Madison experimental device dedicated to LWR fuels studies in Jules Horowitz Reactor - Feedback on Mock-Up Loop tests performed by IFE Halden

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summary

1. **JHR & First fleet of experimental devices**
2. **Madison specifications**
3. **IFE design process**
4. **IFE test program**
5. **Tests results**
6. **Main feedbacks & Conclusions**

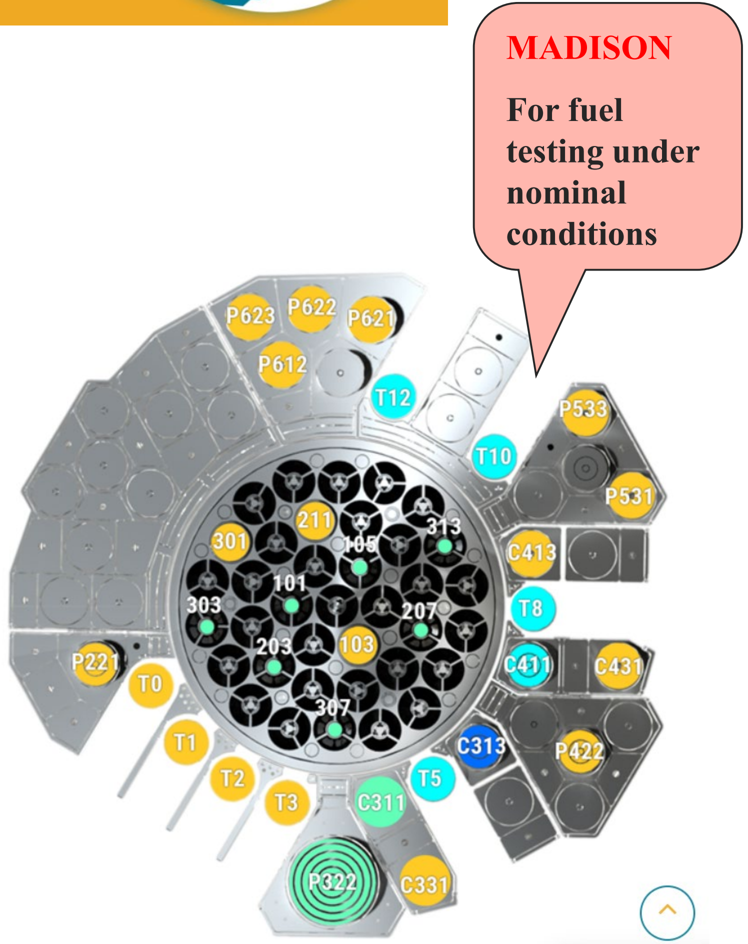
Appendix

See F. Huet & al presentation
For further details
MADISON & ADELINE experimental devices
Features and design challenges

Jules Horowitz Reactor (JHR)

- Material Test Reactor currently under construction at the CEA Cadarache centre

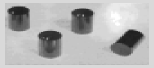
- Main Characteristics
  - Power : 70 to 100 MW_{th}
  - Fast and Thermal flux up to 5. 10^{14} $n.cm^{-2}.s^{-1}$
  - Displacement per atom (dpa/year) : Up to 11.5



- Objectives
  - Choose, characterize and qualify nuclear fuels and materials,
  - Produce various radioelements for medical and Industrial applications

Madison's specifications & Fuel experimental needs

Madison's specifications converged very early on a device allowing irradiations of LWR fuel (PWR and BWR) at this stage) and allowing to irradiate several rod samples simultaneously or highly instrumented rod samples whose objectives and applications are summarized below :



Fuel Selection
(Screening Test)

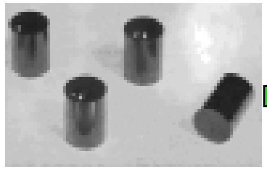
Fuel Characterization
(Properties measurement)

Fuel Qualification
(LWR conditions representativeness)

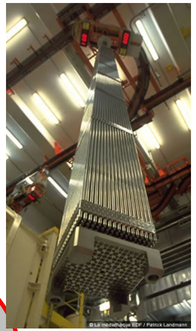
LWR fuel irradiation in nominal conditions and several transients conditions (normal)
Adaptable power (device on displacement system, in core reflector)

