EU OFFERR Project. IRRADCOEFH Gamma Tolerance Test of Thermal CoefH innovative Sensors

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***Abstract* — In the context of experiments aimed at characterizing the thermal exchanges between fluids, the determination of the h thermal exchange coefficient at the wall is requested.**

In this objective, the innovative COEFH thermal sensor has been developed and optimized to precisely measure this coefficient. The robustness of its measurement is obtained by performing various tests of the COEFH sensor's resistance to severe environmental conditions (pressure, temperature, irradiation...). In this case, the tests presented in this paper aim to check the gamma dose tolerance resistance of the sensor (at room temperature, without pressure).

The framework of this action is the European OFFERR program underway over the period [2022-2026] and which aims to carry out R&D actions in the facilities identified in the OFFERR network (https://snetp.eu/offerr/). The present action is called IRRADCOEFH.

This action was carried out in 2024 April-May through a collaboration between the CEA-DES-IRESNE (France) and the CVR located in the Czech Republic.

Tests performed with CVR's gamma irradiator (*) allowed the electrical characteristics of the COEFH sensor to be continuously tested up to a gamma dose of 50 kGy. These tests were carried out over a period of 3.5 days. The first results obtained show a good behavior of the sensor in the face of gamma irradiation without any observed degradation of its characteristics.

These tests made it possible to validate the use of the sensor under gamma radiative environment.

After a general description of the OFFERR project, the paper describes the irradiation tests performed with the COEFH sensor at the CVR and provides the first results obtained.

Note: *the presented results were obtained using the CICRR infrastructure, which is financially supported by the Ministry of Education, Youth and Sports - project LM2023041.*

***Keywords* — Innovative Sensor. Thermal CoefH sensor, Gamma dose tolerance test, CEA, CVR, EU OFFERR Project**

I. INTRODUCTION

As part of the European OFFERR Project for the period [2022-2026] aimed at carrying out collaborative R&D projects in support of the nuclear industry [R1], [R2] the action called IRRADCOEFH [R3] presented in this paper aims to verify the resistance under gamma irradiation of an innovative sensor for measuring heat exchange coefficient at the wall. The results obtained [R4],[R5] make it possible to specify the field of use of the sensor in a gamma radiative environment. This project was carried out between CEA-DES-IRESNE (France) and CVR (Czech Republic) in the spring of 2024.

II. SENSORS DESCRIPTION

The COEFH sensor allows the characterization of thermal coefficients, using miniaturized thermocouples or resistive tracks implanted on a ceramic substrate [R4].

Different models used are described hereafter:

<u>STANDARD COEFH</u>

COEFH sensors are specially designed to measure experimentally all the thermal parameters at the interface of a convective heat transfer; wall temperatures (three measurements), fluid temperature, wall temperature (at the interface), heat flux density, and the exchange coefficient (h factor). This last parameter is original. Few sensor manufacturers propose this experimental measurement.

This feature has been patented since 2008.

THIN COEFH

The new sensor uses the technology of thin layers in ceramic (Al2O3) cofired at T=1600°C with platinum micro-tracks inserted. Its manufacturing process, like the components of the nanotechnology, is carried out in the form of a wafer, thus accessing to a series production. Another particularity, the sensor is fixed by glue to the sensible surface, no more machining of the wall, thus the installation on a thin wall is possible as long as its thickness is compatible with that of the sensor. This is precisely the reason for the drastic reduction pathway in its thickness from 6 mm to 0.6 mm for the new generation.

