DE LA RECHERCHE À L'INDUSTRIE

Networking Advanced Experimental Capacities in Operating European MTRs for Qualification of Innovative Fuels and Materials:

The FIJHOP R&D program proposal

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OUTLINE

- Material Testing Reactors (MTRs) as support of the qualification process of nuclear fuels and materials

- The Jules Horowitz Reactor Consortium

- The FIJHOP initiative:
  - Context and objectives
  - Description of the two scientific proposals: Fuels and Materials

- Current status of FIJHOP and future steps

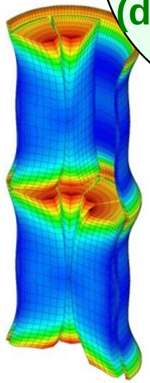
Key-Role of Material Testing Reactors for Fuels and Materials qualification under irradiation

The « knowledge loop »

Output

CODES Validation

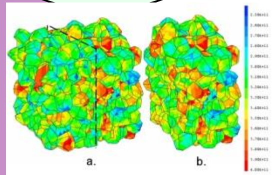
QUALIFICATION (documents, fuel product…)



EXPERIMENTAL DATA EXPERTISE

Input

Expressed Need (Basic research, Simulation, Industry…)



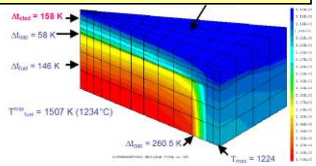
Irradiation of lead test assemblies in power reactors ??

Often not possible

Surveillance programs

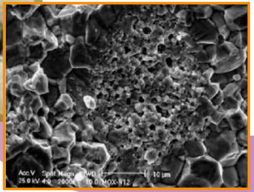
Self-qualification

SAMPLE DESIGN (Objectives, irradiation conditions…)



POST IRRADIATION EXAMINATIONS + SINGLE EFFECT EXPERIMENTS

Hot cell Laboratory

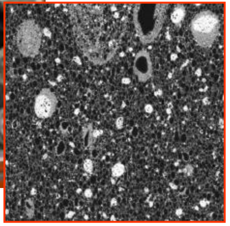


BEHAVIOR UNDER IRRADIATION

Material Testing Reactor

MANUFACTURING or REFABRICATION + CHARACTERIZATION

Hot cell Laboratory

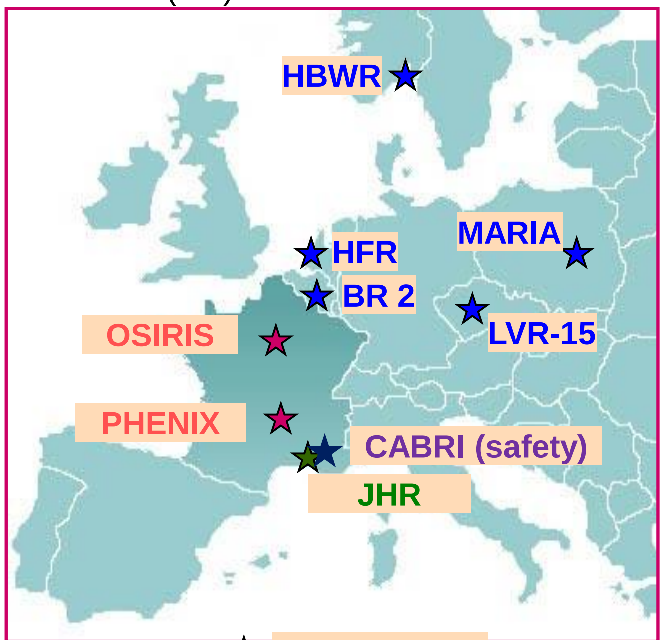


Situation of main MTRs in Europe

Large multipurpose irradiation infrastructures in Europe: Efficient but limited in number and ageing….

