Intense absorbed dose rate measured on-line thanks to specific calorimeters inside research reactors

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Summary

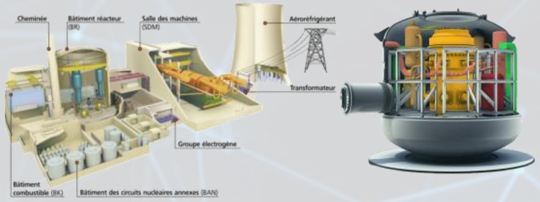
- ❑ Context
- ❑ Example of research reactor: JHR
- ❑ Nuclear heating rate
- ❑ Calorimeter and challenges
- ❑ Approach and results obtained with the CALORRE calorimeter
- ❑ Conclusions and outlooks


CONTEXT

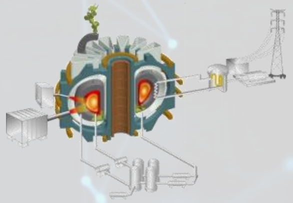
The general context

Nuclear Energy

- Energy produced by fission
  - NPP at present, SMR/AMR in project



- Energy produced by fusion
  - In the future (first industrialization step: DEMO)



Research work required and carried out to improve knowledge, innovate, answer challenges by means of research programs in **Major Nuclear Research Facilities** (**Reactors and Tokamaks**)

Safety
Live span
Dismantling
Fuel improvement
Radioactive waste management
Future power-plant generation

Reactors
JHR, JSI-TRIGA, CABRI, MITR, MARIA, BR2, ATR, TREAT …

Tokamaks
WEST, JET, ITER, EAST, JT-90, CFETR …

Demonstration of the feasibility of fusion as a massive and continuous energy source
Confinement
Fuel breeding and management
Heat extraction

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Generation of specific harsh conditions and nuclear environments for specific experiments

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Research Work

Fuel, material and structure characterization from normal to accidental conditions (scenarios possible)
Better understanding of phenomena
Design and qualification of Innovative instrumentation and diagnostics for online measurements
Validation of high-performance multi-physical and multi-scale numerical simulation tools

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Research Work

Design and qualification of Innovative instrumentation and diagnostics for online measurements

- Neutron detectors
- Fission product detection systems
- Temperature sensors
- Absorbed dose rate sensors → Calorimeter for intense values called nuclear heating rate

The general context

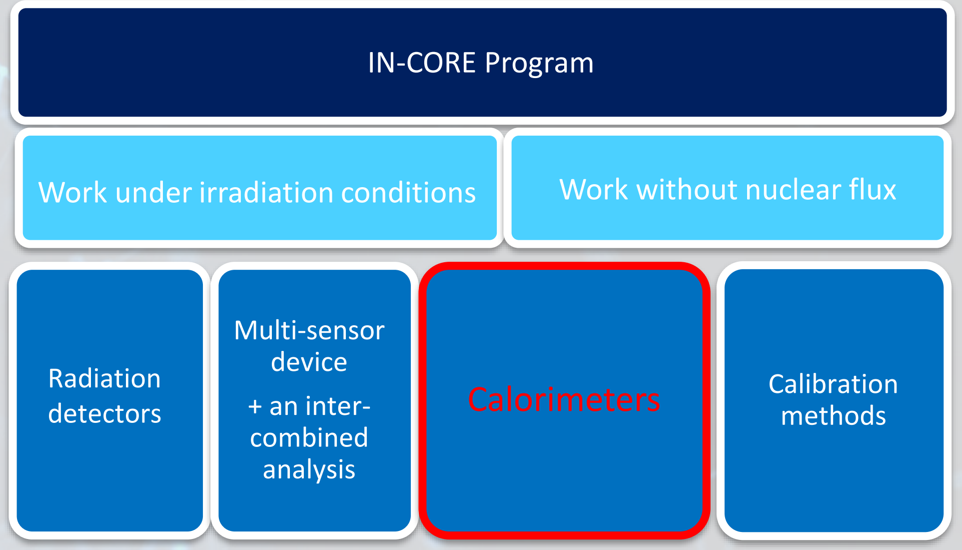
- **A key research thematic on nuclear heating rate measurement by calorimeter**
  - Created in 2009 at Aix-Marseille University in the South of France
  - Realized within the framework of a joint laboratory called LIMMEX (Laboratory of Instrumentation and Measurement Methods under EXtreme conditions) with the CEA
  - Generated by needs associated to Jules Horowitz reactor (MTR under construction in France)

a joint AMU/CEA research program initiated in 2008-2009 by the national JHR program→

IN-CORE program (Instrumentation for Nuclear radiations and Calorimetry Online in Reactor)

➢ **<u>IN-CORE program aims</u>**

Design and characterize innovative, high-performance sensors/detectors, methods and diagnostics
to carry out on-line quantification of key conditions/parameters into JHR experimental channels in order to propose a multi-sensor device for mapping



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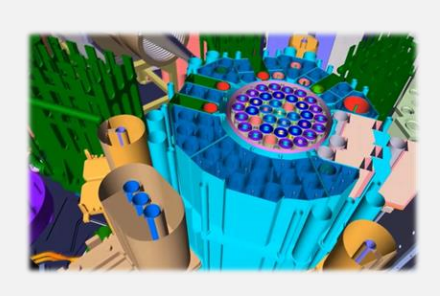
The targeted nuclear environment

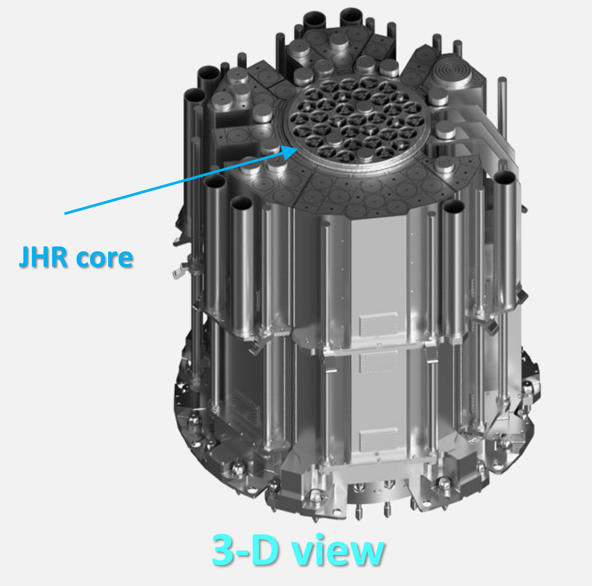
- Research reactors such as the Jules Horowitz Reactor (JHR)
  - a Material Testing Reactor under construction in the South of France
    - Used for a better understanding of the ageing of inert materials under irradiation conditions and of the behavior of nuclear fuel
    - Used for the production of medical radio-elements (up to 50% of European needs)

Video of the JHR core

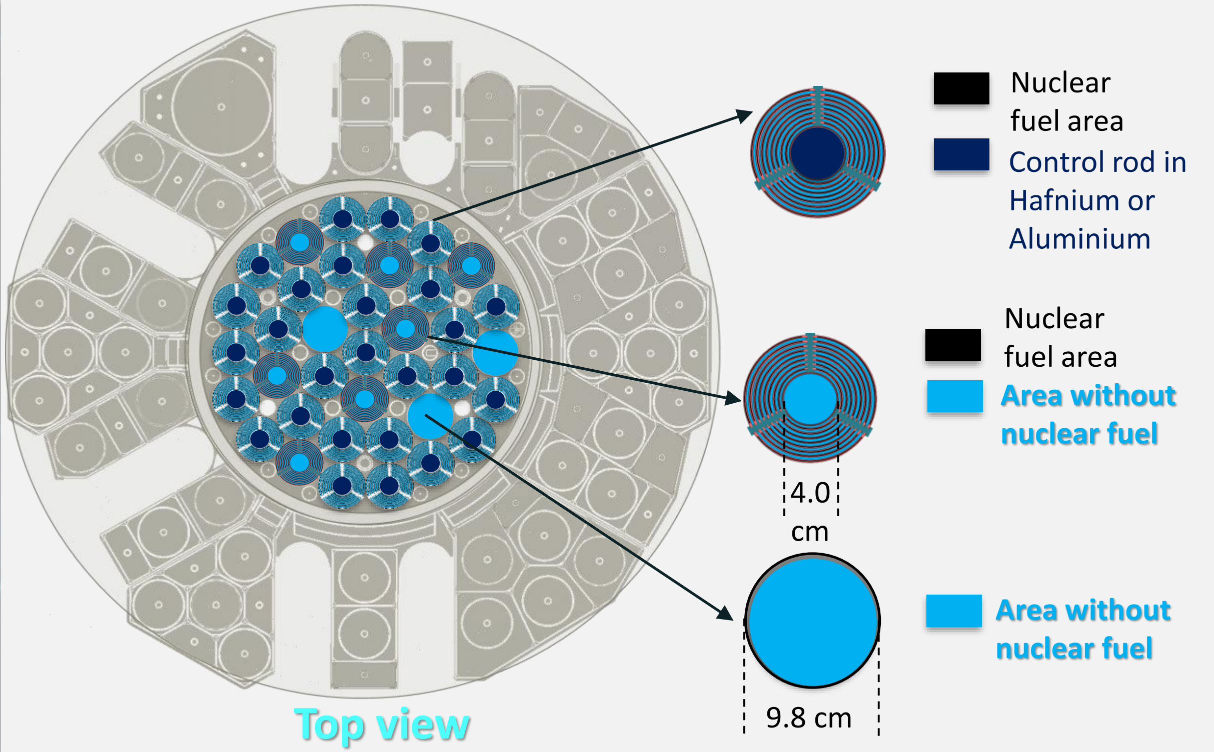
The targeted nuclear environment

- Research reactors such as the Jules Horowitz Reactor (JHR)
  - JHR core characteristics
    - 100 MWth
    - Core diameter and height: 60 cm
    - Thermal neutron flux: 3.5 10^{14} n.cm^{-2}.s^{-1}
    - Fast neutron flux: 5.5 10^{14} n. cm^{-2}.s^{-1} (> 1 MeV)
    - Displacement per atom: 16 dpa.year^{-1}
    - **Nuclear heating rate: 20 W.g^{-1}**





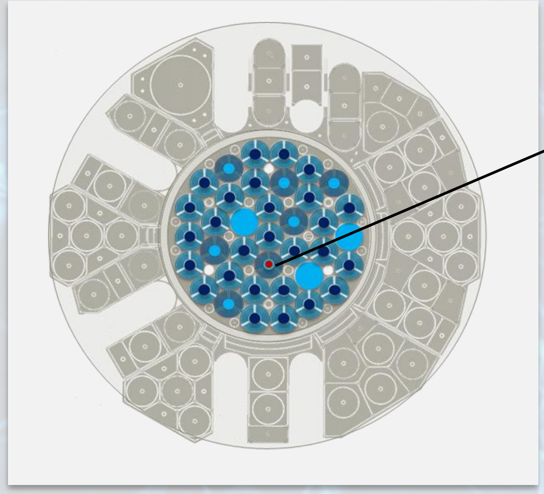
3-D view

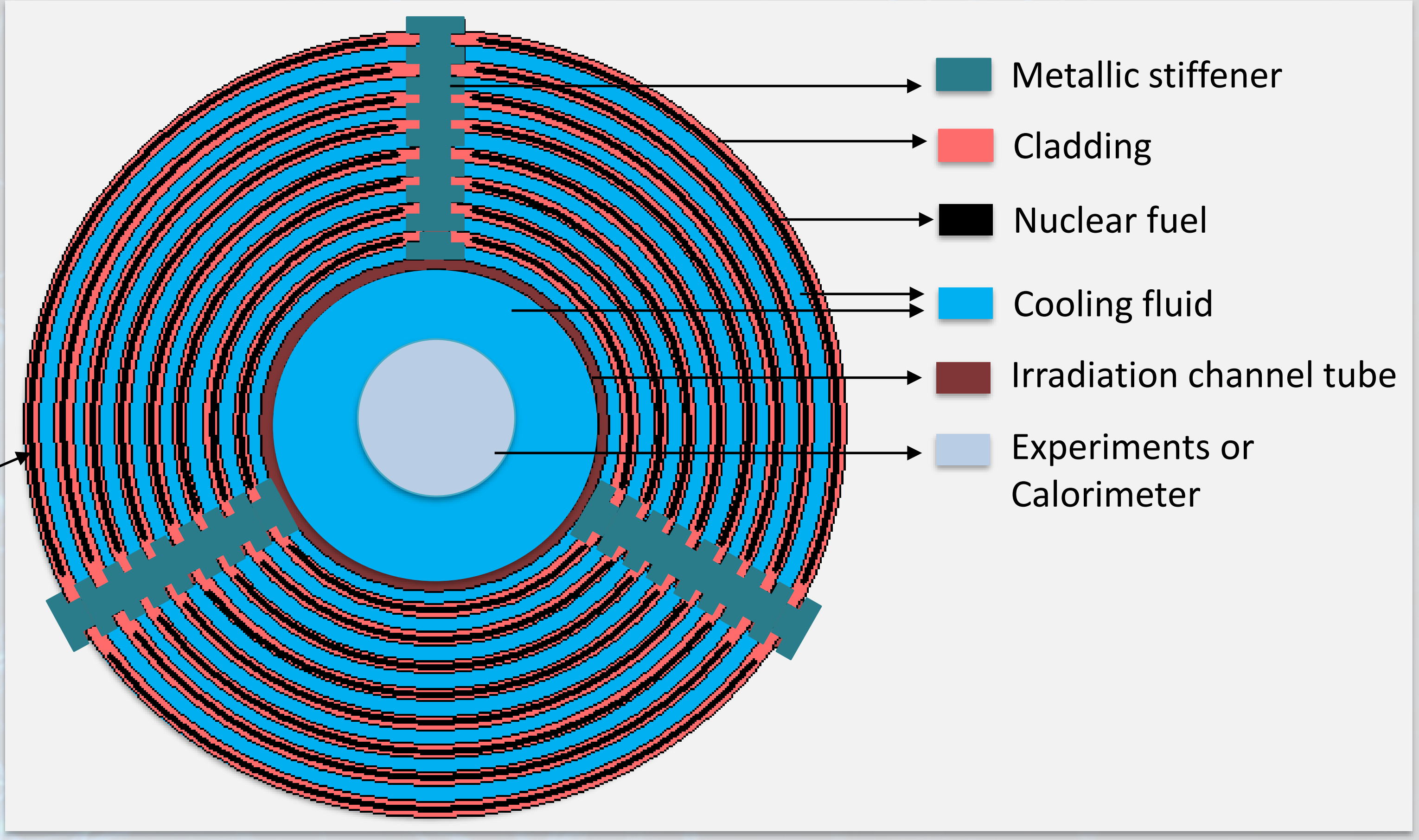


Top view

The targeted nuclear environment

- Research reactors such as the Jules Horowitz Reactor (JHR)
  - Nuclear heating rate will be measured inside JHR irradiation channels dedicated to experiments