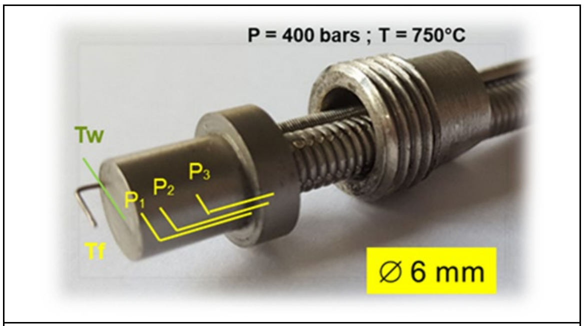

Fig.1 view of the standard COEFH sensor

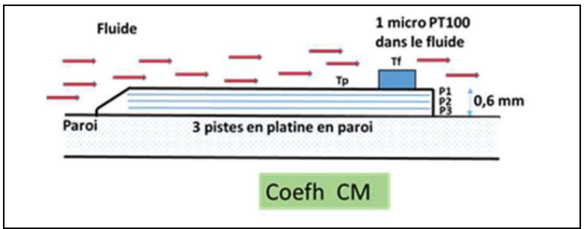

Fig.2 new generation of Coef h CM with 3 platinum tracks (P1, P2, and P3) inside the body sensor and Tf (PT100 or PT1000) outside the body sensor

In the IRRADCOEFH action, two versions of the sensor will be tested: COEFH, the standard model and the THINCOEFH which stands for an optimized sensor design based on ceramic substrate.

Fig.3 view of standard COEFH Sensor

Fig.4 view of optimised thin COEFH sensor

III. GAMMA TOLERANCE TEST OBJECTIVES

The objective of these tests is to check the sensors with a gamma dose of 10 kGy (at minimum).
These tests will be performed at room temperature.
The total duration of the irradiating experiment will be about one week. The control of the sensor will be given by verifying electrical resistivity's measurements during the irradiation phases. Nevertheless, if the sensors are not off after this first phase, higher gamma tolerance tests will be achieved.
In a first phase, CVR will prepare the irradiation campaign by performing dosimetry measurements in the test chamber using alanine detectors.

IV. CVR IRRADIATION FACILITY OVERVIEW

The irradiation has been performed in the Gamma Irradiation Facility. The Gamma Irradiation Facility uses 60Cobalt with activity of about 67 TBq as a source of ionizing radiation. The source is enclosed in a stainless-steel tube with an erecting mechanism. The stainless-steel tube with source is retracted during the manipulations. For irradiation, the source is erected to the irradiation chamber. The irradiated samples are placed on a moveable irradiation table. The moveable irradiation table can slide out of the irradiation chamber for easier manipulation with irradiated samples. The movable irradiation table can be equipped with additional apparatus, e.g., supplementary shielding, high vacuum chamber, inert atmosphere (Ar, N_2, …) chamber, cooling or heating system (in range between T=196 °C and T=400 °C), or various online monitoring systems.

Fig.5 view of CVR irradiation chamber

Fig.6 view of Irradiation Chamber (internal part)

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V. SENSORS IRRADIATION TEST DESCRIPTION

COEFH Sensors were located on the moveable irradiation table as shown in fig.7 & 8.

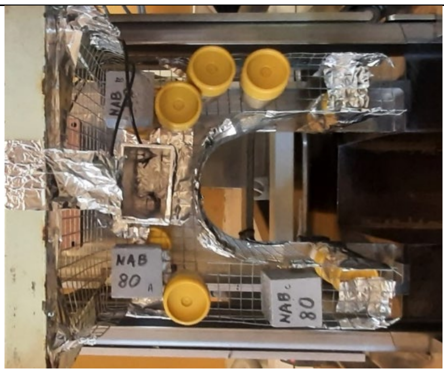

Fig.7 location of sensors
on the the moveable irradiation table

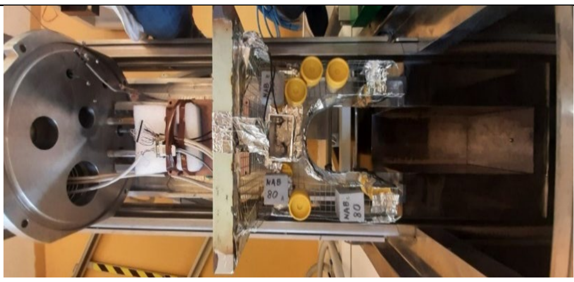

Fig.8 overview of the moveable irradiation table
with sensors in place

The sensors were connected throughout the irradiation chamber's shielding to the measuring station. During the instalment, it was found out that some channels give incorrect results for the measurement of resistivity.