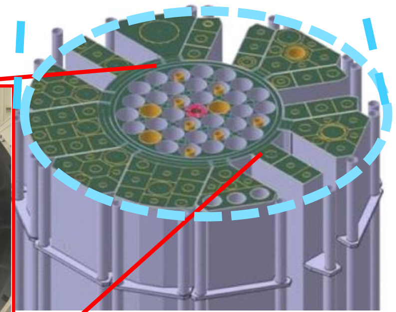
Age of current main E.U. MTRs in 2017:

BR2 (BE)	54 years
HBWR (NO)	59
HFR (NL)	56
LVR 15 (CZ)	59
MARIA (PO)	44



★Operational ★Under construction ★Shut down

Core (Φ 70cm / h 60 cm) and Be reflector



Casier for fuel elements

The JHR Program: An appropriate answer for fulfilling R&D and indutry needs

May 2017

IAEA ICERR labelling (awarded in 2015)

Hot cells delivery (Czech partners)

Réacteur / Jules / Horowitz / Reactor

Programme pour les Investissements d'Avenir

Support from French PIA (since 2010)

Preparation for pool-liner setting-up

JHR Framework

JHR Consortium partnership for construction and operation: Research centers, industrial companies and international organizations

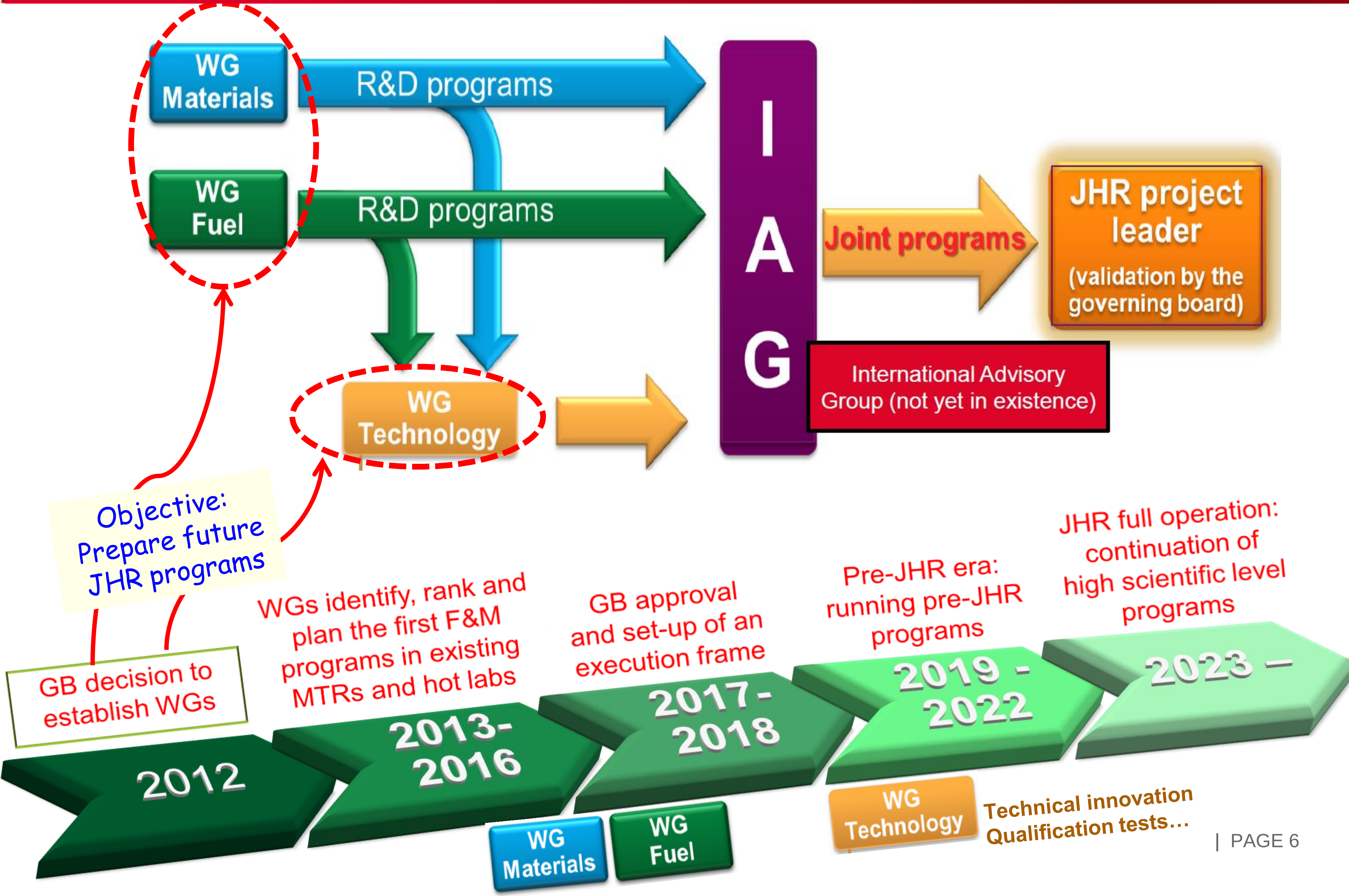
- CEA = Owner & nuclear operator
- JHR Members owners of guaranteed access rights in proportion of their financial commitment to the construction

