STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Access to irradiation capacity in the BR2 reactor

Irradiation devices and access procedures

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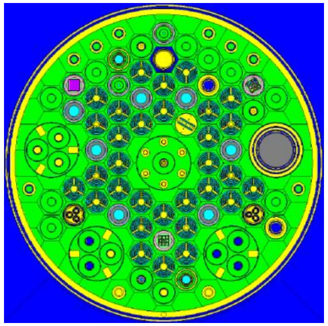
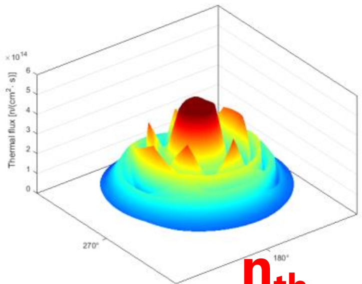
Presentation content

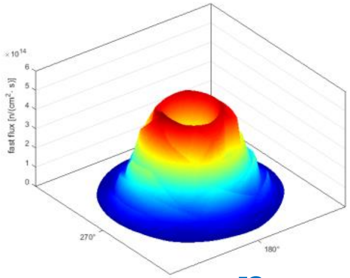
- General features of the BR2 reactor
- Irradiation device loading
- Generic devices for material irradiation
- Generic devices for fuel irradiation
- Administrative procedures

General features of the BR2 reactor





n_{th}



n_f

- BR2 = high performance material test reactor
  - Achievable flux levels (at mid plane in vessel)
    - Thermal flux: 7 10^{13} n/cm^{2}s to 10^{15} n/cm^{2}s
    - Fast flux (E>0.1MeV): 1 10^{13} n/cm^{2}s to 6 10^{14} n/cm^{2}s
  - Maximum rated power: 125MW cooling capacity of primary cooling system
    - Allowable heat flux in primary coolant
      - 470W/cm^2 for the driver fuel plates
        - » Demineralised light water
        - » Pressure to 1.2MPa, temperature 35-50°C
        - » 10m/s flow velocity on fuel plate
      - Up to 600W/cm^2 can be allowed in experiments
  - Compact core design with good access
    - Be + water moderated
    - Diverging core channels

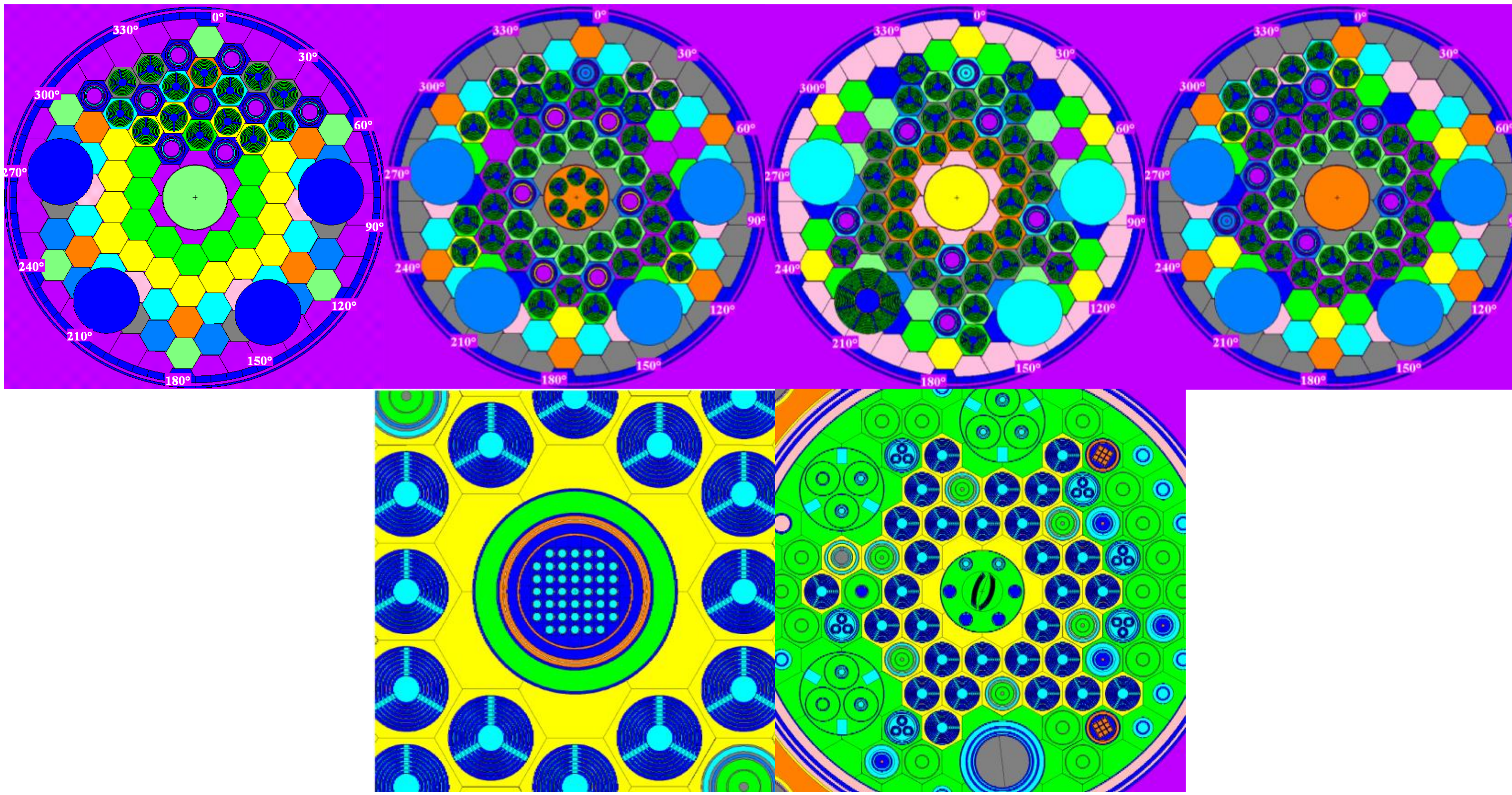
Flexible reactor configuration

- Combination of multiple experiments in core load
  - Position of fuel, control rods and experiments are optimised
  - Choice of type of fuel elements
  - Adapted reactor power and cycle length

- Reactor load is optimised for each operating cycle
  - 3D MCNP model with burn-up evolution of entire core
  - Detailed model of experiment if required
  - Verification by measurement before start

- BR2 reactor management is ISO 9001 certified (including irradiations)

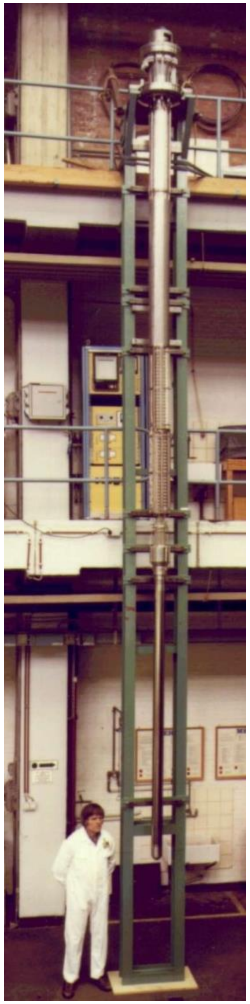
Flexible reactor configuration



Experimental accessibility BR2

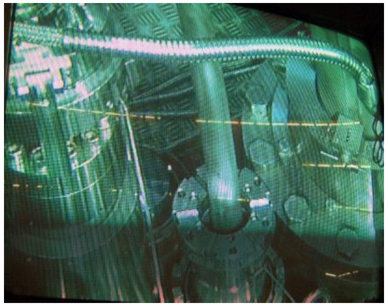
- Experiments can be loaded in full channel or inside central cavity of fuel element
- Typical fluxes and dimensions are given below

