Networking Advanced Experimental Capacities in Operating European Materials Testing Reactors for Qualification of Innovative Nuclear Fuel and Materials: The FIJHOP R&D Program Proposal

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Abstract

The Jules Horowitz Reactor (JHR) is a Material Testing Reactor under construction at CEA Cadarache in Southern France and foreseen to be in operation by the beginning of the next decade. Operated as an User's facility at international level, it will promote coupled operation between the operating European MTRs (BR2, HFR, LVR-15, HBWR, MARIA…) for performing multilateral programs associating one or several MTRs and hot cell laboratories for post-irradiation examinations (PIEs). These programs will beneficiate from a strong support of state-of-art models and codes, either for defining the experimental protocol or pre-calculating the sample behaviour, or finally assessing results.

This last way has been recognized as essential by the JHR Consortium, which endorsed the objectives of a proposal called FIJHOP (Foundation for future International Jules HOrowitz experimental Programs), submitted to the last H2020 call in October 2016. Supported by some communities such as NUGENIA, it addressed following scientific issues:

- For nuclear fuels (FIJHOP-F): to discriminate and quantify phenomena having an impact on clad loading and deformation during a power transient: fuel thermal expansion, fuel swelling, fission gas release and volume change at incipient fuel melting. Such final status will be reached with a high burn-up and multi-instrumented experimental fuel rod,
- For nuclear materials (FIJHOP-M): to study irradiation effects on Internals and more specifically to check effects of the neutron spectrum on damage accumulation kinetics, which may impact their mechanical properties. Associated particular interest is to harmonize interpretation of such evolution versus dpa (displacement per atom).

FIJHOP targeted an implementation in 3 European MTRs in operation (BR2, HFR and LVR-15) and 9 Hot Cell Laboratories, and was accompanied by a code benchmarking. Although the proposal was not accepted for the last H2020 call, partners decided to search for other possible tools/frameworks to maintain or even enlarge the objectives of the former FIJHOP proposal. In particular, contacts are in progress with the Nuclear Science Committee (NSC) of the OECD/NEA.

This paper presents the FIJHOP proposal, the scientific objectives in relation with stakes for power reactors operation, its innovative feature, and details on both experiments (fuel and materials). It highlights the added value provided by qualified models for optimizing the experiment preparation, and in turn the interest of expected results for participant's database improvement, development and qualification of their simulation tools.

1. Introduction: The Working Groups of the Jules Horowitz Reactor Consortium

Ageing of operating service oriented Material Testing Reactors (MTRs) in Europe lead to significant changes (real or potential) in the irradiation infrastructure landscape (e.g. the OSIRIS definite shut down end of 2015). This trend leads globally to a decrease in available experimental capacity and skilled resources. On the other hand, and given the time-frame for developing and qualifying new nuclear fuels and materials, both sustainable and state-of-the-art research capacity are required in existing MTRs for support to the nuclear power industry.

To counteract the risk to face insufficient adequate European experimental capacities to fulfill middle- and long-term requests from industry and Safety Authorities, two main ways are currently considered as efficient:

- The Jules Horowitz Reactor (JHR) [1], under construction at CEA Cadarache and foreseen to be in operation by the beginning of the next decade [2], will reinforce the link between the operating European MTRs (BR2, HFR, LVR-15, HBWR, MARIA…) for performing advanced experiments. It is consequently identified for this purpose within various European road maps as ESFRI, SNETP, NUGENIA… The reactor is also being optimized for medical isotope production,
- The implementation of multilateral programs associating one or several MTRs, through their coupled operation as an irradiation service network, and hot cell laboratories for post-irradiation examinations (PIEs). These programs shall beneficiate from a strong support of state-of-art models and codes, either for defining the experimental protocol fulfilling the request, or pre-calculating the sample behaviour or finally assessing results. This allows in turn enlarging databases and validation domain of participant's simulation tools, even under development.

To structure the path of this last way, JHR Project has set up an International Consortium, for close partnership between the funding organizations. Within it, it has organized in 2013 three Working Groups, namely Fuel, Materials and Technology (FWG, MWG and TWG) [3]. They gather scientific representatives and experts from the JHR Consortium members. Their role is to give orientations and recommendations, as a technical support and without commitment, to the future "International Advisory Group" (IAG) indicated on the Consortium Agreement, to prepare future programs in JHR. It is interesting to quote that such future programs could be open to non-Members of the Consortium, to enlarge the scientific community on JHR.

