Fuel Irradiation Devices
Test of Feedthroughs Equipped With Optical Fibers
in support of the development of innovative instrumentation.

Authors: S.Gaillot (1),*, C.Destouches (2), G.Cheymol (3), J.Brinster and Al (1)

(1) CEA, DES, IRESNE, Nuclear Technology Department
(2) CEA, DES, IRESNE, Reactors Studies Department
(3) CEA, DES, ISAS, Chemical & Physical Department
(1,2) CEA, French Alternative Energies and Atomic Energy Commission, Division of Energies, CEA Cadarache.13108 Saint Paul lez Durance. France.
(3) Université Paris-Saclay, CEA, Service d'Études Analytiques et de Réactivité des Surfaces, 91191, Gif-sur-Yvette, France

(*) stephane.gaillot@cea.fr

Abstract: As part of the activities for developing experimental devices for research reactors and associated test loops, some concern the development and qualification of instrumentation. The on-board instrumentation makes it possible to monitor online the evolution of physical parameters of samples and/or components subjected to different stresses (thermal, hydraulic, chemical and nuclear, etc.). In addition to the so-called "classic" instrumentation implemented in this type of equipment (pressure, temperature, flow, elongation), R&D actions are in progress in order to propose innovative instrumentation, able to improve the experimental offer and describe the physical phenomena with more accuracy. This is the case of optical measurements which present many advantages (compactness, insensitivity to EM waves, complex measurements by optical interrogation of a single fiber).
In addition, actions are underway for the selection of optical fibers that can be used for applications in a nuclear reactor (in particular resistance to the irradiation).
The tests presented in this paper relate to the behavior of sealed feedthroughs for optical fibers to the thermal hydraulics conditions of light water reactors. These tests are part of the safety demonstration in so-called degraded operating cases i.e. corresponding to a configuration where the optical fiber is placed directly in the process fluid (pressurized water). One note that in normal operation, the optical fiber is isolated from the process fluid by a jacket consisting of a metal capillary.
After an introduction and a brief presentation of the use of optical fibers in experimental equipment, the paper describes the tightness feedthroughs used, the tests carried out, indicate the main results obtained and opens up some perspectives for future development phases.

Keywords: Experimentation, Thermal Hydraulic tests, Feedthroughs, Optical Fiber

I. INTRODUCTION
To carry out technological irradiations in Materials Research Reactors (MTR), experimental devices are implemented in the core or in the reflector.

These devices make it possible to reproduce on a small scale the physical stresses on material or fuel samples. The stresses applied to the samples can be of different types: thermal, thermal-hydraulic, nuclear, chemical, etc.
These stresses come from the operating conditions of the reactor (neutron flux, gamma heating) or can be linked to the operations of the device (thermo-hydraulics, thermal, chemistry of the coolant, mechanical stress on the sample).

It is in this context that the resistance tests of tightness feedthroughs with optical fibers are identified.

These tests are carried out under light water reactor (LWR) conditions.

Fig. 1. Typical design of irradiation device

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II. CONTEXT REMINDER

The realization of the experimental devices in a MTR is the result of a long and complex design process [1] taking into account the experience feedback on other reactors, the thermal hydraulics parameters in normal and degraded conditions, the safety analysis defining the number of constructive provisions (number of barriers) and management (operating area) in order to ensure reliable and long-lasting operation of the device as well as taking into account the current regulations (in particular the Nuclear Facilities Quality Order (INB) as well as French Nuclear Pressure Equipment Order ESP(N)).

III. THE TIGHTNESS FEEDTHROUGHS

As mentioned above, the irradiation device constitutes a closed and sealed enclosure to accommodate the samples and also makes it possible to reproduce the experimental conditions necessary for irradiation. In order to communicate with the outside, the device is equipped with tightness feedthroughs of the fluid and electrical type, instrumentation allowing the test to be controlled and the evolution of the experimental parameters to be monitored online [2].

Depending on the safety analysis carried out, the sealed passages constitute a single or even double barrier connection between the process fluid (area where the test sample is placed) and the surrounding environment (reactor pool).

Another objective concerning the leak tight passages of devices in the reactor is to be able to maximize the integration of connections in a given geometry. This generally involves multiple watertight passages in order to increase the number of connections.

Generally, watertight passages allow different types of connections to be made:

- Fluid: pressure measurement, gas gaps, etc.
- Electrical: heating power supply,
- Instrumentation: flow meter, thermocouples, LVDT, nuclear measurements,

IV. OPTICAL MEASUREMENTS

In addition to the classic instrumentation, progress in R&D actions now makes it possible to consider other types of instrumentation. Optical measurement is part of this panel of innovative instrumentation that we seek to implement in irradiation devices.

Its advantages are numerous:

- Geometry: an optical fiber has a diameter of about 200 microns compared to 1 mm or more for a standard thermocouple. A hardened Fabry-Pérot type fiber optic elongation sensor for MTR application has a diameter of 2 mm compared to more than 10 mm for an LVDT [3].

- FOS (Fiber Optic Sensors) allow measuring numerous parameters like vibrations, temperature, pressure, elongation, displacement, strain. Chemical measurements also possible.

- Multipoint response by interrogation of a single fiber equipped with Bragg gratings [4] or response all along a fiber by analyzing Raman, Brillouin, Rayleigh backscattering. Immunity to electromagnetic interference

- Progress in resistance to irradiation in particular through the appropriate choice of fiber material (cf. TESCA program with CEA & BR2 foreseen in 2023).

