PROPOSAL FOR A MULTILATERAL EXPERIMENTAL PROGRAM IN THE FRAME OF THE OECD NEA

Initiative launched by the core group: SCK.CEN, CEA, EDF

Advancements in Nuclear Fuels and Materials: Quantifying Thermomechanical Clad Load Mechanisms during LWR Transients (Task 1)

GENERAL CONTEXT

The Nuclear Science Committee (NSC) of the NEA organized in January 2018 a Workshop titled "Enhancing Experimental Support for Deployment of New Fuels and Materials" in order to support advanced and optimized experimental technology for supporting the validation and qualification activities required in deployment of new fuels and materials. This workshop gathered industry (utilities, fuel makers), regulatory bodies, technical support organizations, research organizations and experimentalists in order to reach a mutual understanding of the requirements of the validation/qualification process for innovative fuel and to enhance the effectiveness of experimental programs.

One of the main outcomes of the workshop consists of establishing proposals to performs joint experimental projects to test ATF concepts, such as the initiative presented below, which has been established by a gathering a core group of the three following partners: SCK.CEN, CEA and EDF. It represents a very good proposal for launching a new ambitious NEA joint project combining simulation, advanced experiments in MTRs (BR2 for this Phase 1) and in Hot Laboratories for PIE.

1. INTEREST OF THE NEW PROGRAM

Flexibility of nuclear power plants to follow grid demand evolution implies quick and large amplitude changes in thermal power. At the fuel rod level, they provoke immediate thermal-mechanical stresses that are mainly applied to the clad. Achieving plant flexibility without penalizing safety or jeopardizing fuel reliability is of paramount importance, in particular with progressive introduction of advanced or new fuels and clads, such as Accident Tolerant Fuels (ATFs), in reactors.

Moreover, safety analyses must take into account associated specific incidental situations (e.g. when one or several protection actions are considered as inefficient) which could provoke locally larger stresses and enhance the risk of fuel rod failure. These situations can correspond to specific types of power transients, called "long-lasting transients", for which the slow kinetics i) do not induce a risk to reach the technological failure limit of the cladding, and ii) may not trigger preventive safety actions of the reactor (which would terminate the transient), even if the transient persists for a long time. Consequently, high values of local power and temperature can be reached in the fuel pellet, favoring moderate to high mechanical stresses on the clad. In accidental transient conditions, incipient fuel melting at the pellet center can be initiated.

A specific interest is also to extend the validation domain of calculation tools used for the fuel core safety analysis, by complementing the current databases with fuel rod behavior results in these new conditions. It will help the designers to quantify available margins and possibly relax some of the current fuel related operational constraints.

2. SCIENTIFIC OBJECTIVES

Main objective of the proposed program is to identify, rank and quantify mechanisms that appear in a LWR fuel rod during any type of power transients, with a focus on those provoking a moderate to high load on the clad and potentially a clad deformation. These mechanisms are mainly i) fuel thermal expansion, ii) fuel gaseous swelling, iii) fission gas release, and iv) fuel volume change at melting.

The experimental target is to be able to activate successively, and consequently to discriminate between, these mechanisms thanks to a separate effect approach based on successive power plateaus with progressive increased values and low power change rates to forbid risk of fuel rod failure. At the end a terminal level will specifically initiate a central melting of the fissile material.

As effects will be enhanced by a large quantity of available fission gases, experiments will focus on reaching high linear heat rates (LHGR) for high burn-up fuels. On-line measurements equipping the experimental rod will monitor fuel rod conditioning / deconditioning kinetics during each power plateau.

3. SUPPORT OF THE MODELING

State-of-the-art fuel performances codes will be used for:

- pre-calculating the experiment, for defining the most relevant test conditions and instrumentation specifications,
- predicting expected results regarding margin to central melting, fission gas distribution and release and clad deformation in hot and cold conditions, estimated fuel melted volume at terminal power level...., and
- addressing post-test comparison between calculation and experimental results.

In turn, experiments will improve fuel performance codes and models, with databases enlargement. A benchmarking between participant’s codes is another interest point, allowing extensive positive feedback on the quality of modelling.

4. INDUSTRIAL APPLICATIONS

The proposed program will address issues facilitating power plant flexible operation, fuel manufacturing and procurement processes, while preserving safety and clad reliability in “long-lasting-transient” incidental situations. Focus will be put on improving quantification of available margins on current fuel management for modern fuels in use or for anticipating introduction of new fuels and clads, for which databases are less complete. This includes:

- reassessing clad maximum allowable strain criterion at high linear heat rate, in relation with current NPP ramp rate constraints,
- quantifying the impact of incipient fuel melting on cladding deformation versus burn-up in accidental conditions,
- transposing by modelling the experiments outcomes to power reactor conditions, and
- gaining licensing data usable for new fuel products and for new licensing methodologies.

5. EXPERIMENTAL RODS

As this program mainly addresses knowledge gain on advanced fuel and claddings, experiments will be implemented on various materials, integrating further proposals from participants: standard and doped UO_2; UO_2 with burnable absorbers; ATF fuels such as U_3Si_2; modern Zy-based claddings; and SiC claddings... Burn-up will be in the range of 40-60 GWd/t, depending on sample availability. Rod sections will be extracted from pre-irradiated long rods, if possible, already characterized after base irradiation.

