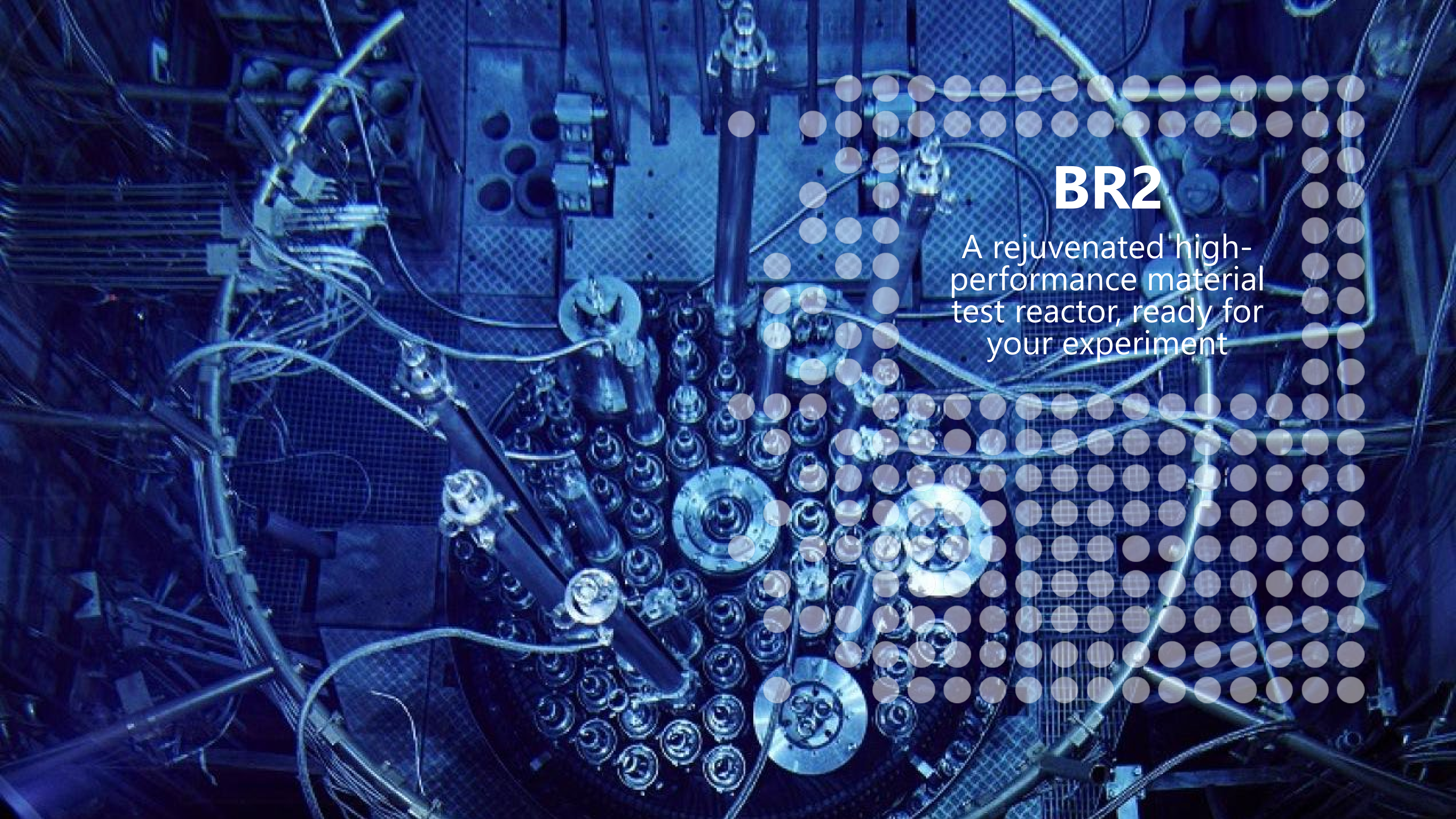
sck cen
Belgian Nuclear Research Centre

Simon Billiet - 04/09/2024

Present status of BR-2 and hot laboratories at SCK CEN



BR2

A rejuvenated high-performance material test reactor, ready for your experiment

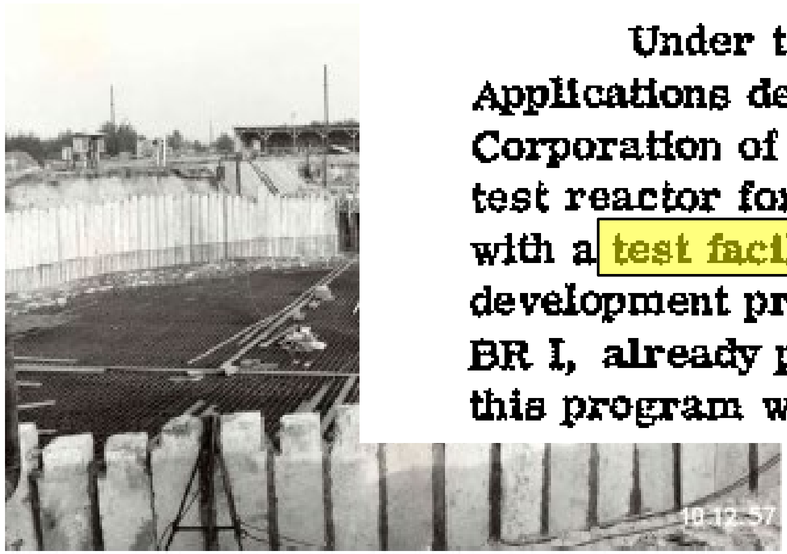
BR2 Historical overview

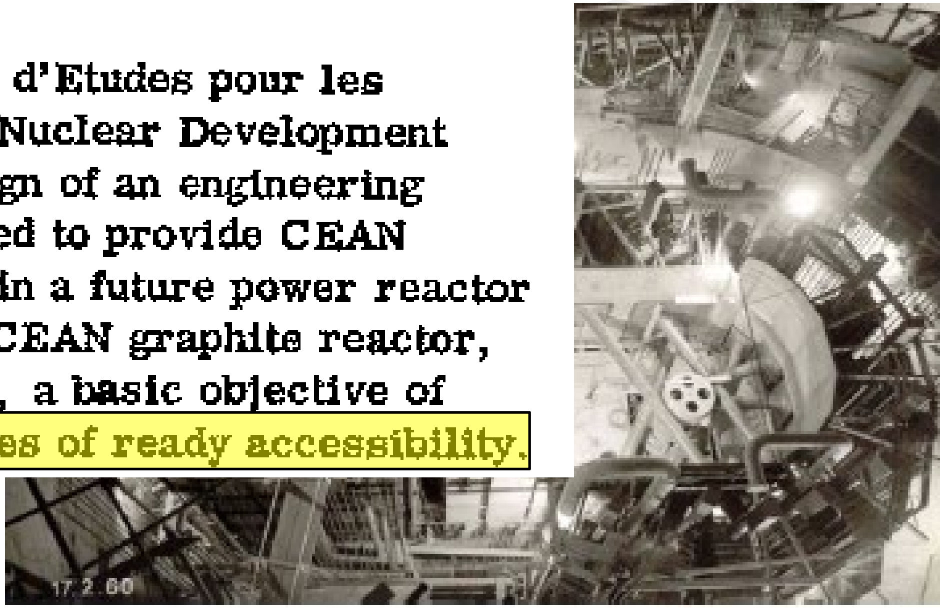
NDA

III. INTRODUCTION

A. PURPOSE OF PROJECT AND PHASE I

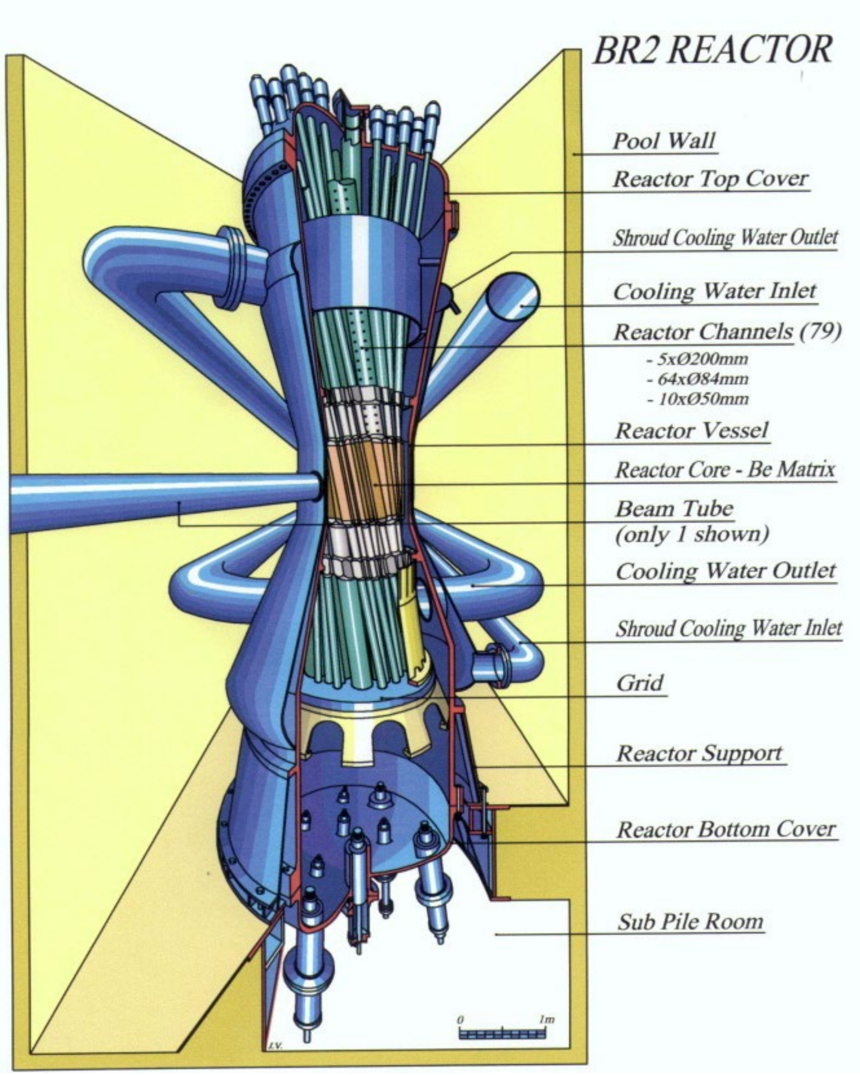
Under terms of a contract with the Centre d'Etudes pour les Applications de l'Energie Nucleaire (CEAN), the Nuclear Development Corporation of America (NDA) undertook the design of an engineering test reactor for Belgium. This reactor is intended to provide CEAN with a test facility of greatest overall usefulness in a future power reactor development program. Inasmuch as the present CEAN graphite reactor, BR I, already provides low neutron flux facilities, a basic objective of this program was to provide high flux test facilities of ready accessibility.