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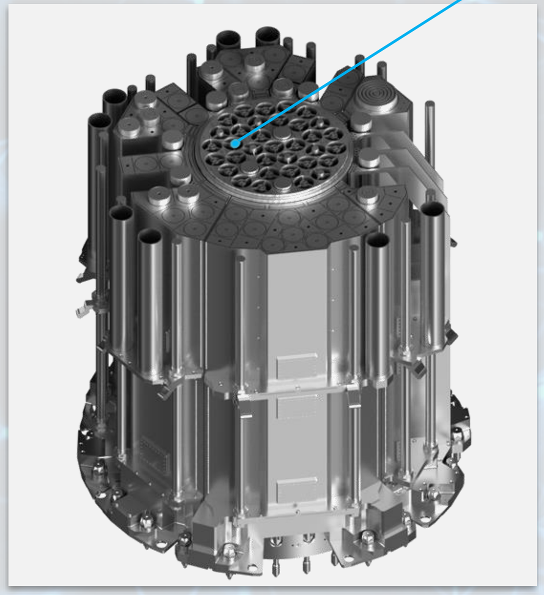
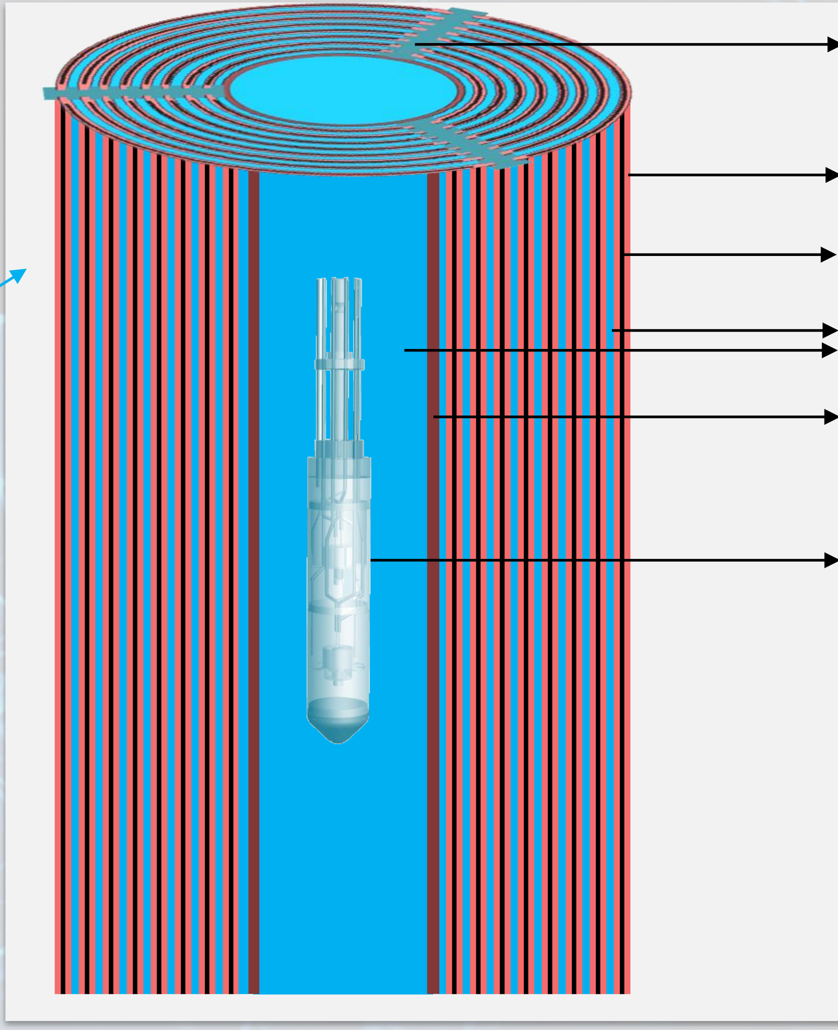
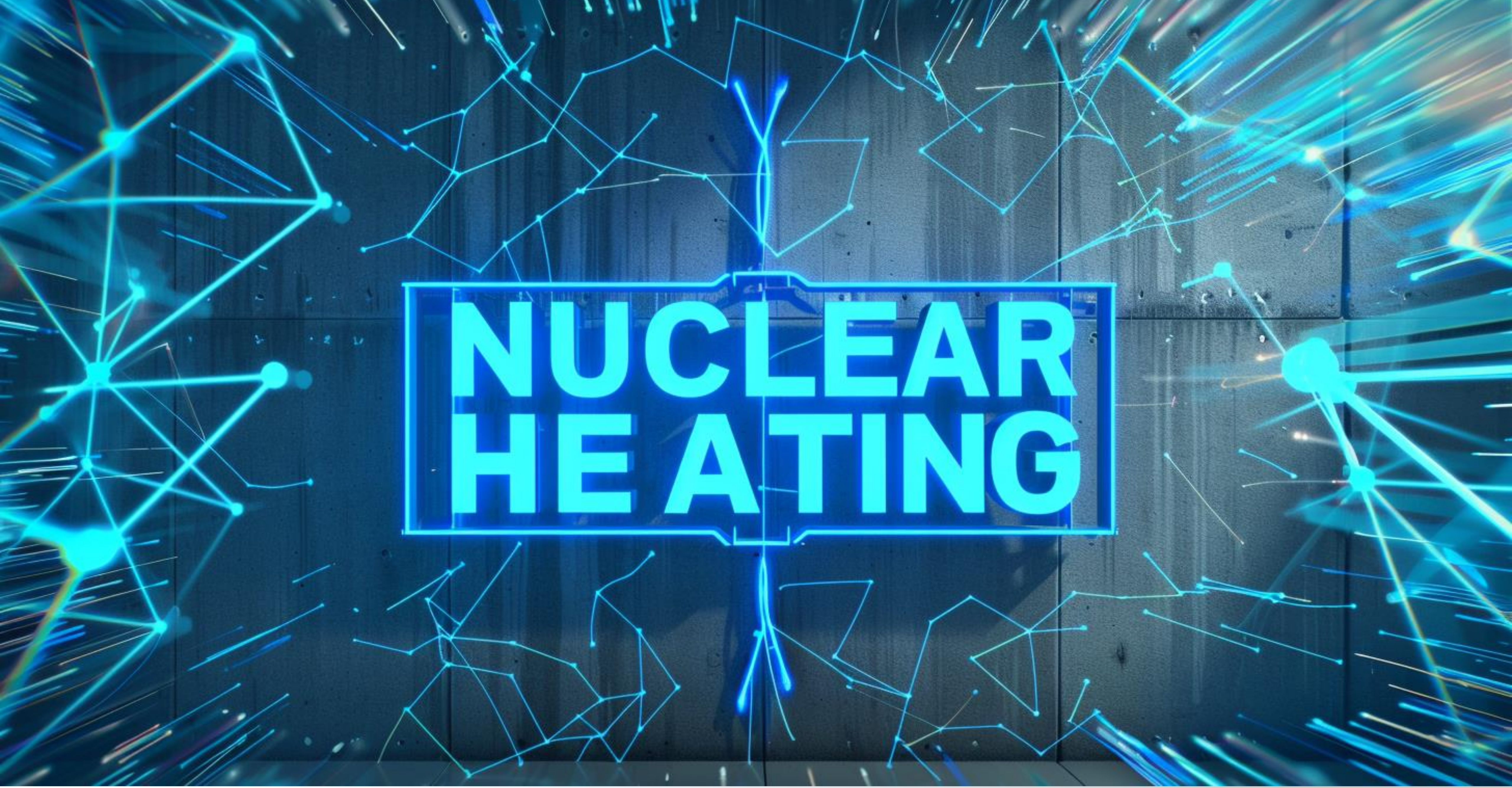
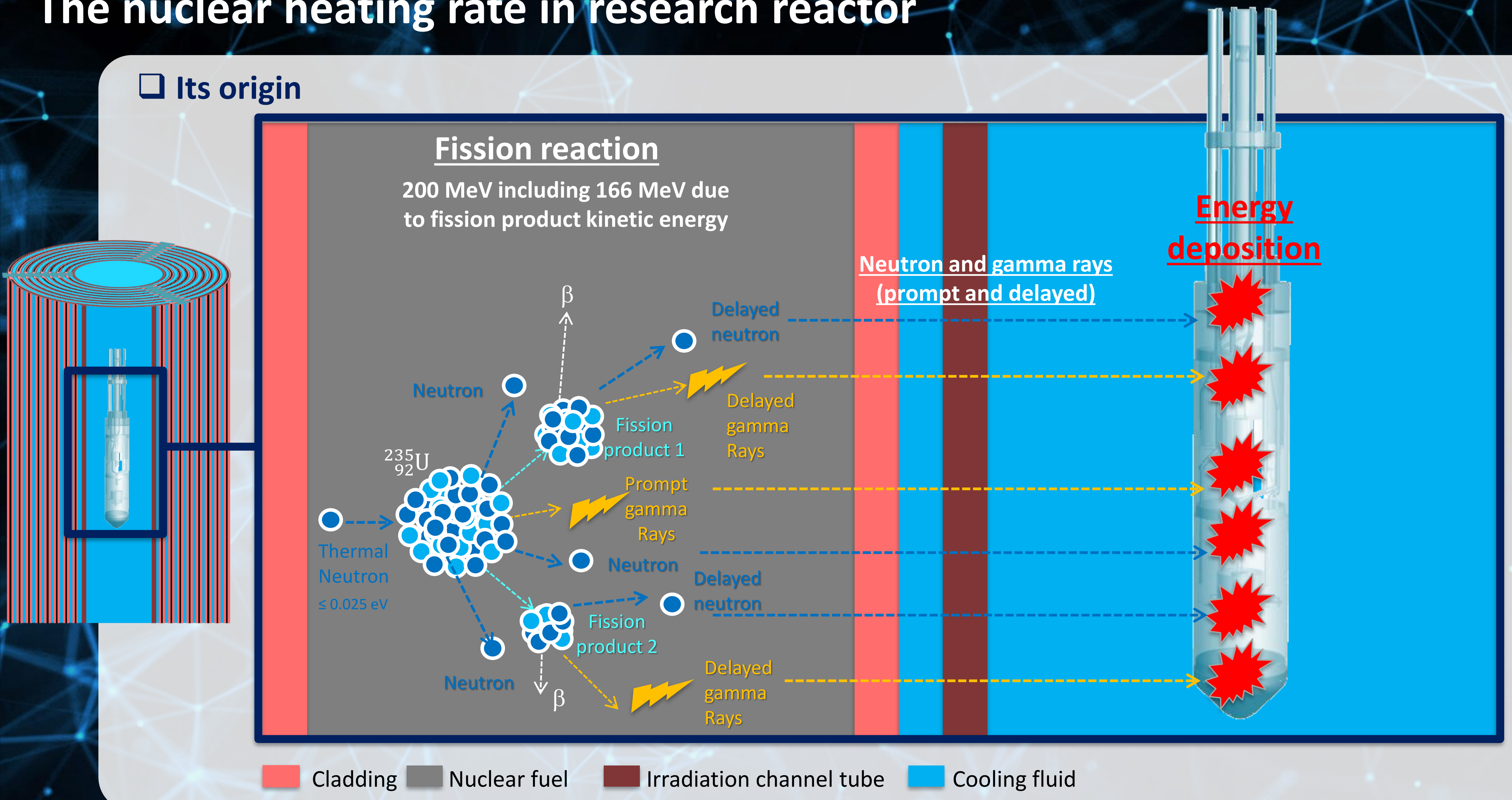





NUCLEAR
HEATING

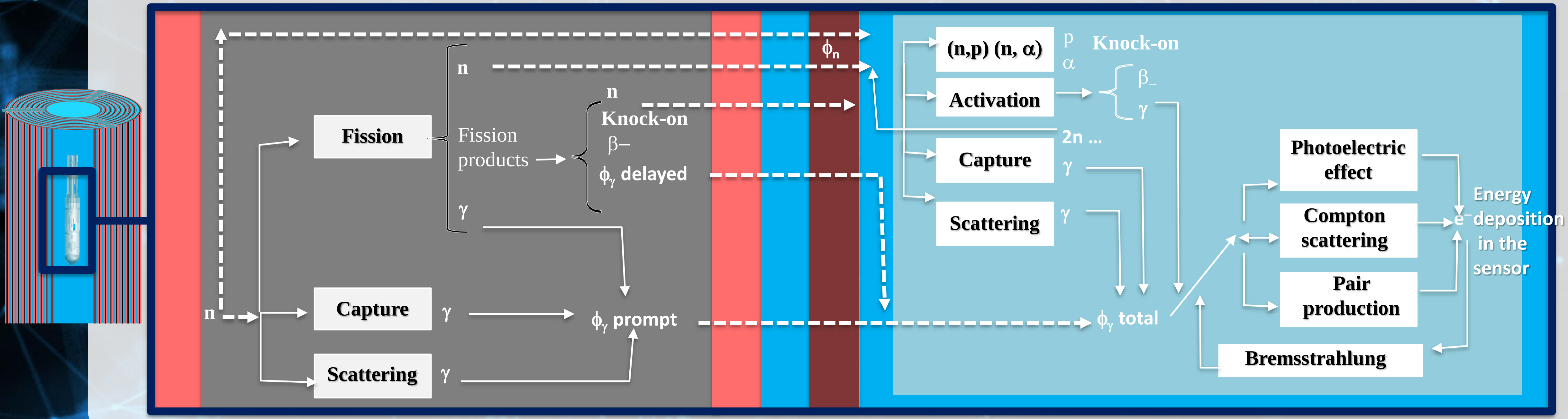
The nuclear heating rate in research reactor

❑ Its origin



The nuclear heating rate in research reactor

❑ Its origin

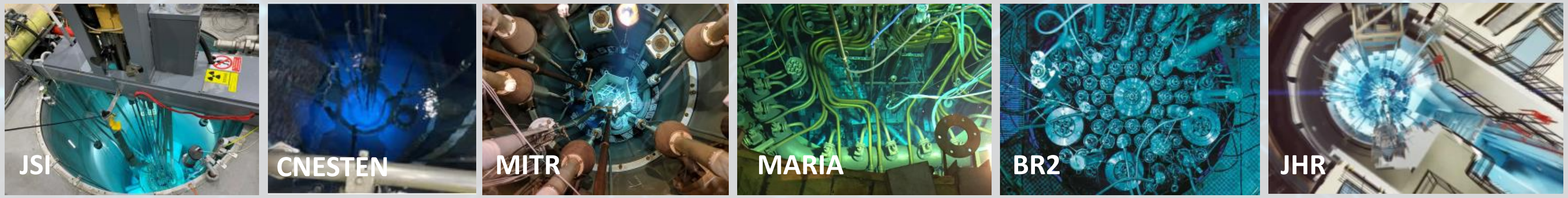


❑ Its definition and unit

- Absorbed dose rate = Energy deposition per mass and time unit induced by several ray-matter interactions
  - in $J.kg^{-1}.s^{-1}$
  - in $Gy.\ h^{-1}$ if low values
  - in $W.g^{-1}$ if intense values and thus called nuclear heating rate