Extension cables for both, online and before and after the irradiation measurements were used. The cables were connecting the measuring device and the Sensor 1 bus. The values of the resistance of the extension cables are shown in Table 1. The measured values include both directions, to and from the Sensor 1 bus. Note that the values for P2 Transparent and P3 Light purple are lower. That is caused by the use of power cables with bigger diameter.

EXTENSION CABLES RESISTANCE				
Color	Tf(ohm)	P1(ohm)	P2(ohm)	P3(ohm)
Brown	1,25			
Black	1,15			
Grey		1,12		
White		1,16		
Red			1,16	
Transparent			0,73	
Blue				1,17
Light Purple				0,7

Table 1: Values of resistance of the extension cables connecting the measuring device and the Sensor 1 bus.

VI. DOSIMETRY

Before the experiment an offline dosimetry using alanine was performed. Alanine dosimetry is a common industrial process for use in gamma, electron beam, or X-ray applications that require a wide dose range, e.g., medical device sterilization or food irradiation. Alanine pellets were placed in the same place as the sensors in the following experiment. Alanine pellets were irradiated and sent for gamma dose measurements.

Fig.9: Location of the alanine dosimetry samples.

The alanine dose measurement was performed by ÚJV Řež's Testing Laboratory of the Radiation Chemistry and Environmental Qualification Department. The dose rate at the place of alanine pellets, i.e., at the place of sensors in the following experiment, was determined to be 0,605 kGy/hour with k=2 (95 % probability) uncertainty of 0,019 kGy.

Alanine standards used were produced by Far West Technology. The Electron Paramagnetic Resonance spectrometer was e-scan Bruker Biospin, type ES 200A, serial No SC0260

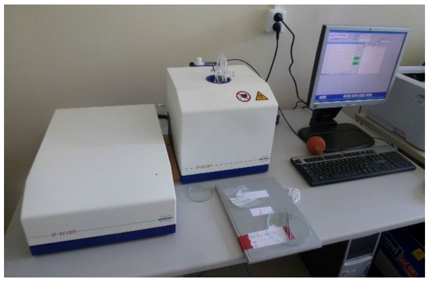

Fig.10 : EPR spectrometer e-scan Bruker Biospin, type ES 200A used for the alanine dosimetry

VII. IRRADIATION PROCESS

During the irradiation, the sensors were located in a distance of about 15 cm from the source.
The dose-rate at the place was determined to be 0,605 kGy/hour measured using alanine dosimetry (Fig.9) as mentioned above. Therefore, in order to gain a dose of 50 kGy, the irradiation was set to 82 hours and 38 minutes (Three days, 10 hours, and 38 minutes).
The irradiation started on 8th April at 20:50 PM and ended on 12th April at 7:40 AM.
There were no breaks in the irradiation – the irradiation was carried out in one continuous session.
The absorbed dose was approximately 50,1 kGy with k=2 (95 % probability) uncertainty of about 1,6 kGy.

VIII. ON-LINE MEASUREMENTS

The values of resistance for temperature sensor, Sensor 1, and Sensor 2 were measured online during the irradiation phase. As the measurement was carried out online the channels and pins could not be measured individually and independently. Therefore, due to the problems encountered and described in the previous chapters, the measured resistances were :
Tf Brown, Tf Black, S1 P1 White, S1 P2 Red, S1 P2 Transparent, S1 P3 Blue, S2 P1, and S2 P3.
The measured values are shown in fig.11 & 12
All the data are enclosed in a specific file.
For the online measurement, COMET MS6D data logger was used.

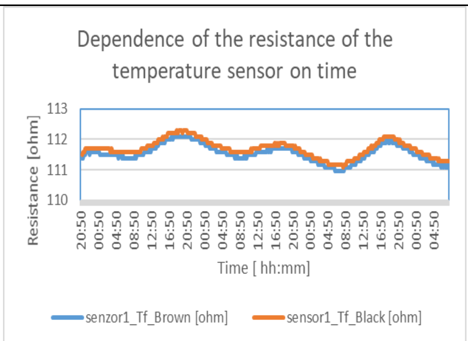

Fig.11 a graph of the dependence of the resistance of the temperature sensor on time.