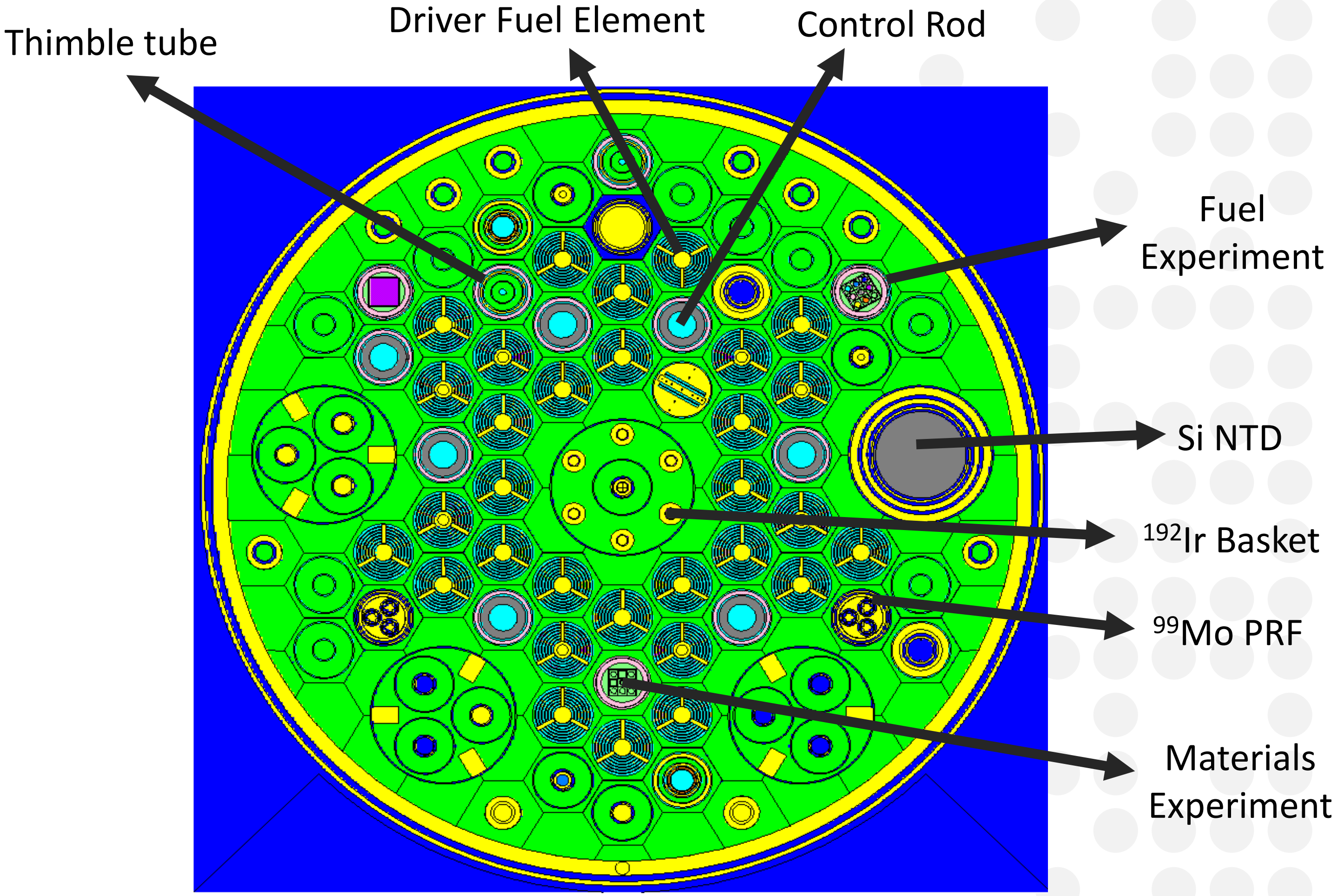


Reactor geometry

- Light water cooled (12 bar), water+Beryllium moderated MTR
- Inclined reactor channels for compact core (Ø 1m) and good access at cover (Ø 2m, 79 channels)
- Reactor channels accessible from top (all) and bottom (17 for through loops)
- Irradiation in rigs in reactor channel or in axis of fuel element

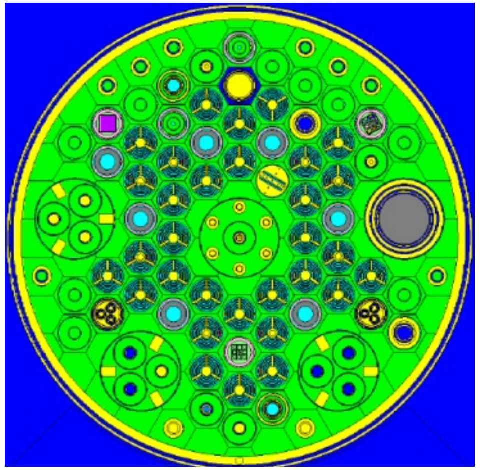


BR2 = Multipurpose Reactor



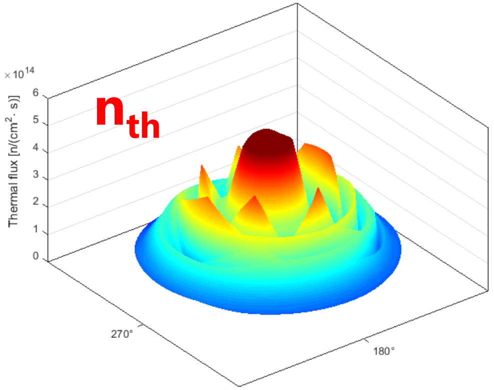
Mid-plane cross section of a typical BR2 core

Reactor core performance of BR2

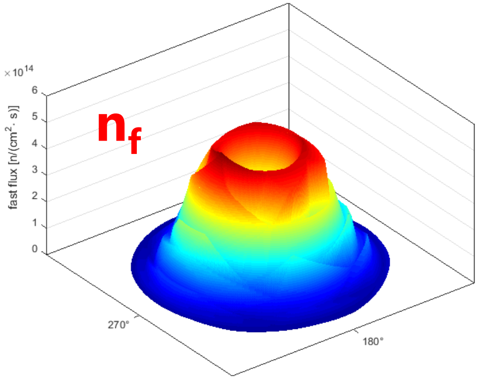


- Design goal: thermal neutron flux up to 10^{15} n/cm²s
  - Material choice: Be moderator and metallic uranium fuel
  - High overall core power (50 to 100MW upgrade in 1968)

- Achievable flux levels (at mid plane in vessel)
  - Thermal flux: 7×10^{13} n/cm²s to 1×10^{15} n/cm²s
  - Fast flux (E>0.1MeV): 1×10^{13} n/cm²s to 6×10^{14} n/cm²s



- Allowable heat flux
  - 470W/cm² is allowed for the nominal T-H conditions of the BR2 primary
    - Demineralised water
    - Pressure to 12 bar, temperature 35-50°C
    - 10m/s flow velocity on fuel plate
  - Up to 600W/cm² can be achieved in experiments



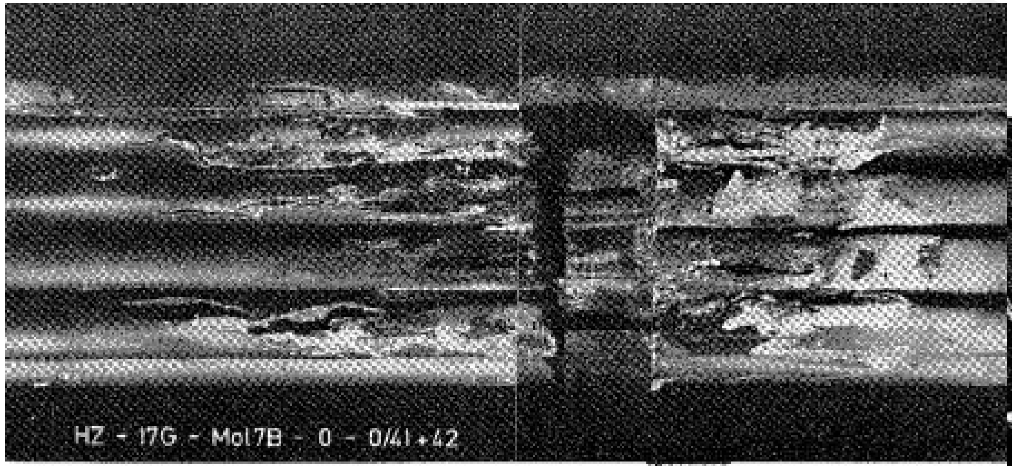
Reactor configuration

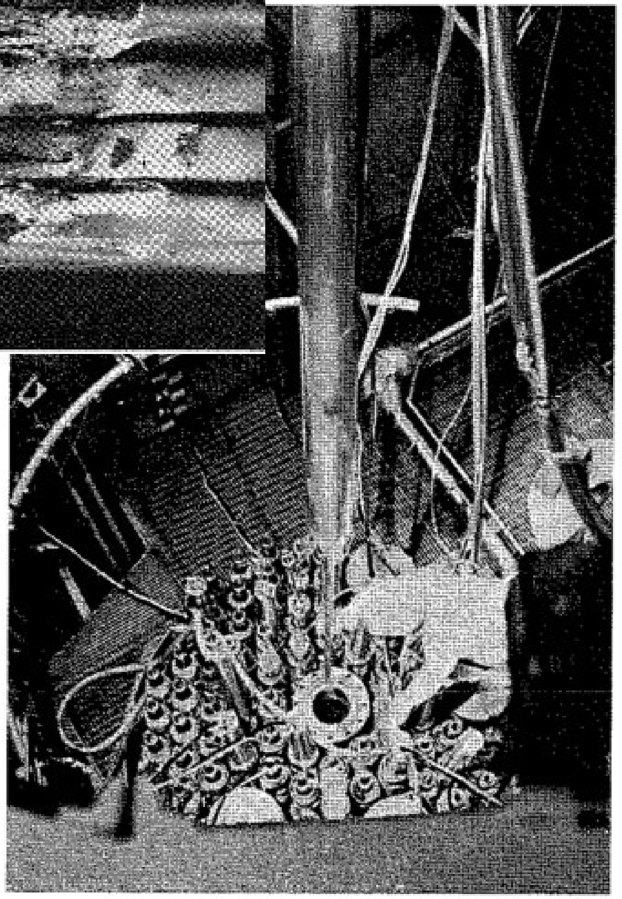
- Configuration flexibility:
  - Position of fuel, control rods and experiments
  - Type of fuel elements
  - Reactor power and cycle length

