Nuclear Science and Technology Symposium - SYP2019
Helsinki, Finland, 30-31 October 2019

Jules Horowitz Reactor – the Future of European Materials Testing Reactors

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ABSTRACT

As the mean age of the existing fleet of currently operating European materials testing reactors approaches fifty years, the need for a new facility, to ensure continuity and provide the necessary support to the nuclear power plant community and nuclear industry becomes paramount. The Jules Horowitz Reactor, aims to fill this gap and respond to the ever-increasing industry needs. The Jules Horowitz Reactor is currently under construction at the CEA Cadarache research center and its first criticality should be reached during the mid-2020's. In this paper, the JHR experimental capabilities at start-up along with the Finnish in-kind contributions to the JHR will be briefly described.

1 INTRODUCTION

Over the past forty years, materials testing reactors (MTR) in Europe have provided essential and invaluable support to the nuclear power plant community and nuclear industry. They have played an important role in the development and qualification of both materials and nuclear fuel used in today's nuclear power plants (NPP), along with ensuring the continued safety in current and future reactor concept designs. As the existing feet of MTRs continues to age, they will face an increasing probability of shut down due to outdated safety standards and experimental capabilities that are no longer able to respond to today's increasing demands and requirements. As of May 2019, the IAEA research reactor database showed a total of 225 operational research reactors, nine under construction and fourteen planned, twenty-five in temporary or extended shutdown, fifty-eight permanently shut down, and 510 decommissioned or in the decommissioning phase. Most of the operational and temporary shutdown research reactors are over forty years old. In Europe, there are currently only four MTRs under operation and they are all more than forty-five years old. There is only one MTR under construction in Europe – the Jules Horowitz Reactor (JHR), at the Commisariat à l'Énergie Atomique et aux Ènergies Alternatives (CEA) in Cadarache, France, see Figure 1.

The JHR has been labeled as a European Strategic Forum Research Infrastructure (ESFRI) since 2008 and will become an important part of European nuclear research infrastructures (NRI) in the coming years. The JHR is designed to (i) provide a high neutron flux, (ii) run highly instrumented experiments, (iii) support advanced modeling needs, (iv) operate experimental devices capable of simulating NPP environment in terms of coolant chemistry, pressure, temperature and neutron flux, (v) respond to the experimental need of current and future generations of power reactors and (vi) provide a major part of radioisotopes for medical purposes in Europe.

Finland is participating in the construction of the JHR with at 2 % in-kind contribution, which includes the delivery of several experimental devices to serve the needs of the JHR and the nuclear community. This paper will briefly present the experimental capabilities of the JHR, at the start of operation, along with specific items related to the Finnish in-kind contributions.

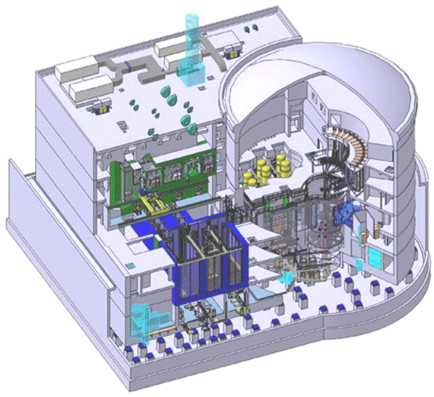


Figure 1. The Jules Horowitz Reactor.

2 JHR EXPERIMETNAL CAPACITY AT START-UP

At full capacity, the JHR will allow for approximately twenty simultaneous materials and nuclear fuel experiments. At start-up, a number of experimental devices and facilities will be available. These experimental devices include: MADISON, ADELINE, MICA and the necessary test devices for “start-up tests” and facilities including the hot cells and non-destructive examination (NDE) benches[1].

Both MADISON and ADELINE are highly instrumented experimental devices for studying and evaluating the behavior of nuclear fuel. MADISON, “*Multi-rod Adaptable Device for Irradiations of experimental fuel Samples Operating in Normal conditions*”, see Figure 2a, is dedicated to the study of nuclear fuel under nominal operating conditions, with no anticipated cladding failure. MADISON will be located in the reflector of the core on a displacement device and can be used for both short- and long-term irradiations.

ADELINE, the “*Advanced Device for Experimenting up to Limits Irradiated Nuclear fuel Elements*”, see Figure 2b, is dedicated to nuclear fuel testing under off-normal conditions, up to failure. This is the first experimental device designed specifically for power ramp experiments on nuclear fuel. ADELINE has been optimized to reach a high linear power of up to 620 $W \cdot cm^{-1} \cdot min^{-1}$ and a high power ramp rate of up to 700 $W \cdot cm^{-1} \cdot min^{-1}$.