- *Open to new member entrance until JHR completion*

Consortium managed by a Governing Board
which will rely on an International Advisory Group (IAG)
for experimental programs selection and implementation

JHR annual Technical Seminar
June 2017

JHR Working Groups



How to reinforce the irradiation service offer in Europe: The FIJHOP initiative

Outputs from the 3 JHR WGs work

- An irradiation program lasts from 3 to 10 years…
- A whole qualification program for a new fuel product ~15 years….

=> A long-term vision is mandatory:

- ✓ For programs (e.g. Accident Tolerant clads and Fuels ATF…)
- ✓ For irradiation infrastructures: high safety level, performances...

« Synthesis Document »

« Position Paper »

Released in January 2016

Networking existing European MTRs and Hot Labs through advanced joint programs is a relevant answer for assessing complex scientific issues with operational applications:

- ✓ Takes profit from the MTR's complementarity
- ✓ Is beneficial for preparation of JHR future programs

The FIJHOP Initiative

Foundation for future International Jules HOrowitz experimental Programmes

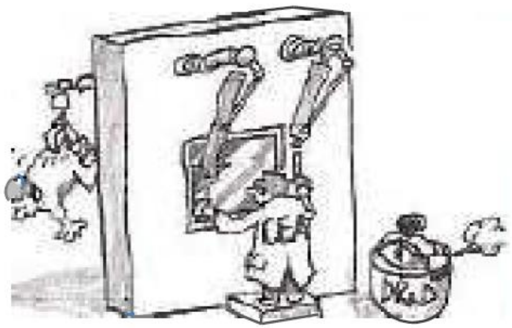
NUGENIA
NUclear GENeration II & III Association

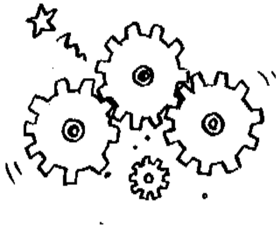
WGs meeting at VTT in Espoo (FI)
November 2017
Temperature lower than in Provence…

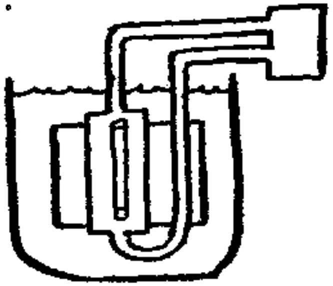
➔FIJHOP Initiative vision:

To build a pilot multilateral experimental program addressing key technology gaps on nuclear fuel and structural materials, gathering:

- ✓ Scientists from advanced simulation & modeling
- ✓ Material Testing Reactors
- ✓ Hot cell Laboratories



