelling measurement


Fig 6. Optical module of the sensor inserted

in device with a piston simulating the feeler piece

### 5.2 Technological description:

The system based on the use of an optic-mechanical sensor making it possible via the displacement of a feeler piece in contact with the sample. This part takes into account metal bellows to follow the phenomena of deformation. The fibers and the system of detection are contained in an isolated volume (containment) making it possible to uncouple the environmental conditions of the process of the operating conditions of the sensor (gas). The body of the sensor offers a mechanical protection with respect to the conditions of the experimental environment (fluid, temperature and pressure).
The equi-pressure between the sensor and the fluid of the process is obtained by pressurization with gas in the box of the sensor. This operation makes it possible to avoid pre-stressing the bellows and improve the sensitivity of the sensor.

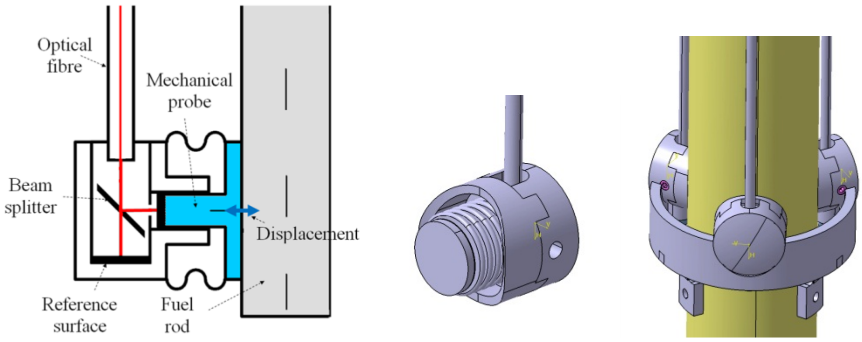

Fig 6. Conceptual design of mechanical part

Nota: due to its actual geometry, the system is located in the downcomer zone and detect the deformation of the rod through holes permitting the penetration of the sensor.

Nominal operating conditions :

- around the test channel: pressurized water (155b,320°C),
- in the sensor: inert gas (155b,320°C),
- nuclear input data:
  fast neutron flux: $0,8.10^{14} n.cm^{-2}.s^{-1}$,
  thermal neutron flux: $1.10^{14} n.cm^{-2}.s^{-1}$,

gamma heating: 3 to 4 $W.g^{-1}$

### 5.3 Advantages of the proposed system:

The solution proposed is designed to offer an integrated solution of low dimension, allow measurement radial deformations (swelling) and functioning under pressure conditions and high temperature. The optical assembly selected allows a wide measurement range with a high degree of accuracy. The design suggested takes into account operation in degraded mode (loss of pressure and confinement conservation).

### 5.4 Next steps

#### 5.4.1 Prototype manufacturing phase

The objective of the next phase will be to validate the industrial manufacture of the sensor. That called upon low-size parts (a few mm), optical components. The phases of machining and assembly request a high level of accuracy. Up to now, a prototype of the optical module part has already been performed [3]. For the mechanical part, the assembly runs require the control of techniques as laser welding types and brazing.

#### 5.4.2 Qualification tests

Once the prototype manufactured, the performance tests will be performed to check the functionalities of the sensor submitted to different stresses:

Normal operation:

- simulating at room temperature, the swelling of a sample by the displacement of the sensor and to check the dynamics of measurement performed by the optical module,
- checking the behavior of the sensor in pressure and in temperature conditions. Leaking tests of the assembled parts and of the tight passages will be performed.

Note that a preheated test of the optical sensor up to 400°C has been already realised with success [4].

Off normal operation:

- testing the integrity of the sensor following the loss of pressure in the measuring chamber,
- testing the global integrity following the loss of sealing of the sensor (failure of the bellows).

## 6. Conclusion et perspectives

Within the framework engineering phase (design and manufacture) of the experimental equipment's for the JHR, this actual proposal concerns the settling of innovative instrumentation regarding a system answering the need for measurement in real time and with the experimental conditions of the phenomena of swelling of a fuel rod during its irradiation. The innovation suggested is based on the use of a mechanical module submitted to deformation (taking into account metallic bellow to accommodate the deformation) coupled to an optical module functioning on a interferometer principle.

The results obtained lead to a robust, reliable solution covering the nominal and or degraded operating conditions (integrity request). In addition to the initial application considered relating to the measurement of the swelling of a rod in a device of irradiation, this type of sensor can be adapted for the measurement of other types of deformation like the lengthening of a fuel pin under flow or the measurement of deformation of interns, of assemblies in industrial environments presenting of the severe conditions of environments (ex: hot fluid and under pressure). Note that a pattern has been established for this work.

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