Hardened FOS or measurement using optical fibers for irradiation rig have already been developed (for temperature [ref 2 ter], elongation [3]) and tested under irradiation (ATR, MITR, BR2,...) up to more than 10E20 n/m² and GGy. One
studied application correspond to a sensor for measuring displacement / swelling. The physical principle is based on interferometric measurement of the Michelson type [5]. Moreover a non-contact measurement is also in development [6].

![Diagram of cladding deformation sensor]

Fig. 5. Cladding deformation sensor (simplified scheme)

Moreover a non-contact measurement is also in development [6].

The "standard implementation configuration" of an optical fiber in a device can be described as following:

The fiber is located in a metal capillary closed at its end (jacket) which physically isolates it from the surrounding environment (in this case the process fluid). This configuration prevents the degradation of the fiber's silica by dissolution in pressurized water. The mini metal tube protecting the fiber constitutes the first isolation barrier in terms of safety.

The watertight passage through the flange constitutes the second barrier in terms of safety.

The objective of the resistance tests of airtight passages with optical fiber is to test a so-called “degraded” configuration corresponding to the consequences of a degradation of the first barrier constituted by the mini-tube and protecting the fiber. This case falls within the field of investigation of “defence in depth” in the sense of security.

In this case, the fiber is in direct contact with the process fluid and the purpose of the tests is to verify the behavior of the sealed passage (second safety barrier) under these experimental conditions.

VI. EXPERIMENTAL TESTS CONFIGURATION

The configuration identified for the tests is described as follows:

- The watertight passages are fixed to the flange by various processes: welding, compression seal facing.

![Diagram of experimental test section]

Fig. 8. Experimental test section. Cross section
Note: For these tests, the screwed connections are positioned in the fluid in the enclosure (device). This configuration makes it possible to monitor the tightness of the sealed passage during the test. This configuration is specific to these tests and does not correspond to the "classic" configuration: seal fittings outside the flange.

Note: monitoring of the leak tightness of the leak tight passage during the tests is carried out by monitoring the pressure on capillaries fixed downstream of the leak tight passage.

The configuration identified for the tests is described as follows:

- The watertight passages are fixed to the flange by various processes: welding, compression seal fitting.

In order to check the behavior of airtight passages with optical fiber in "degraded configuration", various tests were carried out:

The first test corresponds to the configuration of an ADELINÉ V0 [2] type device which would be equipped with optical fibers included in metal capillaries. For example, the optical fiber could figure FBG to produce temperature profiles.

The test carried out on the sealed passage corresponds to a situation where it is considered that the first seal (represented by the capillary) is lost or is degraded. In this case, the tightness of the leaktight passage is checked (second leaktightness).

For this test, the fiber is in contact with the primary fluid. The duration of the test is set at one week, typically corresponding to the duration of an ADELINÉ type test.

The thermo-hydraulic conditions of the test correspond to those prevailing at the level of the sealed passage at the head of the device, i.e. \( P=155 \text{b} \) and fluid temperature \( =100\text{°C} \).
The second test carried out corresponds to the resistance of the leak tight feedthrough to the following thermal-hydraulic conditions: 150b, 280°C.

For this test, the duration was set at 24 hours.

Finally, the 3rd test corresponds to the resistance of the leak tight feedthrough to the conditions of LWR reactors (155b, 320°C), also over a period of 24 hours.

For this test, water characteristics have been recorded: pH=6, 23 at T =21°C.

**VIII. FIRST RESULTS OBTAINED**

At the end of the three tests campaigns carried out, the following results can be noted:

The technology of tightness feedthroughs with mini metal tube and special glue in order to create the seal between the optical fiber and the capillary is validated.

The assembly technology by welding between the sealed passage and the flange is validated.

The compression seal fitting technology remains to be confirmed.

Nevertheless, subsequent tests carried out at CEA-Saclay showed the feasibility of implementing and using this type of assembly.

Other tests have also been carried out to demonstrate that tightening the screws beyond what is necessary for sealing does not affect the optical signal to be transmitted.

**IX. POST TESTS EXAMINATIONS**

At the end of the tests carried out, the sealed passages were removed from the test flange. X-ray controls have been carried out in an attempt to determine the length of silica dissolved by the pressurized water during the tests.

Then, the watertight passages will be, if possible, cut out in order to carry out some final visual examinations.
X. FIRST CONCLUDING REMARKS & PERSPECTIVES

The use of irradiation devices in research reactors requires the implementation of instrumentation to allow online monitoring of the physical parameters of the experiment.

In addition to the use of conventional sensors, the use of optical fiber sensors is promising.

It is in this context that watertight feedthrough resistance tests were carried out.

They made it possible to validate a tight passage technology and thus to have initial results in support of the associated safety demonstration.

On notes, that experiment has also been conducted to validate the behavior of these feedthroughs in the PWR conditions.

In the light of the first results obtained, the objective today is to continue the development of optical measurement in devices.

The next step will aim to study, produce and test, in representative thermo-hydraulic conditions, an instrumented sample holder equipped, among other things, with several optical lines.

This instrumented sample holder will make it possible to validate in particular the operations of multiple integration of optical fibers via the head plugs.

These actions will aim to consolidate the use of optical fibers for carrying out experimental measurements in research reactors.

XI. LIST OF REFERENCES