The nuclear heating rate in research reactor

❑ Its range



EOLE/ MINERVE in France (Shutdown) A few Gy/h

TRIGA-JSI in Slovenia **0.05 W/g**

TRIGA-CNESTEN in Morocco **0.4 W/g**

MITR in USA **2 W/g**

MARIA in Poland **5 W/g**

OSIRIS in France (Shutdown) **13 W/g**

BR2 in Belgium **14 W/g**

JHR in France **20 W/g**

100 Wth — **ZPR** (Zero Power Reactor) — **TRIGA, MTR** — **100 MWth**

TLD, OSLD

❑ The sensor used to quantify it

Intense absorbed dose rate in W/g = Nuclear heating rate

=

Heat energy per time and masse unit measurable by means of calorimeter

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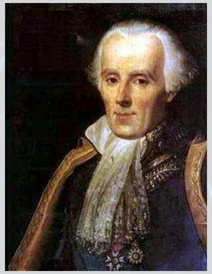
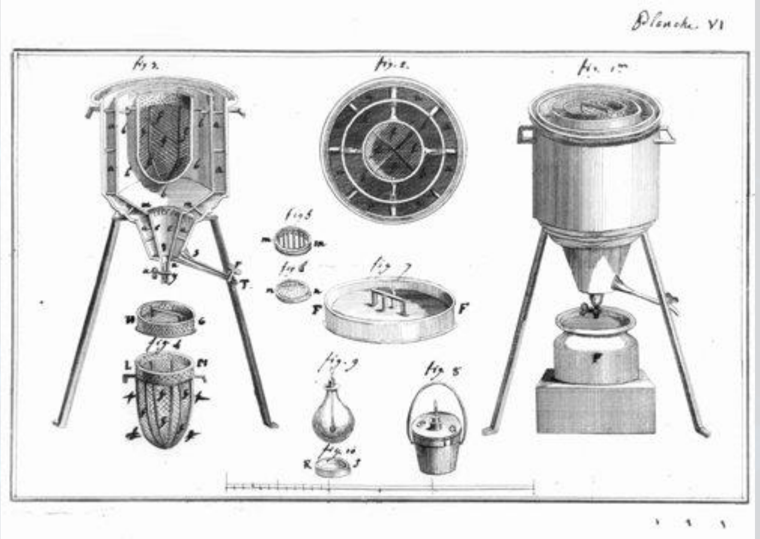
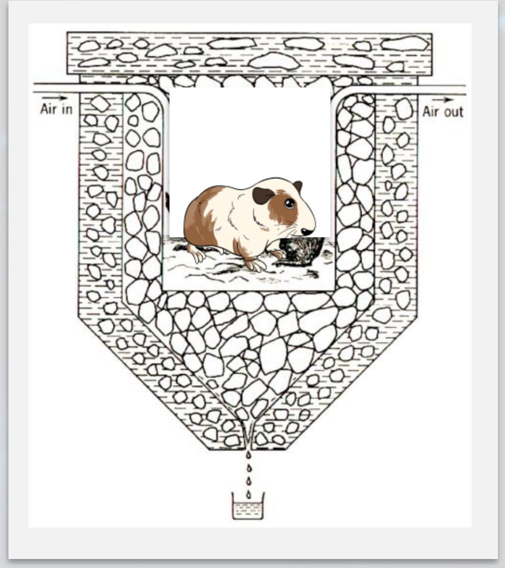
A bit of history regarding calorimeters in general

- Device used to measure the amount of heat energy released or absorbed by a body/sample under certain conditions
- Created at the end of the XVIII century
  - By Lavoisier and Laplace (French scientists)
  - First calorimeter: ice calorimeter
  - To study the breathing







- Applied in various fields including the nuclear domain (before, during and after nuclear conditions)

General principle of calorimeters

❑ Thermal sciences

Heat energy released or absorbed by a sample to be characterized inside the calorimeter = heat source in the sensor

↓

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \vec{V} . \overrightarrow{\nabla T} = \nabla . \left(\lambda \overrightarrow{\nabla T} \right) + S + \cdots$$

↓

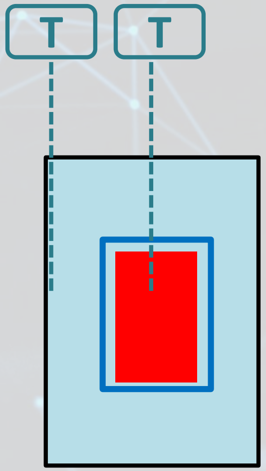
Temperature field generated in the calorimeter

↓

Temperature measurements with temperature sensors

Inverse calculation method

❑ A simplified schematic



- ❑ Sample holder
- ❑ Sample of inert material to be characterized
- ❑ Gas
- ❑ Jacket
- ❑ Temperature sensors

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Calorimeter classification

❑ Three main criteria

Operating mode	Adiabatic	Heat flow	Phase change	…
Assembly/ fabrication	Single-cell	Multi-cells		
Measurement method	Heat compensating principle	Heat accumulating principle	Heat exchanging principle	

Calorimeter classification

- Three main criteria

For applications in nuclear research reactor

Operating mode	Adiabatic	Heat flow	Phase change	…
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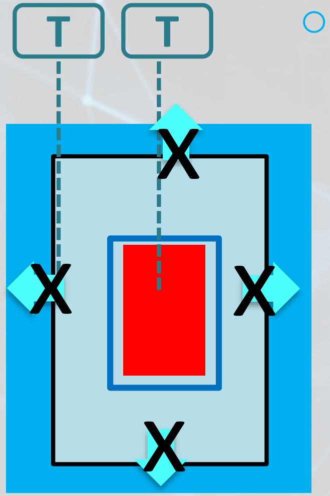
Calorimeter types used in research reactor

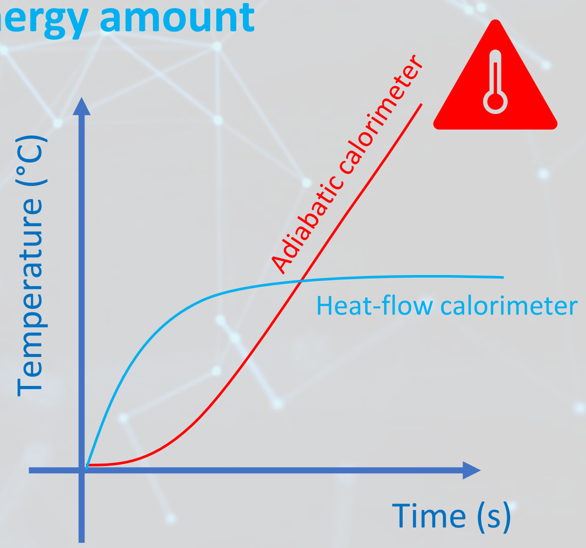
❑ Heat-flow calorimeters (non-adiabatic sensors)

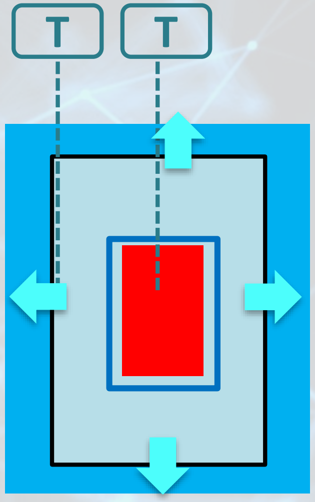


- ○ Adiabatic calorimeter **not possible to be used** due to the intense energy amount
  - ➢ **No heat exchanges with the external cooling fluid**
    - → an infinite thermal resistance between the sample and the external surrounding

Adiabatic calorimeter = No heat exchange

→ 10 g Aluminum at 20 W/g
Material melting in 30 s





- ○ **Heat-flow** calorimeters (**non-adiabatic** sensors) are used
  - ➢ **Heat exchanges with the external cooling fluid (natural or forced convection according to the reactor type or power)**
    - → a non-infinite thermal resistance between the sample and the external surrounding
  - ➢ **Response depending on the thermal resistance induced by heat transfers** (conduction, convection, thermal radiation) **between the temperature measurement points**

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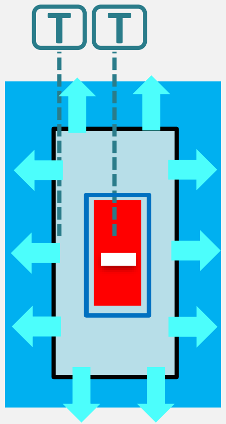
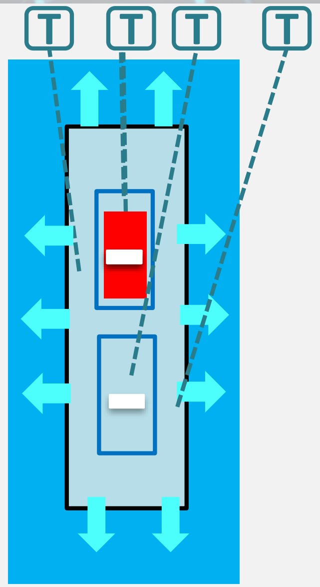
Calorimeter families used in research reactor

❑ Two families of heat-flow calorimeter

- Single-cell calorimeter without a reference cell
  - ➢ Single-cell calorimeter



- Multi-cell calorimeter composed of a sample cell and a reference cell at least
  - ➢ Differential calorimeter



- ❑ Cooling Fluid
- ❑ Heat exchanges
- ❑ Sample of inert material to be characterized
- ❑ Gas
- ❑ Temperature sensors
- ❑ Jacket
- ❑ Heating element
- ❑ Sample holder

Calorimeter families used in research reactor

❑ Single-cell calorimeter without a reference cell

- In various countries

MARIA reactor – Poland
Sample: Graphite or Lead

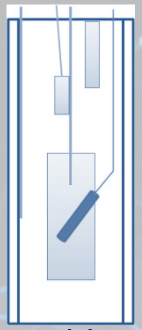
120°C.g.W^{-1}
20°C.g.W^{-1}

[Tarchalski, 2016]

HANARO – Korea
Sample: Aluminum

400-800°C.g.W^{-1}

[Kim, 2020]



BR2 reactor – Belgium
HALDEN reactor – Norway
MNR – Canada
RSG-GAS – Indonesia
Sample: Stainless steel

[Van Nieuwenhowe, 2019,2020]
[Fourmentel, 2013]
[Tarchalski, 2016]
[Alqahtani, 2020, 2022]
[Rohanda, 2020]

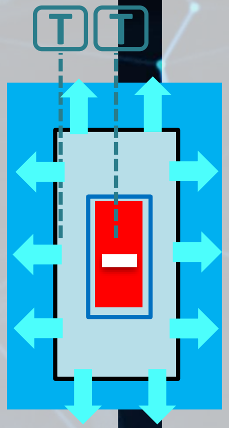
SAFARI – South Africa
Sample: Stainless steel and Molybdenum

[Makgopa, 2008]

GGR-1 reactor – Greece
Sample: Iron

90- 200°C.g.W^{-1}

[Varvayanni, 2008]



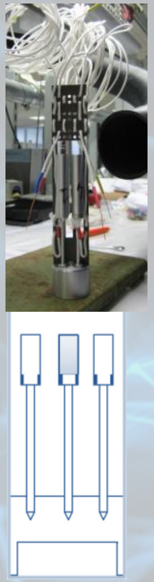
➢ **Advantages**
- ✓ Very basic design
- ✓ Small size
- ✓ Very high sensitivity possible

➢ **Drawbacks**
- ✓ No reference cell to compensate for unwanted energy deposition in areas that do not correspond to the sample
- ✓ Complex transient calibration requiring the knowledge of heat capacity (Cp) of the sample
- ✓ Less modular than differential calorimeter

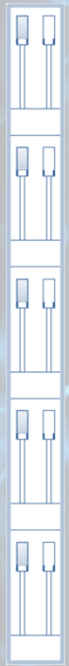
Calorimeter families used in research reactor

❑ Multi-cell calorimeter: differential calorimeter composed of a sample cell and a reference cell at least

- In France and tested in other countries



In the past



Five-stage calorimeter
Sample: Graphite

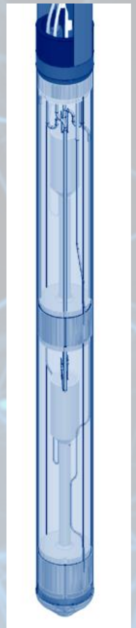
[Péron, 2015]
[Malouche, 2012]

CALMOS calorimeter
Sample: Graphite

11°C.g.W^{-1}

[Carcreff, 2011-2019]

[CEA patent in 2010]

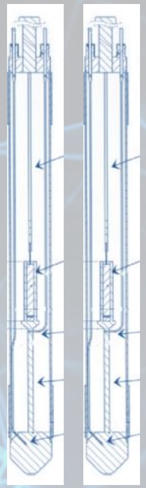


CARMEN calorimeter
Sample: Graphite

65°C.g.W^{-1}

[De Vita, 2016]

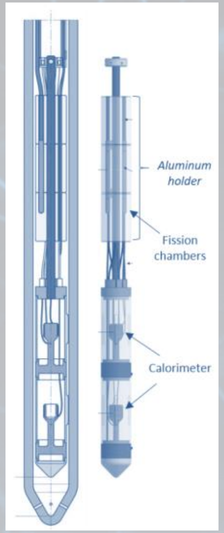
[Fourmentel, 2013]



CALMOS 2 calorimeter
Sample: Graphite, W, Eurofer, Al, Stainless steel

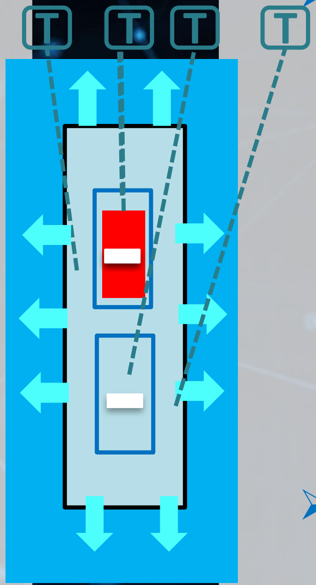
Various values°C.g.W^{-1}

[Carcreff, 2022]



CARMEN for JHR
Sample: Al

[Blanchet, 2021]



➢ Advantages

- ✓ A reference cell to compensate for unwanted energy
- ✓ Easy calibration based on steady thermal states (Cp not required) by using the heaters
- ✓ 3 measurement methods possible to be applied in reactor thanks to the heaters

➢ Drawbacks

- ✓ Complex assembly
- ✓ Various cables due to the thermocouples and the heaters
- ✓ Greater size than that of single-cell calorimeters

Calorimeter families used in research reactor

❑ Temperature measurements

- Temperature sensors used: K-type Thermocouples instead of Pt100 resistance
  - Active sensor (no power supply required)
  - Less number of cables
  - Lower absorption cross-section
  - Lower drift

Matter	Absorption cross section for 2200 m/s neutrons (Barn)
Al	0.231
Cr	3.05
Ni	4.49
Pt	10.3
Re	89.7
W	18.3
Rh	144.8

Type	Thermal drift (after 1500 h)	Neutronic drift (after 1500 h)	Overall drift
K	-10 to -20 °C	Negligible	-10 to -20 °C
N	-5 to -10 °C	Negligible	-5 to -10 °C
S	< 5 °C	-75 °C (-1.2 °C/day)	-80°C
C ou W5	< 5 °C	-56 °C (-0.9 °C/day)	-60 °C