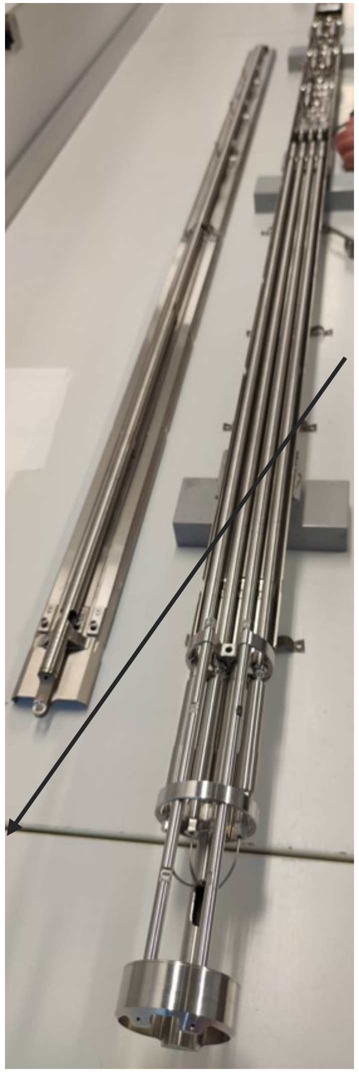
All MADISON specifications, as well as those of Adeline and others experimental devices, were the subject of a report issued in 2021 as part of the JHOP20404 project (an EU-funded project supporting the development of the JHR's strategic research roadmap to 2040), which was circulated to all RJH consortium members.

Fuel experimental needs



Sélection → Characterization → Qualification →





Sélection

- **Main objectives:**
  - Basis irradiation of several innovative products under similar conditions
- **Main requirements:**
  - High embarking capacity
  - Few instrumentation
  - Post irradiation examination

Characterization

- **Main objectives:**
  - Measurement of physical properties under neutron flux
  - Investigation of: Burn-up effect / Fission gas release / Pellet-Clad interaction / Chemical effect / Creep phenomena
- **Main requirements:**
  - High instrumentation
  - Accurate control of environment conditions (steady or transient)
  - Single effect experiments

Qualification

- **Main objectives:**
  - Reproduction of environment conditions of power reactors in normal, incidental or accidental situations
  - Envelope situations targeted
- **Main requirements:**
  - Good representativeness of power reactor (steady and transient states)
  - Long term or short term irradiations

- **Sample Holder with :**
  - 2 to 4 rods capacity,
  - Mulitple instrumentation
- **PWR Conditions (320°C) & Ø >> safety Pressure vessel**
- **Pressure Vessel Material with mechanical properties first rather neutrons transparency => stainless Steel**

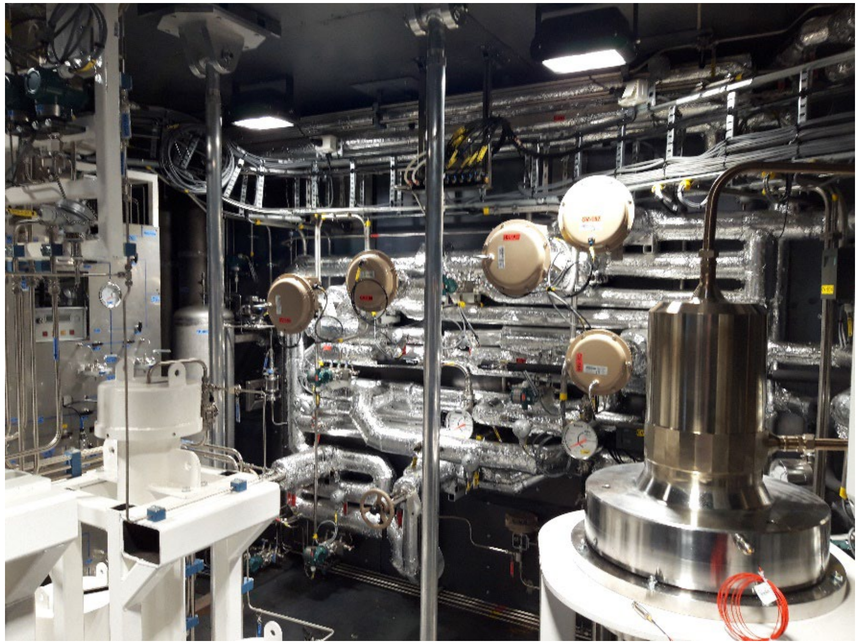
Collaborative Work IFE – CEA

At the HBWR (Halden Reactor) IFE has great feedback and has been building and running loops since 1986.