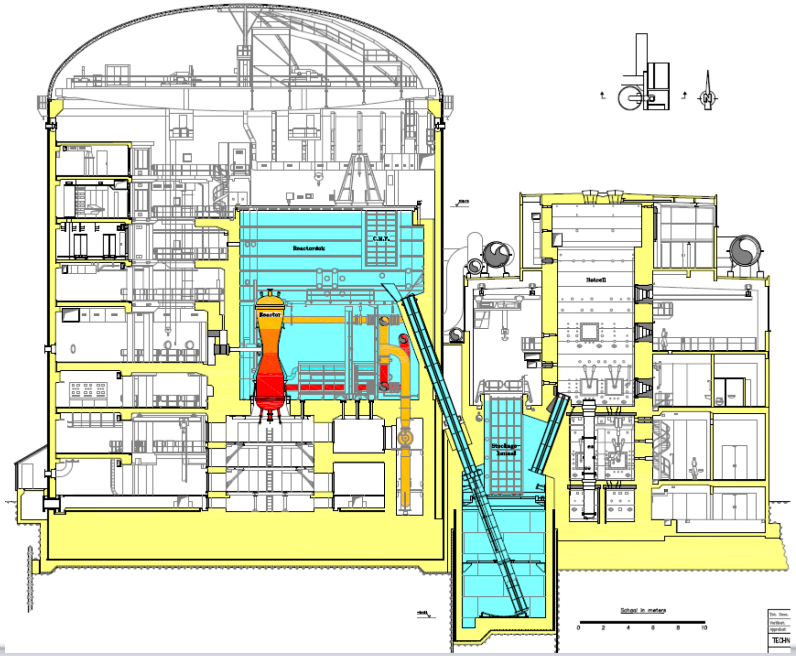
Channel type	thermal flux range ($10^{14}n/cm^2s$)	fast flux range ($10^{14}n/cm^2s$) (E>1MeV)	gamma heating (W/g Al)	diameter (mm)	typical number available
Fuel1	1 to 3.5	0.5 to 2.8	1.7 to 8.8	25.4	30
Fuel2	up to 2.5	up to 2.5	up to 6.8	32	2
Standard	1 to 3.5	0.1 to 0.7	0.9 to 2.3	84	24
Central large channel H1	up to 10	up to 1.8	3	200	1
Peripheral large channel Hi	3	1.3	0.1	200	4
Peripheral small channel P	0.7 to 1.5	0.05 to 0.1	0.4 to 1	50	9

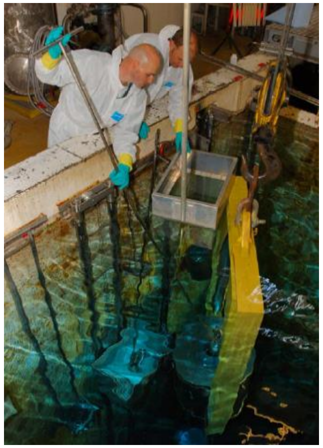


Experimental manipulation in BR2

- Tank in pool reactor
  - Irradiated materials can be inserted/retrieved during operation
  - Underwater transfer outside reactor building
- Pool connected to hot-cell for experiments mounting and dismantling





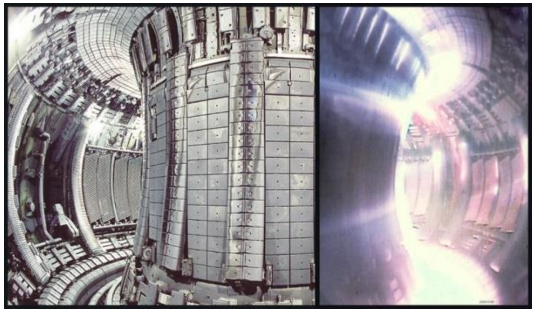


Generic devices for material irradiation

- SCK•CEN provides a full scope R&D capability on structure material research
- Qualification and safety studies of irradiation induced ageing effects on structure materials
  - Irradiation devices for high dose and low dose irradiation in representative conditions
  - Mechanical testing and corrosion studies in hot cell
  - Microstructure characterisation from atomic scale to full specimen size
- Scope

Ageing of current power reactors

Development of GEN4 & fusion

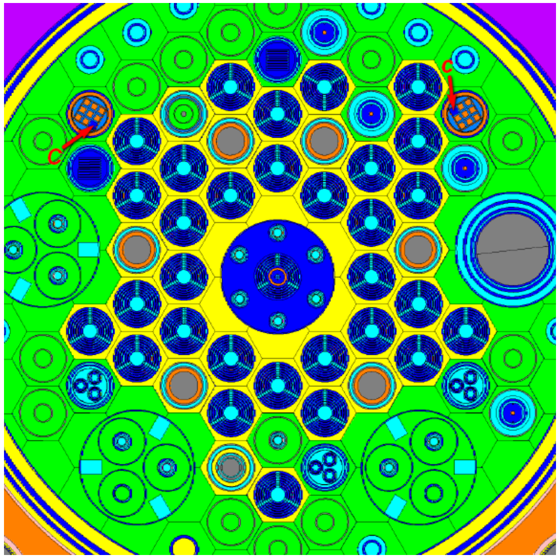


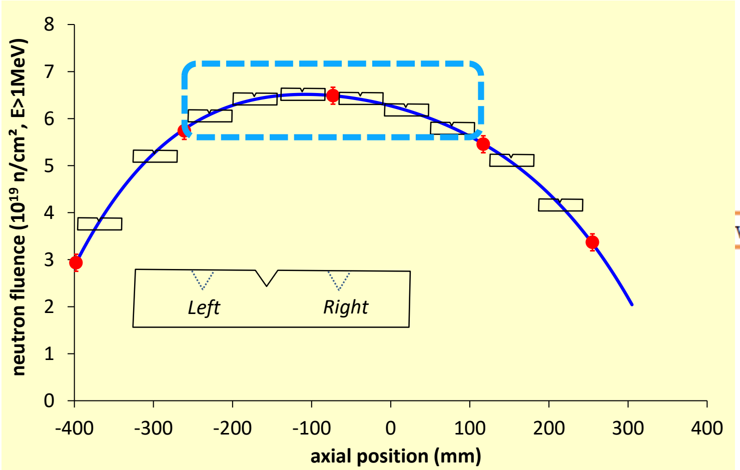
Ageing of pressure vessels: the new RECALL device

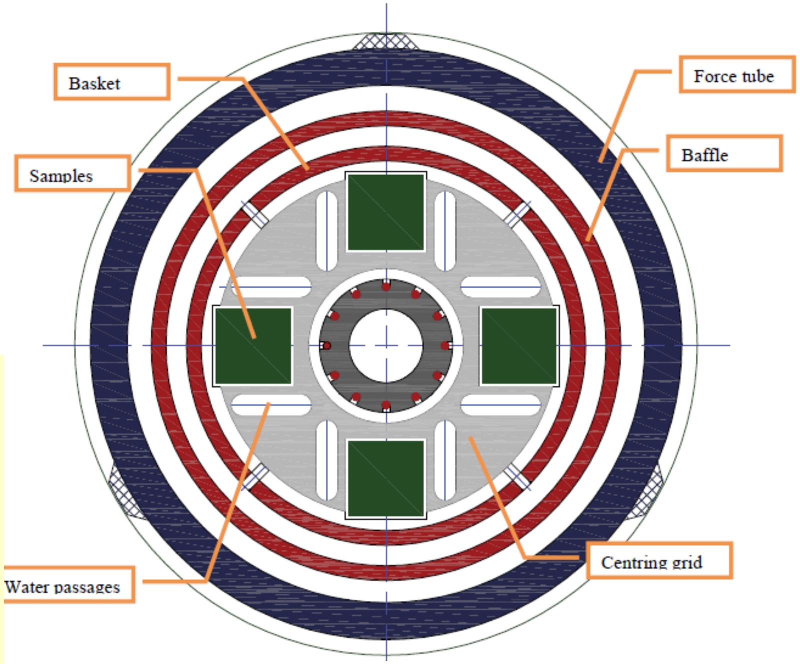
- Requirement: material irradiation in typical LWR conditions
  - Loading of full size Charpy specimens (>10)
  - Stable irradiation temperature before, during & after irradiation (250-320°C)
  - Flux levels relevant for LWR plant life management: 0.05 to 0.15 dpa per reactor cycle of 3 weeks

