



CARMEN measuring device for the Jules Horowitz reactor Status of development

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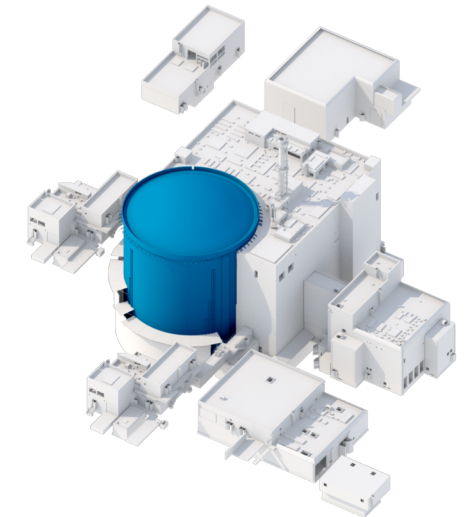
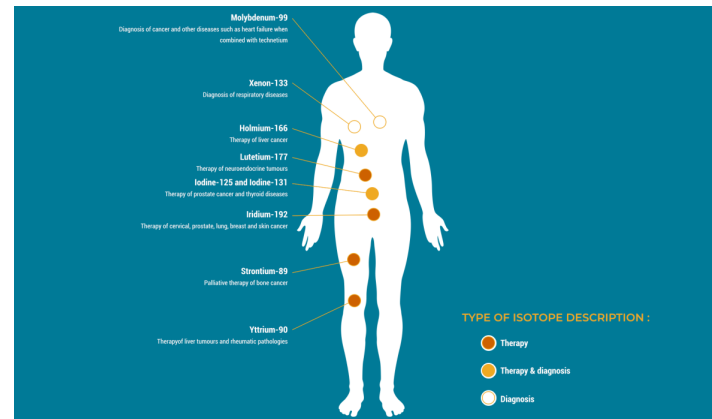
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1. Jules Horowitz Reactor (JHR)

- MTR currently under construction at the CEA-Cadarache center (FRANCE)
- Main objectives
 - R&D to support the nuclear Industry (material and fuel behavior under irradiation)
 - Radioisotope production



⇒ see Gilles BIGNAN's presentation

2. CARMEN objectives



Multi-detector measuring device able to acquire data on neutron and photon fluxes and nuclear heating deposits with a positioning accuracy of less than 1 mm

- Improve the overall knowledge of the reactor for better modeling
- Improve the knowledge of experimental conditions for better quality results
- Validate the performance during the reactor start-up tests