The MADISON LWR idea started out as a copy of a Halden Loop, but soon developed into something a bit more complex.

Constructed with a combination of high and low-pressure circuits designed to initially meet both BWR and PWR conditions.

The principle was tested in the HBWR test facility at Halden.



Design process summarized

Find out what goes into the Cubicle and Cold Compartement.
.

Do studies with the CAD tool to see what would be the most efficient way. (Operation and maintenance)

01
Cubicle and Cold Compartment

02
Loop design

03
Equipments of loop

04
CAD Model

05
implementation

- Dimensions were decided before the loop was designed

Assume some sizes for pumps, heaters, valves, etc. (Boxes)

Gave temporary areas that designer could fit systems and equipment it.

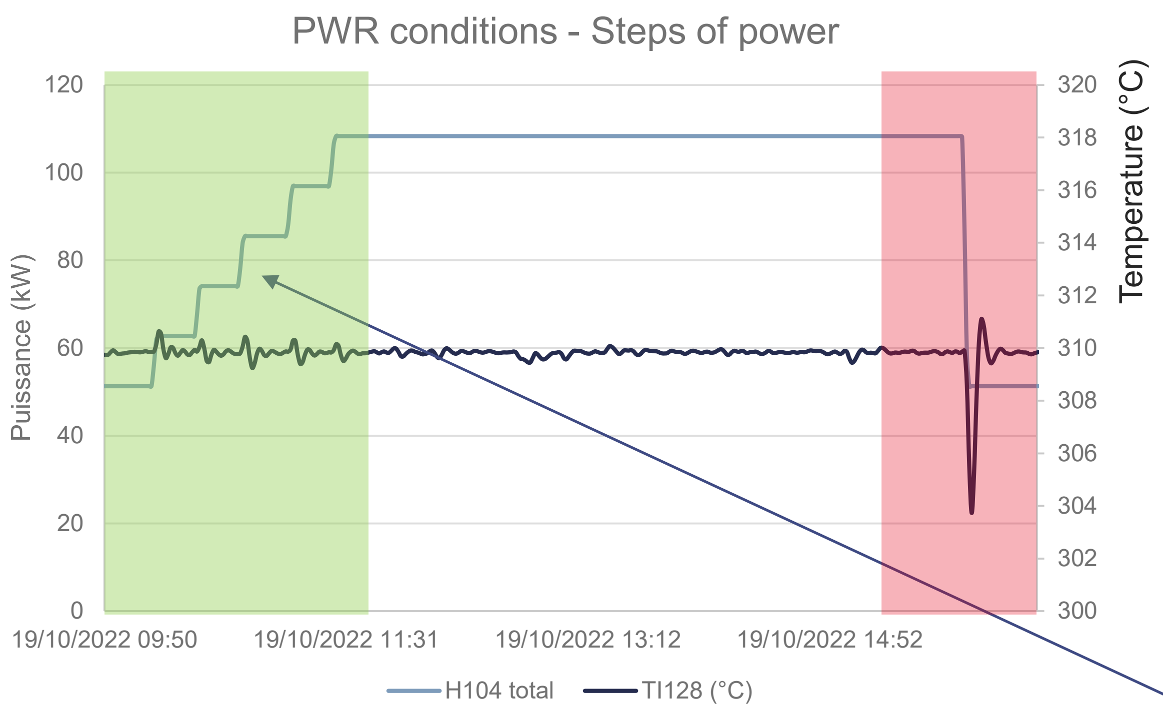
Loop test program

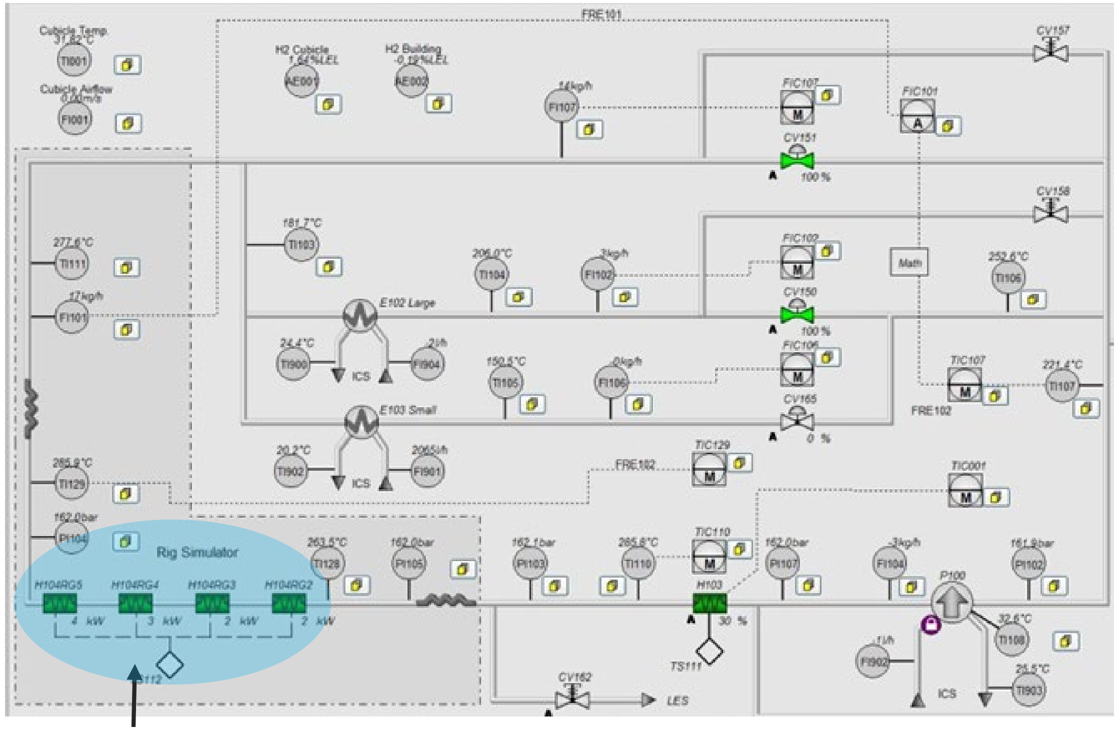
⇨ Commissioning tests at cold conditions
⇨ PWR nominal conditions test

Purposes of tests performed :

- Optimization of the loop transient of start-up and stop
- Investigate the maximal capability of cooling
- Investigate the operating range in term of flow
- Investigate the pressure drop of the loop
- PWR conditions – Abnormal and Incidental situations Tests
- Loss of electrical power
- Transient of unwanted closure/open valves
- Loss of nuclear power (simulated by electrical heater) => See Following slides

Loop 17 test program – Power variations





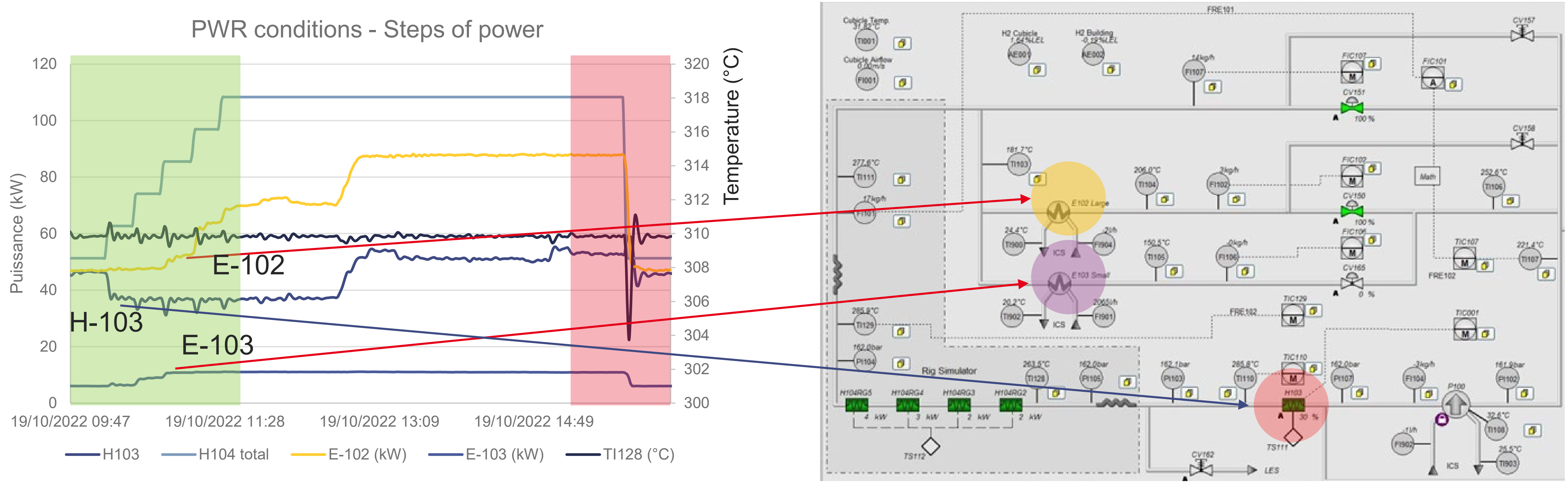
Electrical heaters for simulate nuclear & gamma heating
(~50 to 110 kW)