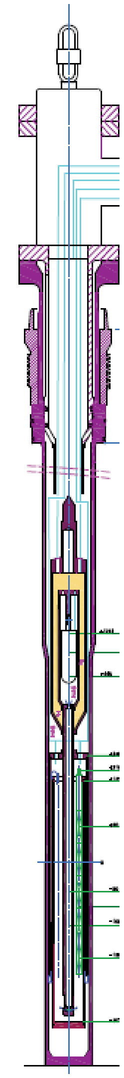
- Solution
  - Reusable rig with flexible loading position in reactor
    - Short lead times
    - Limited impact on other experiments
    - Variable position in reactor yields required range of dose rates within cycle
  - >16 Charpy specimens in flux range >85% maximum
    - Alternative geometries (mini CT) also loadable

RECALL rig concept



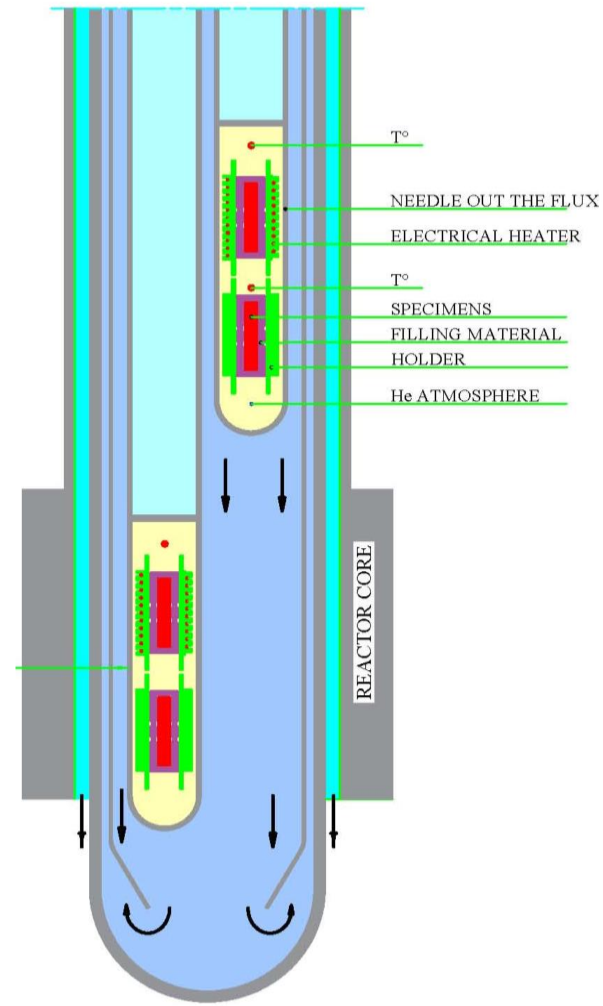


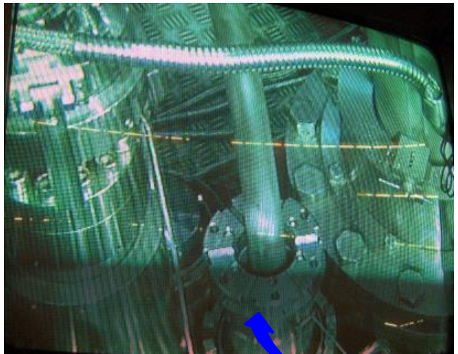




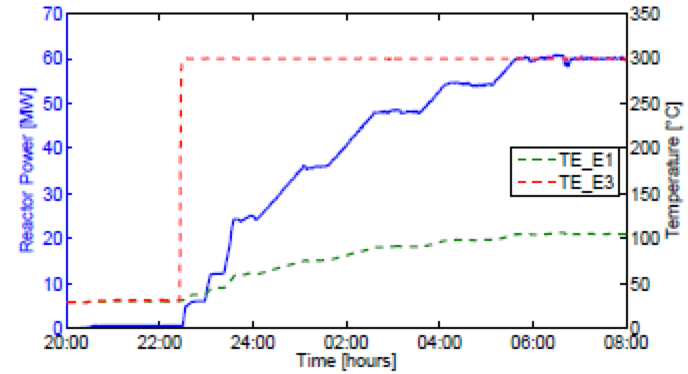
The LIBERTY rig for material irradiation

- Maximum flexibility irradiation rig
  - 5 independent capsules in single rig in thimble tube: multiple temperatures
  - Very flexible irradiation time (minutes to weeks): multiple dose
- Individual temperature control for each capsule
  - Each capsule is designed for own temperature range
  - Active or passive capsules can be combined
- Sample geometry very flexible
  - Irradiation of large specimens, e.g. mini CT-Specimens (10 x 10 mm^2) possible
  - Adaptive single use capsule design

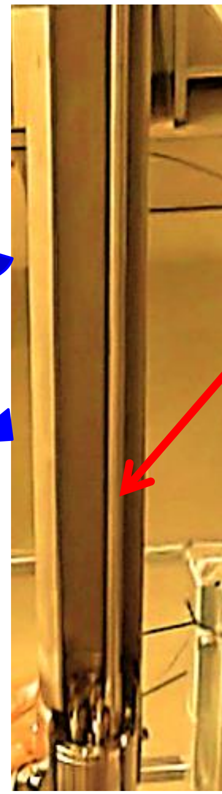


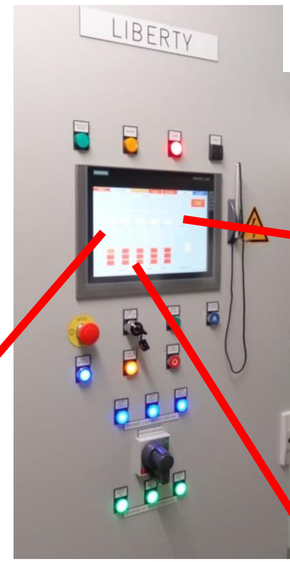


Temperature Control

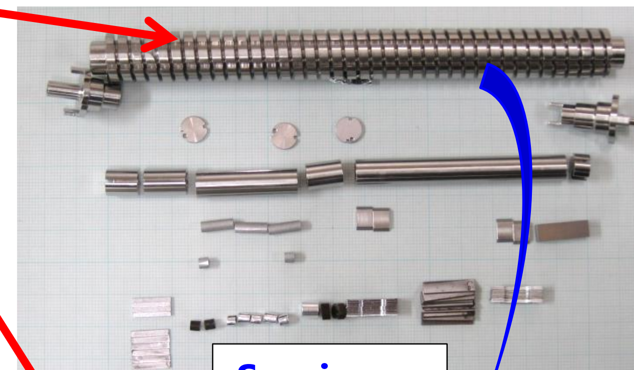


Loading “LIBERTY” in the thimble





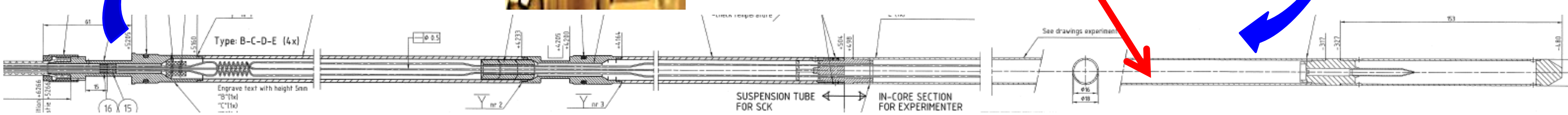
Holder preparation



Specimens

Loading the needle in “LIBERTY”