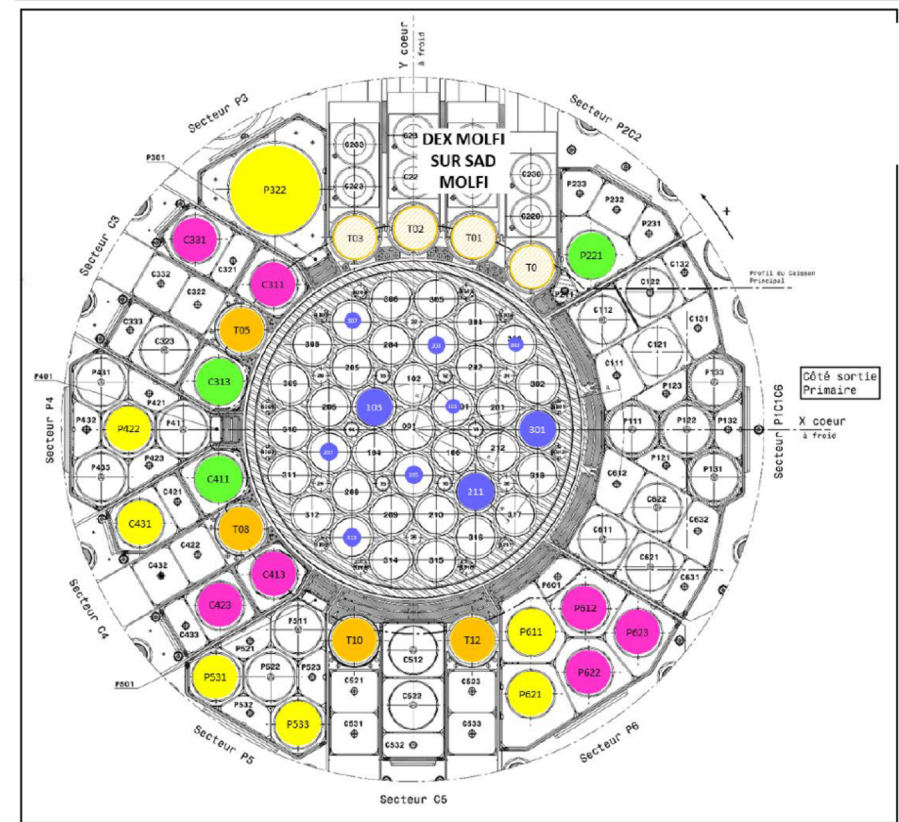
2. CARMEN objectives

Different experimental locations to be characterized

- In core:
 - 10 experimental locations
 - high fast flux: **up to $6 \cdot 10^{14} \text{ n.cm}^{-2} \cdot \text{s}^{-1}$** ($>0.907 \text{ MeV}$)
 - high thermal flux: **up to $5 \cdot 10^{14} \text{ n.cm}^{-2} \cdot \text{s}^{-1}$** ($<0.625 \text{ eV}$)
 - high nuclear heating rate in aluminum: **up to 20 W/g** at 100 MWth
 - ❖ installation plane accessible through the reactor vessel head: elevation: -5694 mm

- In reflector:
 - 14 experimental locations to be characterized
 - high thermal neutron flux: **up to $3.5 \cdot 10^{14} \text{ n.cm}^{-2} \cdot \text{s}^{-1}$** ($<0.625 \text{ eV}$)
 - ❖ installation plane accessible from the seismic support structure: elevation: -7085 mm

- CARMEN must be inserted in these main different experimental locations to carry out the expected measurements

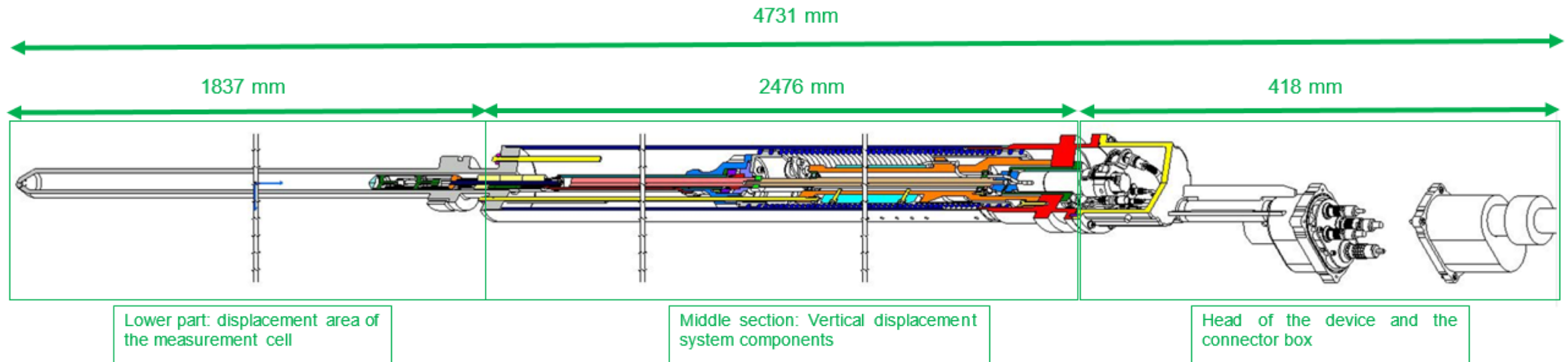


		Location type	To be characterized by CARMEN
In-core	●	7 inside a fuel element (device $\varnothing 33 \text{ mm}$)	✓
	●	3 instead of a fuel element (device $\varnothing 86 \text{ mm}$)	✓
In-reflector	●	4 on displacement system (device $\varnothing 100 \text{ mm}$)	✓
	●	4 on displacement system (device $\varnothing 100 \text{ mm}$ – radioisotope production)	-
	●	9 fixed on the Be reflector (device $\varnothing 97 \text{ mm}$ – long devices)	✓
	●	1 fixed on the Be reflector (device $\varnothing 200 \text{ mm}$ – long device)	✓
	●	7 fixed on the Be reflector (device $\varnothing 97 \text{ mm}$ – short devices)	-