Type	Metal A (+)	Metal B (-)	Temperature range	Seebeck coefficient α (µV/°C) at T°C
B	Platinum-30% Rhodium	Platinum-6% Platinum	0°C to 1820°C	5.96 µV at 600°C
E	Nickel 10% Chromium	Copper-Nickel alloy (Constantan)	-270°C to 1000°C	58.67 µV at 0°C
J	Iron	Copper-Nickel alloy (Constantan)	-210°C to 1200°C	50.38 µV at 0°C
K	Nickel-Chromium alloy (Chromel)	Nickel-luminium alloy (Alumel)	-270°C to 1372°C	39.45 µV at 0°C
N	Nickel-Chromium-Silicium alloy (Nicrosil)	Nickel-Silicium alloy (Nisil)	-270°C to 1300°C	25.93 µV at 0°C
R	Platinum-13% Rhodium	Platinum	-50°C to 1768°C	11.36 µV at 600°C
S	Platinum-10% Rhodium	Platinum	-50°C to 1768°C	10.21 µV at 600°C
T	Copper	Copper-Nickel alloy (Constantan)	-270°C to 400°C	38.75 µV at 0°C
W	Tungsten	Tungsten-26% Rhenium	+20°C to +2300°C	
W3	Tungsten-3% Rhenium	Tungsten-25% Rhenium	+20°C to +2000°C	
W5	Tungsten-5% Rhenium	Tungsten-26% Rhenium	+20°C to +2300°C	


CHALLENGES
CALORIMETER

Challenges in calorimeter

❑ From the sensor to the methods

- Expansion of the measurement range from very low to high nuclear heating rate ($mW.g^{-1}$ → 20 $W.g^{-1}$)
- Optimization of metrological characteristics of the sensors (sensitivity, linearity, response time, etc.)
- Miniaturization of calorimetric cells and calorimeters
- Diversification of calibration and measurement methods
- Behavior and response prediction by 3-D simulation
- Detailed knowledge of the thermal properties of materials and their evolution

Important for

- ➢ local and faster measurements
- ➢ devices coupling different types of sensors for simultaneous multi-measurements such as CARMEN device
- ➢ devices coupling several calorimeters with different material samples
- ➢ simplification of the in-pile operating protocol
- ➢ integration in irradiation device

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APPROACH

A comprehensive approach to innovate in calorimetry at AMU

- Work carried out using an incremental approach combining experiments and simulations from laboratory conditions to reactor conditions

Need

Idea

Analytical theoretical studies and 3-D numerical simulations (thermal and RMI Monte-Carlo)

Measurement of thermal properties as a function of temperature

TRL3

Design and manufacture of a prototype sensor model

Experimental studies to characterize sensor response under laboratory conditions

TRL4

Design and manufacture of an advanced prototype

Experimental studies on custom-designed test benches reproducing a representative environment

TRL5

Experimental characterization in a real reactor environment

TRL6

Optimizations

TRL = Technology Readiness Level


EXAMPLE
RESULTS

Two types of calorimeters patented: differential calorimeter and single-cell calorimeter

- A differential calorimeter and a single-cell calorimeter including a thin heating-element

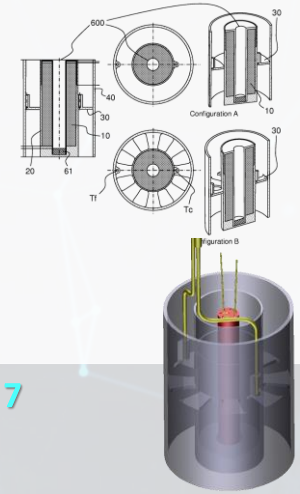
Need

Miniaturization of calorimetric cells and calorimeters

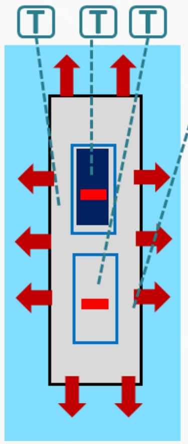
Ideas

CALORRE

A differential calorimeter with radial heat transfer



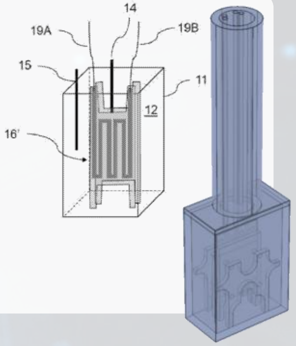
Cell size divided by 7



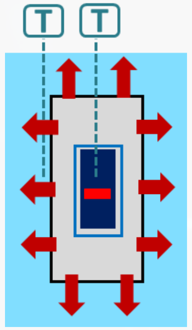
Patent 2015 AMU/CEA, M. Carette *et al.*

MONO-CALO

A single-cell calorimeter integrating thin layers



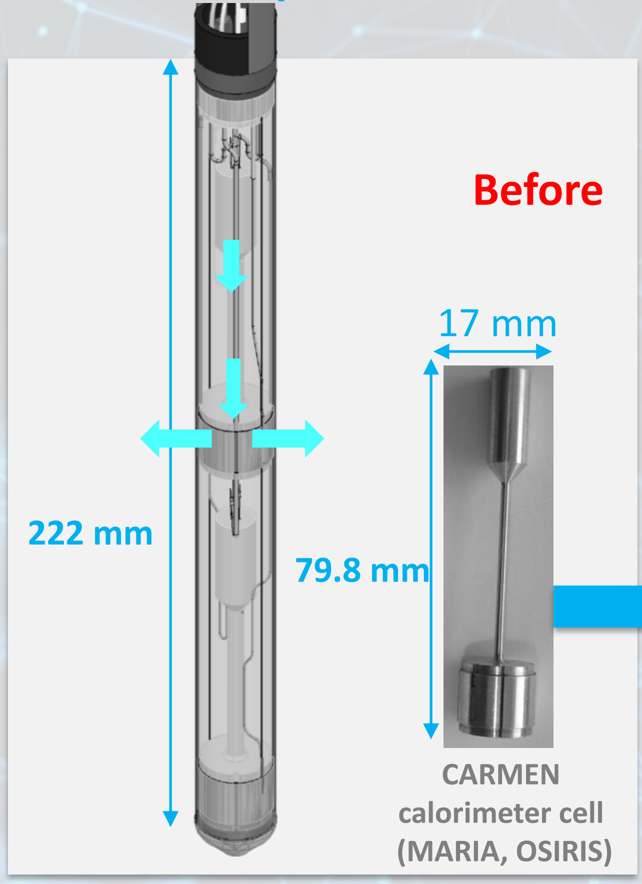
Calorimeter size divided by 10

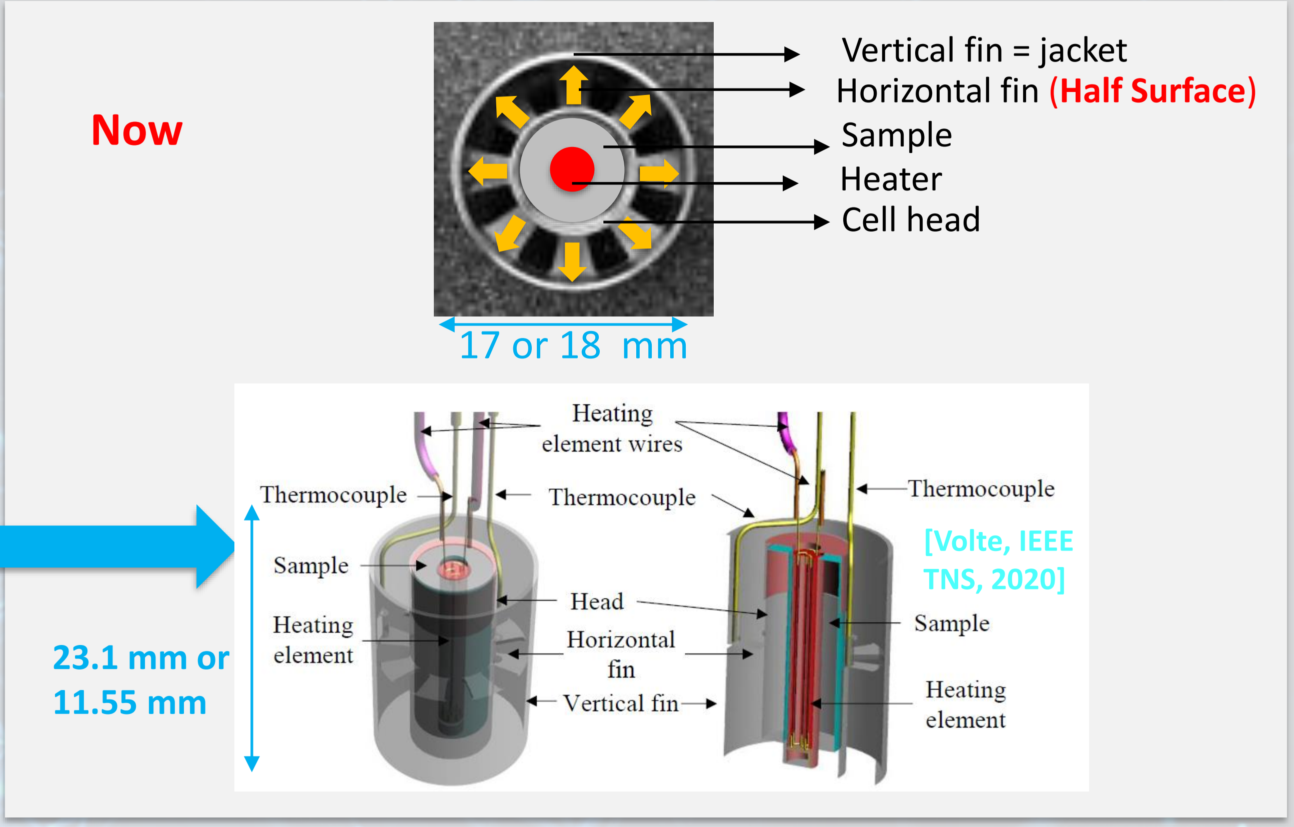


Patent 2020 AMU/CEA/CNRS C. Reynard-Carette *et al.*

CALORRE calorimeter design

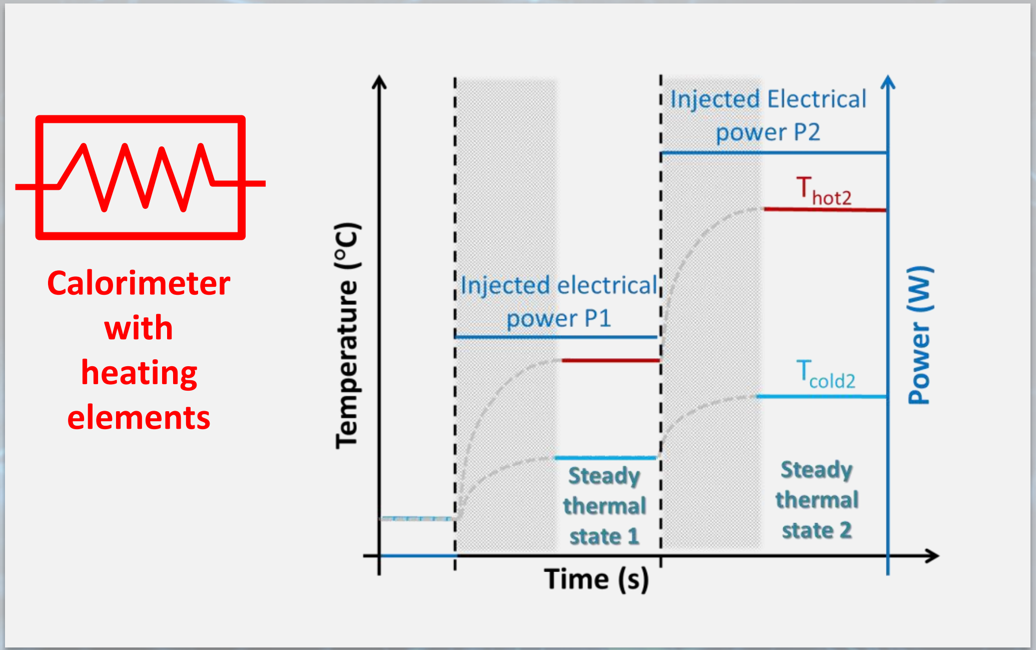
- **A new design to have a reduced-height calorimeter**
  - **with main heat transfer in radial and azimutal directions in each calorimetric cell (instead of axial direction with previous calorimeters)**

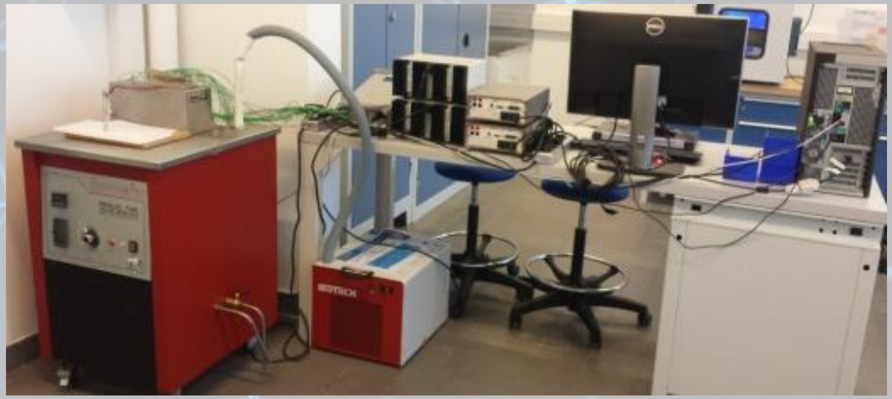




CALORRE calibration

- 2 methods depending on the calorimeter type: steady-state-based calibration method or transient-state-based calibration method
  - Method#1: Steady-state calibration method

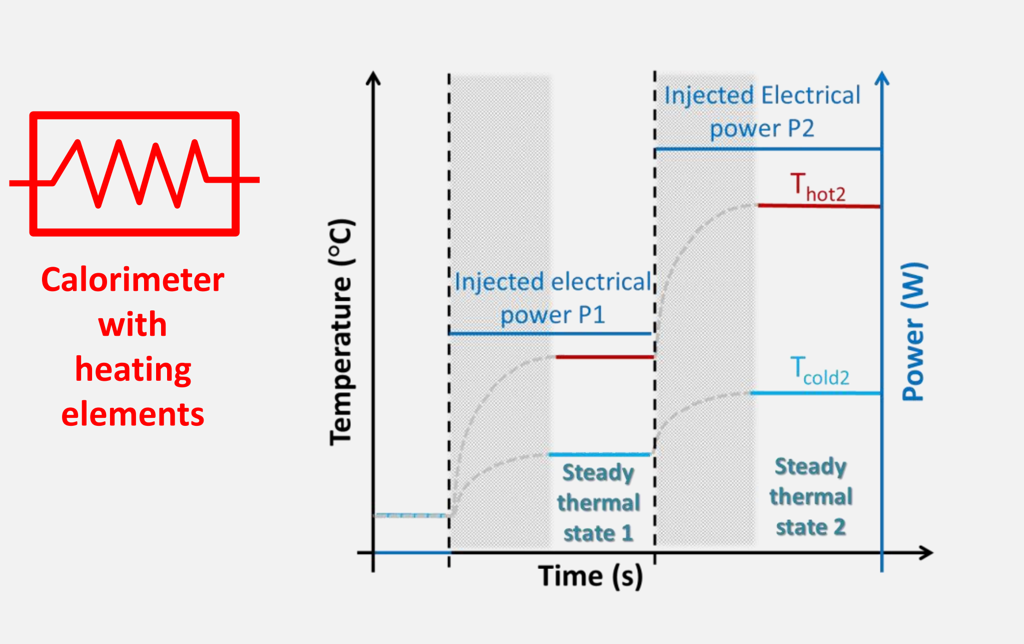




- **Under laboratory conditions without nuclear rays**
  - ✓ By using specific experimental benches
  - ✓ By generating a heat source by Joule effect inside each calorimetric cell thanks to heaters and to simulate the absorbed dose rate
- **Inside the reactor during shutdown**
  - ✓ By generating a heat source by Joule effect inside each calorimetric cell thanks to heaters and to simulate the absorbed dose rate