After identification of open issues in the field of nuclear fuel and nuclear materials development and qualification, Fuel and Materials WGs elaborated and quoted a "ranking grid" for having a more quantified and detailed evaluation of interest experiments from participants. The grid assessment lead to set up a "priority list", based on received answers, and then a proposal for potential joint or multilateral experiments in JHR, with special attention to programs which could fulfill the needs of both FWG and MWG.

Feasibility of these first programs was then considered, in particular the possible role of existing MTRs associated with (hot)-labs as support for qualification and/or benchmarking experiments and, as a second step, the added value offered by the JHR. To help to set up this roadmap, the TWG provided a description of the JHR experimental capacity available at the reactor start-up and gave the main operating parameters of JHR fuel and material irradiation devices. Moreover the TWG checked the good compliance of the experimental capacity under development versus these potential needs expressed by the FWG and MWG.

2. The JHR "Position Paper" as a first proposal for International Joint Programs

After 3 years of fruitful scientific and technical exchanges, the Working Groups have finalized a "Synthesis Document", internally distributed to the Board Members in December 2015, resuming the above methodology and the common work done during this period. As output, a priority list of the topics of common interest in the Fuel and in the Materials domain was set up, and recommendations were formulated for finalizing a choice among these proposals. They were based on their potential implementation in JHR, with associated scientific, integration and safety stakes.

A generic question was discussed in the both groups about in-pile experiments dealing with severe accidents experiments (and at least beyond LOCA conditions): it has been decided to not consider this topic in the first phase of the work, mainly because the JHR experimental capacity doesn't integrate such possibility during its first years of operation. However, an internal study has been done by JHR team detailing constraints related to implementation of such experiments: progressive adaptation of the JHR reactor block versus increasing complexity of an integral safety experiment, consequences on other experiments simultaneously present in core and in reflector…

A second and more strategic document, named "Position Paper" was issued in January 2016 for the JHR Governing Board. An objective of this output, successfully reached, was to create a "JHR Scientific and Technical Community" allowing scientists from all Consortium Members to exchange their future interest in the JHR. Moreover a key finding of this paper was the consensus expressed within the 3 Working Groups to define, between now and the first operation of the JHR, some "pre-JHR" irradiation experiments of common interest, with added value in terms of either qualifying the experimental conditions or explore the performance limits of the devices. These qualification experiments will be proposed, as a first step, in existing MTRs and/or hot cell laboratories, according to their possibilities and for starting a first International Joint Program in the coming years before continuing it in JHR.
This main outcome of the "Position Paper" paved the way for defining and elaborating first common experiments aiming at validating/benchmarking either the experimental devices under development and/or the irradiation parameters expected in specific locations within JHR. This view fully complies with the recommendations resulted from the previous JHR Scientific and Technical Seminars, in particular in 2014 and 2015.

3. From the "Position Paper" outcomes to the FIJHOP program proposal

The two first common irradiation experiments, recommended by the WG experts in the "Position Paper" for further development study and implementation, concerned:

- For the "Fuel" domain: discriminate and quantify phenomena activated during any type of power transients, creating clad loading and provoking clad deformation. This R&D topic will be studied thanks to slow power ramp – type experiments without considering any industrial fuel qualification. It is in relation with potential operational concerns for utilities, as Nuclear Power Plants (NPPs) will be in the future more solicited for electricity need follow-up, thus putting the fuel under more demanding power transients.
- For the "Materials" domain: study irradiation effects on Internals and more specifically check the effect of ratio between epithermal neutron flux and fast neutron flux on their mechanical properties. This specific point appears of particular interest for harmonizing interpretation of such physical parameters versus dpa (displacement

per atom) thus having an impact for NPP both for Internals components management and for Long Term Operation. In fact, previous experiments have shown that the nature of the neutron spectrum may affect damage accumulation kinetics (e.g. segregation, bubbles/voids formation, precipitation …) and hence influencing the response of the material when subjected to external stresses in primary water environment.

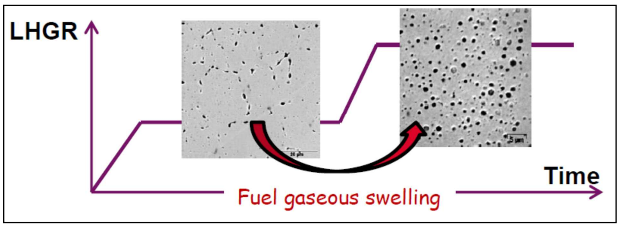
Basically, these two programs structured the so-called “FIJHOP” (Foundation for future International Jules HOrowitz experimental Programs) R&D proposal, comprising the two above programs: “FIJHOP-F” for Fuel and “FIJHOP-M” for Materials. This proposal was submitted to the European Union call for projects “Horizon 2020” of October 2016, in the category “Research and Innovation Action”.