Needle



Material irradiation for selection and qualification

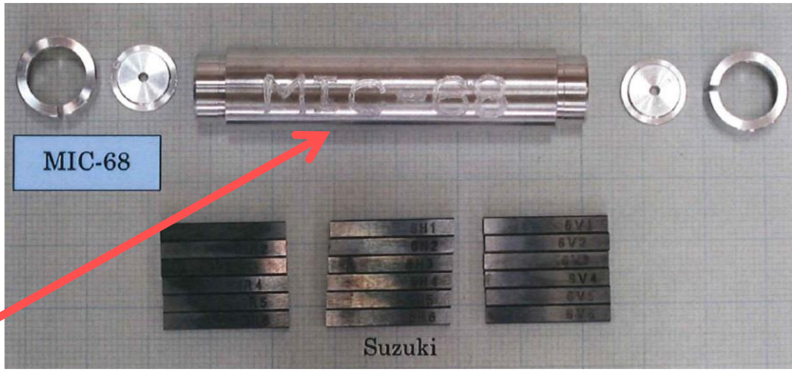
- New applications of nuclear energy
  - Issue: application target is beyond current database
    - Higher temperatures
    - Higher (fast neutron) fluence
    - Different environments
  - Materials: wide variation for screening
    - Stainless & high chromium steels: GEN 3&4
    - Ceramics & cermets: ATF claddings & fusion
    - Copper, tungsten, steel: fusion
  - Solutions
    - Provide rigs with high flexibility in irradiation conditions
    - Select high fast flux positions: ≥0.5 dpa / cycle
    - Provide cost effective solutions for irradiation of many samples

BAMI capsules for screening irradiation

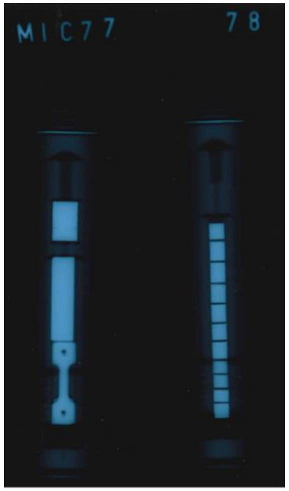
- Capsule irradiation in BAMI
  - Low temperature & high flux
  - Variable small specimens
  - Low cost, 8 capsules/position

Device	BAMI
Environment	He or BR2 coolant
T [°C]	<100
P [bar]	12.5
Fast flux* [10^{18} n/m²/s]	1
Fast fluence* [10^{24} n/m²]	2
Max. diameter [mm]	13

* Fast flux/fluence is the flux/fluence for E>1 MeV



Sample holder with specimens



X-ray of a BAMI capsule containing a sample holder

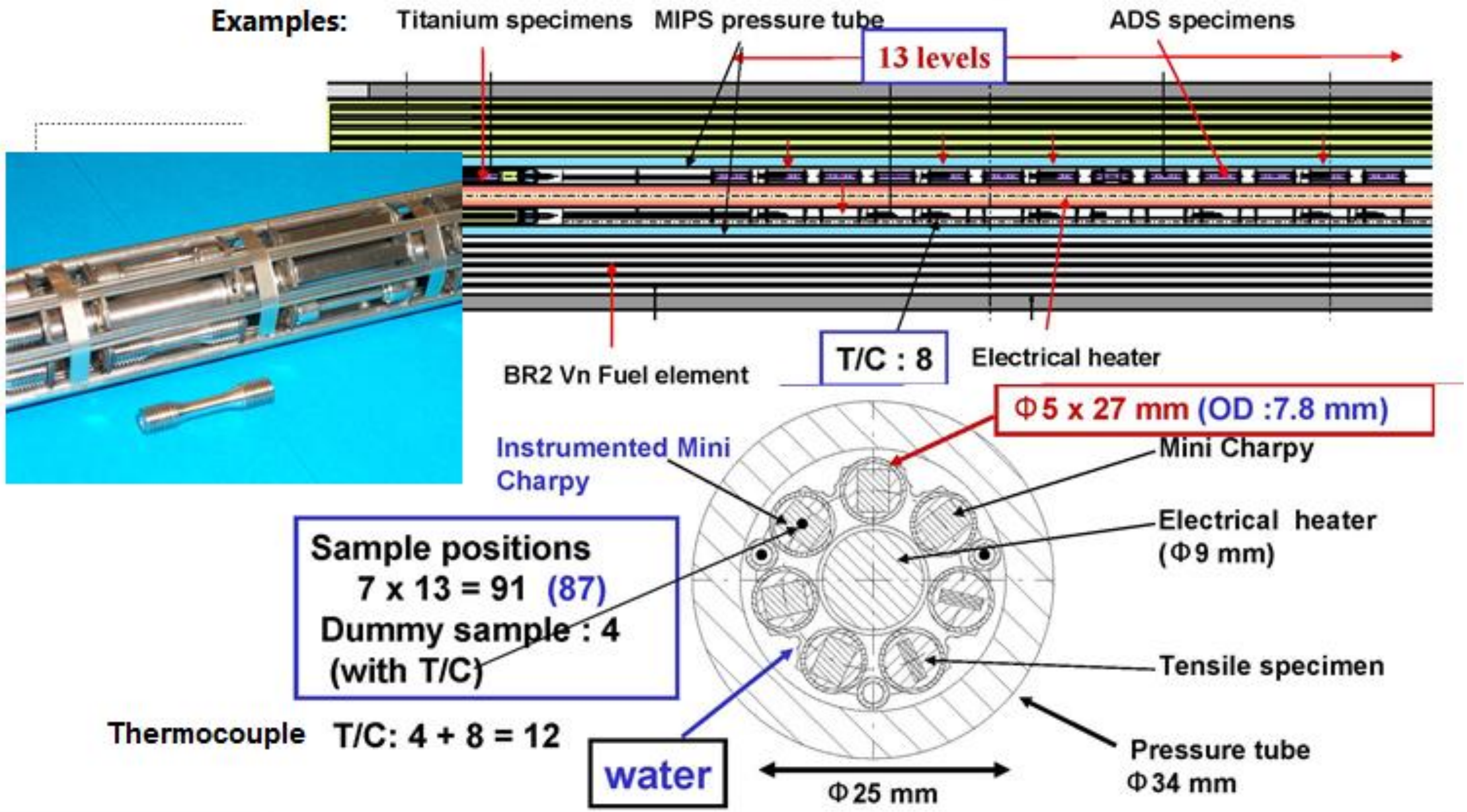
The MISTRAL device for database generation

- Application: material irradiation at high flux and moderate temperature
  - High dose rate: loading inside fuel element
  - Stable irradiation temperature before, during & after irradiation
  - Reusable rig with flexible loading position in reactor

- Solution
  - Pressurised water capsule inside element with electrical heating
  - Boiling water for stable temperature
  - Use 5 plate fuel element: 87 positions for miniature specimens