Simulate normal ramp of power

Incidental situation (loss of « nuclear » power)

Main goal: Limite the pressure and temperature fluctuation of the coolant to avoid an automatic action threeshold

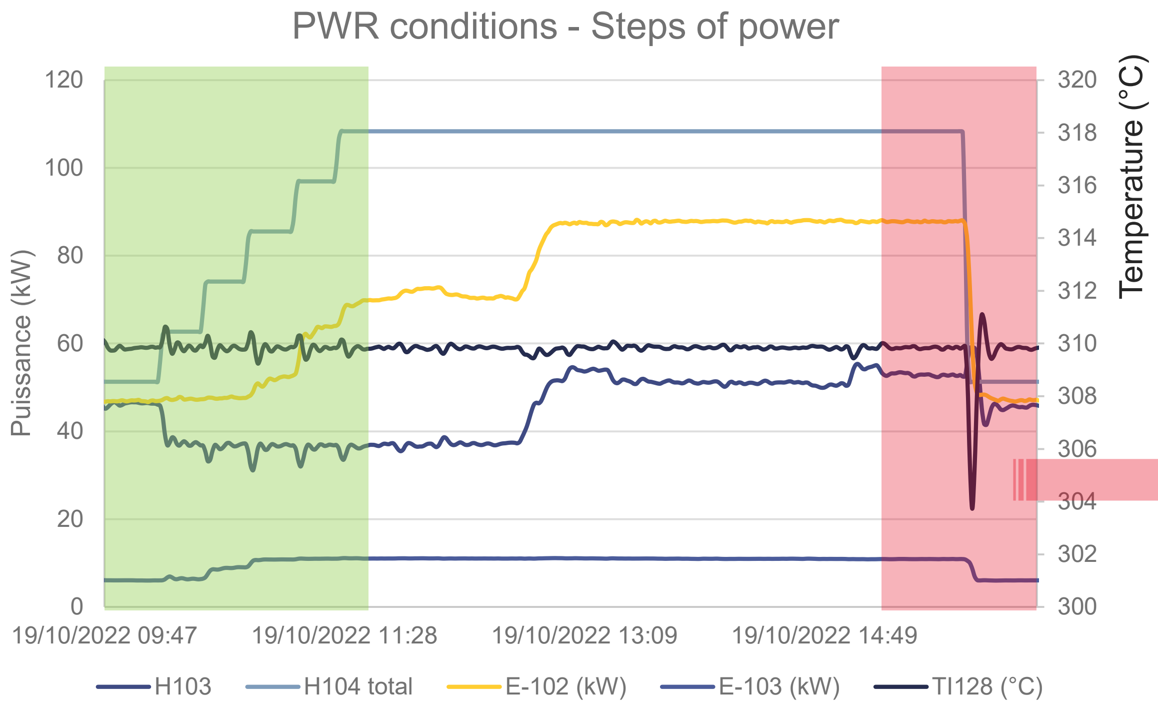
Loop 17 test program – Power variations



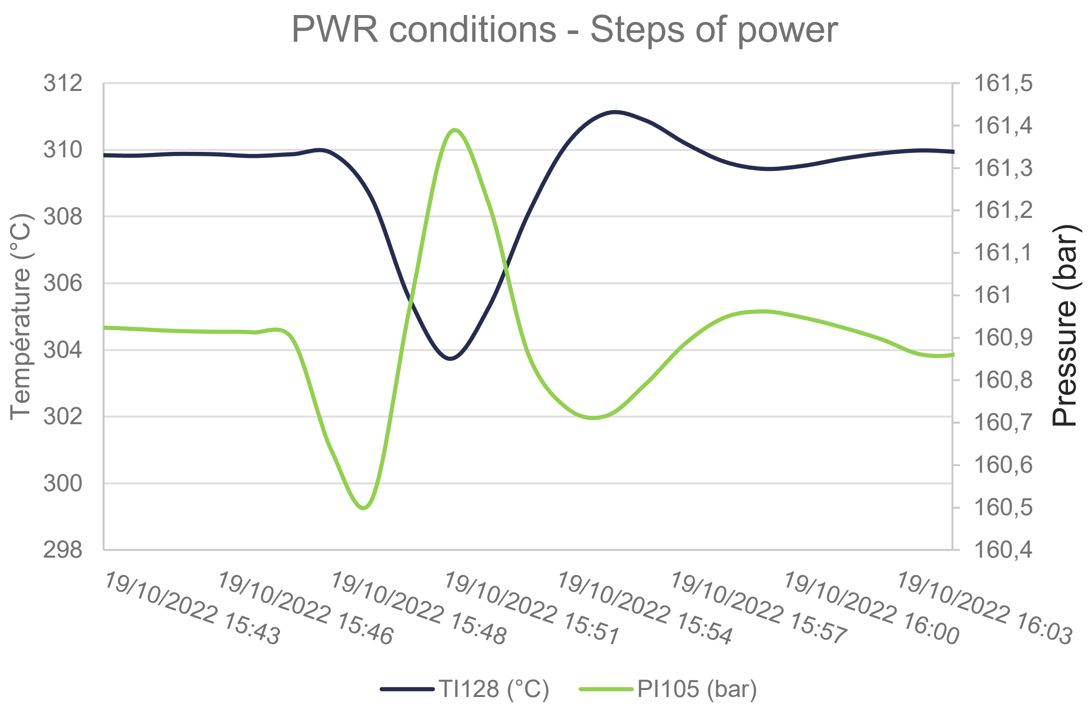
Coolant temperature in the in pile part in the is controlled by the combination of:

- Reduction of electrical power of the heater (fine tunning) (H103)
- Increase in heat exchanger (big E-102 and small E-103)

Loop 17 test program – Power variations



Focus on the incidental loss of power



For this high power loss (60 kW decrease), the pressure and temperature fluctuation are very limited

Main feedbacks & perspectives

These tests aimed to make preliminary assessment that the loop will have a large capacity and could provide a wide range of experimentations:

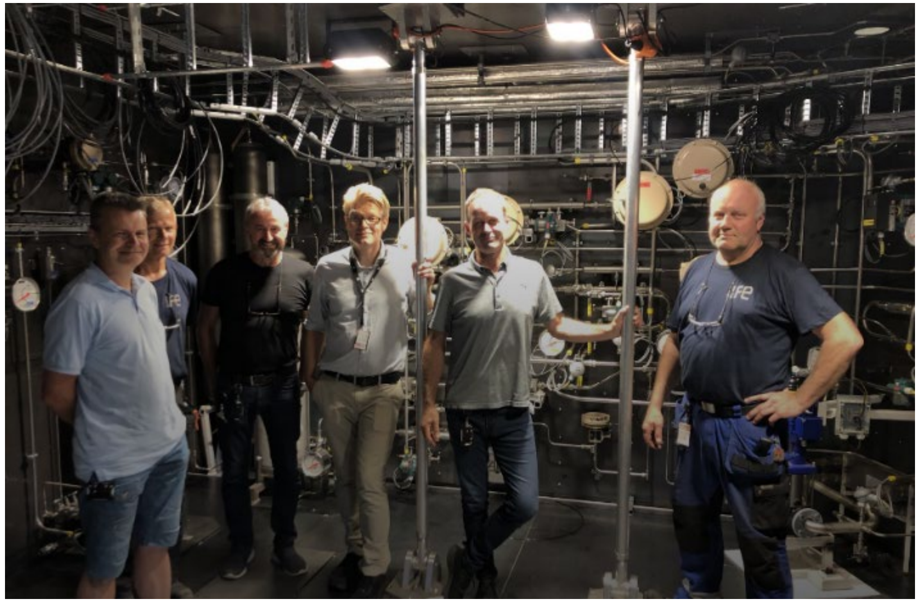
- Wide range of flow, pressure available for experimentations and most configuration, making the loop a device able to respond to multiple experimental needs in the future,
- I&C intuitive allowing a loop easy to control,
- Robustness to transients is a goal achievable.

In addition, this mock up is a Quasi scale 1 Mock up of the future Madison loop.

It is a facility that will help CEA teams for multiple needs during the phase of design of the Madison loop such as, the MA mock-up loop successfully validated the normal operating conditions and demonstrated its robustness under different scenarios.

The tests provided valuable insights for the design and operation of the Madison loop, ensuring its safety, reliability, efficiency, pre-design validation, exploration of future experimental needs.

