CARMEN measuring device for the Jules Horowitz reactor Status of development

M. ANTONY, P. GUIMBAL, D. FOURMENTEL, P. LENOIR, L. VIGNERON, L. BESSE, S. BREAUD, R. PALHIER

CEA, DES, DIMP, DCET, Cadarache F-13108 Saint-Paul-Lez-Durance, France

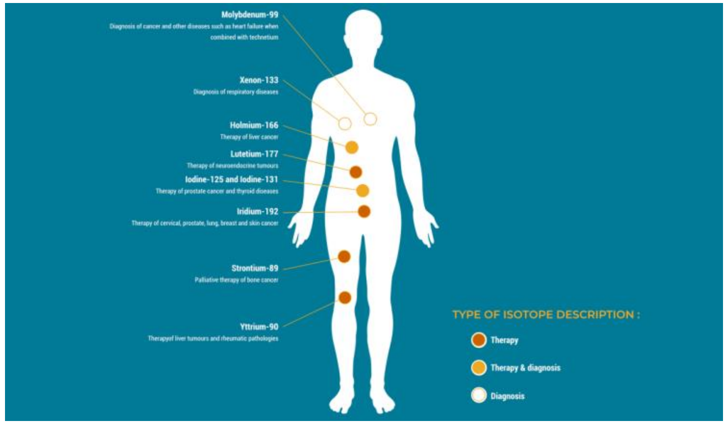
muriel.antony@cea.fr

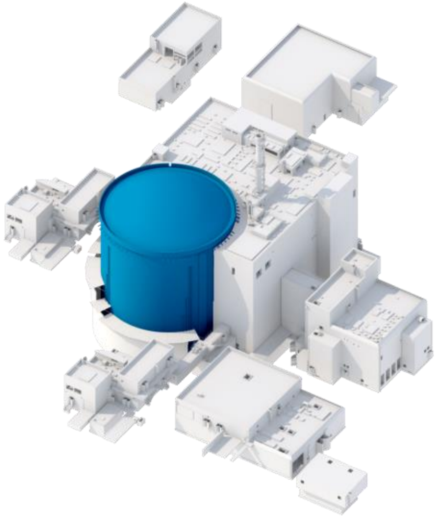
Contents

1. Jules Horowitz Reactor (JHR)

- MTR currently under construction at the CEA-Cadarache center (FRANCE)