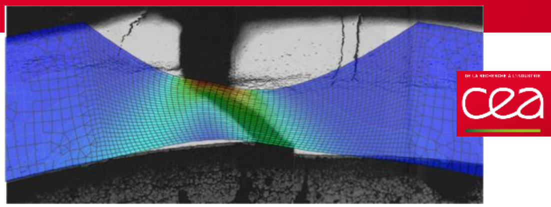




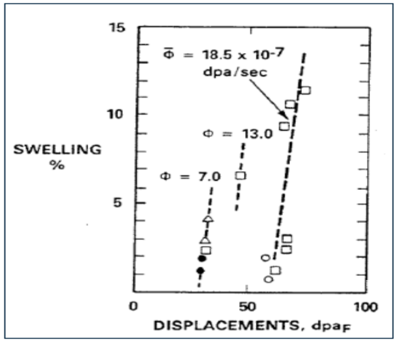
➔FIJHOP Initiative is expected to:

- ✓ Develop experimental tools to address challenges on current and future irradiated fuel and material development along with the appropriate expertise
- ✓ Contribute to the development and qualification of advanced models of Fuels and Materials behavior under irradiation
- ✓ Tackle scientific/technological gaps to enable later on JHR to deliver highly reliable data

FIJHOP Content : Advanced experiments coupled with up-to-date multi-physics simulation



Example of clad deformation assessment in RIA conditions: Plastic strain quantification (ALCYONE code)



Swelling in materials vs dose rate: Incubation period

R&D needs

Existing MTRs and Hot Labs capacities

Detailed specifications

Pre-calculation simulations

Experiments

FIJHOP

Result analyses and PIEs

Post-calculation simulations

Validation of simulation tools

Contribution to SOTERIA / simulation programs

Optimization of JHR protocols

Two programs:
- ✓ **Fuel**
- ✓ **Materials**

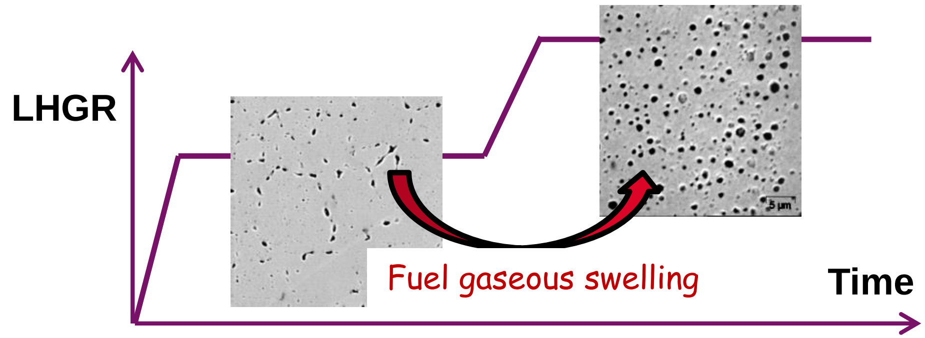
First step in existing MTRs

Second step in JHR

« FIJHOP-Fuel »: Scientific objectives

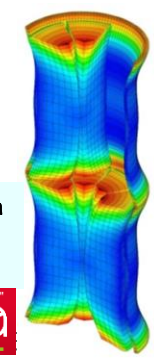
Fuel

- Improving understanding of mechanisms involved in **power transients** and having an **impact on clad loading**
  - Fuel thermal expansion
  - Fuel gaseous swelling
  - Fission gas release
  - Fuel volume change at melting



- Quantification of them through an experimental separate effect approach
  - Dominant phenomenon versus LHGR and BU ? Activation threshold(s) ?
  - Effect on clad strain and relation with material properties

- Industrial fields covered by the proposed experiments
  - Modeling of fuel rod behavior during long-lasting transients (e.g. AOOs)
  - Nucleate boiling onset => Higher linear heat rates / higher pellet and clad temperatures
  - Maintain or relax some NPPs operational constraints (power change rate...) while preserving clad reliability and safety