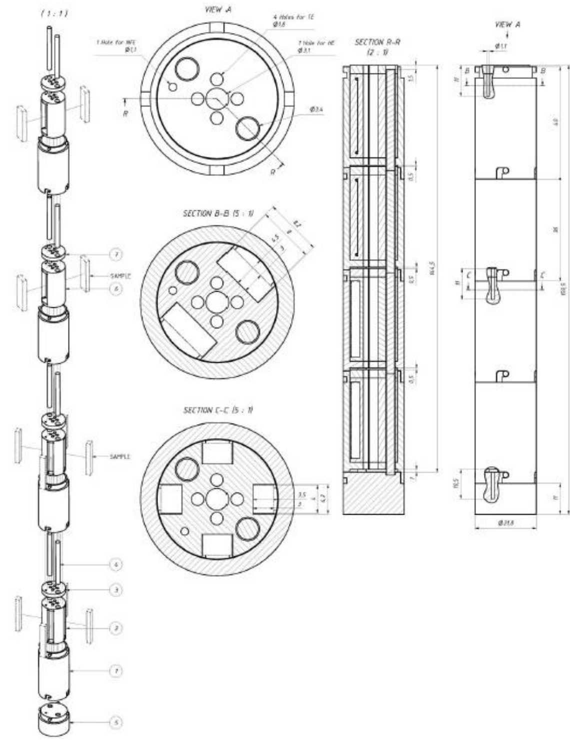
- Characteristics
  - Temperature 150-350°C
  - Up to 0.5 dpa per reactor cycle of 3 weeks

MISTRAL cross section



The High Temperature High Flux device

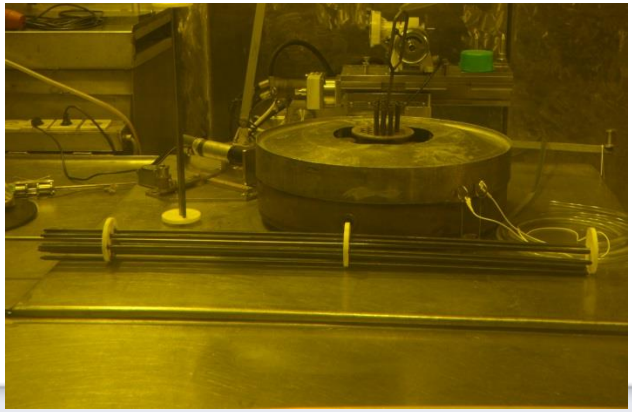
- Material irradiation for GEN 4/fusion conditions
  - High dose rate (>0.5 dpa per reactor cycle)
  - Stable irradiation temperature during irradiation
  - Low cost rig with flexible loading position in reactor
- Solution
  - Gas filled capsule inside 6 plate fuel element and electrical heating
  - Control of temperature by gas gap design and gas pressure
  - Miniature specimens
- Characteristics
  - Temperature 300-1000°C
  - Single use capsule
  - Up to 0.75 dpa per reactor cycle of 3 weeks
    - fluence 4.7 to 5.2E20 n/cm^2 (E>1MeV) in hottest channel



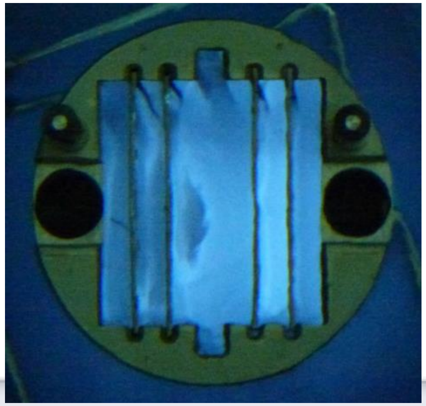
Nuclear fuel irradiation experiments

- SCK•CEN provides a full scope R&D capability on fuel research
- Development of new fuels and safety testing of current fuels
  - Determine safe operational conditions for fuel in representative and under overpower conditions
  - Steady state irradiation: power and burn-up limits
  - Transient irradiation: test safety margins
  - Safety tests: experience in accident condition testing and PIE
- Scope

Power reactor fuels

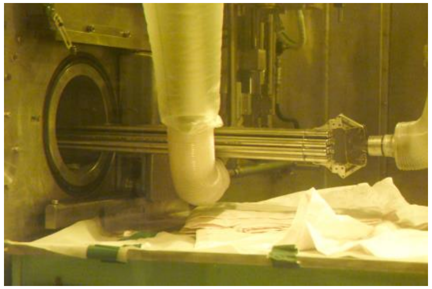


Test reactor fuels



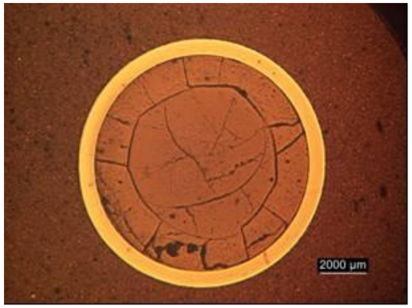
Power reactor fuel tools

- Fuel fabrication:
  - Oxide fuel laboratory
  - Sectioning and refabrication of irradiated fuel pins



- Fuel irradiation:
  - Pressurised water capsule for steady state/transient test
  - Dedicated rigs (also for fast neutron irradiation)

- Fuel characterisation
  - Full scale Non Destructive and Destructive Testing in hot cell
  - Radio-chemical laboratory



Fuel pin irradiation

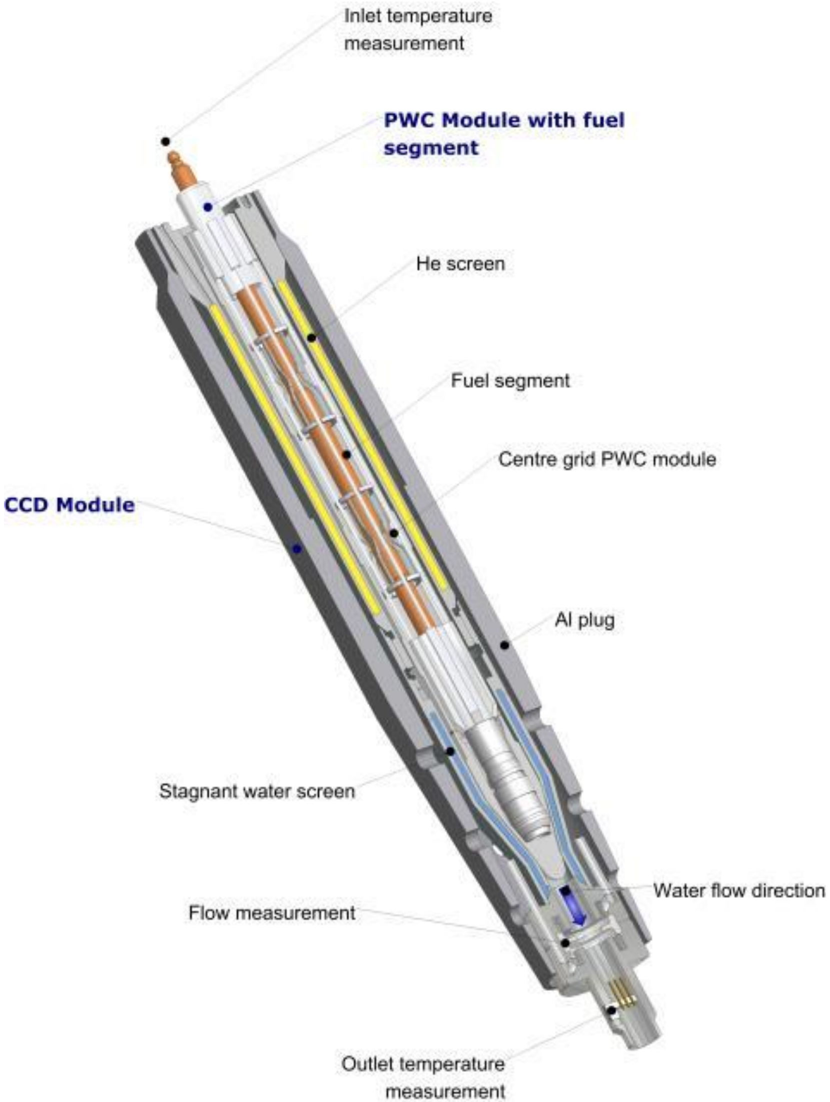
- Steady state conditions or transient conditions
  - Linear power levels up to $q_{l,max}$ = 750 W/cm
  - Rod power variation by reactor power variation
  - Power increase rate $\Delta q_l/\Delta t_{max}$ = 100 W/cm/min
  - Accuracy of the rod power can be measured within 5%