4. Description of the FIJHOP-F program

4.1 Scientific objectives of FIJHOP-F

Three main R&D objectives are targeted by FIJHOP-F:

- Mechanisms study: Identify, discriminate and quantify mechanisms that appear in a LWR fuel rod during any type of power transients, with a focus on phenomena provoking a moderate to high load on the clad. Main expected ones are fuel thermal expansion, fuel gaseous swelling (see Figure 1), fission gas release and even (at high linear heat generation rate, or LHGR, level) fuel volume change if a melted zone is formed,
- Irradiation test implementation in MTR and Post-Irradiation Examinations (PIEs): A power transient test covering conditions different from standard power ramp conditions is foreseen. Objectives are i) to have a terminal power level sufficiently high to reach the incipient fuel melting limit at the maximum rod temperature plane and ii) to avoid a rod failure during the phases of the experiment comprising a linear power increase. After the test, non-destructive examinations (NDEs) and destructive examinations (DEs) will be performed in hot cell (see details in § 4.4).
- Support of state-of-the-art modeling: Test results will enlarge current databases for calculation tools validation, including codes benchmark and transposition to reactor conditions. Moreover modeling will be intensively used for :
  - ➢ Pre-calculation of the rod behaviour and evolution of interest parameters, for defining precisely test conditions and instrumentation specifications,
  - ➢ Prediction of expected results: Fuel central temperature and margin to fuel central melting versus LHGR, fission gas distribution, migration and release, expected clad deformation in hot/cold conditions (see Figure 2) etc.,
  - ➢ Post-test comparison of calculations versus experimental results.



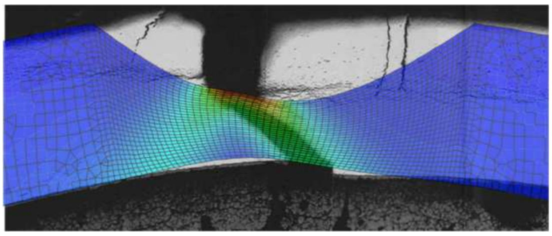


FIG. 1 (left): Schematic of fuel gaseous swelling during a power increase
FIG. 2 (right): Example of clad deformation assessment in RIA conditions with the ALCYONE code: Plastic strain quantification

4.2 Operational objectives of FIJHOP-F

The above information will address issues facilitating NPP flexible operation, fuel manufacturing and procurement processes, while preserving safety and clad reliability. More precisely, they will improve quantification of available margins on current fuel management with a potential effect on current NPP power change rate limitations.

In this domain, main industrial needs addressed are i) fuel performance codes and models improvements, ii) licensing data usable for new products and for new methodologies and iii) recurrent licensing issues with the regulators.

Such new data will be specifically used for improving the modeling of fuel rod behavior during "long-lasting transients", i.e. when one or several protection actions are considered as unavailable (e.g. damaged Instrumentation and Control system or loss of Reactor Protection System RPR). In this situation, higher linear heat rates or higher pellet and clad temperatures, due to nucleate boiling onset, might lead to activate physical phenomena described in § 4.1 at a significant level (see Figure 3). As a consequence, it is of prime importance for an Operator to be able to predict the clad allowable strain at high linear heat rate, the margin to incipient fuel melting and the associated gas release.

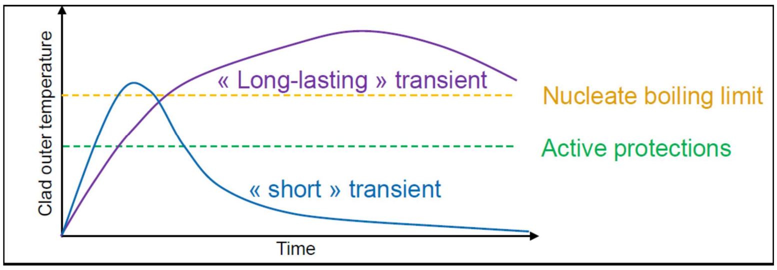


FIG. 3: Schematic of the clad outer temperature evolution during a long-lasting transient

Industry is interested in quantifying the impact of high power ramps and possible incipient fuel melting (only in design basis conditions for this last parameter) because:

- Few experimental data are currently available, especially on new-generation fuel products,
- Some criteria linked to incipient fuel melting are over-conservative,
- New experiments would help improving the knowledge.