CALORRE calibration

- 2 methods depending on the calorimeter type: steady-state-based calibration method or transient-state-based calibration method
  - Method#1: Steady-state calibration method



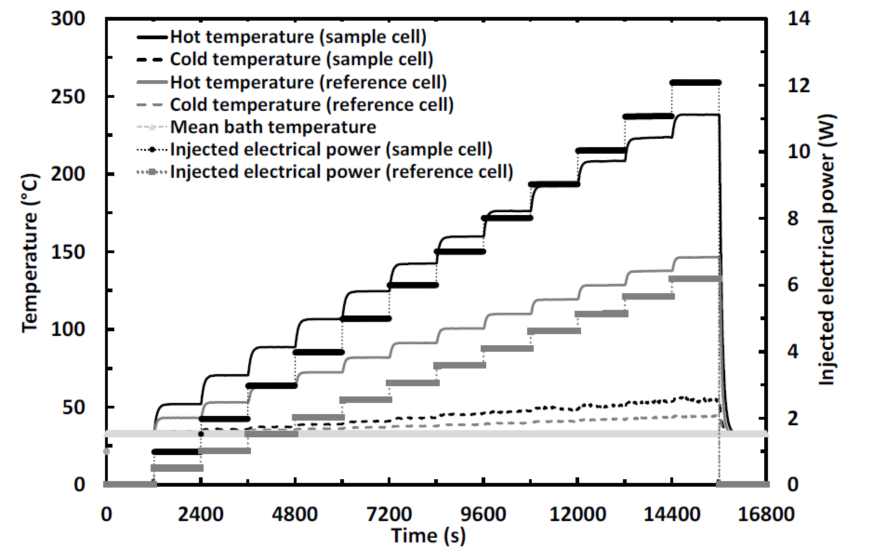
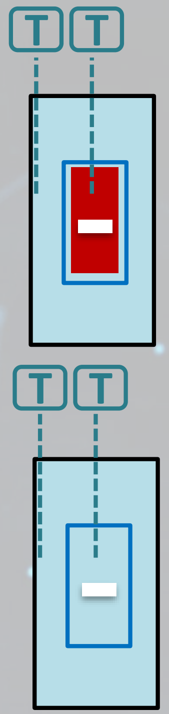


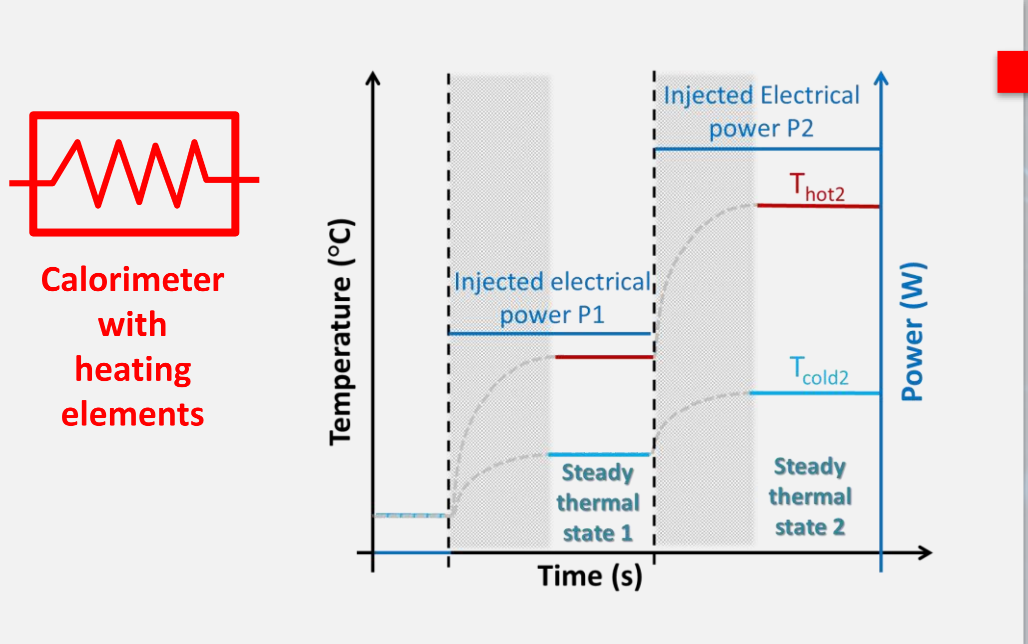
Fig. 14. Temperatures and injected electrical powers versus time for the sample and reference cells, a fluid temperature of 33 °C and a Reynolds number of 1607 obtained with the second operating protocol.



[Volte, IEEE TNS, 2024]

CALORRE calibration

- 2 methods depending on the calorimeter type: steady-state-based calibration method or transient-state-based calibration method
  - Method#1: Steady-state calibration method



Calibration curve giving T_{hot}-T_{cold} for the steady states versus P for each calorimetric cell

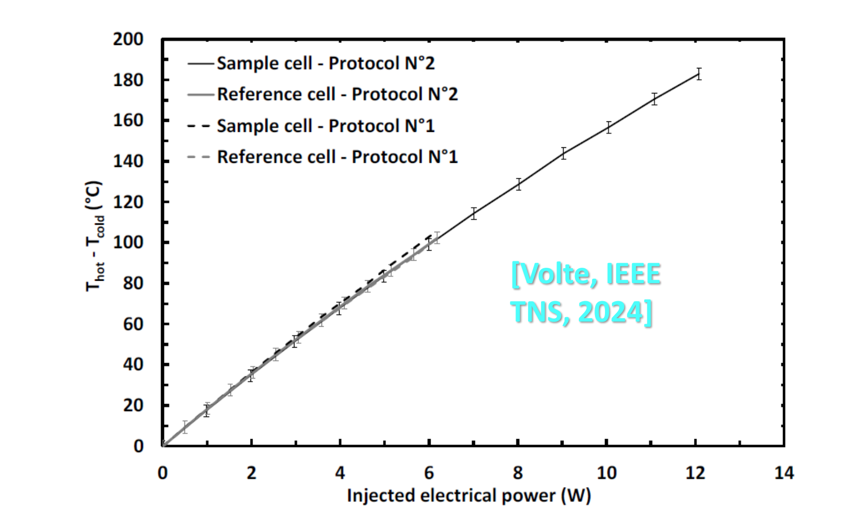
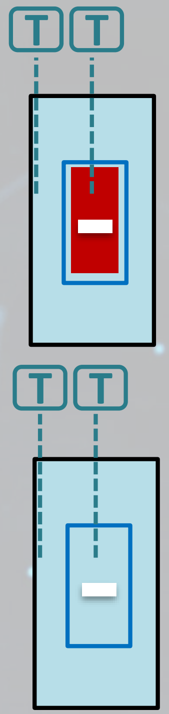
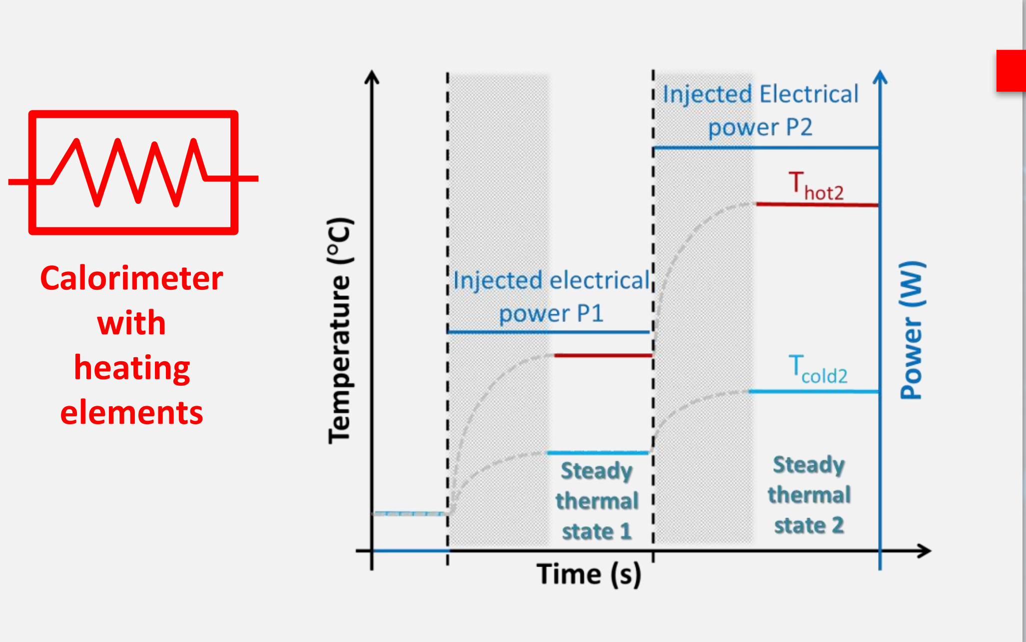


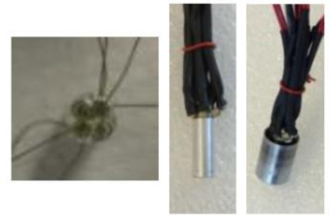
Fig. 15. Calibration curves of the sample and the reference cells obtained by applying two protocols for a fluid temperature of 33 °C and a Reynolds number of 1607.



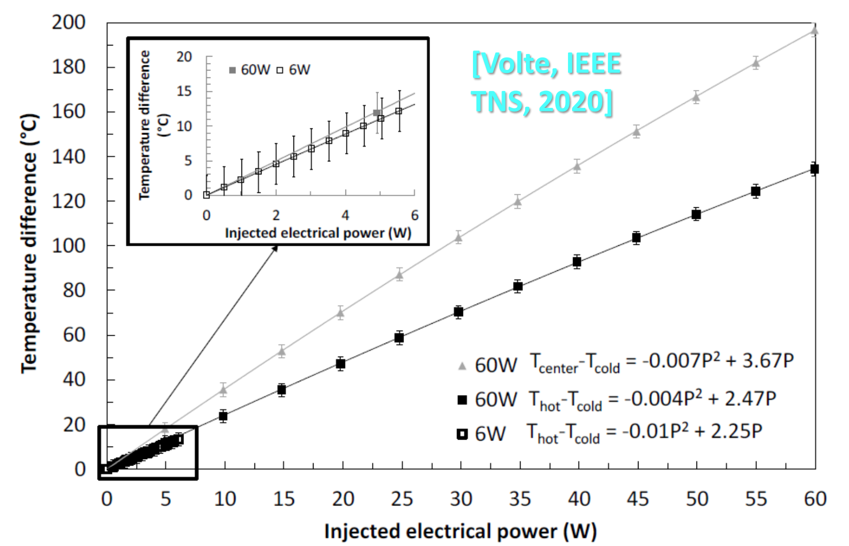
CALORRE calibration

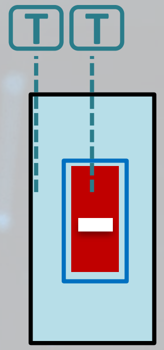
- 2 methods depending on the calorimeter type: steady-state-based calibration method or transient-state-based calibration method
  - **Method#1: Steady-state calibration method**





Calibration curve giving T_{hot}-T_{cold} for the steady states versus P for each calorimetric cell

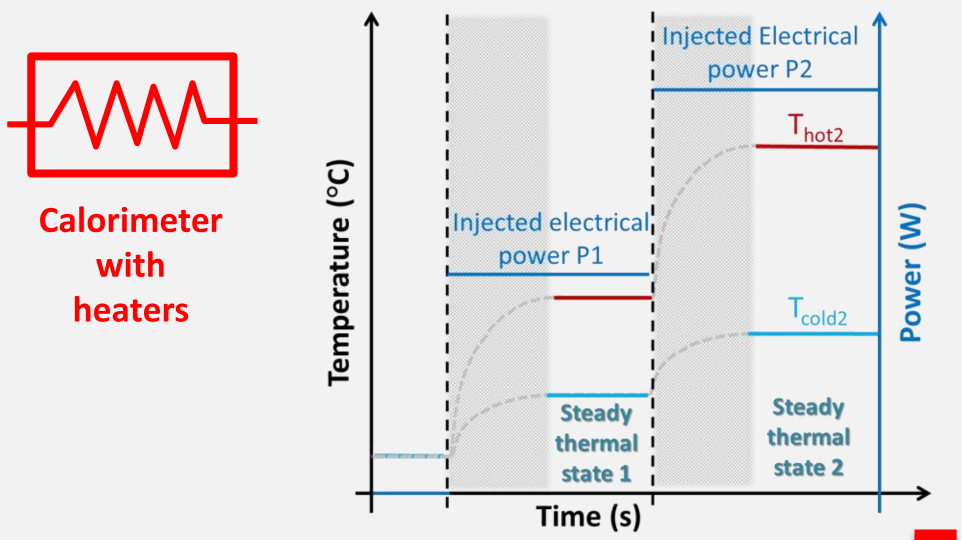




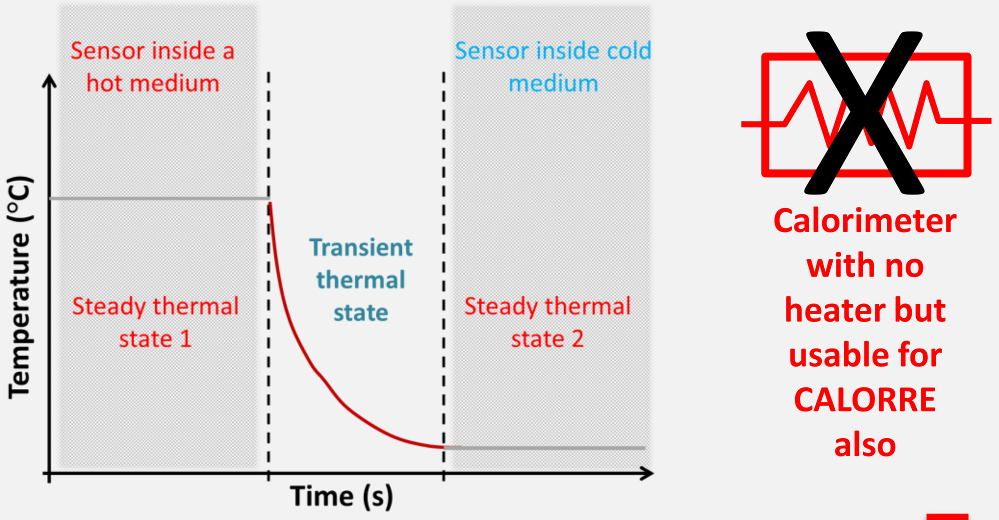
- The chosen electrical power range depends on the targeted range of the nuclear heating rate

CALORRE calibration

- 2 methods depending on the calorimeter type: steady-state-based calibration method or transient-state-based calibration method
  - Method#1: Steady-state calibration method
  - Method#2: Transient-state calibration method



Calibration curve giving T_{hot}-T_{cold} versus P for each calorimetric cell → Cell sensitivity