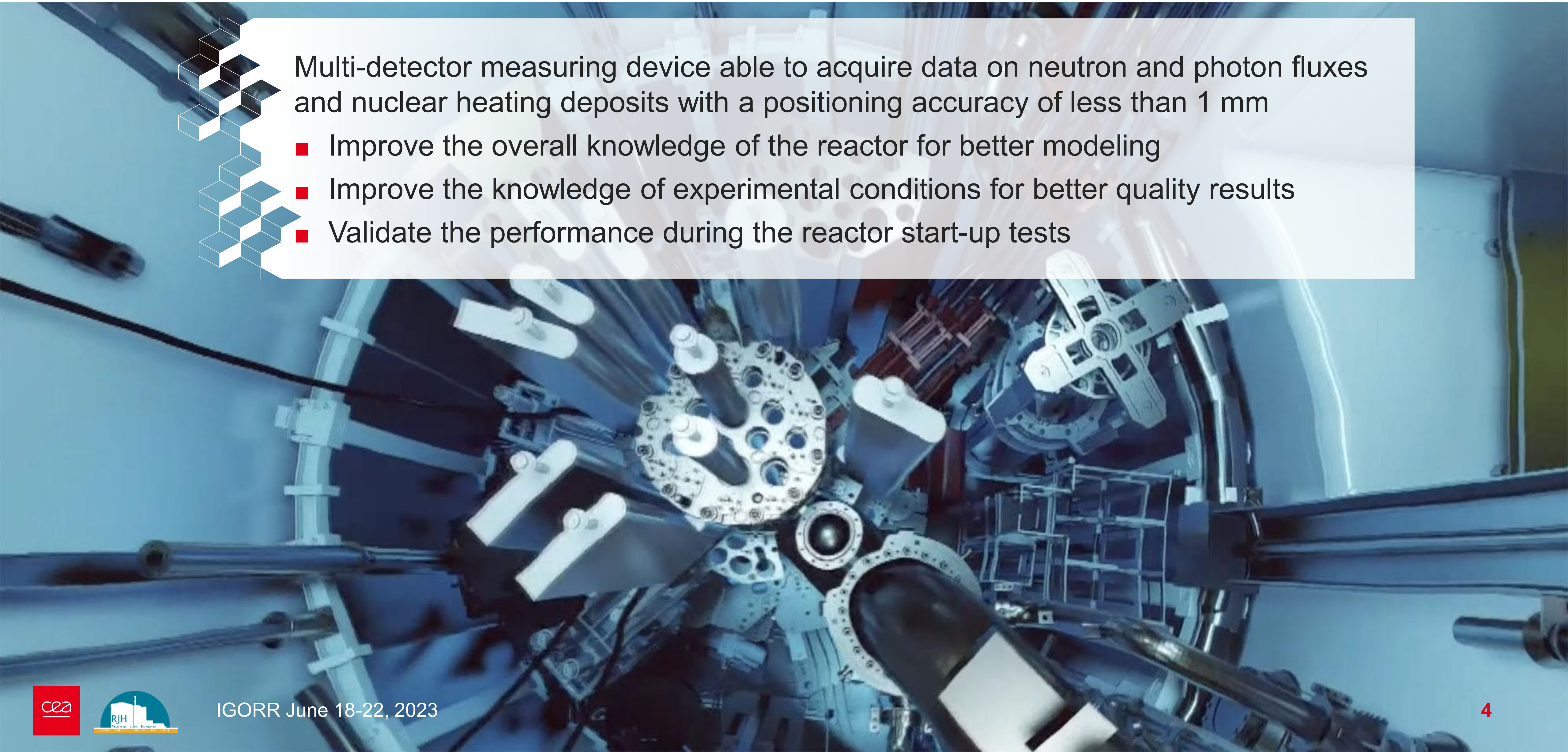
- Main objectives
  - R&D to support the nuclear Industry (material and fuel behavior under irradiation)
  - Radioisotope production