4.3 Project plan proposed for the first FIJHOP-F experiment

As all issues cannot be covered by only one experiment, priorities have been made for the first one, considering that i) this first experiment will be a "scoping test" and ii) the test shall prove that the objectives are reachable experimentally. So following choices have been decided by FWG members:

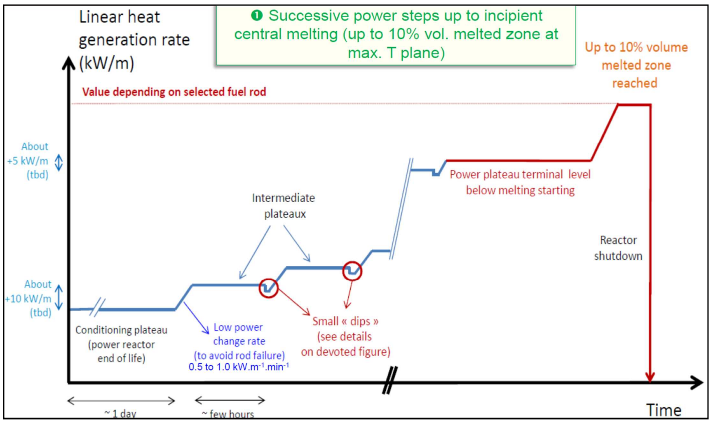
- To work on a high burn-up (HBU) fuel (40-60 GWd.t_U^{-1}), for having a significant available quantity of fission gases and a significant final clad deformation in cold conditions. The fuel material and the cladding will be modern ones, e.g. UO_2 doped with Chromium oxide and M5 or equivalent clad. The used segment will be if possible already characterized thanks to other programs, to be able to carry out a full pre- and post-test rod status comparison,
- To refabricate and instrument the experimental rod in order to monitor on-line the kinetics of phenomena [4], at least evolutions of internal gas pressure and/or gas composition [5] and fuel central temperature (other qualified sensors might be implanted, depending on irradiation device possibility or instrumentation progresses),
- To go step by step to high values of LHGR (up to > 60 kW.m^{-1} even with a HBU fuel), for discrimination of successive phenomena, prohibit clad failure occurrence and

reach, on a well mastered way, incipient fuel melting in the central part of the hottest fuel pellet(s),

- To use an experimental irradiation device existing “on the shelf” or operable with minor adaptations,
- To strongly rely on modeling for designing the sample, the sensors specifications and the experimental protocol.

4.4 Implementation of the FIJHOP-F experiment in MTR and in hot cell laboratory

Above specifications lead to define an experimental LHGR protocol under the form a staircase, with power variations at a slow rate for forbidding a clad failure (see Figure 4). As a large power range will be covered, the mechanisms identified in § 4.1 are expected to be successively activated.



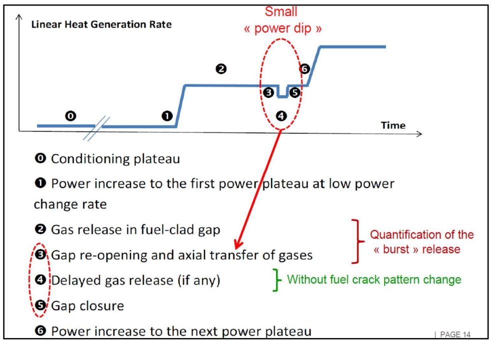


FIG. 4 (left): Schematic of the LHGR protocol proposed for the FIJHOP-F experiment
FIG. 5 (right): Mechanisms activated during a “power dip” made at the end of a power plateau

Duration and level of each plateau will be accurately predetermined by qualified modeling, and will comply with a full conditioning status for the rod, this means with firstly a significant evolution of monitored parameters and then followed by a stabilization (e.g. internal pressure). Moreover, at the end of each plateau, a small “power dip” will be performed for reopening the fuel – clad gap, favoring the axial transfer of gases without provoking supplementary release from fuel (see Figure 5). So pressure measurements, done at rod extremity, will be reliable.

The before last plateau will be at a LHGR value just below the incipient fuel melting at the maximum flux plane and fixed by qualified modeling. Finally, the last LHGR plateau will be also defined by modeling and is targeted to provoke an up to 10% melted zone at the same plane for optimizing mechanisms quantification (see Figure 6).