- Reactor load is optimized for each operating cycle
  - 3D MCNP model with burn-up evolution of entire core
  - Detailed model of experiment/production if required
  - Verification by criticality approach before start

- BR2 reactor management and irradiations are ISO 9001 certified

First era of operation 1963-1978



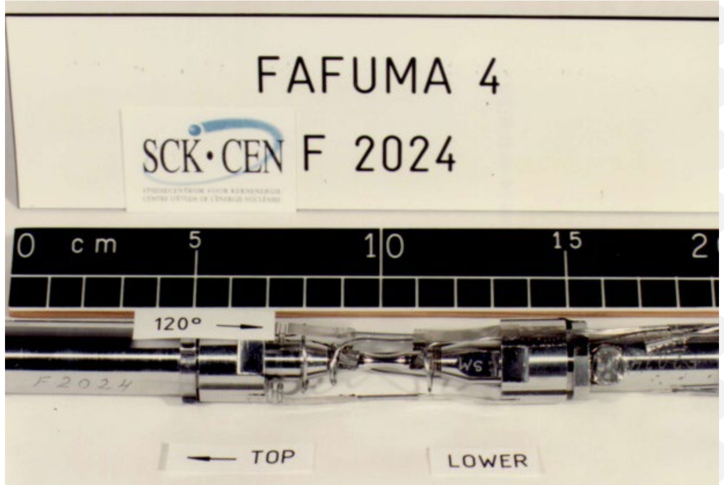


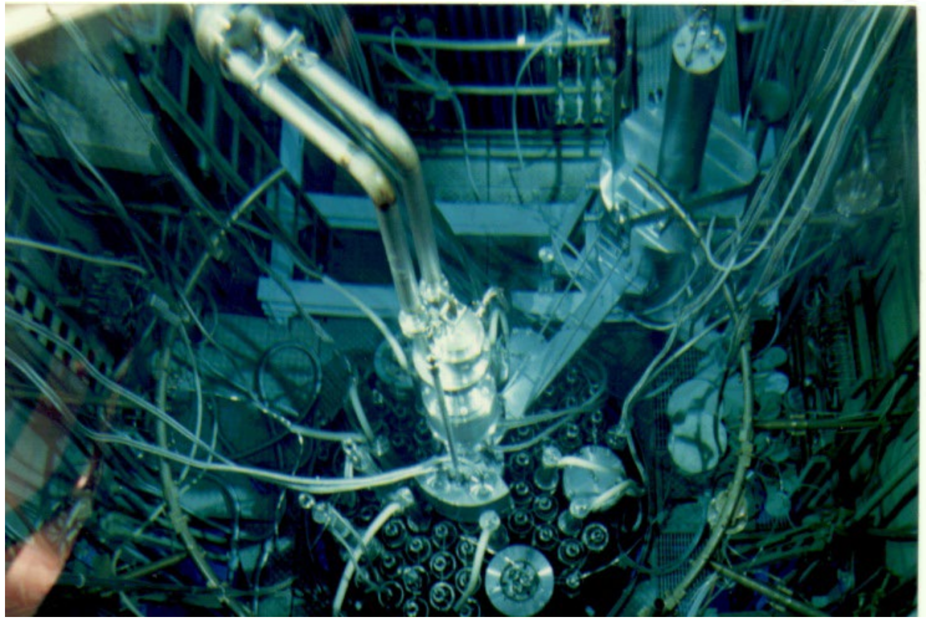
- Prototype experiments for
  - Light water reactor
  - Gas cooled reactor
  - Sodium cooled reactor
- First irradiations of MOX fuel
- Production of isotopes for energetic applications
- First replacement of Be matrix: 1978-1980

Second era of operation: 1980-1995

- Experiment portfolio:
  - Safety experiments Na cooled reactors
    - Loss of Flow accident
    - Post Accident Heat Removal
  - LWR license support experiments (BR3 shutdown 1987)
    - Base irradiation (100 – 400 W/cm)
    - Transient testing (up to 600 W/cm)
  - Instrumented material irradiations
    - e.g. in-pile fatigue/creep testing

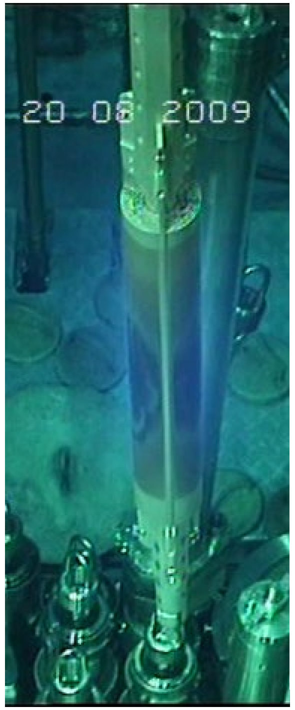
- 2nd replacement of Be matrix: 1995-1997

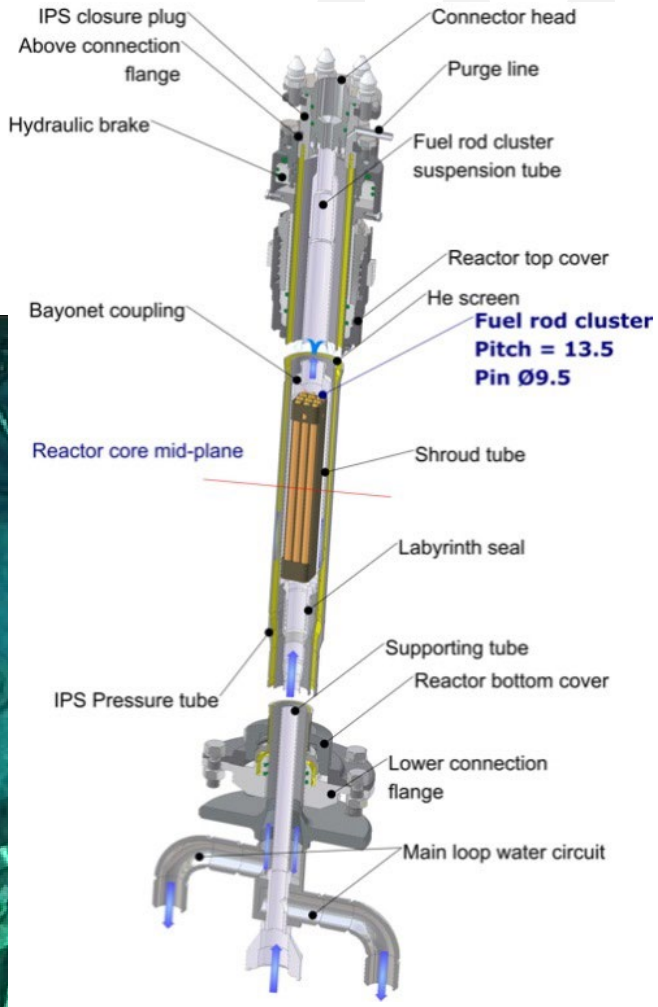




Third era of operation: 1995-2015

- Experiment portfolio
  - LWR license support experiments (CALLISTO loop)
    - Base irradiation & transient testing
  - MTR fuel test irradiations
    - EVITA: qualification of RJH Fuel
    - FUTURE series: LEU Fuel tests
  - Materials irradiations
    - RPV steel irradiations in support of LTO
    - Fusion reactor material tests
- Production portfolio
  - Neutron Transmutation Si doping:
  - Medical & non-medical radioisotope
- 3rd replacement of Be matrix: 2015-2016

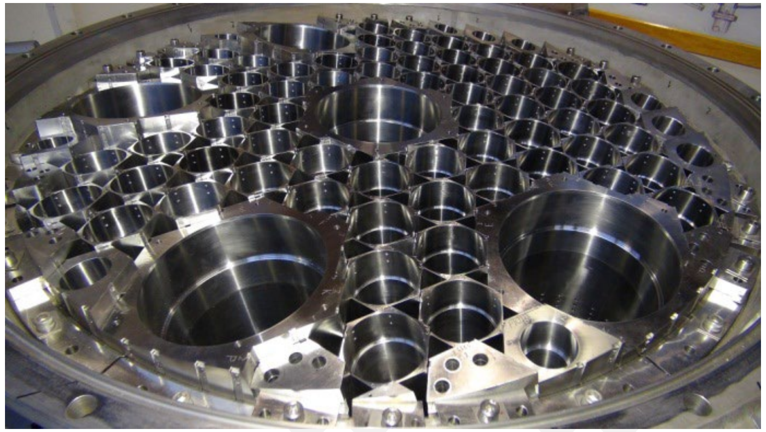


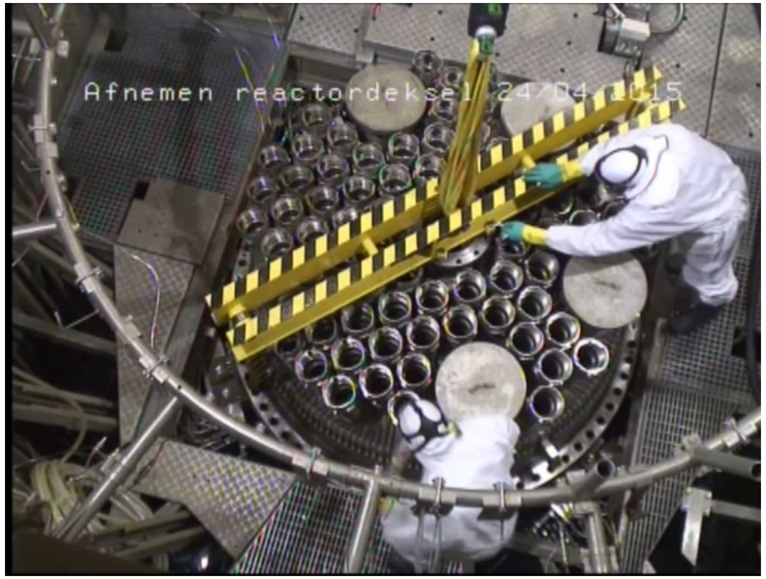


4th operation period: 2016-2036

- Major overhaul completed in June 2016
  - Replaced beryllium matrix
  - Performed major maintenance operations and inspections
  - Updated instrumentation to meet future challenges
  - Potential for improved operational regime (higher up-time)