Regards



IFE Madison team

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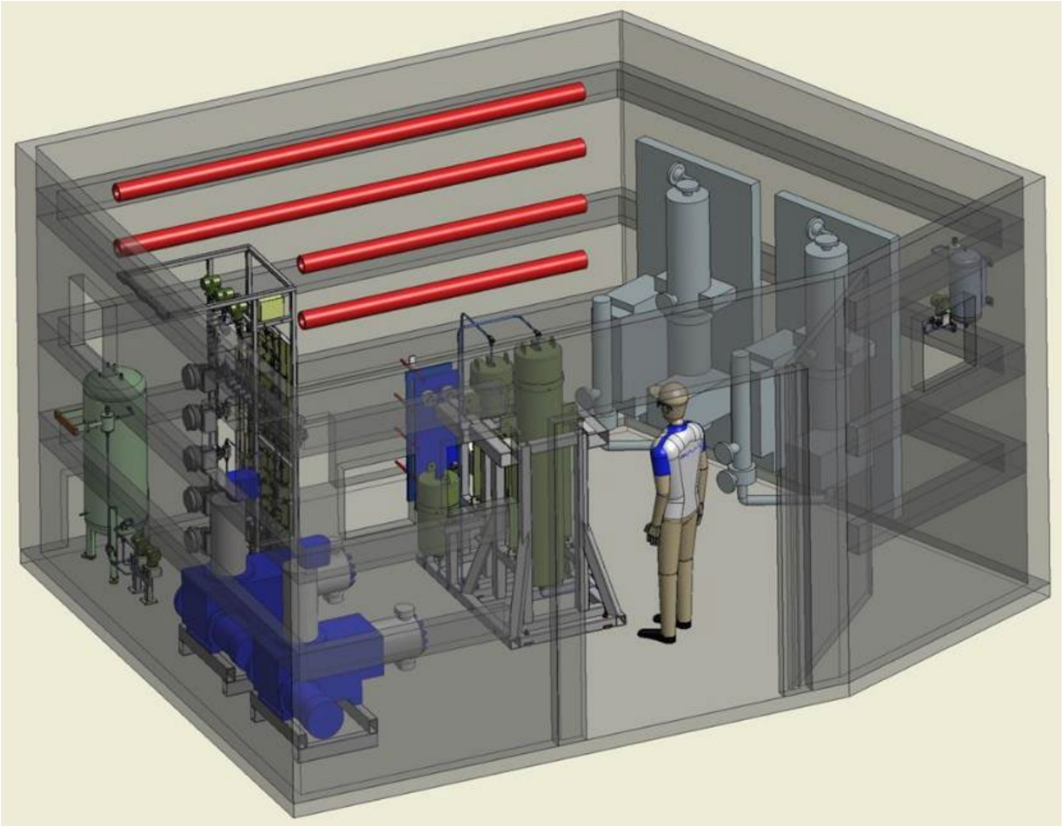
Emplacement logotypes financeurs/partenaires

Design process

For the MADISON loop a different approach was chosen by IFE , that allowed an efficient way of designing loop.

- Cubicle and Cold Compartment dimension (Was decided before the loop was designed so we had to make do with the space CEA gave us.)
- Find out what goes into the Cubicle and Cold Compartment.
- Assume some sizes for pumps, heaters, valves, etc. (Boxes)
- Do studies with the CAD tool to see what would be the most efficient way. (Operation and maintenance)

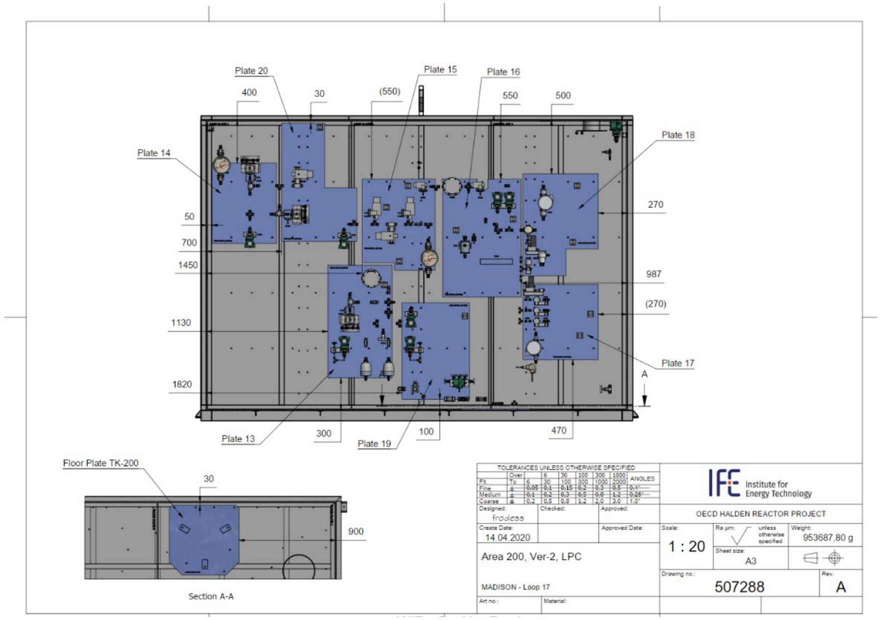
This gave IFE temporary areas that we could fit systems and equipment on. E.g., almost a whole wall for the high-pressure circuit, center position for the purification system etc.