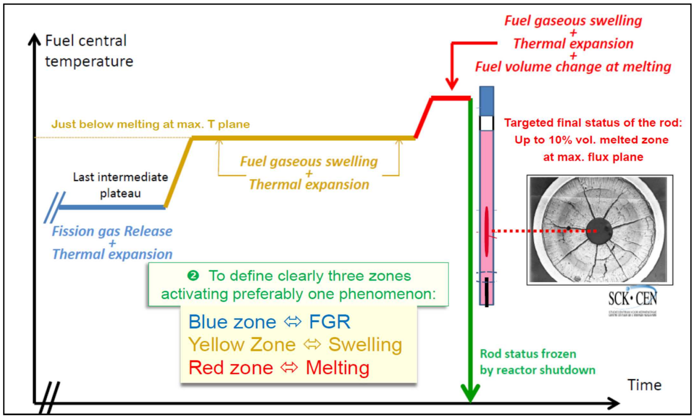


FIG. 6: Physical mechanisms successively activated in the fuel material at the end of the test

As the irradiation device shall be capable of implementing such type of experiments without large adaptation, with the already obtained adequate authorizations, the capsule PWC-CD operated in BR2 [6] has been identified as the reference hosting system in the H2020 FIJHOP proposal. In a similar way, few European hot cell laboratories were pre-selected for PIEs (e.g. LECA at CEA Cadarache and LHMA, at SCK•CEN Mol). Indeed proposed PIEs will comprise NDEs tests, such as checks before and after refabrication (rod tightness control, electrical test of instrumentation…), rod status before and just after test on site (gamma scanning, metrology…) and finally more detailed DEs (rod puncturing, metallography cut at the maximum temperature plane).

4.5 Main outcome expected from the FIJHOP-F program

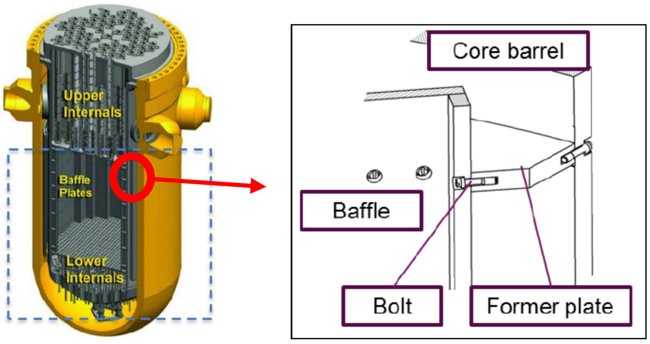
Besides the R&D objectives about discrimination and quantification of mechanisms impacting clad loading and deformation, detailed above, this program will also:

- Provide relevant physical data to enlarge current databases which are used to validate calculation tools (codes and models). Fine pre-calculation of the experiment and results assessment will include benchmarks between calculation tools. This benchmarking task is one of the main interest points of FIJHOP-F, because it allows the gathering of a large number of laboratories and research institutes on a common comparative work, allowing extensive positive feedback on the quality of modelling,
- Improve methodology and ways to transpose the tests outcomes to reactor conditions, capable of supporting a safety file for a future more flexible reactor operation,
- Constitute a reference experiment for a future benchmark with equivalent tests in JHR in the ADELINE LWR loop [7].

5. Description of the FIJHOP-M program

5.1 Scientific objectives of FIJHOP-M

FIJHOP-M proposes to study the effect of neutron flux and spectrum on the degradation of Light Water Reactor (LWR) internals components. These components belong mainly to structures which support the core (see Figure 7), fix fuel assemblies in position, distribute the coolant flow, support and protect control rods, and shield the reactor pressure vessel. It is known that structural integrity, and consequently mechanical properties, start to degrade under lifetime doses from 10 "displacement per atom" (dpa) for some components such as the core barrel, and up to about 100 dpa for, for example, baffle-former bolts (see Figure 8).



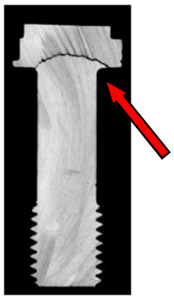


FIG. 7(left): Schematic of a reactor pressure vessel indicating location of the baffle and the bolts
FIG. 8 (right): Example of a damaged bolt

Forms of ageing-related degradation related to lower internals are dependent from the neutron flux and/or the environment. Irradiation impacts hardening, reduction in uniform elongation, fracture toughness, creep and swelling (even if this point is less understood), radiation-induced segregation and precipitation (see Figure 9). On the other hand, environment (and mainly primary coolant chemical characteristics) impacts the irradiation-induced stress-corrosion cracking (IASCC) and the component wear.