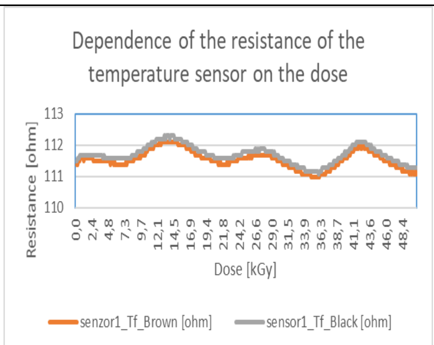

Fig.12 a graph of the dependence of the resistance of the temperature sensor on the absorbed dose

In these graphs, it is easy to see, that the strongest influence is caused by the day-night cycle and the corresponding slight changes in the temperature.

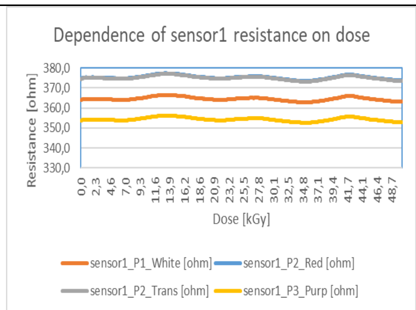

Fig.13 a graph of the dependence of the resistance of the sensor1 on the absorbed dose

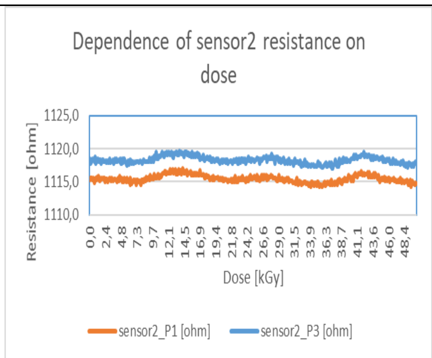

Fig.14 a graph of the dependence of the resistance of the sensor2 on the absorbed dose

IX. ON-LINE MEASUREMENTS

The values of resistance for individual channels of Sensor 1 were measured before and after the irradiation. Each channel and pin were measured individually and independently. For the before and after the irradiation measurements the Keithley 2001 Series: 7.5 Digit Multimeter with Scanning was used.

RESISTANCES BEFORE IRRADIATION				
Color	Tf (ohm)	P1 (ohm)	P2 (ohm)	P3(ohm)
Brown	114,6			
Black	114,9			
Grey		370,6		
White		370,4		
Red			381,9	
Transparent			381,5	
Blue				360,0
Light Purple				360,0

Table 2: values of resistance measured individually and independently for each channel and pin of Sensor 1 before the irradiation.

RESISTANCES AFTER IRRADIATION				
Color	Tf (ohm)	P1 (ohm)	P2 (ohm)	P3(ohm)
Brown	114,05			
Black	114,09			
Grey		368,76		
White		368,67		
Red			380,06	
Transparent			379,81	
Blue				358,72
Light Purple				358,28

Table 3: values of resistance measured individually and independently for each channel and pin of Sensor 1 After the irradiation.

X. CONCLUSION

The Sensor 1 and Sensor 2 were irradiated in the CVR Gamma Irradiation Facility using 67 TBq 60Co source. The sensors were in a distance of about 15 cm from the source with the dose-rate at the place of 0,605 kGy/hour. The irradiation started on 8th April at 20:50 PM and ended on 12th April at 7:40 AM. The absorbed dose was approximately 50,1 kGy with k=2 (95 % probability) uncertainty of about 1,6 kGy.
As it can be seen from both, the online measured data and before and after the irradiation data, it seems that the resistance of the sensors was not influenced by the irradiation. The variation in the measured resistance was probably caused by the day-night cycle and the corresponding changes in the temperature.

XI. PERSPECTIVES

At the end of these tests, the standard COEFH and the optimized thin COEFH sensors gave interesting results on the ability of the sensors to operate under a gamma radiation environment. In addition, the resistances of the platinum wires of the Thin COEFH sensor and those of the thermocouples of the standard sensor were not affected by irradiation. Note that neutrons tolerance tests have not been checked. Nevertheless, these first results open new perspectives on use of the COEFH sensors in Gamma Radiative environments.

XII. REFERENCES

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