➪ 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

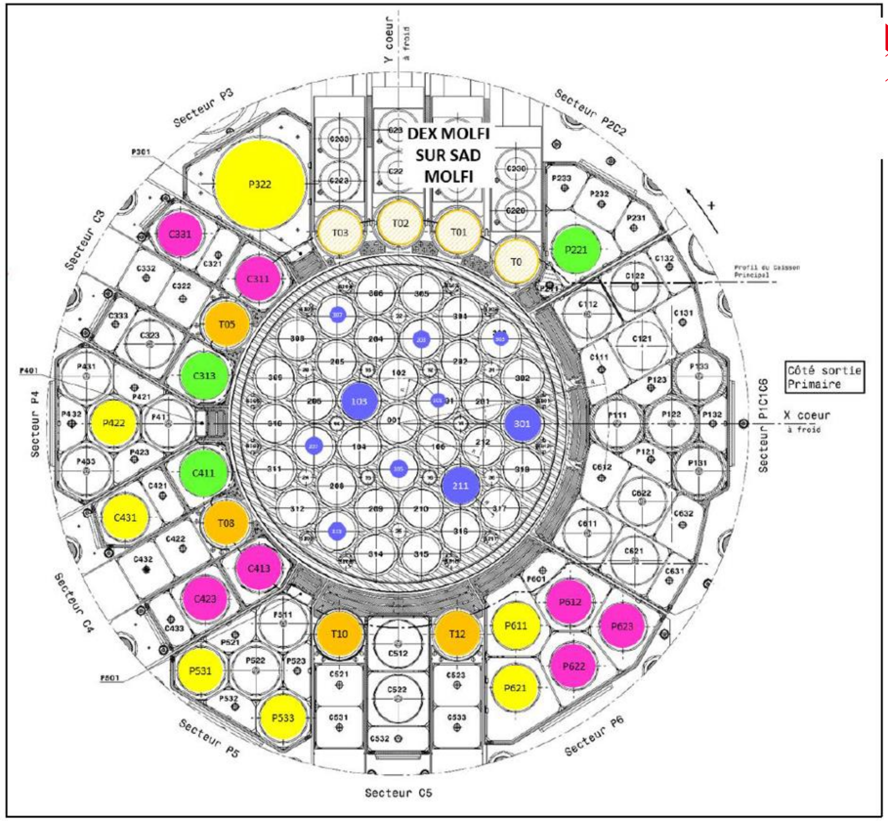
2. CARMEN objectives

Different experimental locations to be characterized

- In core:
  - 10 experimental locations
  - high fast flux: **up to 6.10^{14} $n.cm^{-2}.s^{-1}$ (>0.907 MeV)**
  - high thermal flux: **up to 5.10^{14} $n.cm^{-2}.s^{-1}$ (<0.625 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 10^{14} $n.cm^{-2}.s^{-1}$** (<0.625 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



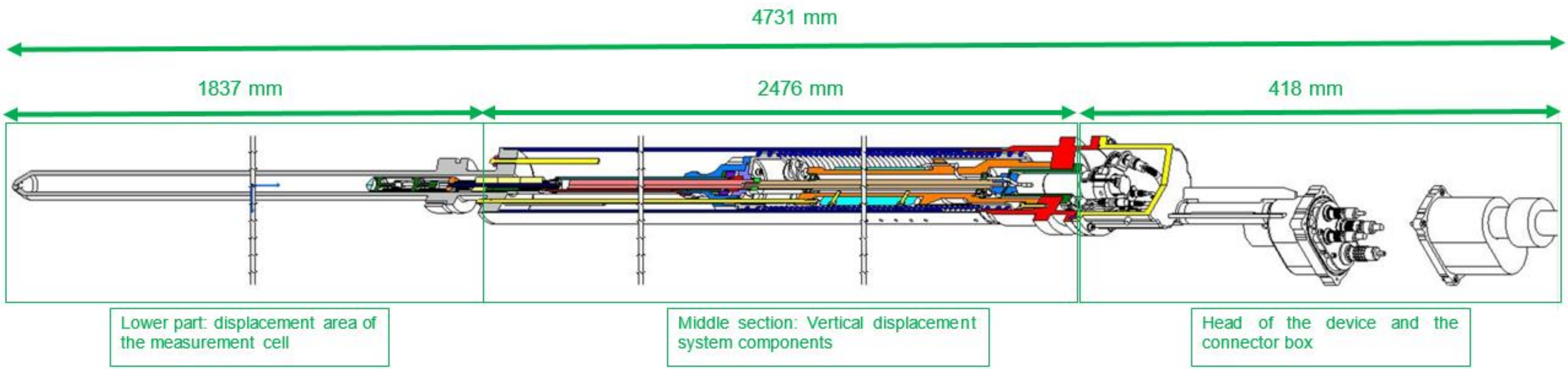
		Location type	To be characterized by CARMEN
In-core		7 inside a fuel element (device ∅ 33 mm)	✓
		3 instead of a fuel element (device ∅ 86 mm)	✓
In-reflector		4 on displacement system (device ∅ 100 mm)	✓
		4 on displacement system (device ∅ 100 mm – radioisotope production)	-
		9 fixed on the Be reflector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