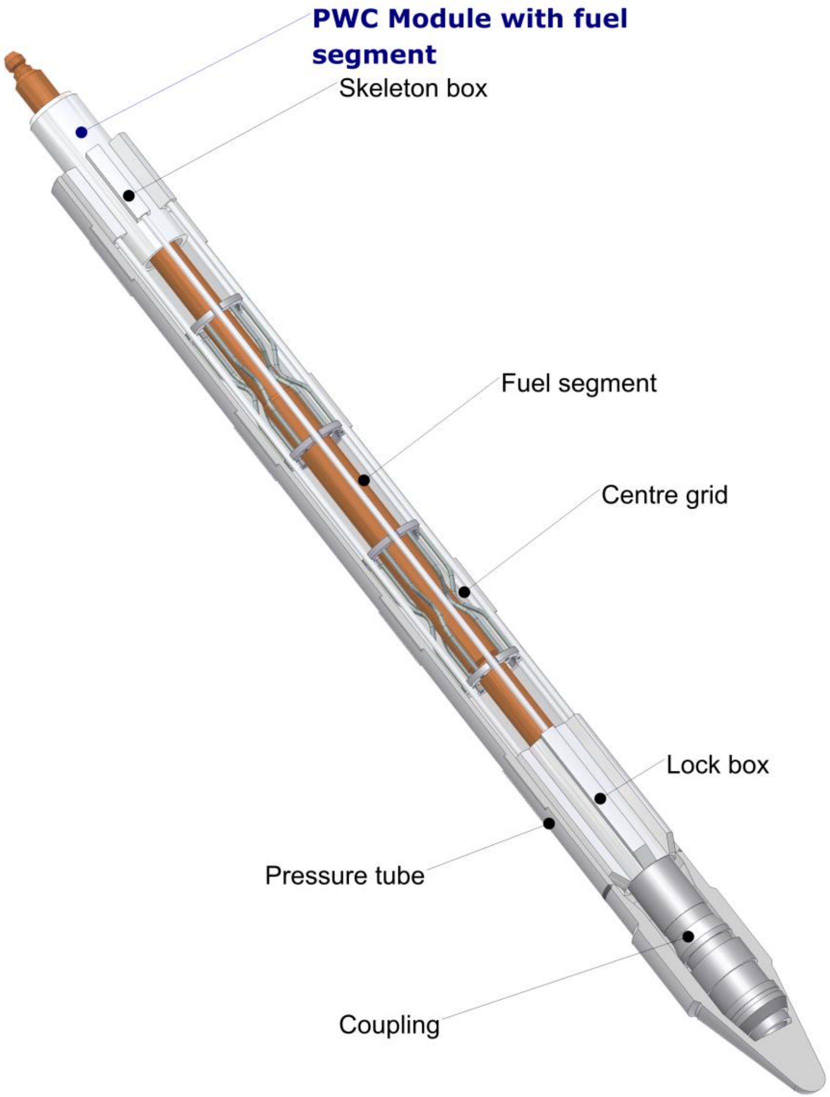
- Fuel pin dimensions
  - Cladding diameters: 8 mm - 12.5 mm
  - Fuel stack length: 20 cm - 100 cm (core height BR-2 80 cm)

- Capsule water pressure from 1 to 160 bar
  - Heat transfer by natural convection at low power levels…
  - … combined with boiling and condensation heat transfer at high rod power levels (depending on the pressure)

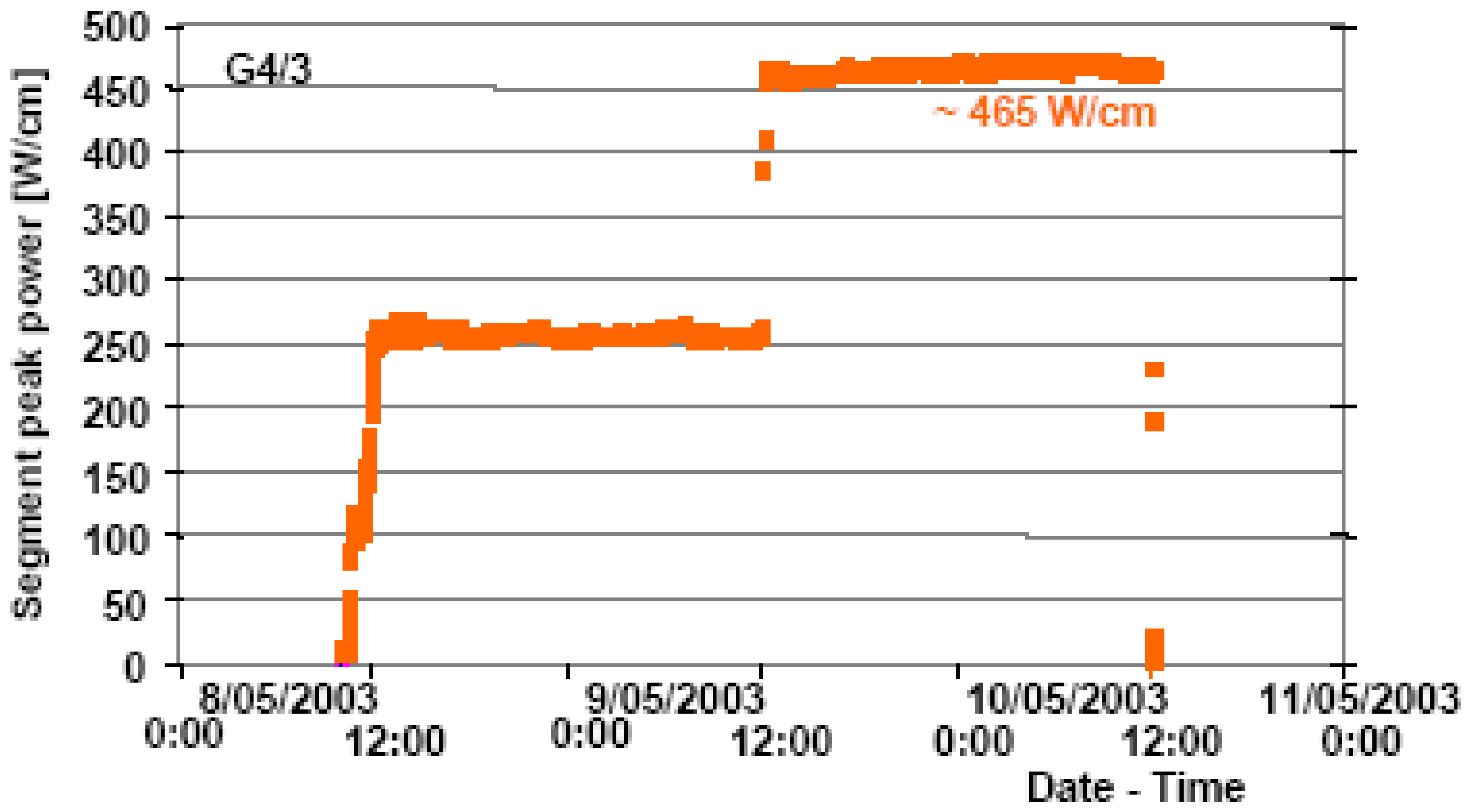
- Applicable for UO_2, MOX, ThoMOX, actinide bearing fuels
  - Thermal spectrum irradiation in PWC
  - Fast spectrum irradiation: see CIRCE device