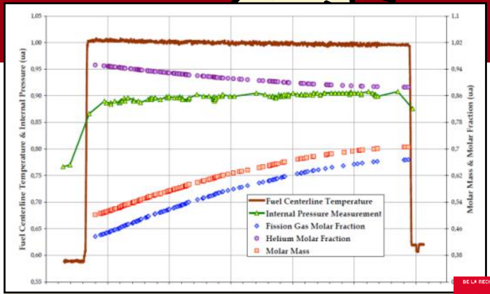


Example of fuel pellet strain during a power ramp test with ALCYONE code

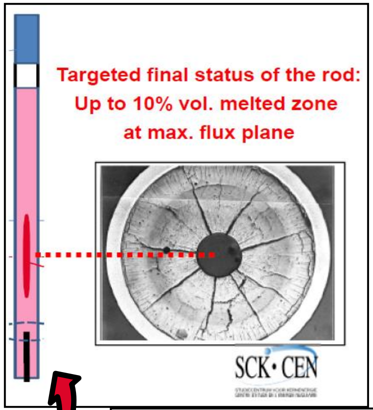
FIJHOP-Fuel: Experiment implementation

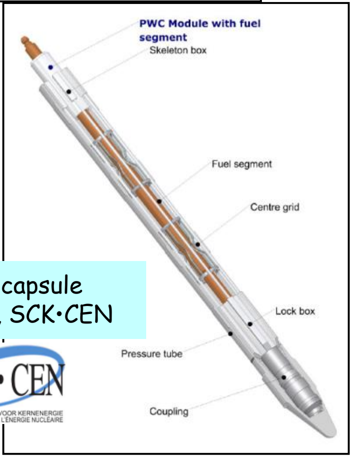
Fuel

- Use of high burn-up UO_2 fuel (40-60 GWd/t_u) and modern cladding (M5...)
  - Large available quantity of fission gases for provoking a significant clad deformation
- On-line measurement of interest parameters
  - Internal gas pressure (FGR kinetics)
  - Fuel central temperature
  - Other versus device possibility and qualified instrumentation
- To conduct successive power plateaux up to high values of LHGR (up to > 60 kW/m)
  - Discrimination of mechanisms + achievement of rod internal equilibrium (gas pressure)
  - Prohibit clad failure occurrence
  - Reach incipient fuel melting in the central part of the pellet
- First experiment in a MTR offering an available irradiation device and suitable operation authorizations
- NDE pre- and post-test (e.g. LECA, CEA and LHMA, SCK•CEN)



Example of on-line fission gas and helium releases during a power step (acoustic sensor of REMORA 3 irradiation) *ANIMMA 2011 Conf. IEEE, TNS*





PWC capsule at BR2, SCK•CEN

SCK•CEN

« FIJHOP-Materials »: Scientific objectives

Materials

❑ Effect of neutron flux and spectrum on degradation of internals components

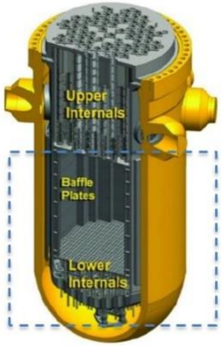
- ❖ LWR internal structures support the core, fix fuel assemblies in position, distribute coolant flow, shield reactor pressure vessel…
- ❖ Structural integrity degrades under lifetime doses of ~ 10 dpa (core barrel) or ~100 dpa (baffle-former bolts)
- ❖ No surveillance program (ageing monitoring based on MTR/FR irradiations + PIE)

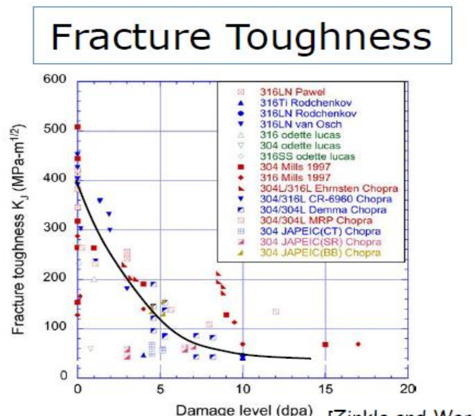
- ✓ Hardening, reduction in uniform elongation
- ✓ Fracture thoughness
- ✓ Creep, Swelling (less understood)…