3. CARMEN design

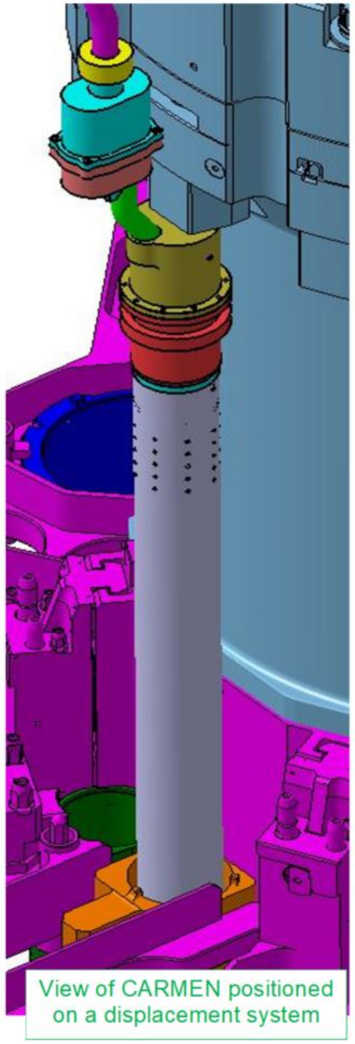
In-pile part of the device

- 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 (∅ 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 (∅ 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



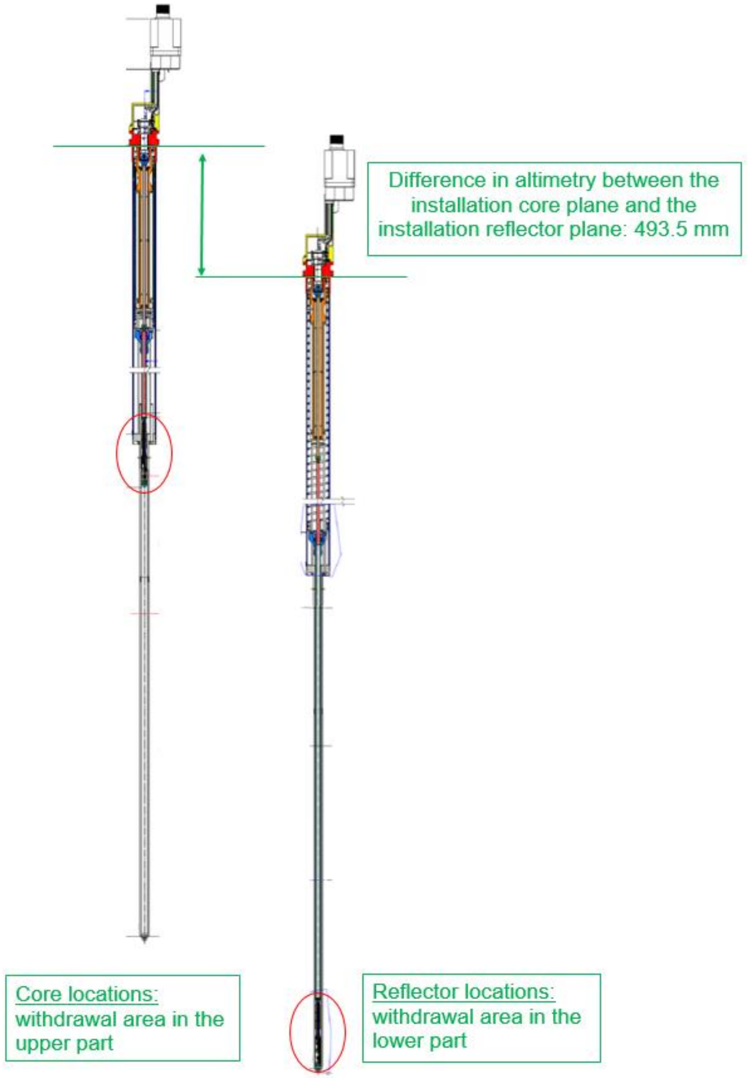
- Objective: to have a back-up device in the event of failure
- Objective: minimize the number of CARMEN devices needed in operation