Pressurised Water Capsule (PWC) & Calorimetric Device (CD)





Typical power transient



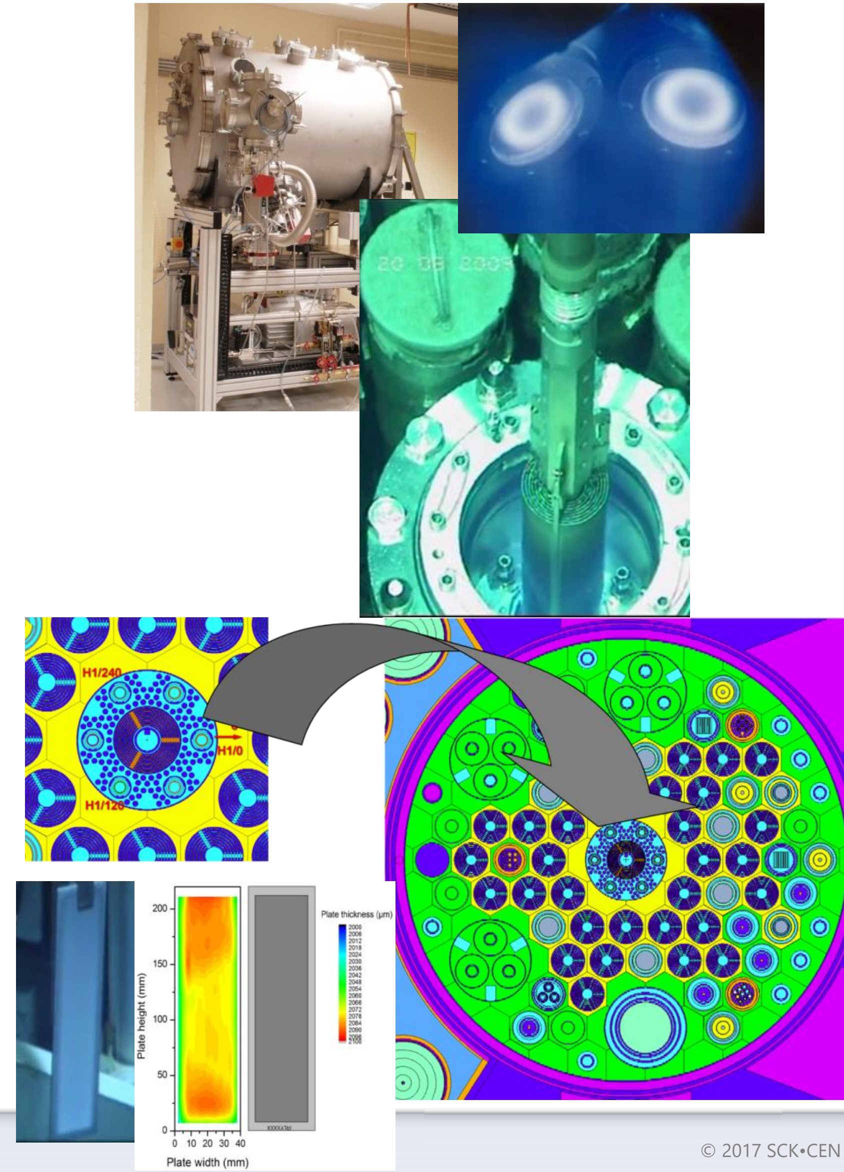
Test reactor fuel programmes

- Research and development programmes for Low Enriched Uranium fuel
  - Screening and validation irradiation of LEU fuel plates for high performance reactors (heat flux 450 to 600W/cm^2)
  - Burn up accumulation to average values >55% (local > 80%)
  - SCK•CEN remains major partner in conversion studies for High Performance Research Reactors and isotope production

- Validation of prototype fuel element design
  - Full scale simulation of thermal-hydraulic conditions of research reactors
  - Optimised neutronic conditions
  - Full PIE capability
  - SCK•CEN is capable of providing a full scale validation programme of RR fuel elements for licensing purpose

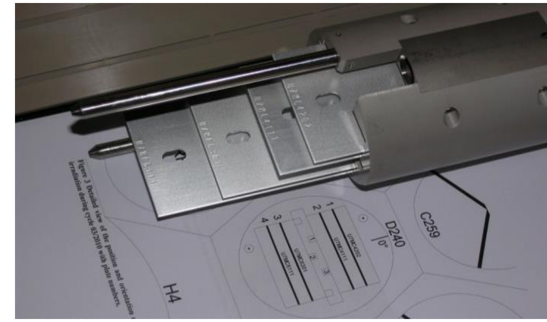
Test reactor fuel tools

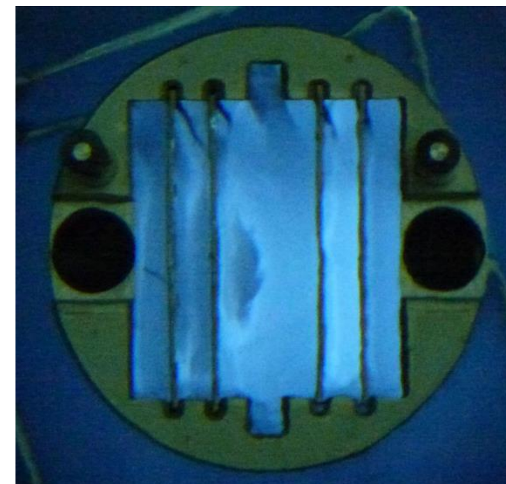
- Fuel fabrication
  - Powder coating device
  - Pre-irradiation characterisation
- Fuel irradiation
  - Test baskets for plate irradiation
  - Instrumented test loops for full element irradiations
  - Advanced modelling of irradiation conditions
- Fuel characterisation
  - Inter cycle inspections
  - Non-destructive + destructive PIE

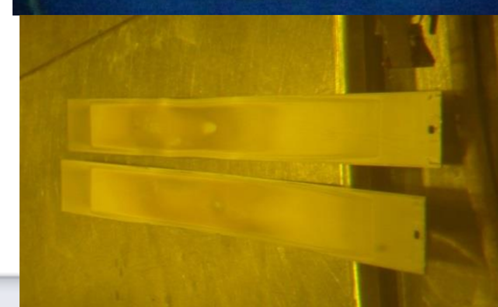


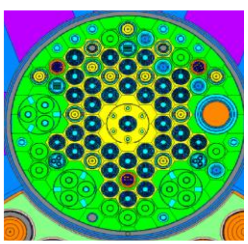
MTR fuel plate irradiation: FUTURE basket

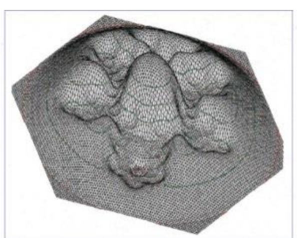
- Qualification of representative full MTR plates up to 600W/cm²
- Non-instrumented basket for low lead time experiments
- Irradiation conditions determined by detailed modelling and validated by quantitative PIE