The displacement cross-section σ_D (E) is the main parameter to be calculated to determine the dose in terms of dpa. This parameter varies with the energy of the incident neutron and its resulting values may be found in various published Tables. Different Tables, even for the same target element, differ according to the development of the models of neutron-material interactions, and non-compromise still exists today on the methodology [8] [9]. In addition to ballistic damage, neutron-nucleus interactions in stainless steels induce gas production according to specific reactions such as e.g. $^{56}Fe(n,\alpha)^{53}Cr$ (capture cross-section for fast neutrons ~ 0.2 millibarns) or $^{58}Ni(n,\alpha)^{55}Fe$ (capture cross-section for thermal neutrons ~ 4.4 barns, and ~ 4.2 millibarns for fast neutrons). The Helium produced stabilizes vacancy clusters, helping to nucleate bubbles which are very strong hardening features.

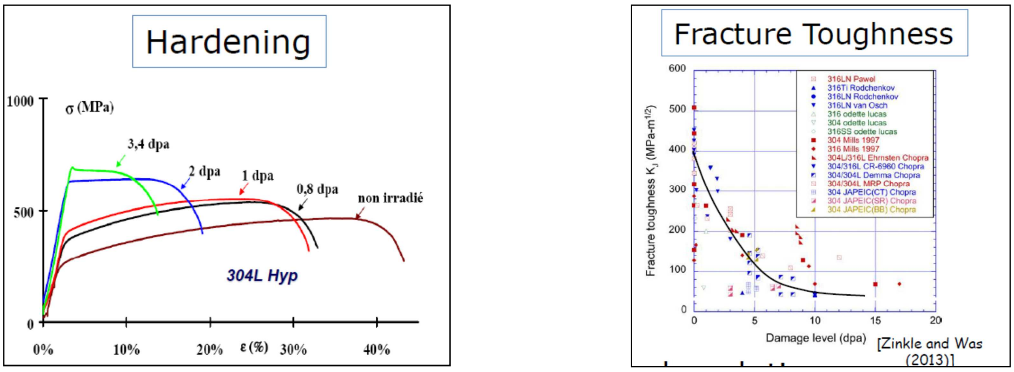


Figure 9: Examples of mechanical properties degradation versus the dose level

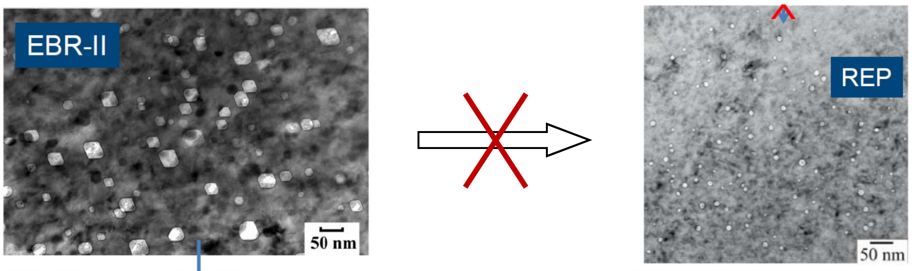
As a consequence, there are clearly strong needs for:

- Determining accurately the effects of neutron spectrum (comparable neutron dose as previous experiments but with different neutron spectra ranging from an LWR to a FBR type), flux and temperature on the microstructural changes of the irradiated materials (formation of precipitates phases, voids, cavities, bubble density….),
- Harmonizing the methodologies of radiation damage evaluation on materials and He production rate, and in particular to check the effect of ratios between {epithermal + fast} neutron flux and {fast} neutron flux. The most commonly considered ratio, called Rs, is expressed with the following energy thresholds: {Neutron flux E > 0.1 MeV} / {Neutron flux E>1 MeV},
- Monitoring of irradiation conditions (on-line fast neutron flux, integrated dose, temperature…) thanks to sensors implemented as close as possible to the individual samples, using state-of-the-art instrumentation.

5.2 Operational objectives of FIJHOP-M

Whereas surveillance programs are set up for reactor pressure vessels (RPVs) with the use of surveillance capsules placed near the vessel inner diameter prior to initial start-up, such programs does not exist for internals components. Most of the ageing monitoring programs for Internals are based on accelerated irradiations performed in MTRs or in fast reactors (FRs), but often under only fast neutron spectrum, and results come from PIEs. For example, most swelling data have been obtained from materials irradiated in FRs at higher temperatures and at dose rates orders of magnitude higher than those in PWRs. Extrapolation of these results, to estimate the void swelling behaviour of PWR/VVER end-of-life or extended life conditions of the Internals, introduces substantial uncertainties, if not concerns, about both the integrity and the functionality of these components.