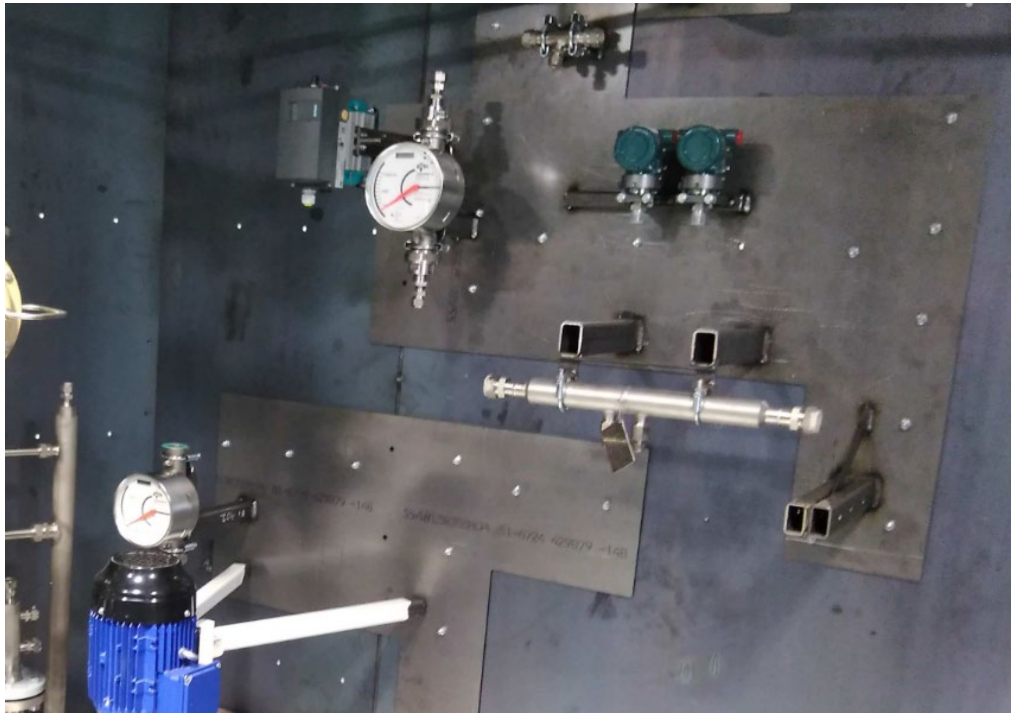


First sketch of main systems layout principles

MADISON Cubicle with holed plates

- The MADISON Cubicle is design and built with certain measurements and holes placed in a special pattern.
- The hole pattern was not very useful to mount equipment directly into.
- Decided early on that we needed to use some kind of plates to adapt the fasteners and fixtures for the equipment to the cubicle wall, ceiling and floor.





⇒ With help of plates and holes possible to give more understandable drawings for manufacture.

From loop 17 to Madison loop

Main CAD Model:

- Loop 17 have less components than the final MADISON Loop.
- Loop 17 should be able to show that the MADISON Loop will work in function, but also in use of space, mainly inside the cubicle.
- Still work left to be able to deliver a complete model.
- The “Representation” function gave the possibility to draw a CAD model with the knowledge that all the equipment would fit for both loops. Especially important with the MADISON Loop.

The CAD program used at IFE has a function called “Representations”. Switches visibility on objects in drawing. Gave the opportunity to have both the MADISON Loop and Loop 17 in the same CAD model.