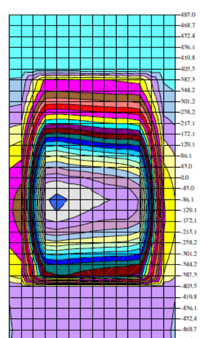


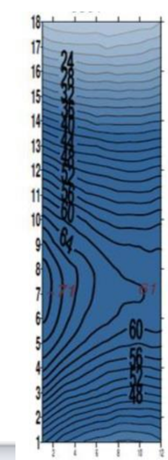


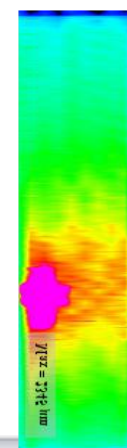






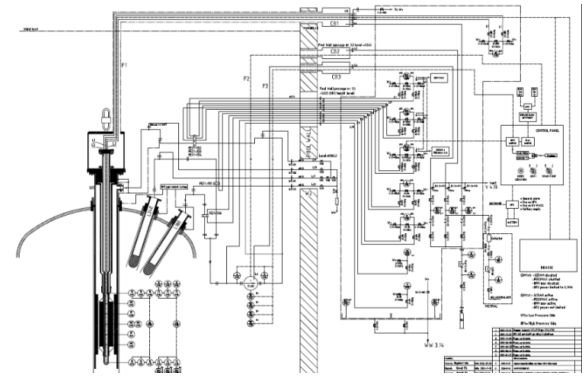


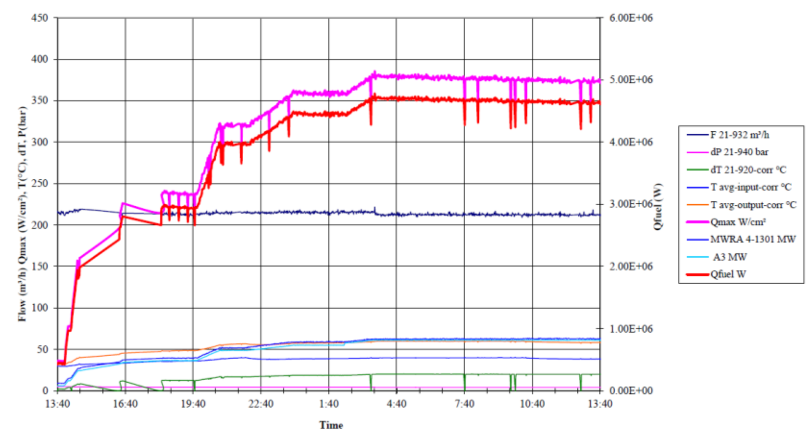




MTR fuel element irradiation

- Dedicated set-up for prototype elements
  - Full size elements/partial elements
  - Separate loop/basket for representative cooling conditions
- On-line monitoring
  - Power, temperature, flux
- Inter-cycle inspection
  - Under water observation
  - Failure detection





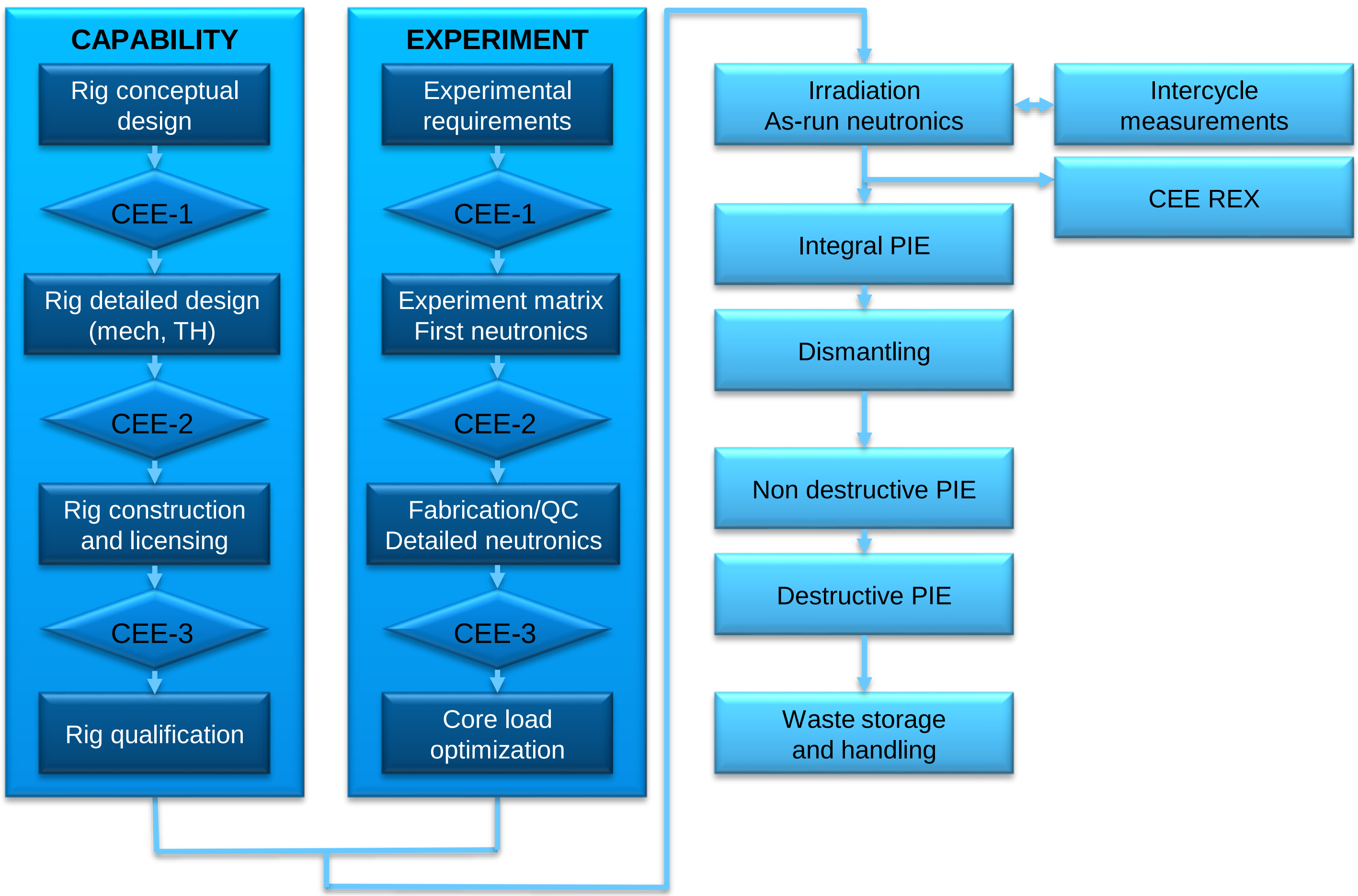
Access for experiments

- Organisation
  - Project responsible: applicant for experiment, owner of result
  - Technical responsible: project engineer, design & safety analysis owner
  - Operator: manipulation and operation of experiment and reactor, final safety responsible
  - Safety committee: evaluation of safety analysis, advisory to internal safety department
  - Internal safety department: reporting to national TSO

- Project preparation
  - Project responsible + Business development & support team SCK●CEN
  - Internal project approval
    - Financial criteria
    - Strategic criteria
    - Scientific criteria

- Procedure of safety approval of experiments (CEE evaluation) described in technical "manual"
  - 4 stage approval: conceptual design evaluation, detailed design evaluation, testing and commissioning evaluation + return of experience
  - Simplified procedure: "repetition" irradiation in qualified rig with similar experimental load

The experiment and rig flow



Collaboration models with SCK•CEN

- Education and training
  - Basic aspects of irradiation experiments inside BR2 are subject of *Practical Course on Irradiation Experiments*, hosted by the SCK•CEN academy

- Bilateral scientific and technological collaboration projects
  - Common interest and equitable sharing of efforts and results
  - BR2 and SCK•CEN hot labs are affiliate infrastructure of US NSUF

- Service contracts
  - Shared scientific results at marginal cost
  - Commercial basis at full cost with full ownership of result

- Strategic partnership
  - Long term commitment with guaranteed access to unique infrastructure

IAEA recognized International centre based on research reactor