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CEA's Optical Pyrometry Technique for Non-Contact Temperature Measurement in High Temperature Surroundings

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The LORELEI (Light-water One-Rod Equipment for Loca Experimental Investigation) device will be integrated into the future experimental Jules Horowitz Reactor [1] of the CEA to provide a feedback on potential nuclear accidents, for example the Loss-Of-Coolant Accident (LOCA) [2]. This device will allow investigating the burst conditions of nuclear fuel claddings when the environment of the cladding, as liquid pressurized water during "normal" nuclear activity, becomes a steam atmosphere. In case of LOCA, the heat produced by the residual power is not evacuated and the cladding surface temperature increases drastically. In the LORELEI device, the thermal contribution of the surrounding rods will be reproduced by using a heating Inconel tube placed around the cladding under test.

To study in detail the temperature profile of the cladding before the burst, the surface temperature of the cladding has to be monitored by a non-intrusive technique avoiding a modification of the thermal environment and, consequently, of the burst conditions. The accuracy of the measurement has to be close to ten degrees.

In preliminary studies, we designed a device and a data treatment procedure able to measure the surface temperature of Zircaloy-4 (Zy-4) claddings, without any contact, under air, up to about 850°C [3, 4]. Two pyrometry methods were investigated: the bichromatic calculation and the Multispectral Radiation Thermometry (MRT) estimation [5]. This latter measurement method revealed an uncertainty < 10°C in the temperature determination in the experimental conditions of the laboratory bench. We selected the spectral ranges 1.0–1.3 µm and 1.45–1.6 µm for the pyrometry measurements according to the future LORELEI conditions [1]. Thermocouples were used to provide a reference temperature and allowed us to validate the constant emissivity profile hypothesis in the spectral ranges of calculation. Emissivity values ranging between 0.85 and about 0.90 were determined, in agreement with the literature [6].

In high temperature surroundings, it appears obvious that a contribution from the surroundings will increase the energy flow collected by the optical fiber, but its impact has not been clearly studied. By using the developed MRT procedure, the objectives of this follow-up study are thus:

(i) To perform a theoretical analysis of the impact of high temperature surroundings on the temperature estimated by MRT, by applying a model of radiative transfers on the conditions of the LORELEI device (i.e., surface properties, temperature range). The aim is to determine potential correction factors to be applied to the retrieved temperature when the pyrometry method will be implemented in the LORELEI device.

(ii) To validate the radiative transfer model by comparing simulated temperature estimations with experimental pyrometry measurements.

Zy-4 is known to present surface modifications under air, for temperatures higher than about 700°C, such as the creation of zirconium nitride [7, 8]. This phenomenon will thus occur in conditions of high temperature surroundings. It was not observed in our previous studies because of the short duration of the experiments and a cladding environment at room temperature. Therefore, measurements will also be performed on an Inconel surface, a material with a more stable surface at high temperature and an emissivity similar to Zy-4 in the temperature range of the experiment.

The simulation of the temperature measurement took into account the major radiative components present in the LORELEI device, with the direct flux from the cladding and all the reflected contributions induced by the presence of a heating Inconel tube to introduce a high temperature surroundings. In the simulations, we noted a temperature difference between the cladding temperature and the temperature estimated by the MRT method as function of the surroundings temperature. These temperature differences will have to be corrected to approach the real temperature of the cladding surface, when the pyrometry method will be implemented in the LORELEI device.

The pyrometry measurements, performed on an Inconel

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surface, presented the same behavior of temperature identification as the simulation, because of the good stability of the surface properties in high temperature surroundings. This surface stability is similar to the Zy-4 cladding stability in the LORELEI environment. The good agreement found between experimental and simulated results validates the radiative transfer model. This good agreement was not found for Zy-4 cladding under air, because of multiple modifications of its surface properties (nitride and secondary oxide formation) during the experiment. These modifications are not representative of the Zy-4 cladding behavior into the LORELEI device because a neutral gas will be used instead of air.

The optical pyrometry method clearly demonstrated its good potential for the temperature measurement of a stable surface in high temperature surroundings and under air. The outlooks of the development will be focused on:

(i) The validation of the pyrometry method for cladding temperatures up to 1200°C and in steam atmosphere, using the EDGAR-2 test facility available in the CEA research center (Saclay, France).

(ii) The validation of the method under irradiation (neutron and gamma fluxes) taking into account a structural modification of the optical fiber during experiment and the Cherenkov radiation.

(iii) The implementation of the pyrometry device in the LORELEI device, after miniaturization at the millimeter scale.

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