- BR2 conversion to LEU by 2026
  - High-performance MTR
  - HEU (>90%) U-Al metallic fuel to LEU (<20%) U_3Si_2 metallic fuel

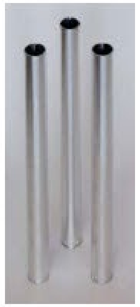


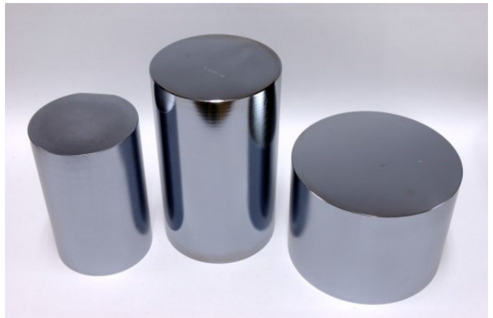


Current focus of BR2 and (some) key irradiation rigs

- Production - radio-isotopes & NTD Si
- Fuel research infrastructure
  - MTR: FUTURE, EVITA, MUSTANG
  - LWR: Pressurized Water Capsules + DISCOVARY
- Materials research infrastructure
  - MISTRAL
  - HTHF, LTHF
  - BAMI, LIBERTY

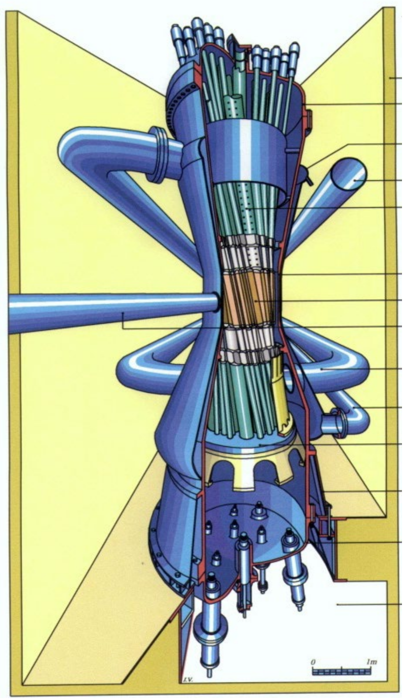
Radioisotopes (PRF) NTD Si (SIDONIE-POSEIDON)

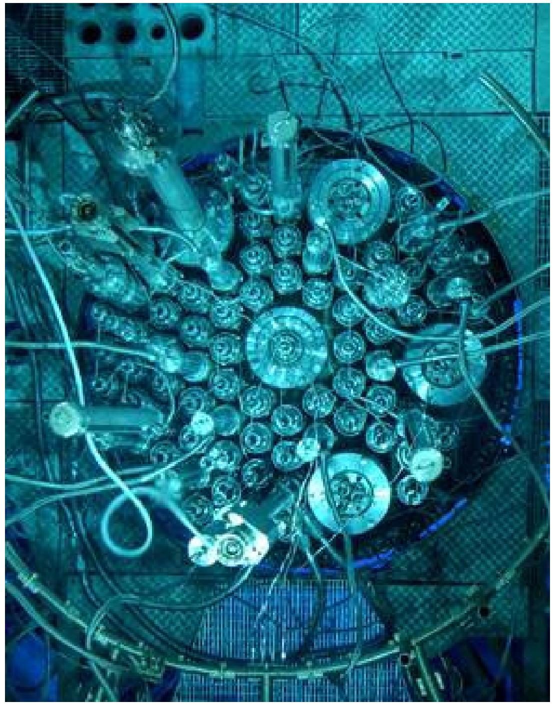




SCK CEN has capacity to produce up to 65% of the weekly worldwide needs for medical radioisotopes

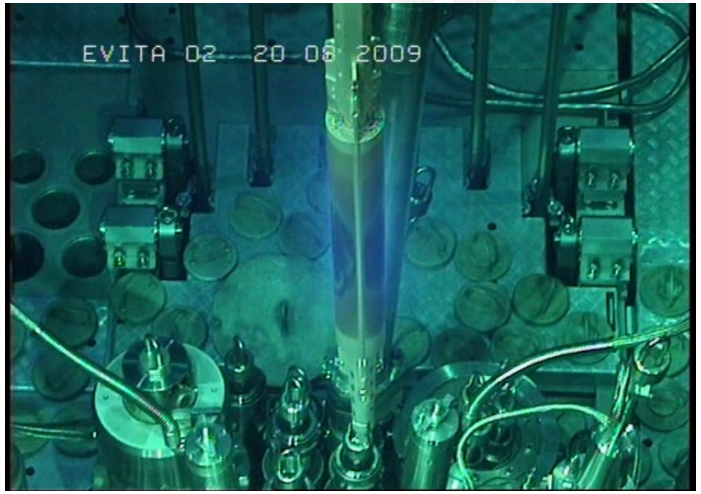
SCK CEN produces on average 25% of worldwide demand of semiconductors for renewable energy applications





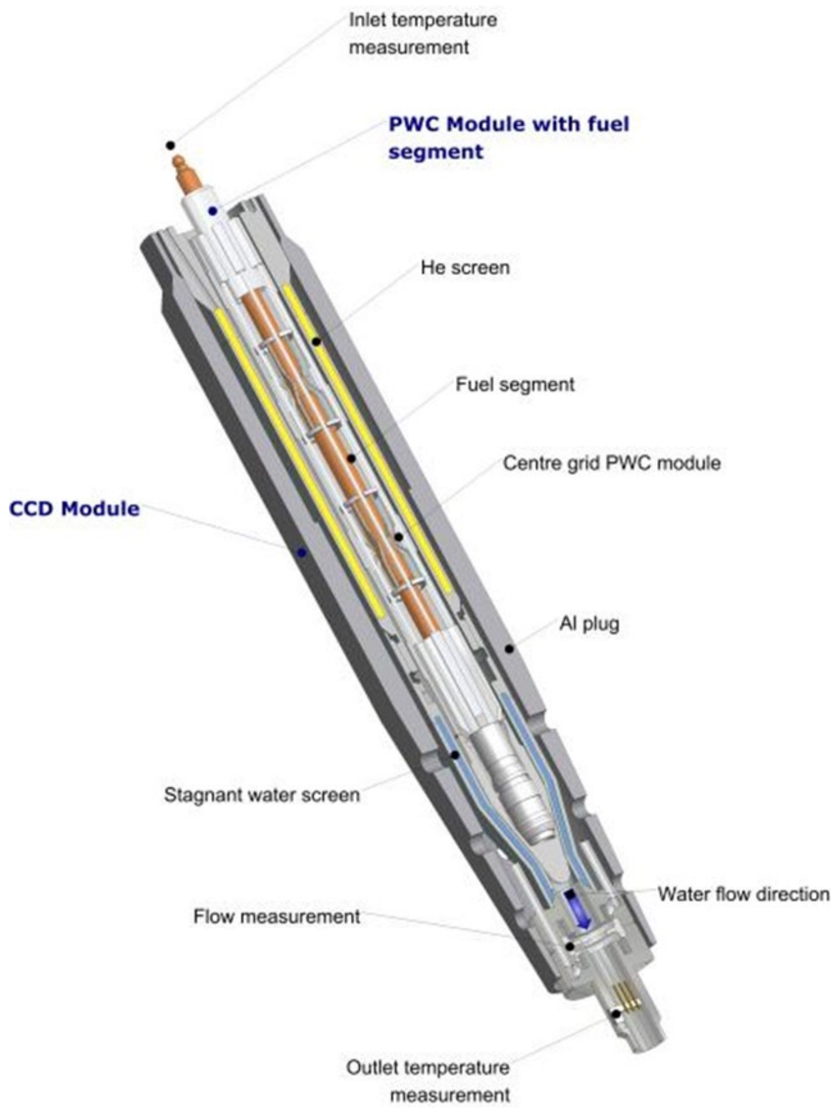
Research Reactor Fuel

- Application: research reactor fuel test irradiations
  - Flat and curved plates in high power conditions
  - High burnup with flux verification
- Technical
  - Basket for 4 full size flat plates with dosimetry (FUTURE)
  - Mixed element (outer plates of standard BR2 element replaced)
  - Dedicated flow rigs for enhanced/reduced flow conditions mimicking e.g. JHR (EVITA) or NBSR (MUSTANG)
- Characteristics
  - Power up to 470 W/cm^2 in standard flow (600 W/cm^2 possible)
  - Typically 3-4 cycle irradiations to reach >80% local burnup