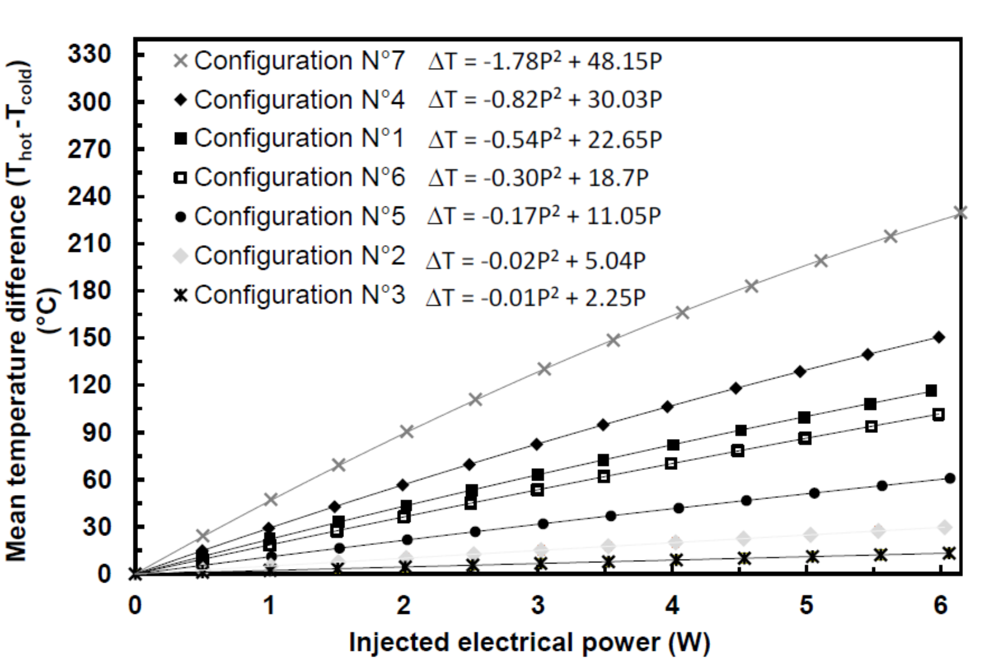


Thermal constant time of the calorimetric cell → Cell sensitivity by considering Cp

CALORRE calorimeter sensitivity

❑ CALORRE: a very modular calorimeter in term of sensitivity to target different nuclear heating rate values

- By changing the geometry of the horizontal fin
  - ➢ Effect of the gas and metal thermal conductivity
- By changing the nature of the material of the calorimetric cell structure
  - ➢ Effect of the thermal conductivity



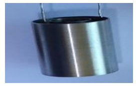
[Volte, IEEE TNS, 2018]
[Volte, PhD 2019]
[Volte, IEEE TNS, 2022]

TABLE II
METROLOGICAL CHARACTERISTICS FOR SEVEN CONFIGURATIONS OF A CALORRE CALORIMETRIC CELL

Configuration	N°1	N°2	N°3	N°4	N°5	N°6	N°7
H (mm)	23.1	23.1	23.1	23.1	23.1	11.55	11.55
Material (-)	AISI 316L	Al 5754	Al 5754	AISI 316L	AISI 316L	AISI 316L	TA6V
Fin (-)	1/2	1/4	1/2	1/4	1	1/2	1/4
$t_{average}$ (s)	291	97	88	418	208	174	287
S_{6W} (°C.W^{-1})	16.2	4.8	2.1	20.3	9.0	15.1	26.8
m (g)	5.22	3.20	3.20	5.22	5.22	2.92	2.16
$T_{hot/6W}$ (°C)	169	72	62	209	122	157	272

Full surface, Half surface, Quarter surface

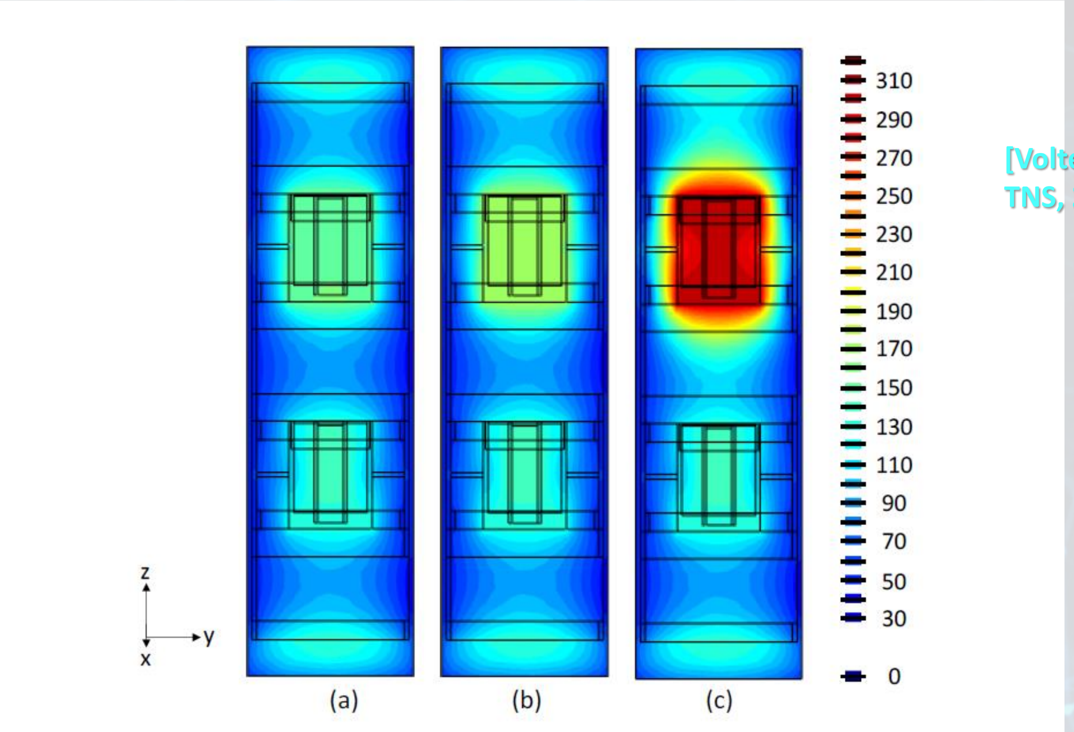
23.1 mm height



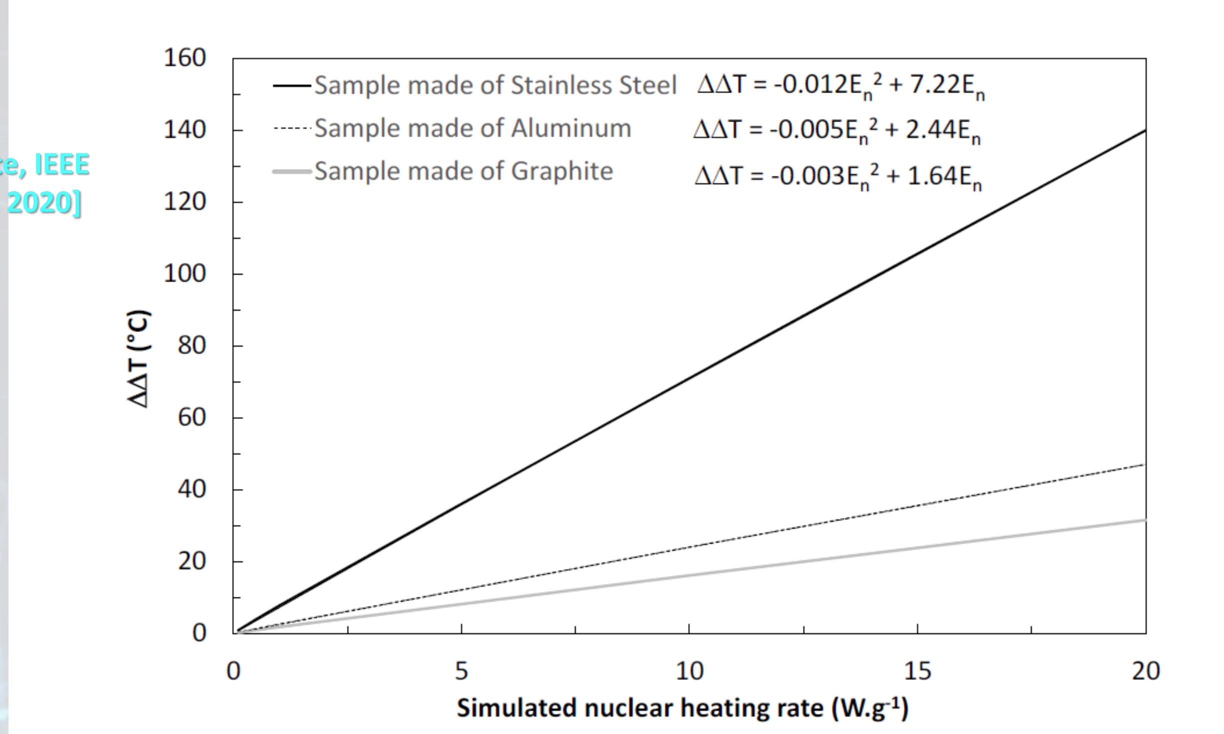
11.55 mm height

CALORRE calorimeter sensitivity

- CALORRE: a very modular calorimeter in term of sensitivity to target different nuclear heating rate values
  - By changing the nature of the sample
    - Effect of the mass

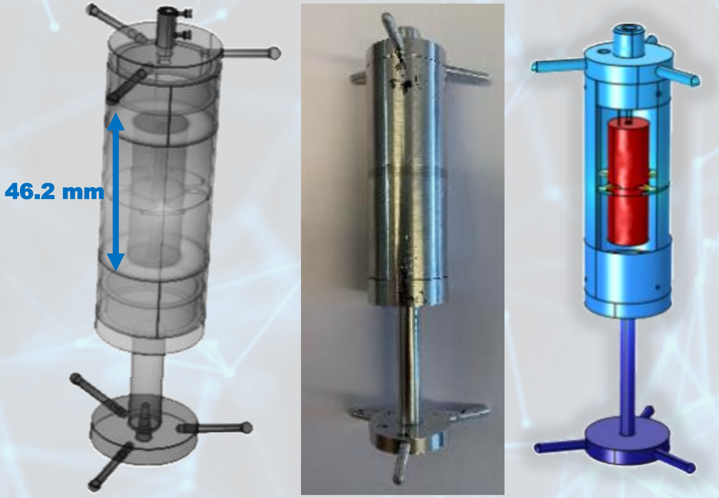


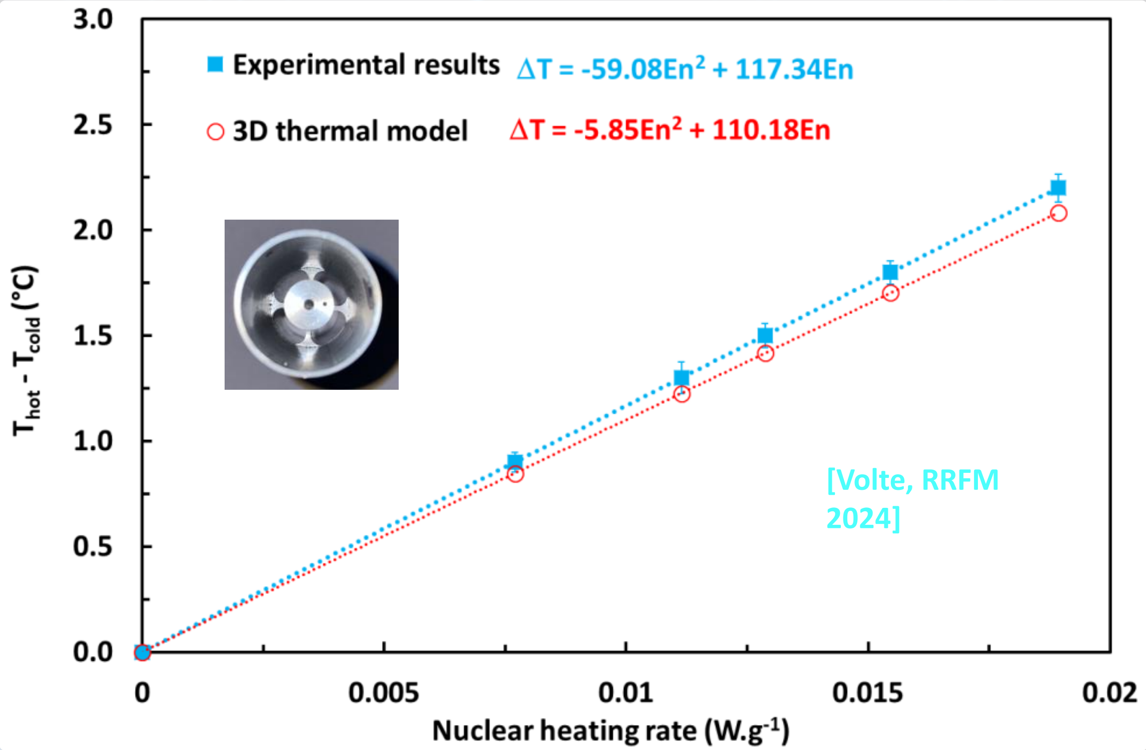
[Volte, IEEE TNS, 2020]



CALORRE calorimeter sensitivity

- CALORRE: a very modular calorimeter in term of sensitivity to target different nuclear heating rate values
  - By changing the dimension of the sample