Irradiation

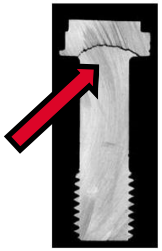
- ✓ Irradiation-induced SCC
- ✓ Wear

Irradiation + environment





[Zinkle and Was (2013)]



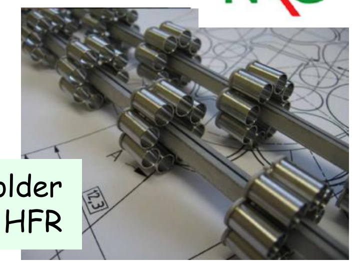
❑ Key requirement is to understand and quantify the transferability of data from MTR/FR to LWR operational conditions

- ❖ Neutron flux ratio R_s' = {"thermal" / "fast"} mastered   {E> 0.1 MeV / E> 1MeV}
- ❖ Neutron flux ratio R_s = {"epithermal + fast" / "fast"} effect to be studied in the range 2 – 5
- ❖ Modelling tools to describe microstructure evolution vs irradiation conditions
- ❖ Damage per "fast" neutron, but also H, He production : e.g. $^{58}Ni(n,He)^{55}Fe$

FIJHOP-Materials: Experiment implementation

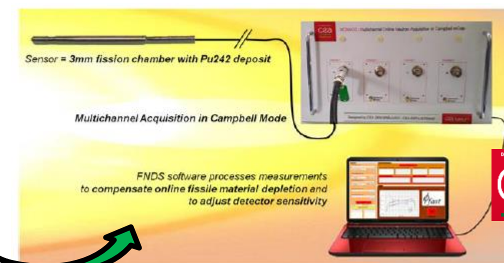
Materials

- Irradiate susceptible austenitic steel (AISI 304) in 2-3 MTRs with tailored neutron spectra (e.g. HFR…)
  - Portions of capsules shielded from thermal neutrons (large range of R_s)
  - Aiming for T_{irr} ~370-380°C with thermal gradient < 10°C
  - Neutron flux > 10^{14} n/cm^2.s (E > 1 MeV) and dpa > 5



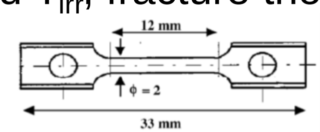
Sample-holder for tests in HFR

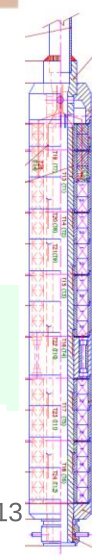
- Well-known irradiation conditions / location in MTR
  - In-pile thermocouples, dosimeters,
  - State-of-the-art real time neutron flux measurement: FNDS



- Latest modelling tools
  - To compare calculated values of neutron flux, dpa, gas production, bubble formation, gamma heating etc.
  - Benchmarking and definition of best practices for describing environment

- PIEs (5-6 hot cell Labs)
  - Mechanical properties: tensile tests at Room T and T_{irr}, fracture thoughness
  - Microstructure evolution : SEM, TEM…..





Irradiation capsule in LVR-15

- Comparing PIE results with prediction of multi-scale modelling simulations

CONCLUSION – FIJHOP Initiative status and next steps

- FIJHOP is a relevant and innovative initiative for gathering European MTRs and hot cell laboratories on common topics bridging the gap between R&D and industry

- Strong support / large scale benchmarking of up-to-date modelling:
  - Pre- and post-calculation of experiments,
  - Transposing results to power reactor conditions

- Proposal made by the JHR WGs and supported by partners from outside the JHR Consortium. Will start as soon as additional funding is available

- A new work frame is under construction:
  - Possibility considered for submitting a proposal at a next H2020 call (in 2019)
  - And/Or to integrate it in another program within the Nuclear Science Committee (NSC) of the OECD/NEA

Thank you

for your attention

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