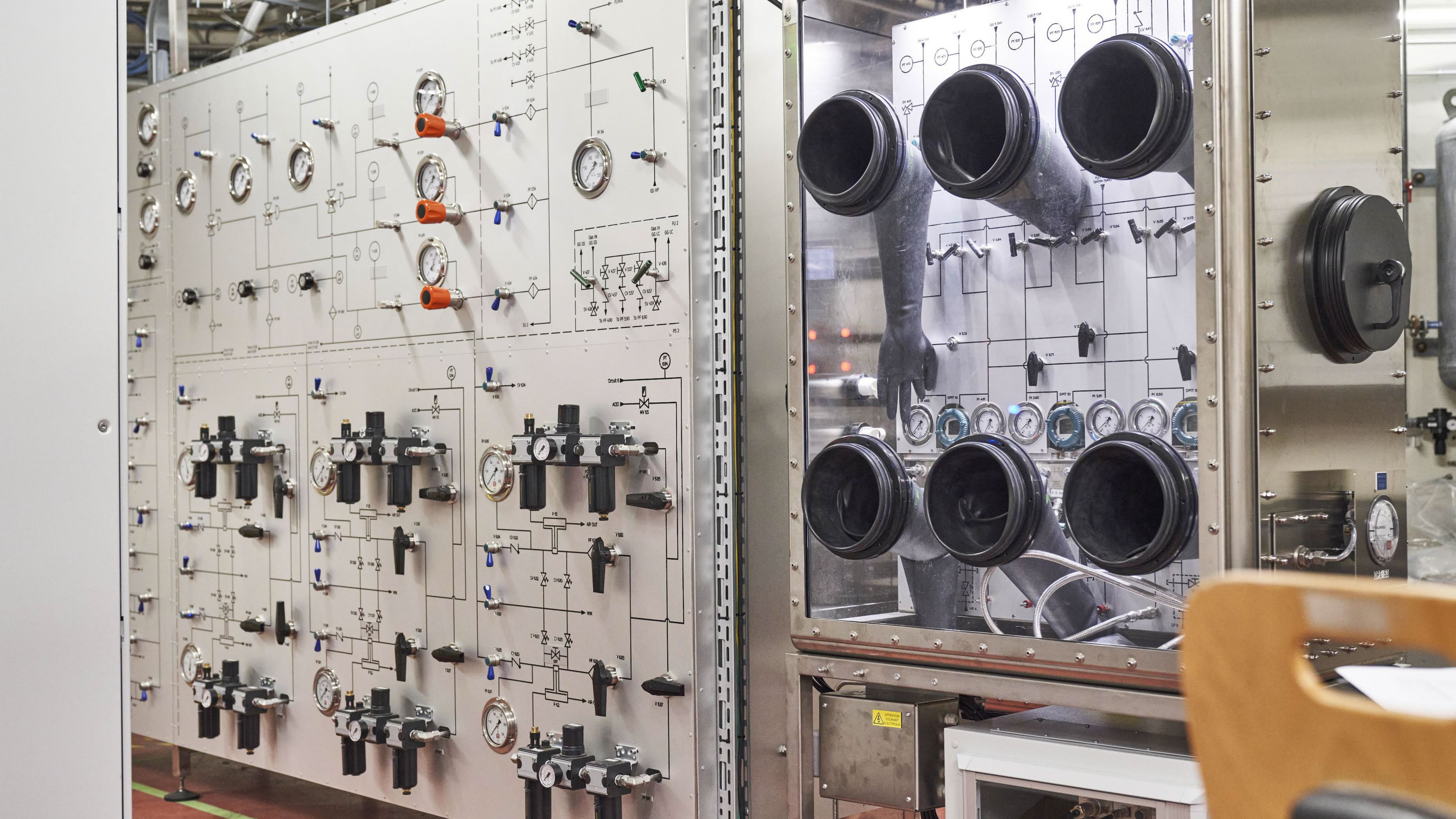
Power Reactor fuel: PWC

- Application: steady state and transient tests of LWR fuel pins
  - High linear rating (up to 700 W/cm)
  - Rapid power transients, instrumented fuel pins
- Technical
  - Pressurized water capsule, nucleate boiling
  - Rod power variations by reactor power
  - Power monitoring by thermal balance
- Characteristics
  - Capsule pressure up to 160 bar
  - Power increase rate $\Delta q_l/\Delta t_{max}$ = 100 W · cm^{-1} · min^{-1}
  - Accuracy of the rod power to within 5%
  - Cladding ∅: 8-12.5 mm, fuel length: 20-100 cm

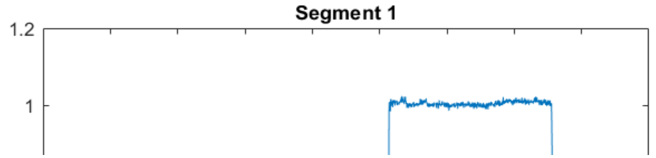


Pressurized Water Capsule (PWC)

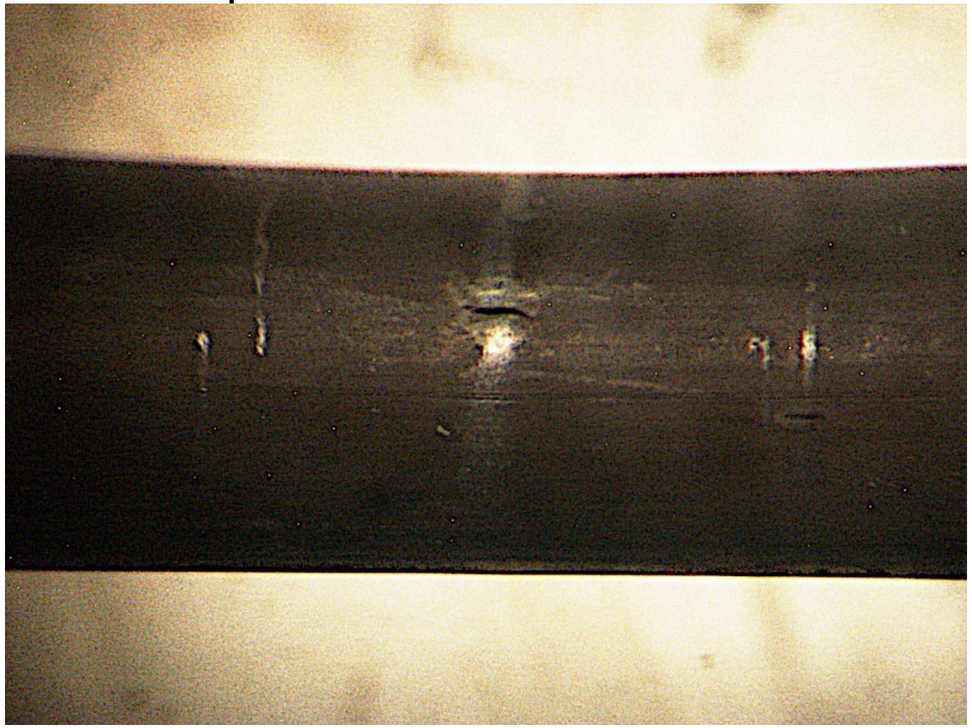
Transient fuel testing

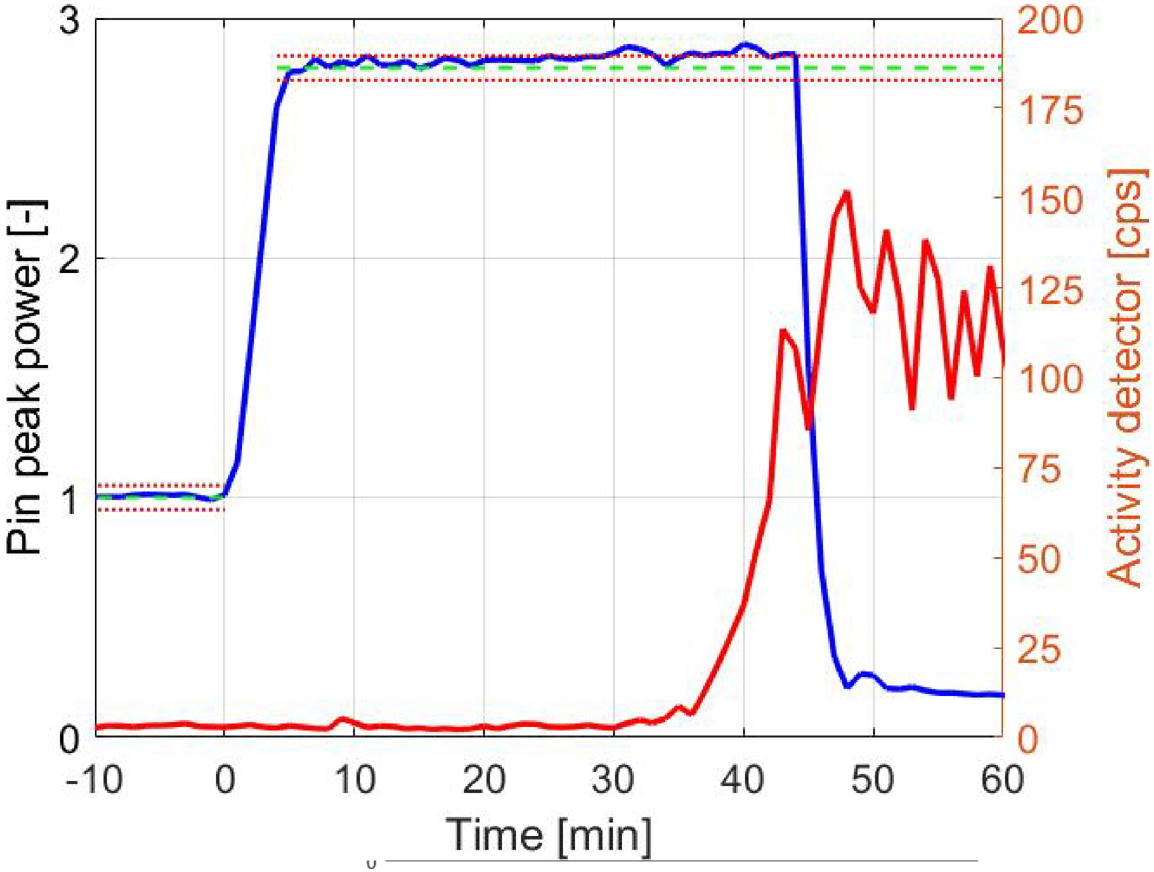

Gas In
GG GS
GG LC
FU 2
To PF 4.90
To PF 5.90
To PF 6.90
PS 2
PI 54
GS HP
Circuit 6
AIR OUT
ATTENTION COURANT ÉLECTRIQUE

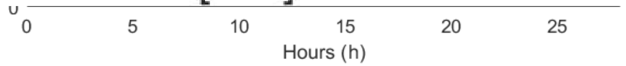
PCMI-type transients with the PWC



- Ongoing qualification program of LWR fuel cladding
- Series of power transient tests in BR2