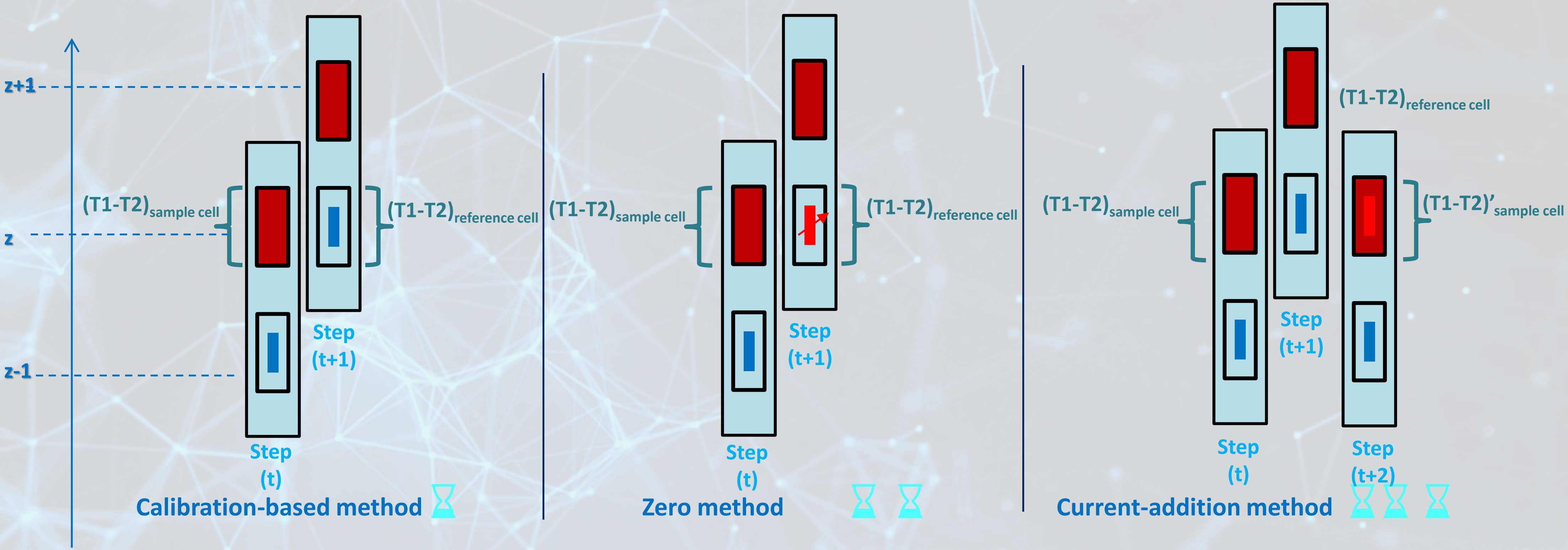




CALORRE measurement method applied in reactor

3 methods in the case of a differential calorimeter

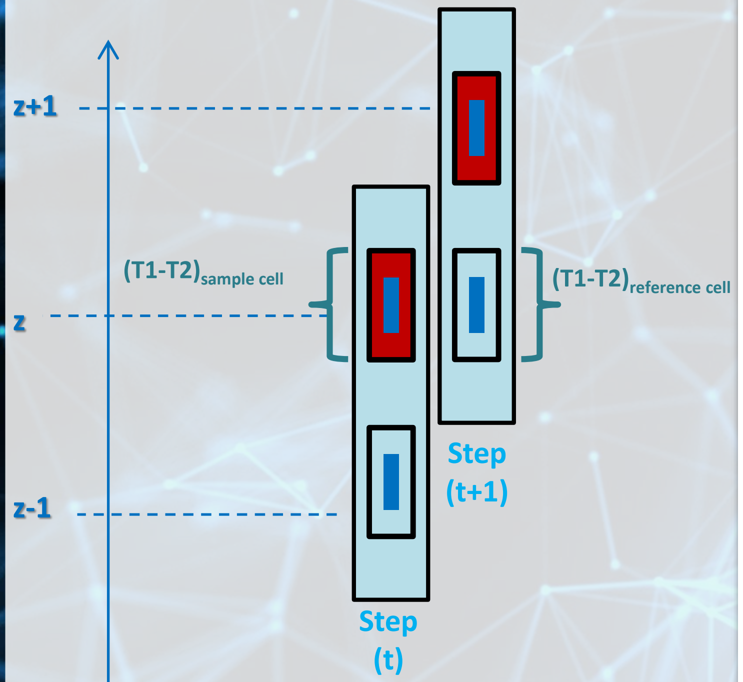
- **Method 1:** with heaters switched-off and using the out-of-pile calibration curves (called calibration-based method)
- **Method 2:** with heater switched-on in the reference cell and injecting a current to reach (T1-T2)sample cell –(T1-T2)reference cell = 0 (called zero method)
- **Method 3:** with heater switched-on in the sample cell (called current-addition method)



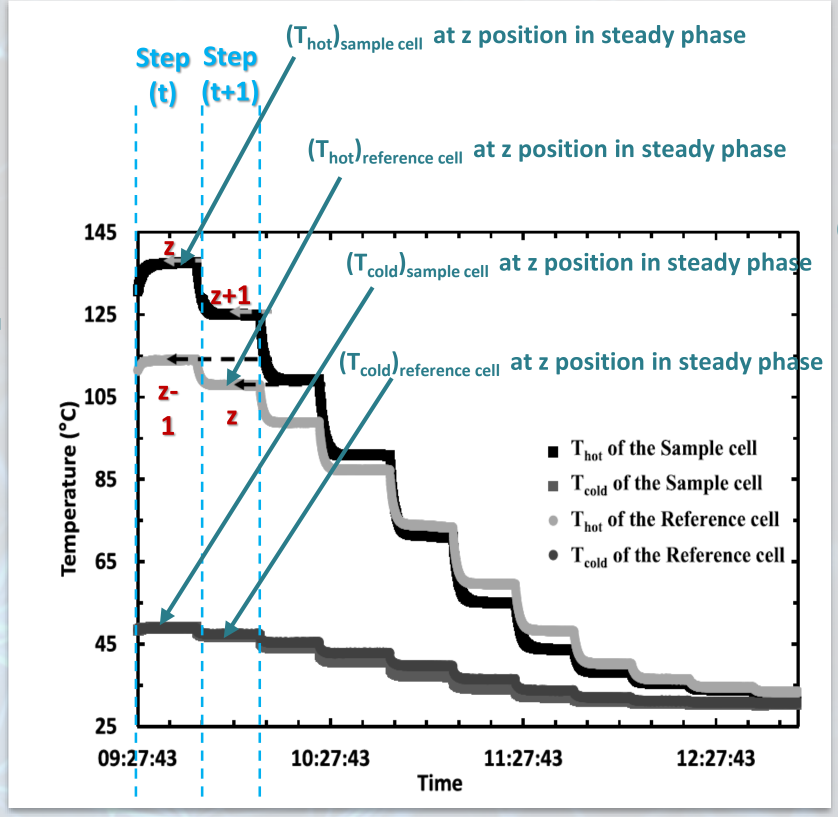
CALORRE measurement method applied in reactor

❑ 3 methods in the case of differential calorimeter

- **Method 1:** with heaters switched-off and using the out-of-pile calibration curves (called calibration-based method)



Calibration-based method



Calibration curve of the sample cell

$(T1\text{-}T2)_{sample\ cell}$ ➜ $P_{sample\ cell} = P_{sample} + P_{cell}$

Calibration curve of the reference cell

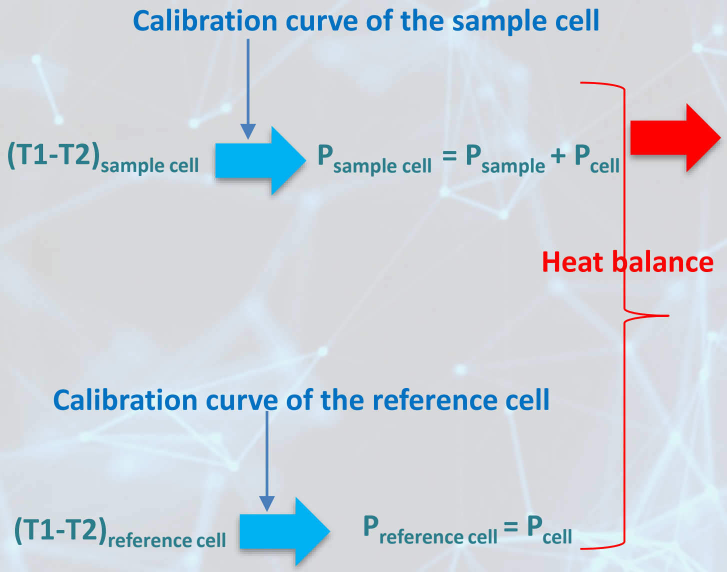
$(T1\text{-}T2)_{reference\ cell}$ ➜ $P_{reference\ cell} = P_{cell}$

Heat balance ➜ $P_{sample} = m_{sample}\,E_n = P_{sample\ cell} - P_{reference\ cell}$

CALORRE measurement method applied in reactor

3 methods in the case of differential calorimeter

- **Method 1:** with heaters switched-off and using the out-of-pile calibration curves (called calibration-based method)



$$E_n = \frac{1}{m_{sample}}\left[Psample_{cell} - Prefere_{nce\ cell}\right]$$

If linear calibration curves

$$E_n = \frac{1}{m_{Sample}}\left[A(T_{hot} - T_{cold})_{sample\ cell} - B(T_{hot} - T_{cold})_{reference\ cell}\right]$$

If second order calibration curves

$$E_n = \frac{-\left(A_{1S}(m_1+m_{sample}) - A_{1R}(m_2)\right) + \sqrt{\Delta}}{2\left(A_{2S}(m_1+m_{sample})^2 - A_{2R}(m_2)^2\right)}$$

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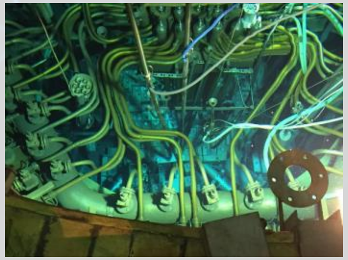
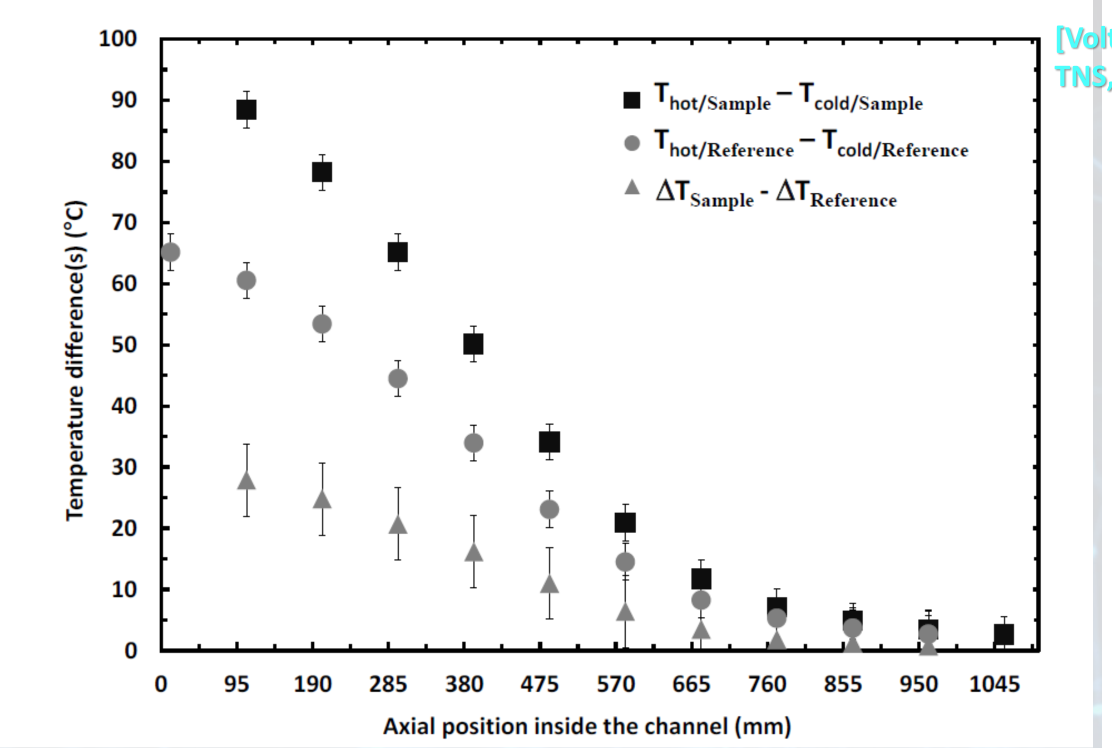
CALORRE measurement method applied in reactor

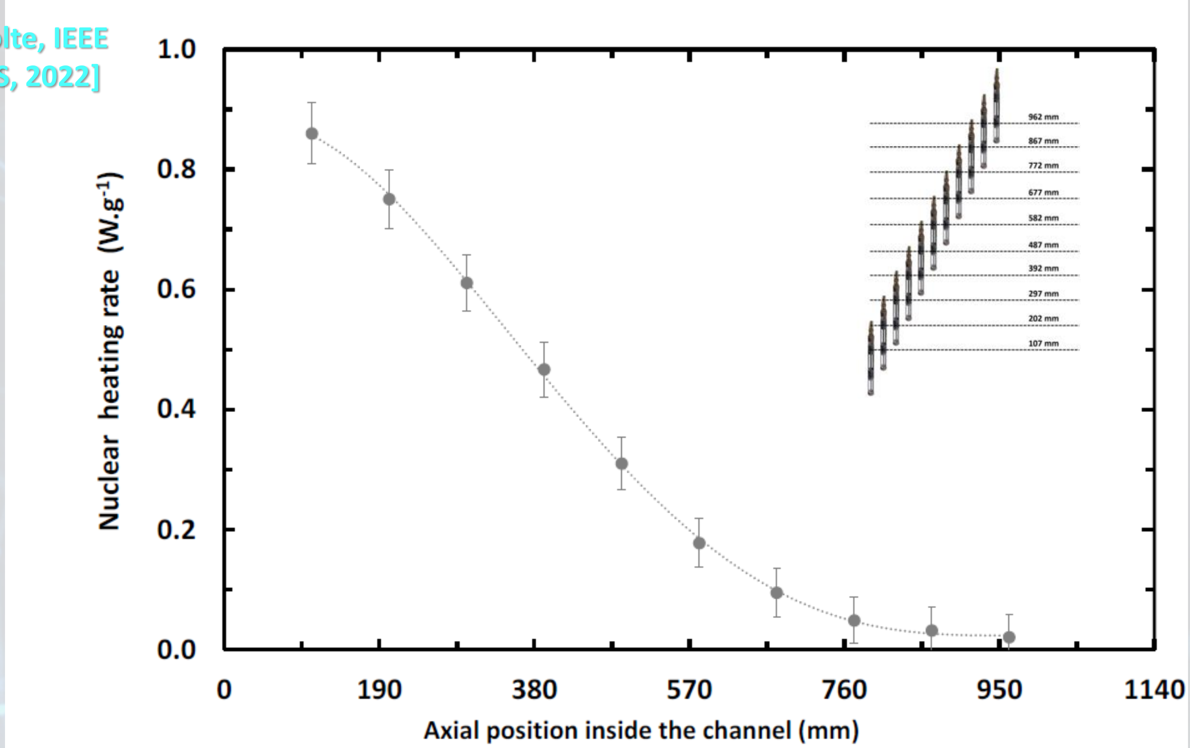
- 3 methods in the case of differential calorimeter
  - **Method 1:** with heaters switched-off and using the out-of-pile calibration curves (called calibration-based method)



MARIA reactor, Poland, 24 MW



[Volte, IEEE TNS, 2022]



An axial mapping of the nuclear heating rate in irradiation channel

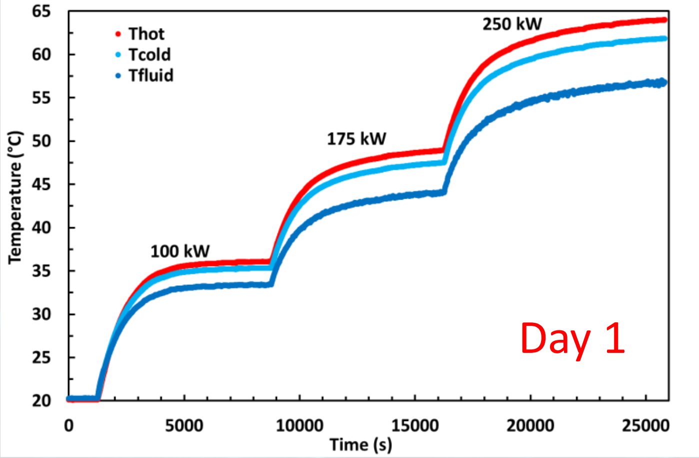
CALORRE measurement method applied in reactor