  - 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 2 σ

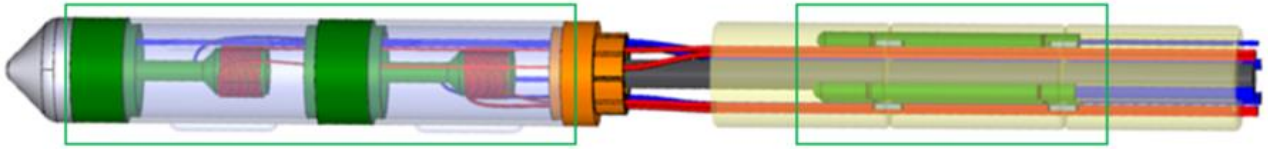
- CARMEN will be equipped with state-of-the-art instrumentation
  - **A miniature ionization chamber** with an external diameter of 3 mm to measure the gamma flux
  - **Two miniature fission chambers** with an external diameter of 3 mm (U-235 and Pu-242 deposit) to measure the thermal and fast neutron 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

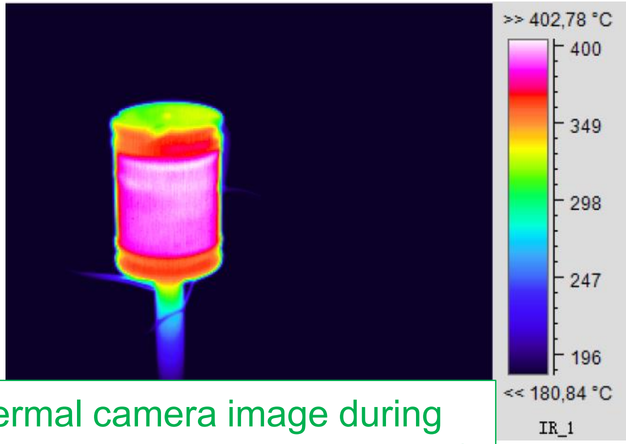


3.2 Measuring cell

- 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

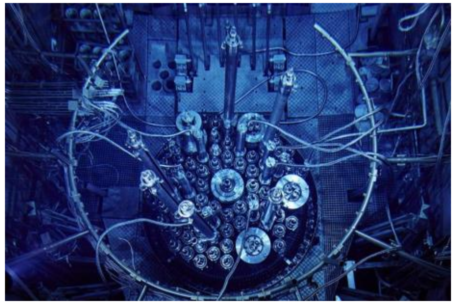
  ⇨ The calorimeter retained its insulation and resistivity during the tests



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

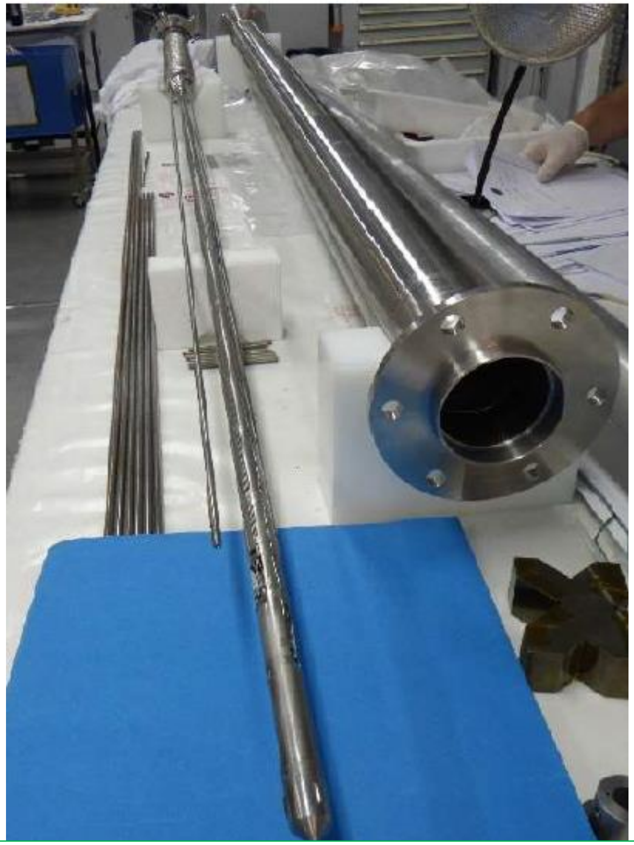
- A full-scale mock-up was made to validate the design and the manufacturing process of the vertical displacement system