So mastering the transferability of data, coming from MTRs with different spectrum towards their use for LWRs ageing monitoring, is critical for the lifetime management of both internals and RPVs.



304, 380°C, 22dpa, 0.8410^{-7} dpa/s, S=1%

316CW, 315°C, 80dpa, 10^{-7} dpa/s

FIG. 10: Example showing the difficulty to transpose MTR results (fast flux) to NPP [Nogaret, 2007]

5.3 Project plan proposed for the first FIJHOP-M experiment

The proposed experimental methodology consists of irradiating austenitic steel susceptible to swelling and to IASCC (e.g. AISI 304 for Western power plants) with tailored neutron spectra, by using 2 or 3 MTRs and with portions of irradiation capsules shielded from thermal neutrons. Target is i) to use a very well-known irradiation location in terms of neutronic performances (flux levels, spectrum, nuclear heating) and ii) to obtain a range of neutron spectra. Irradiation conditions will be based on an irradiation temperature of 370 - 380°C, with a small thermal gradient between samples ($\Delta T < 10°C$), and a neutron flux above 10^{14} $n.cm^{-2}.s^{-1}$ ($E > 1MeV$). Final targeted dose is above 5 dpa.

For that aim, a close assessment of neutron spectra and irradiation conditions will be performed thanks to state-of-the-art real time neutron flux measurement, and in particular the use of the recent on-line Fast Neutron Detection System (FNDS) developed by CEA (see Figure 11) [10], [11].

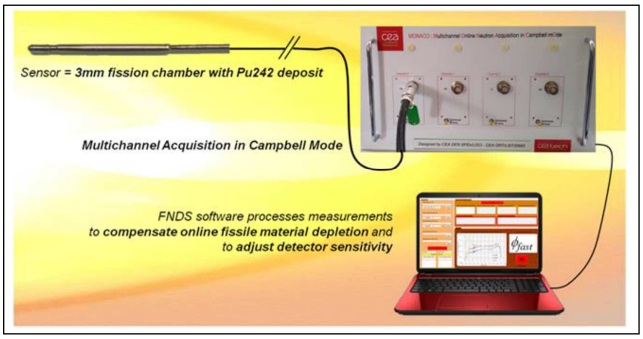


FIG. 11: Fast Neutron Detection System developed by CEA

Experiment analysis will be supported by latest modelling tools, and in particular:

- Various materials performance codes to compare calculated values of neutron flux, dpa, athermal recombination-corrected dpa (arc-dpa), gas production, gamma heating,
- Simulations with multi-scale modelling tools developed in the frame of the FP7 European program PERFORM-60 and the Horizon 2020 SOTERIA Project (an EC-funded project dedicated to simulation of irradiated material properties).

5.4 Implementation of the FIJHOP-M experiment in MTRs and in hot cell laboratories

The above chosen NPP internals steel is proposed to be irradiated at constant Rs and fast flux, but with different thermal to fast ratios, in the HFR MTR (irradiation of about 100 samples at the same time is targeted). This experimental reactor owns an existing ("off-the-shelf") test device, in order to reduce, control and de-risk the duration of the preparation phase, and to launch the irradiation phase itself in compliance with a tight schedule. The different conditions will be achieved either by the use of two irradiation locations or by the shielding of part of the irradiation capsule. Moreover, an RPV steel from Eastern design NPP (for which an extended database has been generated in past international programs) is proposed to be irradiated at constant Rs and fast flux, but with different {epithermal+fast} / fast ratios, in the LVR-15 MTR. The different conditions will be achieved by shielding a part of an on-the-shelf irradiation capsule.

Once the irradiation phase is completed, the coupons will be sent for PIE to several hot cell laboratories operated by partners. Mechanical tests (investigation on hardening, loss of ductility…) and microstructural and micro-chemical analyses will be carried out to characterize the effects of the different exposures on all of these aspects of ageing. The observations will be assessed in the light of current models of radiation-induced ageing such as those produced within SOTERIA.

5.5 Main outcome expected from the FIJHOP-M program

FIJHOP-M will offer the unique opportunity to perform pre-defined and well-monitored irradiations of “well-known” low alloy and stainless steel coupons, to provide unambiguous evidences as regards to the interpretation of radiation damage mechanisms in these materials. It will be also a good reference for establishing best practices for future MTR experiments by a further development of suited guidelines for internals irradiations, and in particular to assist in the development of test protocols for future JHR operations.

The results will inform models of radiation-induced degradation and of macroscopic evolution of materials mechanical properties for improving multi-scale modeling, predictive models and validation or qualification of participant’s models. As a second objective, implications for long term operation of LWRs will be considered by developing transposition tools between MTRs and NPP irradiation conditions.