On the materials’ side, three MICA, “*Material Irradiation CApsule*”, type devices will be available at start-up. The MICA test device is based upon the NaK capsules used in the OSIRIS reactor. The MICA capsule devices will allow for the investigation of material property changes with respect to neutron flux, neutron fluence, temperature and possibly stress. Microstructural and swelling evaluations will be possible, along with tensile and creep tests. The capsules will be located in the core of the reactor, in the center of a fuel element. Using the MICA devices, it will be possible to achieve doses of between 10 – 12 $dpa \cdot y^{-1}$. The sample’s temperature will be controlled and maintained at less than 450 °C.

One MICA device, at start-up, will be the a static NaK capsule device while the other will be equipped with a highly instrumented MeLoDIE, “*Mechanical Loading Device for Irradiation Experiments*”, sample holder, which is designed to perform creep testing with biaxial loading and an online biaxial deformation monitoring via diameter and length measurements.

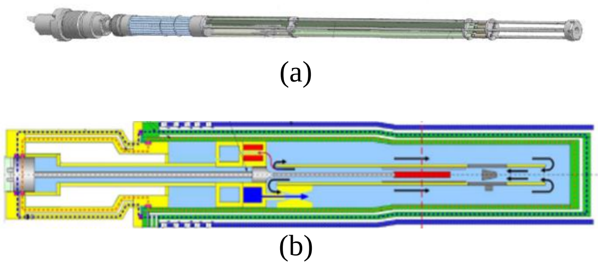


Figure 2.Schematic diagrams of the (a) MADISON and (b) ADELINE nuclear fuel testing devices. [1]

3 FINNISH IN-KIND CONTRIBUTIONS

Finland is participating in the construction of the construction of the JHR through in-kind contributions, which include the (i) Underwater Gamma spectrometry and X-ray Radiography (UGXR) and (ii) Hot cell Gamma spectrometry and X-ray Radiography (HGXR) NDE systems, along with the MeLoDIE experimental device. In the following sections, the contributions will be further detailed.

3.1 UGXR and HXGR NDE systems

Both the UGXR and HGXR are designed to perform non-destructive gamma (γ) spectrometry and X-ray radiography in the reactor pool and in the experimental devices’ storage pool or in hot cell environment, respectively. Within the in-kind contribution, both the hardware and software will be provided for the two systems.

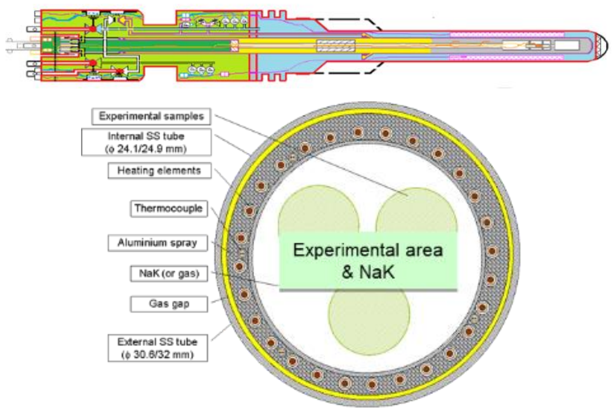


Figure 3. Schematic diagram of MICA test device for materials investigations in JHR. [1]

[1] The NDE benches will be described in detail in Section 3 as they are part of the Finnish in-kind contribution.

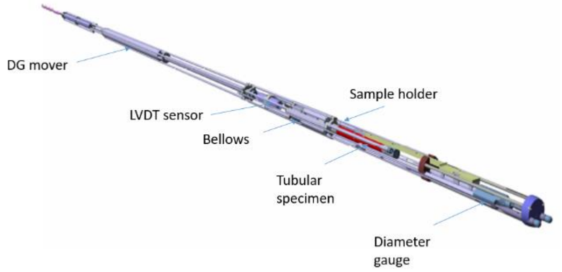
The UGXR and HGXR benches will measure the isotope distribution, via γ-spectrometry, or the density distribution, via X-ray radiography, of a sample or irradiation device in the reactor pool or storage pool. The major differences between the two devices are (i) their implementation environment, i.e. underwater (reactor pool/storage poo) vs air (hot cell) and operation and maintenance considerations linked to operating environment and (ii) the different geometries and (iii) activity levels that they are capable of handling. The GXR devices are comprised of two parts: (1) the bench capable of handling the test device or sample and (2) the collimators to limit the measured segment of radiation or guide the x-ray beam towards the studied object.