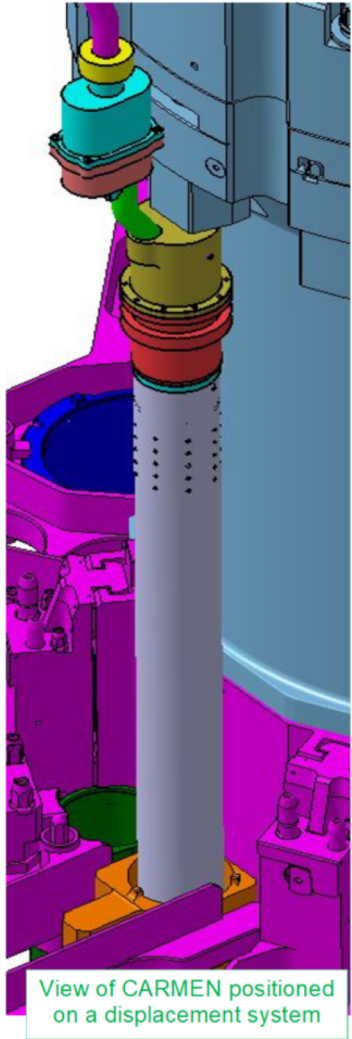
3. CARMEN design

In-pile part of the device

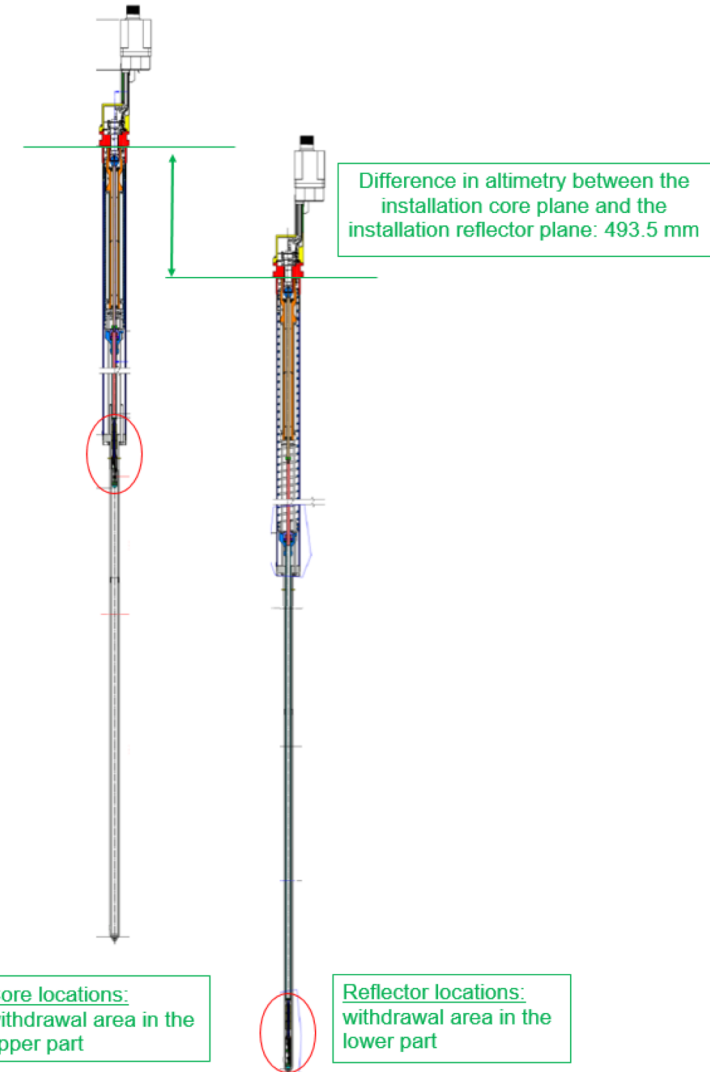
- based on feedback from the CALMOS device, the first mobile calorimeter device used in OSIRIS (previous French MTR reactor)
- based on the narrowest irradiation locations, those in the core, inside a fuel element
- Lower part (\varnothing 33 mm) contains the measuring cell, the displacement area and a withdrawal area out of the neutron flux to prevent drift or decalibration of its sensors
- The middle section (\varnothing 86 mm) contains the vertical displacement system
- The head of the device contains the motorization box and the connector box