One important outcome is networking hot cell Laboratories thanks to elaboration of an European benchmark on PIEs results, by sending the coupons to facilities operated by partners to carry out mechanical tests (investigation on hardening, loss of ductility…) and microstructural characterization using advanced and state-of-the-art techniques. The PIEs will be performed in light of the existing knowledge.

6. Conclusion and future steps

The FIJHOP program is a challenging and innovative initiative for gathering European MTRs and hot cell laboratories on common topics bridging the gap between R&D and industry. Moreover, such networking at the European level offers likely the best answer for implementing large R&D programs with short time-to-result.

Pre- and post-calculations of the experiment are of prime importance in this approach. They will bring a strong support before the irradiation, either for defining the experimental protocol, or for predicting as accurately as possible the sample behavior, to optimize the specifications of the instrumentation. After the experiment, a large scale benchmarking with up-to-date modelling is expected, beneficial for all participants whatever the development status of their own materials or fuel behavior models. Finally, transposition of results to power reactor conditions is a key objective, representing a mutual interest and benefit for R&D and industry.

Besides these R&D considerations, this proposal will be a reference for setting up best practice guidelines for future MTR experiments and for future JHR operations.

A proposal has been worked out by the WGs and supported by several other partners from outside the JHR Consortium, to be started as soon as additional funding is available. So a work frame is under construction, either by considering the possibility to submit a new proposal at a next H2020 call (in 2019), or to integrate it in another program within the Nuclear Science Committee (NSC) of the OECD/NEA. A specific session, at the NSC annual meeting, was held in June 2017 to discuss the NSCs role for building a scientific community around MTRs and establishing a systematic validation/qualification process for innovative fuels and materials. Final aim is to provide experimental support in facilitating the deployment of innovative components in existing and future nuclear power systems. The design of “smart” experiments, together with advanced methods for interpretation and extrapolation of experimental measurements, strives to improve assimilation of experimental data directly into code validation, thereby smoothing the development process and qualification programmes which underpin licensing.

The NSC gave its endorsement to establish a platform aimed at enhancing experimental support, facilitating deployment of innovative components in nuclear power systems. It was decided that the first step towards implementation of this platform is to hold a kick-off Workshop in January 2018.

7. References

[1] BIGNAN G., “The Jules Horowitz Reactor: A new high performance European MTR with modern experimental capacities – Toward an international user Facility”, 16th IGORR Conf., 17-21 November 2014, Bariloche (AR).

[2] BRAVO X., et al., “The Jules Horowitz Reactor: Preparation of the commissioning phase and normal operation”, RRFM 2017 Conf., 14-18 May 2017, Rotterdam (NL).

[3] GONNIER C., et al., “Preparing JHR international Community through the developments of the first experimental capacity”, 17th IGORR – RRFM 2016 Conf., 13-17 March 2016, Berlin (D)

[4] BERDOULA F., et al., “Fuel rod instrumentation techniques implemented in LECA facility – Development of advanced instrumentation techniques”, IGORR 2009 Conf., 27-30 October 2009, Beijing (CN)

[5] ROSENKRANTZ E., et al., “An Innovative Acoustic Sensor for In-Pile Fission Gas Composition Measurements”, IEEE Transactions on Nuclear Science, 2013

[6] VAN DYCK S., et al., “Experimental irradiations of materials and fuels in the BR2 reactor”, IAEA Tech. Meeting on commercial products and services of research reactors, 28 June – 2 July 2010, Vienna (AT)

[7] BLANDIN C., et al., “LWR fuel irradiation hosting systems in the Jules Horowitz Reactor”, ANS Topfuel 2013 Conf., 15-19 September 2013, Charlotte, North Carolina, USA

[8] STOLLER R.E., GREENWOOD L.R., “A comparison of the NRT displacement model and primary damage formation observed in molecular dynamics cascade simulations”, Reactor dosimetry: radiation metrology and assessment, ASTM STP 1398, 2001

[9] NORDLUND K., et al., OECD/NEA Report NEA/NSC/DOC(2015)/9 “Primary Radiation Damage in Materials: Review of current understanding and proposed new standard displacement damage model to incorporate in cascade defect production efficiency and mixing effects”, Publ. OECD 2015.

[10] VILLARD J.F., et al., Nuclear Technology, 173, 89-97, January 2011.

[11] FILLIATRE P., et al., Nuclear Instruments and Methods in Physics Research A 593 (2008) 510-518