Experimental sample will be equipped with on-line instrumentation giving the most relevant information on clad loading and deformation, e.g. central thermocouple, internal gas pressure and mostly clad outer diameter.

A first scenario could be as follows (considering the availability of the products):

- First combined experiments (see § 6 below) using a standard “UO2-Zr” product for calibration.
- Second combined experiments using “UO2 doped with Cr, Zr”.
- Third combined experiments using “ UO2, Zr-Chromium coated).
- Others ATF product candidates…

6. EXPERIMENTAL IRRADIATION DEVICE AND EXPERIMENTAL PROTOCOL

As the main objective is to go to high values of LHGR (up to > 60 kW/m) with high burn-up fuels, a favorable neutron environment in the selected experimental device is mandatory.

It is proposed to proceed on the experiments in 2 tasks:

Task 1: Use of an on-the-shelf available fuel capsule device in BR2 reactor (SCK.CEN, Mol-Belgium) to perform irradiation plateau at high power levels and final plateau framing the incipient fuel central melting,

Task 2 (later on, outside of this present joint project proposal): Develop a dedicated device to perform such irradiation at low and intermediate power levels, favoring the use of a rig with multiple on-line instrumentation, and in particular, measurement of clad outer diameter by axial scanning.

It is recommended to use the IFE from Halden for task 2, getting benefits of their expertise on instrumentation for such types of experiments (potentialities to investigate in MIR PWR loop-ROSATOM- or dedicated loop in ATR-DOE- or others…)

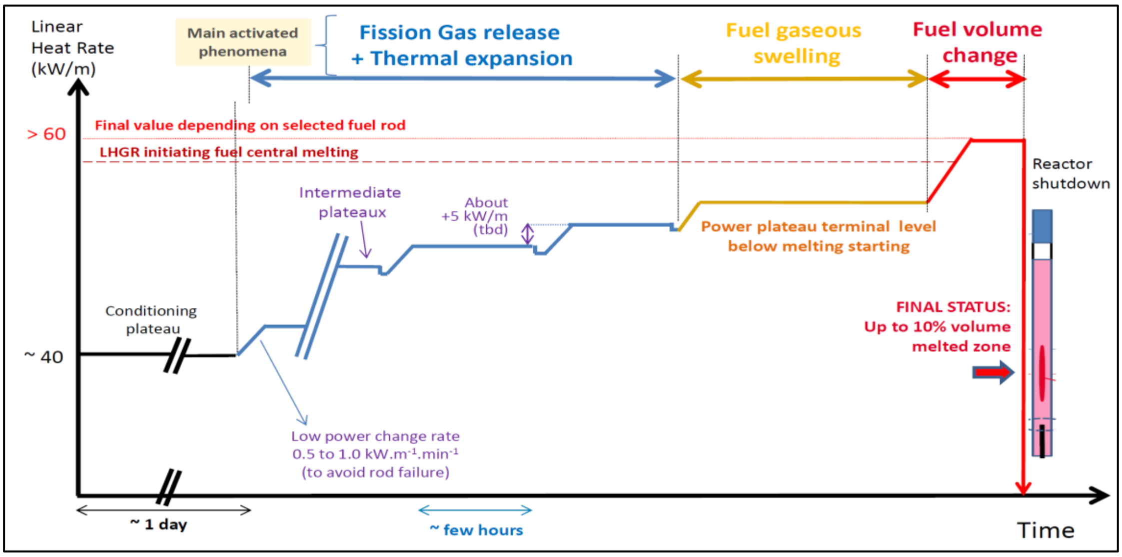

Figure 1: Proposed LHGR time history in BR2

7. EXPERIMENTAL PROCESS

Starting from a LWR father rod (on the shelf at CEA Cadarache) the experimental process for this phase 1 is as follows:

- Extraction of two adjacent segments from this father irradiated fuel rod.
- Refabrication in Hot Laboratory of 2 twin fuel pins.
- Transfer of one of these twin pins to SCK.CEN for experiment in BR2 (high power plateau and incipient fuel melting).
- PIE (NDE and DE at SCK.CEN and CEA).

Note: once the MTR for performing highly instrumented experiment (objectives of the task 2) at low and intermediate power level is identified, the second twin fuel pin will be delivered to this MTR to proceed.

8. POTENTIAL SCHEDULE

If we consider that the core group is starting working on the objectives by mid-2018 and that the NEA will prepare a new International Joint Project by initiating a preliminary meeting this autumn gathering several partners with a view of kick-off by spring 2019, and considering the preparation of the fuel samples, of the experiments, transports….we can set a target date for the first irradiation experiments (using the “calibration product” second semester 2020, having the PIE in 2021).

Such kinds of experiments described above do not need long irradiation in MTRs (few days) and we can focus on having second irradiation (with an ATF type fuel) by mid-2021 and PIE end of 2021-early 2022.

9. FRAMEWORK AND FINANCIAL SCHEME

The core group for task 1 (SCK.CEN, CEA and EDF) will work on the establishment of a detailed budget of such a program during the second semester of 2018, to have reliable financial scheme to present to NEA partners by end 2018.

The funding logic proposed by the core group is that these three main partners of the core group take 50 % of the total cost of the program, and the other partners gathered through NEA joint project pay for the complementary 50 %.