3.1 A single design for all the experimental locations



- Objective: to have a back-up device in the event of failure
- Objective: minimize the number of CARMEN devices needed in operation
- Design adaptation necessary to be as close as possible to the core vessel when the device is on a displacement system
 - ⇒ The connector box has been offset from the axis of the device and the installation height of the device has been shifted axially
- Design adaptation necessary to deal with different installation plane heights in the core and in the reflector
 - ⇒ Measurement cell withdrawal area depending on the location

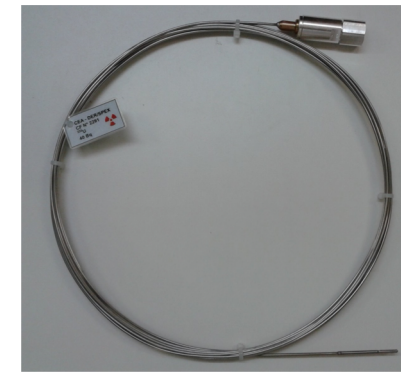


3.2 Measuring cell

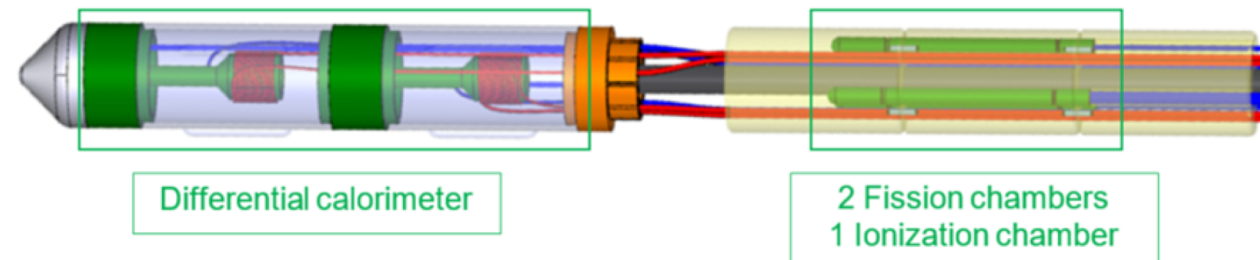
Measurement accuracy of 10% at 2σ

- CARMEN will be equipped with state-of-the-art instrumentation

- **A miniature ionization chamber** with an external diameter of 3 mm to measure the gamma flux
- **Two miniature fission chambers** with an external diameter of 3 mm (U-235 and Pu-242 deposit) to measure the thermal and fast neutron flux
 - ⇒ Used in French and international reactors for many years, does not require further development
- **A recent generation differential calorimeter** made of aluminum and stainless steel with an external diameter of 19 mm and an approximate height of 10 cm to measure the nuclear heating
 - ⇒ Nuclear heating range to be measured in the aluminum will be quite large
 - in the core from about 0.4 W/g at 2 MW power to 20 W/g at 100 MW power
 - In the reflector about 40 mW/g at 2 MW
 - ⇒ Development efforts focused on the calorimeter

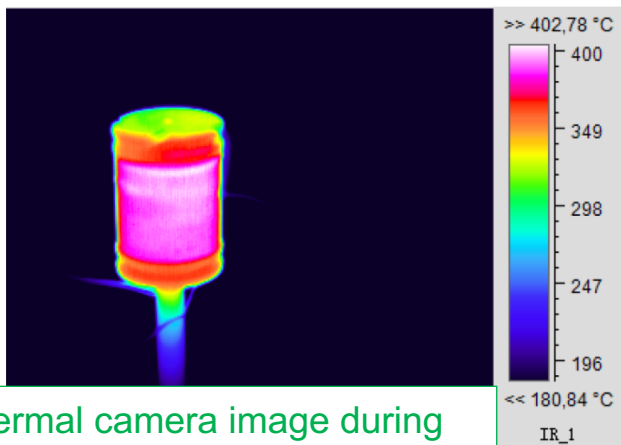


Miniature fission chamber



3.2 Measuring cell

- CARMEN calorimeter: an upgrade of the one used on CALMOS (OSIRIS measurement device)
- Mock-ups made it possible to validate the different stages of the manufacturing protocol
- Thermal cycling tests at 350°C have validated the homogeneity of the temperature in the winding
- ⇒ The calorimeter retained its insulation and resistivity during the tests