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

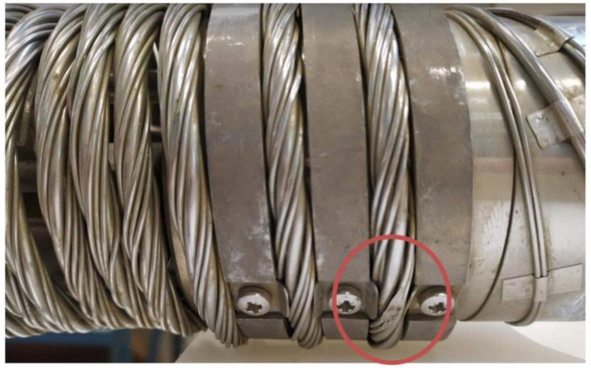
- Endurance tests
  - Mock-up immersed in an upward flow of demineralized water
  - 2000 return trips corresponding to a continuous operating time of 200 hours (over distance of 1650 mm at a speed close to 10 mm/s)

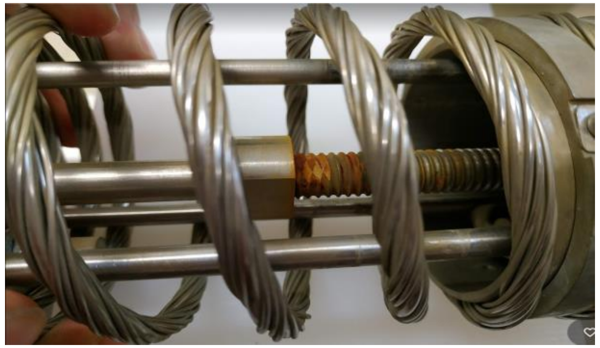
Sensor cables formed in spiral



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

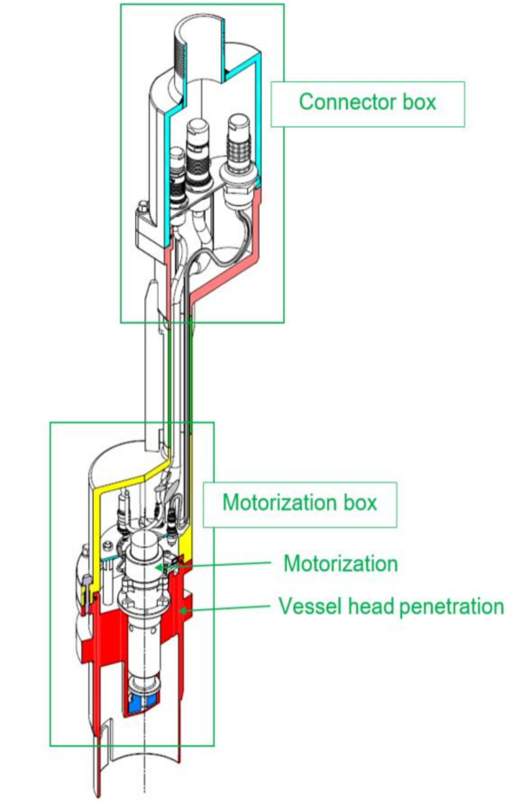
Vertical displacement system mock-up on its test bench

3.4 Device head and connector box

2024

- 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)

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

CEA CADARACHE
13108 Saint-Paul-lez-Durance
France
muriel.antony@cea.fr