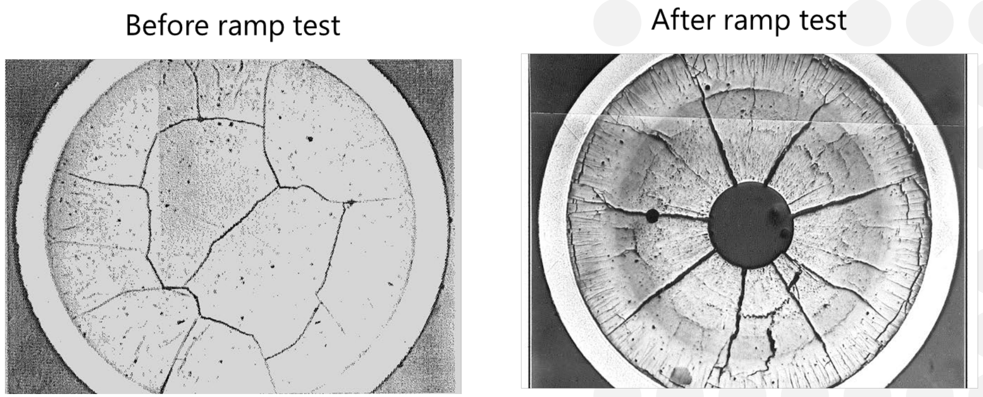


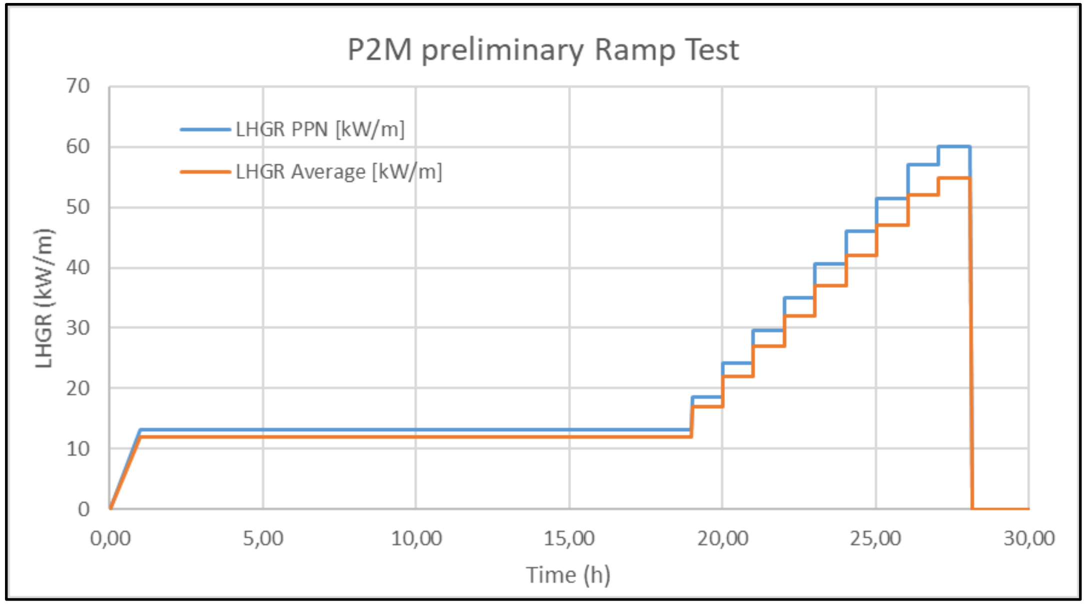


Power-to-Melt (P2M) – project

- Slow power transients on instrumented high burn-up UO_2 fuel pins:
  - On-line measurement of T and FGR
  - Aiming at 10-15% melted fuel volume fraction
- Increase understanding of fuel melting effects, optimize safety margins and fuel code performance
- Cooperation between CEA, EDF and SCK CEN in framework of OECD-NEA-FIDESII

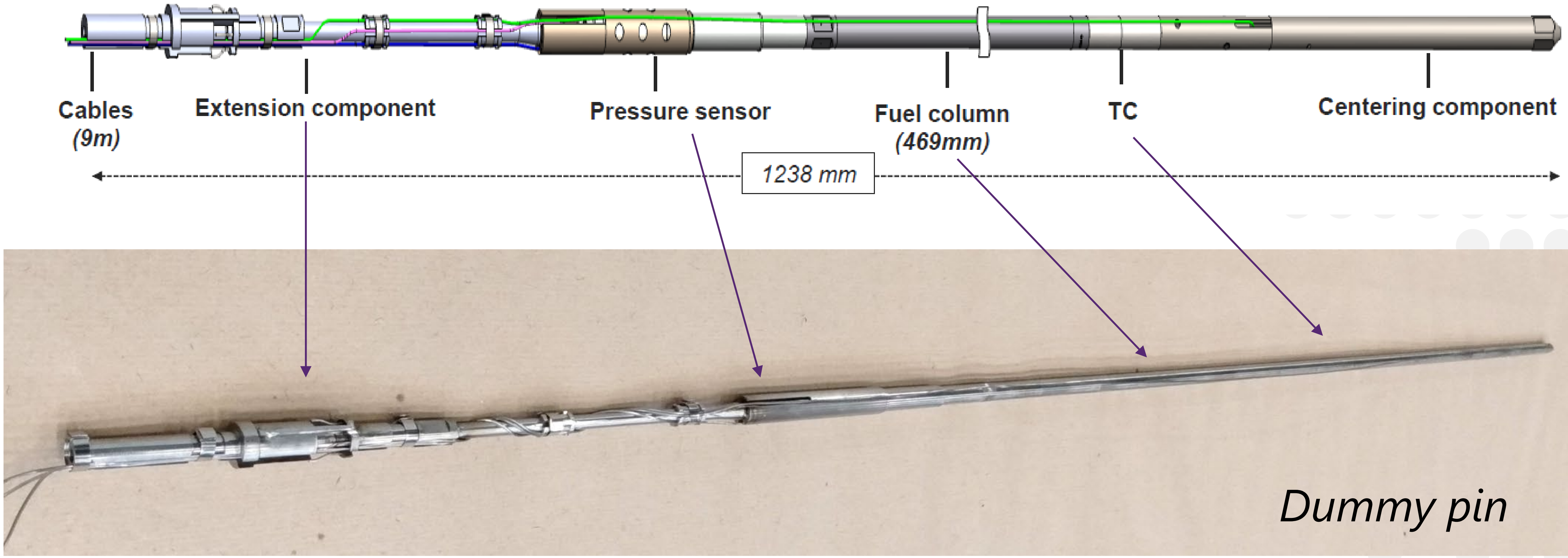
Example of power to melt test (660W/cm) on MOX fuel (57 GWd/t) (SCK CEN, 1997)