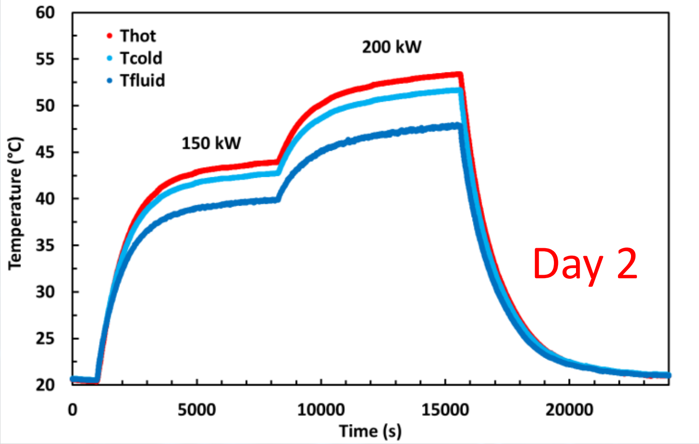
❑ 3 methods in the case of differential calorimeter

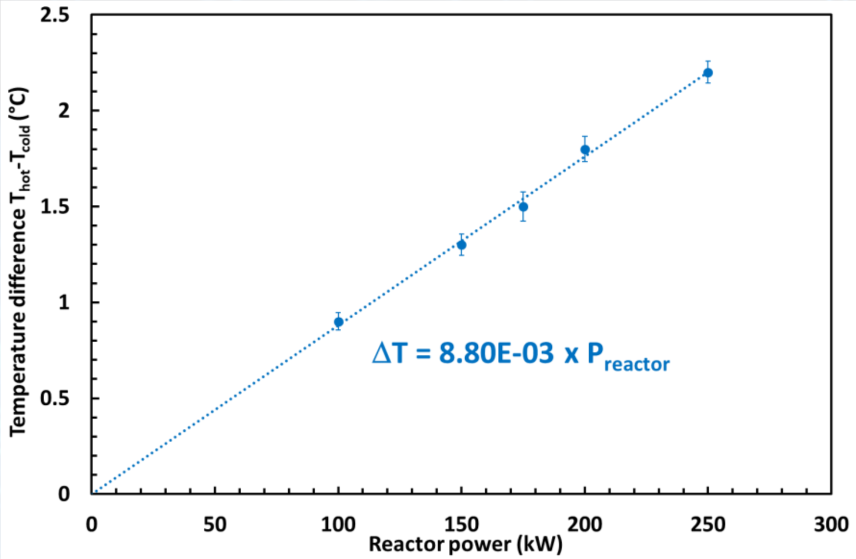
- ○ **Method 1:** with heaters switched-off and using the out-of-pile calibration curves (called calibration-based method)

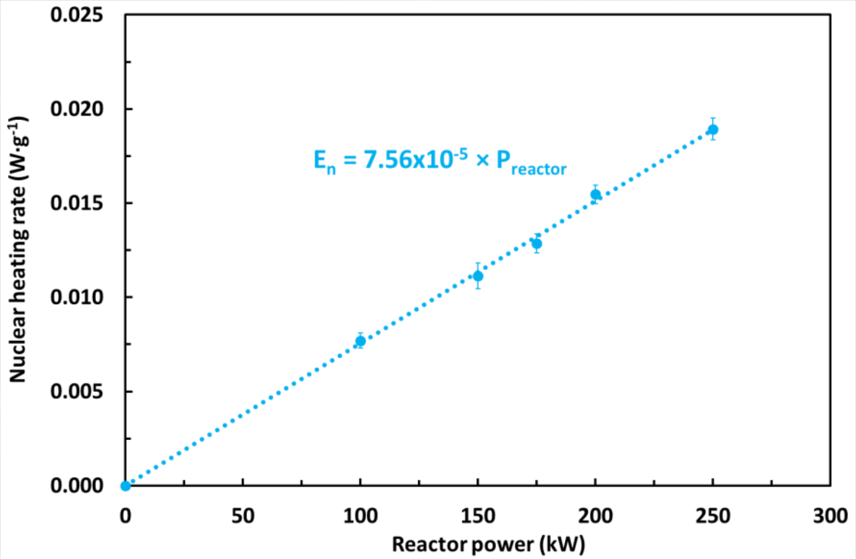
[Volte, RRFM 2024]

[Valero, PhD thesis, 2023]









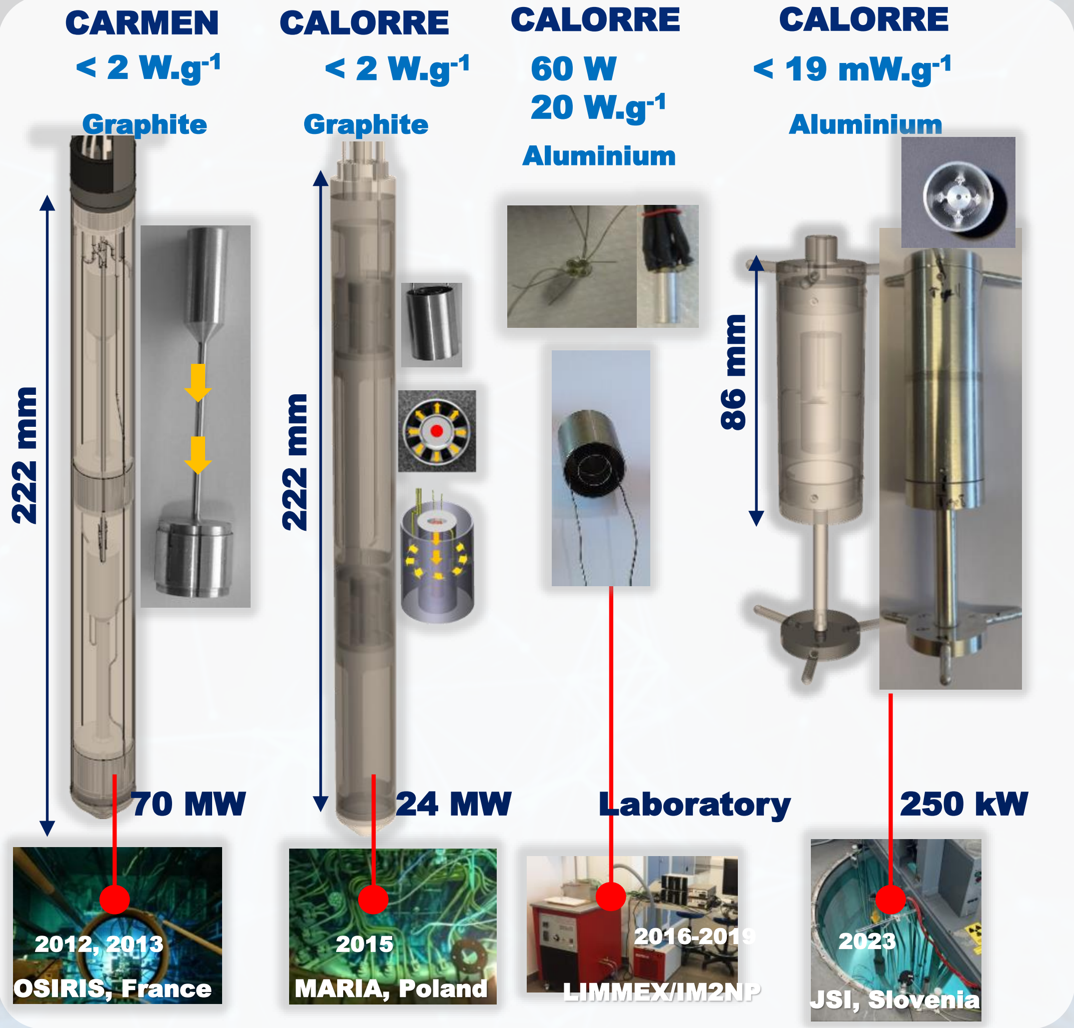
The nuclear heating rate versus the reactor power for one axial position

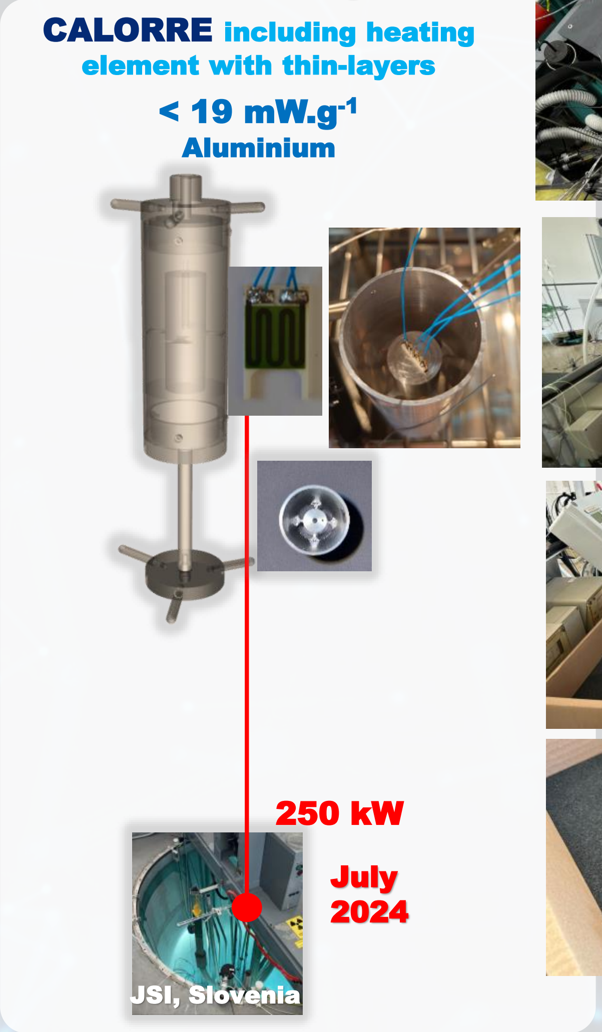

CONCLUSION
OUTLOOK

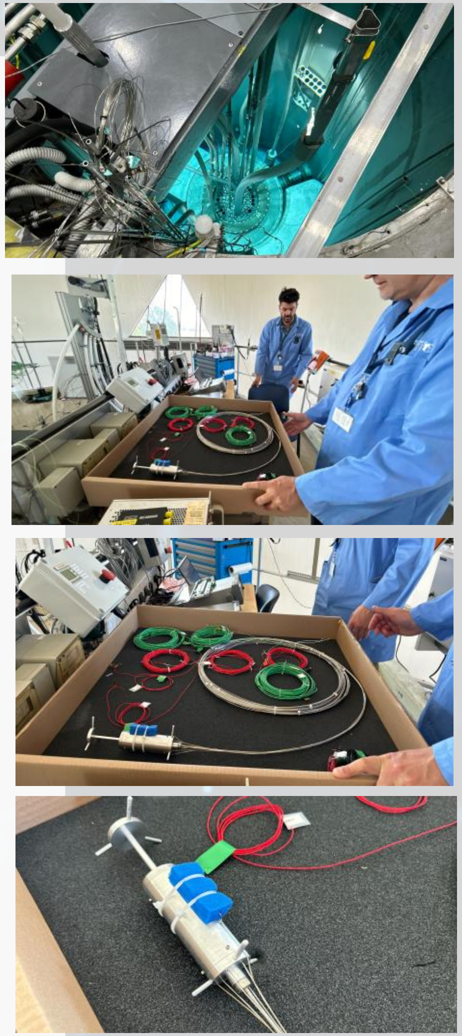
Conclusions and outlooks

❑ Several CALORRE prototypes developed and tested

Irradiation campaign from 1 to 3 of July 2024







IEEE TNS 2012, J. Brun *et al.*
IEEE TNS 2013, D. Fourmentel *et al.*
IEEE TNS 2014, J. Brun *et al.*
IEEE TNS 2015, H. Amharrak *et al.*
IEEE TNS 2016, C. De Vital *et al.*
IEEE TNS 2016, J. Brun *et al.*

Patent 2015, M. Carette *et al.*
PhD thesis 2019, A. Volte
IEEE TNS 2020, A. Volte *et al.*

RRFM 2024, A. Volte *et al.*
PhD thesis 2023, V. Valero

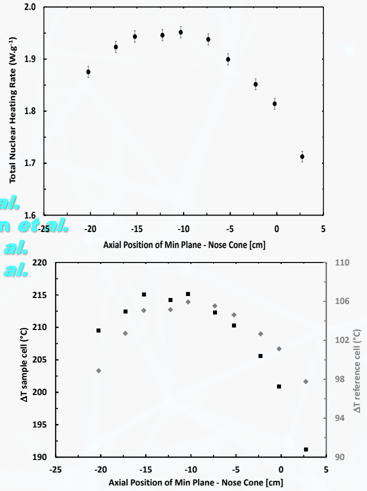
Conclusions and outlooks

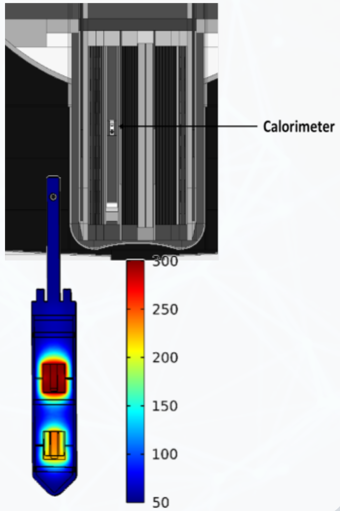
❑ New reduced-size and miniaturized sensors and new purposes for nuclear fusion field

CALORRE

< 2 W.g^{-1}
Stainless steel

ANIMMA 2023, A. Volte *et al.*
ANIMMA 2023, S. Hauptman *et al.*
IEEE TNS 2022, A. Volte *et al.*
IEEE TNS 2024, A. Volte *et al.*





A*MIDEX CALOR-I project with Massachusetts Institute of Technology, Massachusetts Institute of Technology Nuclear Reactor Laboratory, cea

6 MW

October 2024

MONO-CALO

Alumina

PhD thesis 2019, A. Volte
Patent 2020, C. Reynard-Carette *et al.*
ANIMMA 2023, J. Rebaud *et al.*

LIMMEX Micro-CALOR project with cea

250 kW Laboratory

CALORRE for various sample materials (fission and fusion fields)

?

?

CALORRE for tokamak environment

?

?

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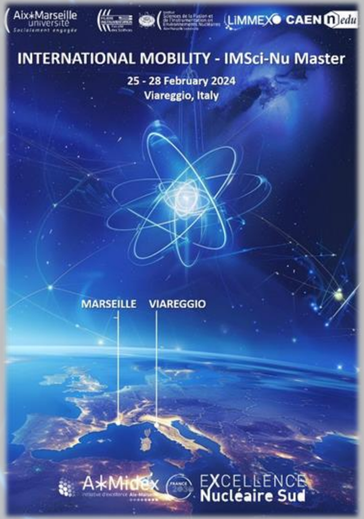
Several actions at master's level

- Developed with a very strong link between research and education

Mobility abroad	Diplomas	Immersive pedagogical tours	Events	Specific pedagogical methods	Education-Research platform
MOBIL-APP program created in 2018 **IMSci-Nu mobility**	**1-year master in Instrumentation and Measurement Science for major Nuclear research facilities (IMSci-Nu, M2)**	**Nuclear research centers** **Laboratories Facilities**	**Thematic days** **IMSci-Nu School**	**Research project** **Escape game** **Virtual reality**	**PLATINUM platform with equipment pool**

IMSci-Nu




THANK
YOU
CALORIMETER