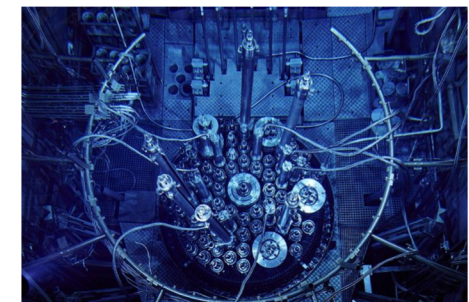


Thermal camera image during temperature stabilization at 350°C

Calorimeter mock-up before and after assembly



- Validation under high flux: irradiation in the BR2 reactor (Belgium) is being prepared and planned for the 2nd quarter of 2025



BR2 core

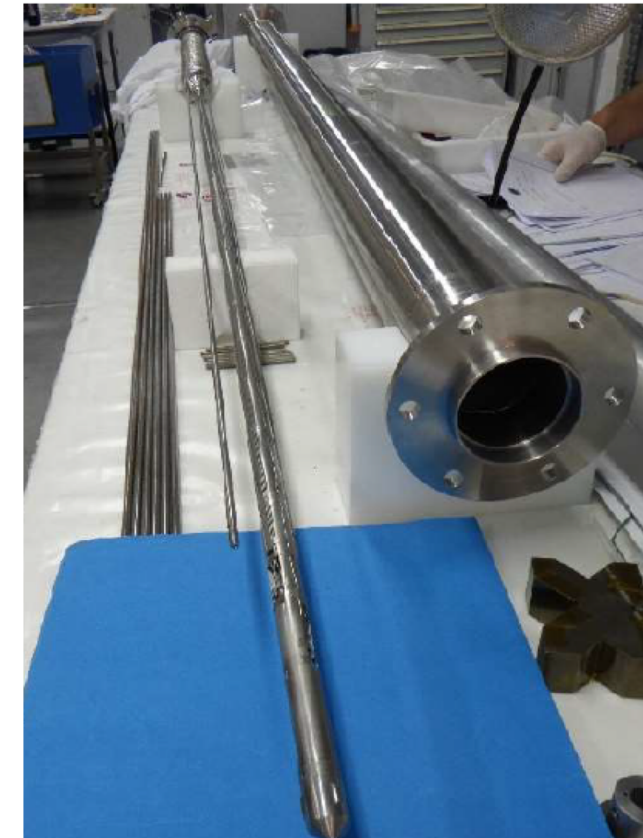
3.3 Vertical displacement system

- A full-scale mock-up was made to validate the design and the manufacturing process of the vertical displacement system

This system includes in particular:

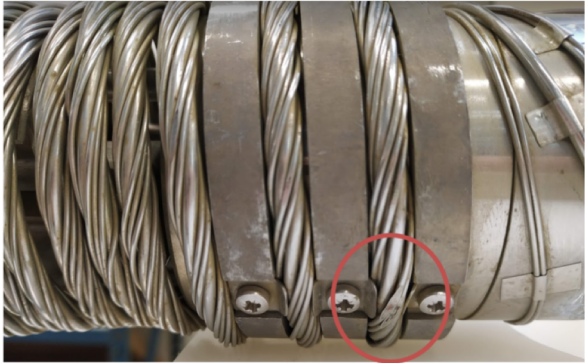
- magnetic coupling motor located in the head of the device
 - screw-nut connection with a recirculating ball screw
 - spiral formed from the sensor cables wound together around the ball screw and working in extension/compression
-
- Endurance tests
 - Mock-up immersed in an upward flow of demineralized water
 - 2000 return trips corresponding to a continuous operating time of 200 hours (over distance of 1650 mm at a speed close to 10 mm/s)

Sensor cables formed in spiral



Vertical displacement system mock-up

3.3 Vertical displacement system



■ Test results:

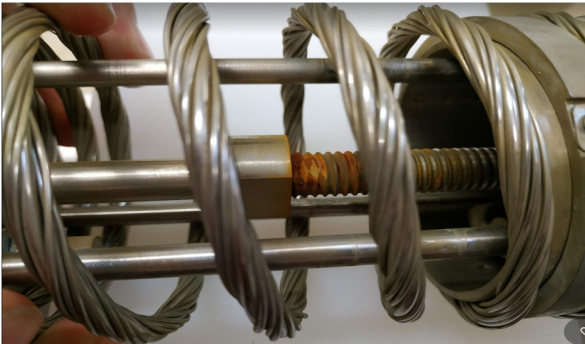
- cladding wear on several cables due to friction on the top part of the mock-up



- Very local traces of corrosion were observed on 3 catalog parts, as well as on the threaded rod of the ballscrew



- sizing of the motorization and the design of the kinematic chain were correct



- Overall, any major issues with design and process choices have been ruled out



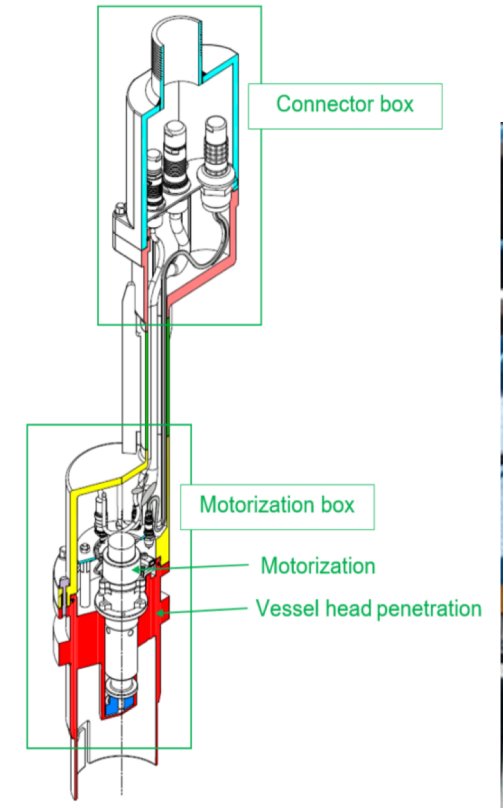
- Cable cladding perforation and local corrosion can be handled without much difficulty



Vertical displacement system mock-up on its test bench

3.4 Device head and connector box

- A mock-up will be made to validate the assembly process of the device head given the restricted space for assembly
- Leakage, endurance and maintainability tests will be carried out to check
 - Motorization box and connector box are leaktight
 - Cycles of connection/disconnection of the underwater lines
 - The motor and all the connectors are replaceable in the event of failure

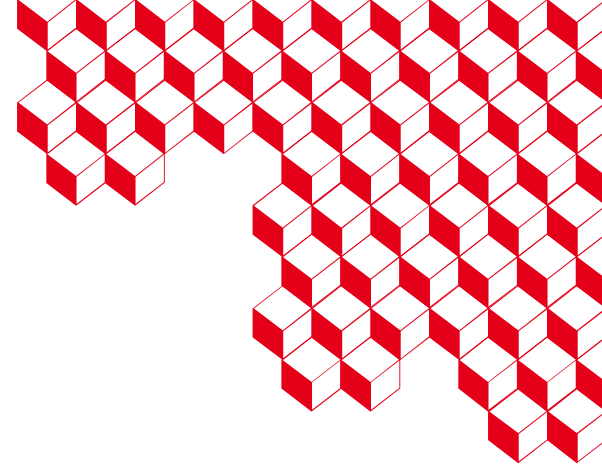


Background photo: TOTEM facility (Cadarache center) regularly used to test mock-ups of experimental devices under conditions representative of the JHR (pool with an equivalent depth)

2024

4. Conclusion

- CARMEN devices will be ready to be manufactured by the end of 2025 thanks to:
 - work of optimizing the design
 - validation tests carried out through numerous mock-ups
- The on-board vertical displacement system will allow fast and very precise measurements
- A fleet of 3 CARMEN devices will be manufactured and available from the JHR start-up tests in order to map the core in an optimized time frame
- CARMEN's unprecedented measurement capabilities are expected to improve our knowledge of the JHR core, thus allowing:
 - an optimized thermal design of the irradiation devices
 - better analysis of the experimental results



Thank you

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