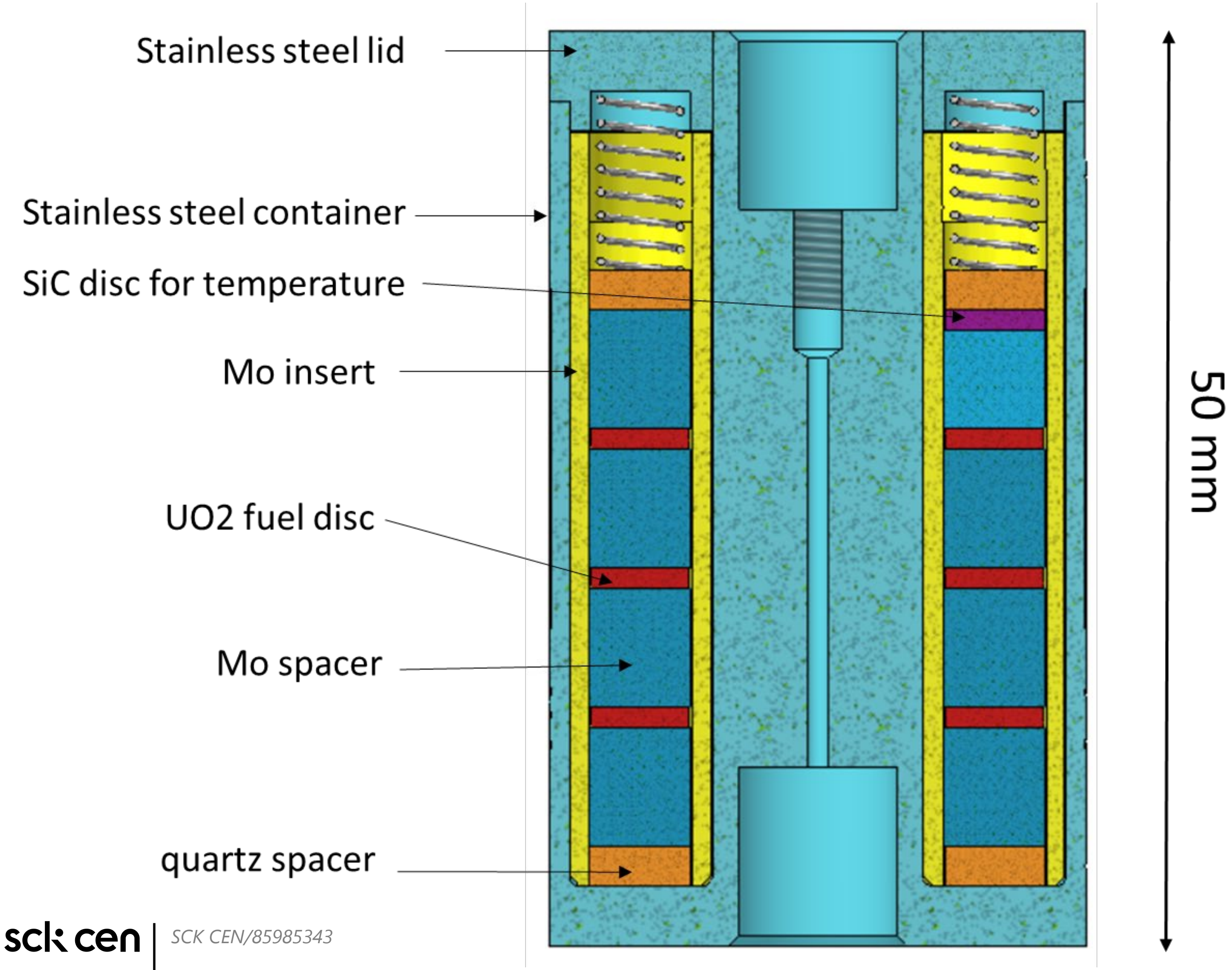


Instrumented fuel pin with 9 meters of signal cables

Fabricated at CEA LECA-STAR hot cells

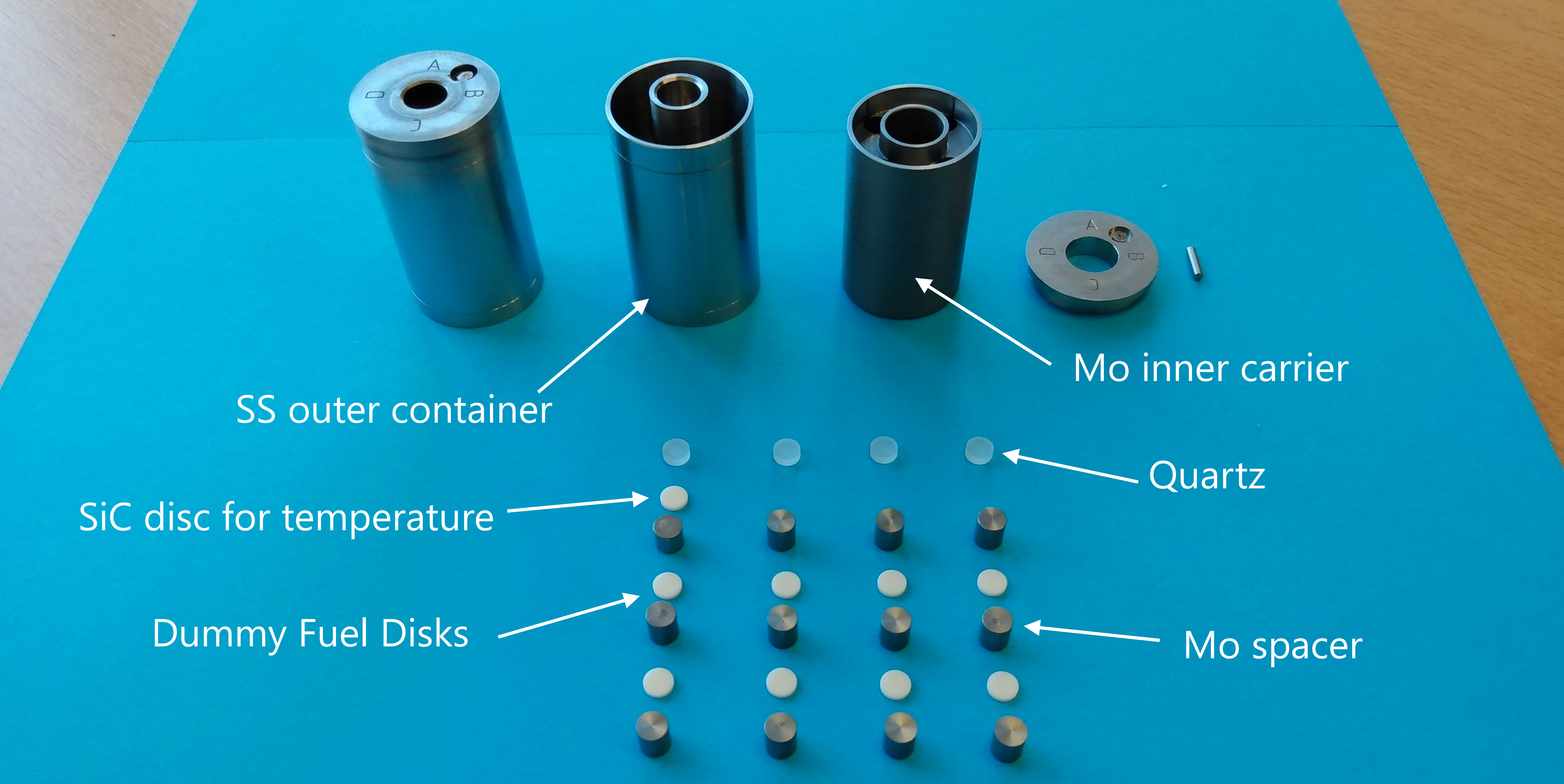


DISCOVARY (fuel disc irradiation)



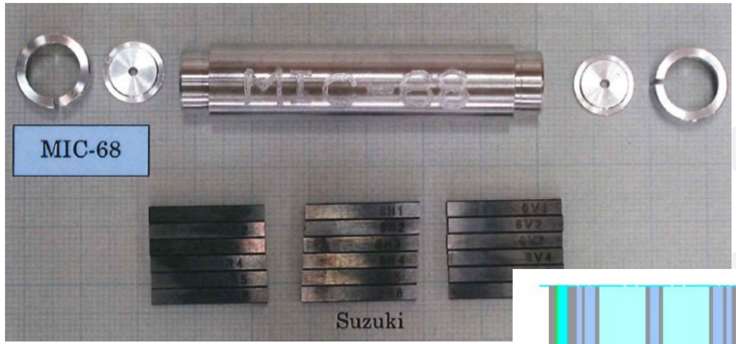
- **Rapid burnup accrual:**
  - 20 GWd/t_{HM} per BR2 cycle
- Variation of fuel / disk types
  - Standard size: ∅ 5 mm x 1 mm height
  - 12 disks per puck
  - Up to 15 pucks per single capsule
  - Mix and Match different fuel types
  - Modified internal carrier allows for other fuel types (TRISO, molten salt)
- **Temperature monitoring:**
  - Online by internal TCs
  - Offline by SiC disk

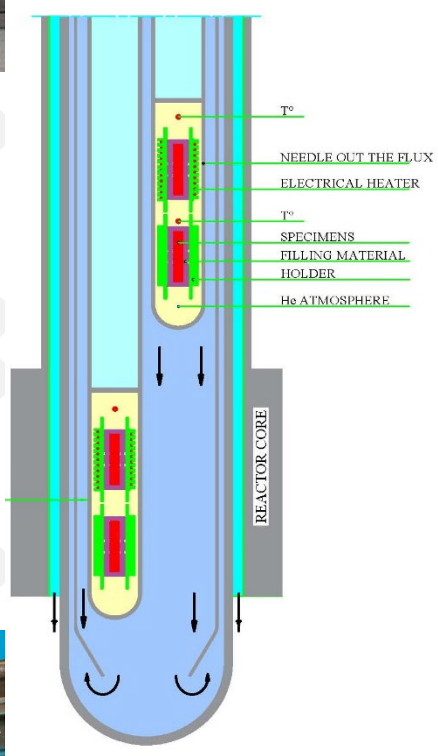
Fabricated puck design and internals

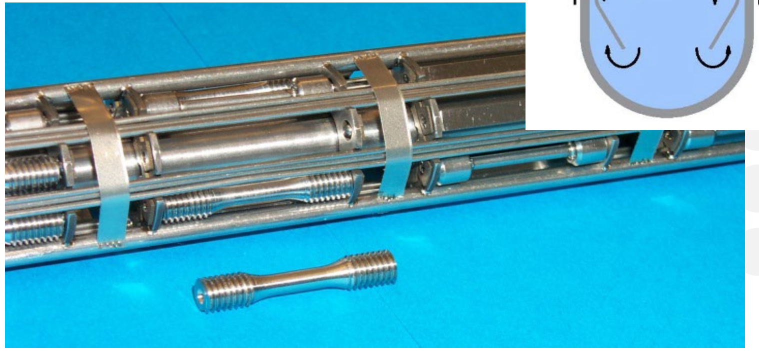


Materials irradiation

- Application:
  - Screening wide variation of new materials
  - Higher temperatures, higher (fast neutron) fluence
  - Different environments
- Solutions:
  - BAMI capsule for quick and cheap screening
  - MISTRAL for high flux at moderate temperature
  - HTHF for high flux/temperature irradiations
  - LIBERTY for flexibility in fluence
  - Dedicated special devices for in-situ testing





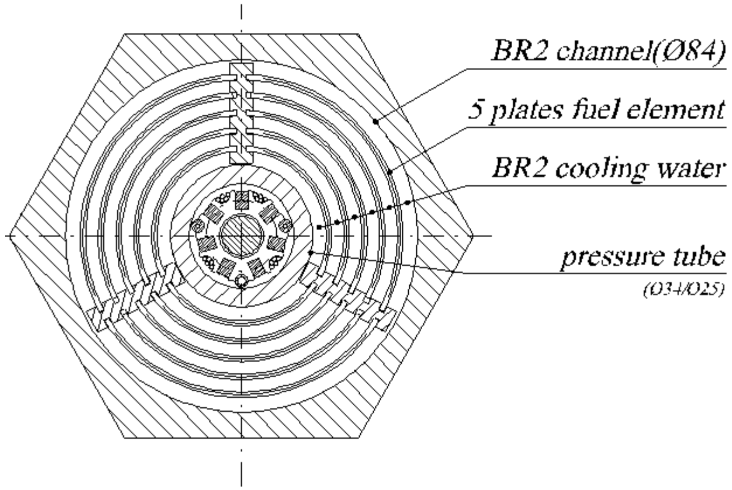


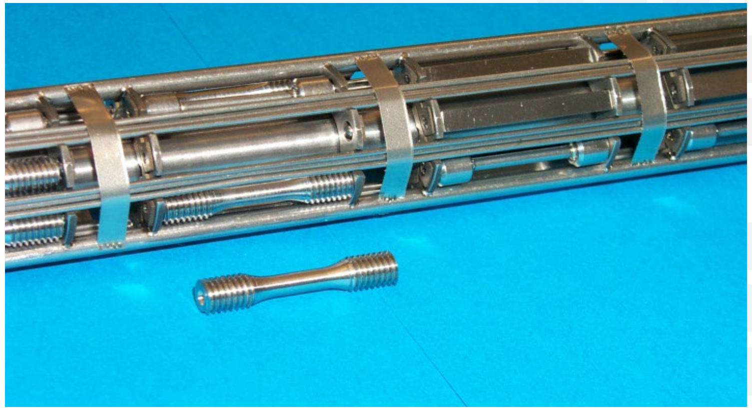
Medium Temperature - High Flux: MISTRAL

- Application: high flux and moderate temperature
  - High dose rate, stable temperature
  - Reusable rig with flexible loading position in reactor

- Solution
  - Pressurized water capsule inside 5 plate fuel element + electrical heating
  - Boiling water
  - Miniature specimens