The status of these in-kind contributions is nearly complete, with the delivery of both the benches and collimators to CEA Cadarache by the end of 2019 or early 2020.

3.2 Mechanical Loading Device for Irradiation Experiments (MeLoDIE)

MeLoDIE is an instrumented in-core experimental device for the study of fuel cladding irradiation creep behavior under biaxial loading. The original MeLoDIE device was designed and delivered to CEA in 2012 for use in the OSIRIS Reactor at CEA Saclay (Saclay, France). A schematic diagram of the lower part of the device can be seen in seen in Figure 4 [2]. The device uses pneumatic controls to create a biaxial loading situation – where the internal pressure and bellows pressure are independently controlled, thus creating hoop and axial stresses in the specimen [2-4].

The pressure is controlled by a closed helium loop to generate a continuous helium gas flow for four pneumatic servo-controlled pressure adjusting loops, which are used to control (i) the internal pressure of the specimen, (ii) the pressures of the two bellows of the loading device and (iii) the pressure of the bellows of the mover [2-4]. Some of the obtained



(a)

Figure 4. Shecmatic diagrams of (a) the lower part of the MeLoDIE sample holder designed for testing in the OSIRIS Reactor [2].

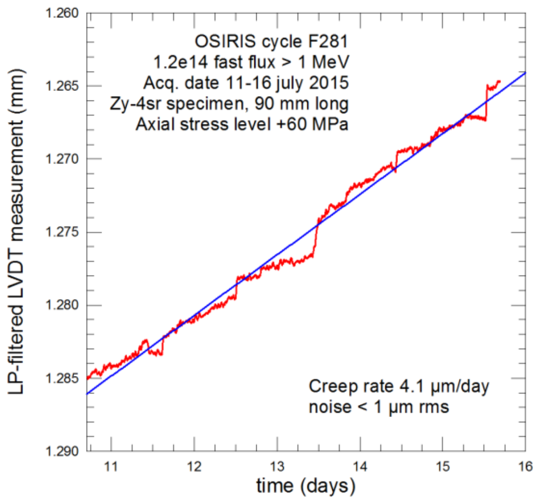


Figure 5. MeLoDIE in-core experimental results obtained in the OSIRIS Reactor, demonstrating the successful test of online measurement of axial deformation of the Zircaloy-4 cladding specimen [5].

results from in-core testing of a Zircaloy-4 cladding tube in the OSIRIS Reactor can be seen in Figure 5. These results demonstrate the devices capability to conduct online measurements of axial deformation of the specimen in-pile.

An updated version of the MeLoDIE device, MeLoDIE II, is currently being developed at VTT according to necessary modifications for exploitation in the LVR-15 (Rez, Czech Republic) MTR. The deployment of the device in LVR-15 would be part of an international joint program under the auspices of the OECD/NEA. This proposal, “IN-pile Creep studies of ATF claddings” (INCA), is currently under preparation and will be coordinated by Centrum výzkumu Řež (CVR). Eventually, based upon both the experience gained and improvements, a third version will be adapted for experiments in JHR.

4 CONCLUSIONS

The Jules Horowitz Reactor will become a key piece of European NRI in the coming years. It will fill the gap left by the shut down of the ever-aging existing fleet of European MTRs to serve the nuclear power plant community, nuclear industry and researchers alike. As the remaining operating MTRs continues to age, they will face an increasing probability of shut down, not only due to outdated safety standards, but may also experience a decrease in their experimental facilities’ and devices’ ability to respond to today’s increasing demands and requirements for nuclear fuel and materials qualification.

The highly instrumented and novel design and applications of the JHR experimental facilities and devices, some of which have been detailed in previous sections, will respond to these needs and ensure continued support to the nuclear industry, in terms of both existing nuclear power plant needs and future reactor designs.

ACKNOWLEDGEMENTS

The authors would like to thank the Finnish stakeholders (Business Finland, Fortum, TVO and Fennovoima) for their support of the JHR Consortium and construction of new European NRI. In addition the authors would like to thank the Finnish Research Programme on Nuclear Power Plant Safety 2014-2018 and 2019 – 2022 (SAFIR2018, SAFIR2022), for both the support of participation in the JHR working groups and associated research activities along with the opportunity to disseminate the progress to the Finnish stakeholders on a regular basis.

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