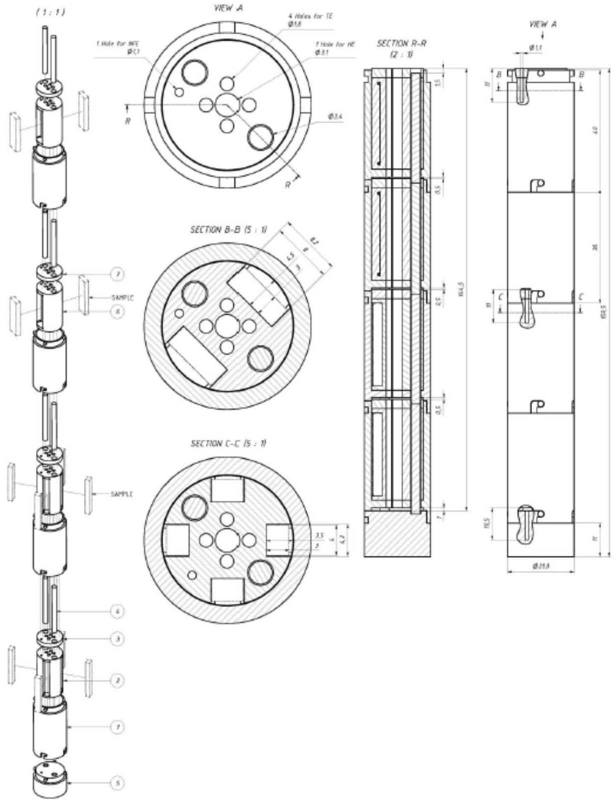
- Characteristics
  - Temperature 150-350°C
  - 0.5 dpa per reactor cycle of 3 weeks





High Temperature – High Flux: HTHF

- Application: material irradiation at high flux and high temperature
  - High dose rate (>0.5 dpa per reactor cycle)
  - Stable irradiation temperature during irradiation
  - Flexible loading position in reactor
- Solution
  - Gas filled capsule inside 6 plate fuel element with electrical heating
  - Control of temperature by gas gap design and gas pressure
  - Miniature specimens
- Characteristics
  - Temperature 300-1000°C
  - 0.6 dpa per reactor cycle of 3 weeks

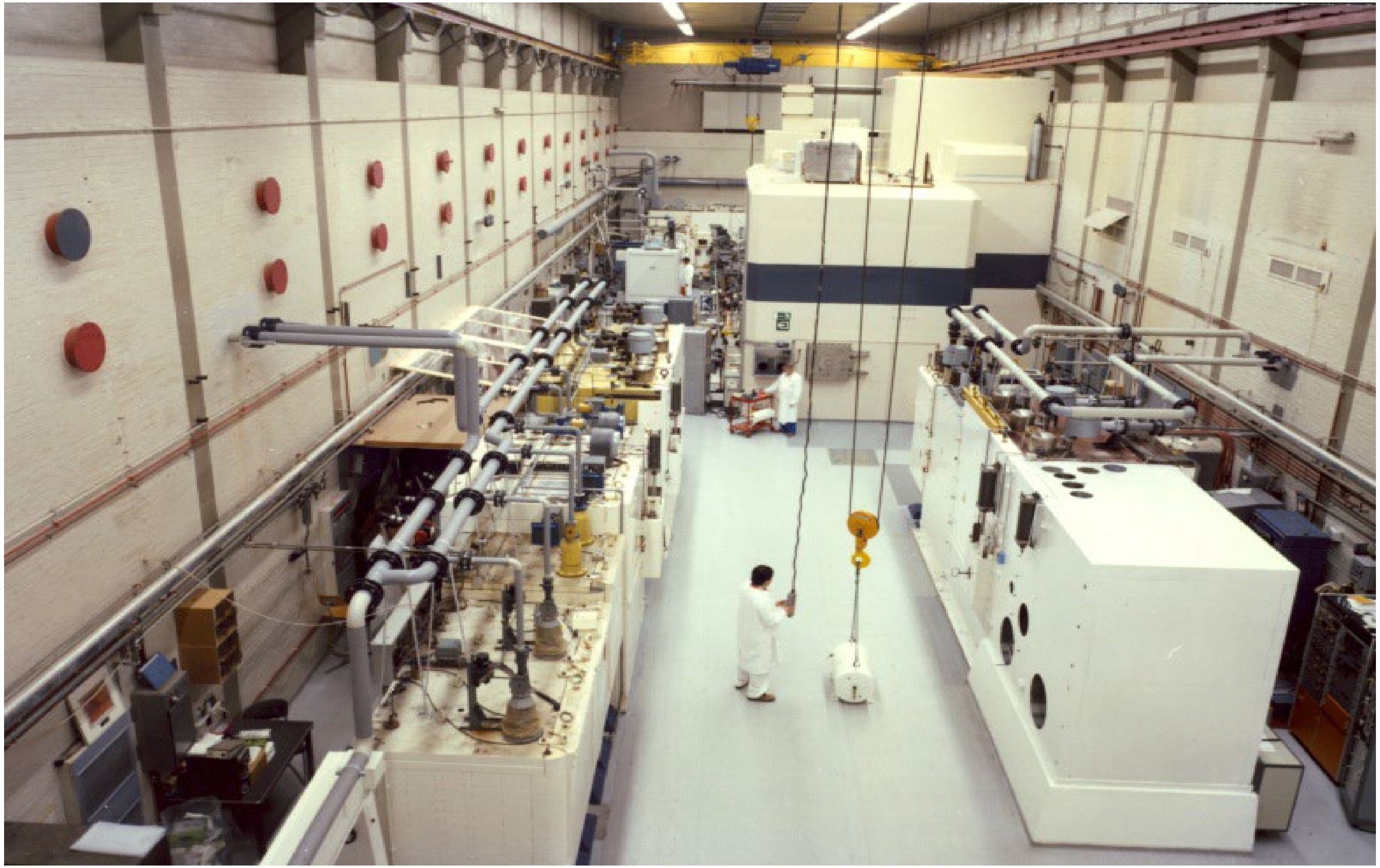



The SCK CEN hotlab
LHMA
High quality and relevant
data on irradiated or
actinide bearing materials
in the shortest time

Laboratory for High and Medium Activity

The LHMA was inaugurated in 1965, has been renovated in 2001 and is state-of-the-art operational today

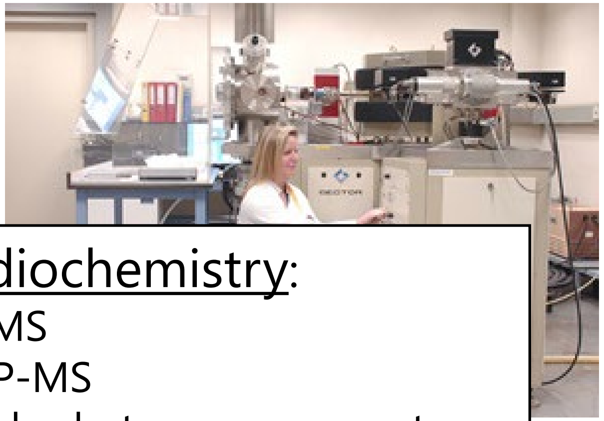
LHMA infrastructure

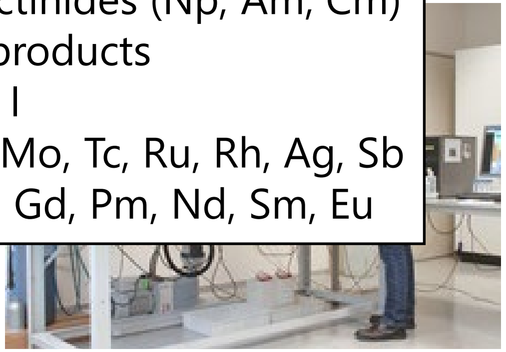


LHMA infrastructure

- Sample preparation and material management
- Fuel analysis and testing
- Mechanical testing for structural materials
- Microstructure analyses (fuel and materials)
- Corrosion testing

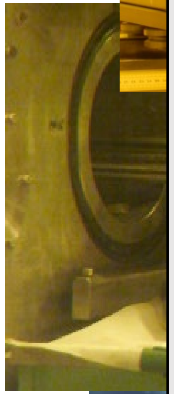
Post Irradiation Examinations on fuel



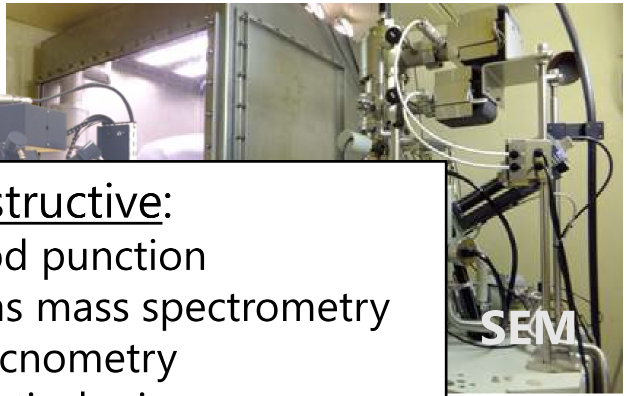
<u>Radiochemistry</u>:
- TIMS
- ICP-MS
- alpha-beta-gamma spectro

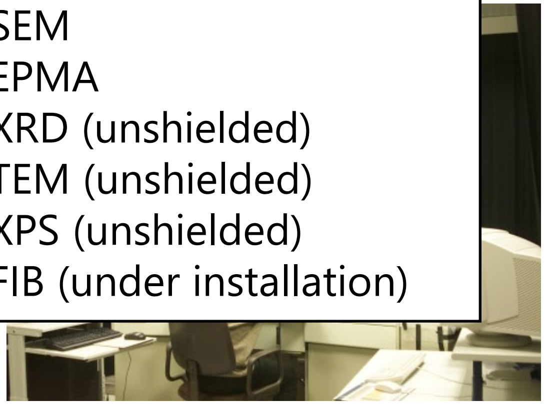
- Base actinides (U, Pu)
- Minor actinides (Np, Am, Cm)
- Fission products
  - Cs, I
  - Sr, Mo, Tc, Ru, Rh, Ag, Sb
  - Ce, Gd, Pm, Nd, Sm, Eu


<u>Non-destructive</u>:
- Visual Inspection
- Clad Integrity
- Oxide thickness
- Rod length
- Profilometry
- Gamma scanning
- Gamma spectrometry
  - ^{85}Kr
  - ^{137}Cs
  - $^{140}Ba/^{140}La$ ^{106}Ru

EPMA



<u>Destructive</u>:
- Rod punction
- Gas mass spectrometry
- Pycnometry
- Optical microscopy
- μ-hardness
- SEM
- EPMA
- XRD (unshielded)
- TEM (unshielded)
- XPS (unshielded)
- FIB (under installation)

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BR2 and LHMA

What can they do for you ?

How can you access them for your needs ?

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Thank you for your time