Utilisation of the BR2 reactor

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

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Content

- General characteristics of the BR2 reactor
  - Historic perspective
  - Core characteristics
  - Supporting facilities
- Utilisation
  - Radio-isotope production
  - Semiconductor irradiation
  - Material testing
    - Structural materials
    - Nuclear fuel
- Summary and conclusions

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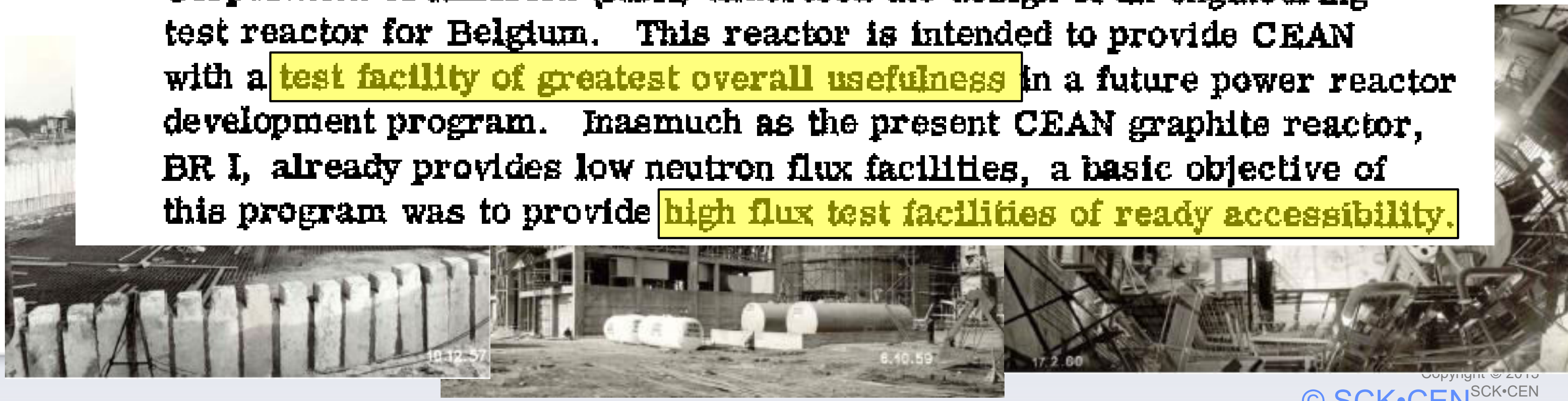
Construction and commissioning period

NDA

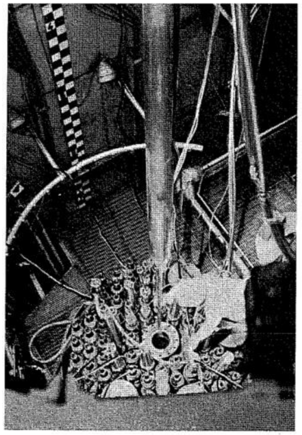
III. INTRODUCTION

A. PURPOSE OF PROJECT AND PHASE I

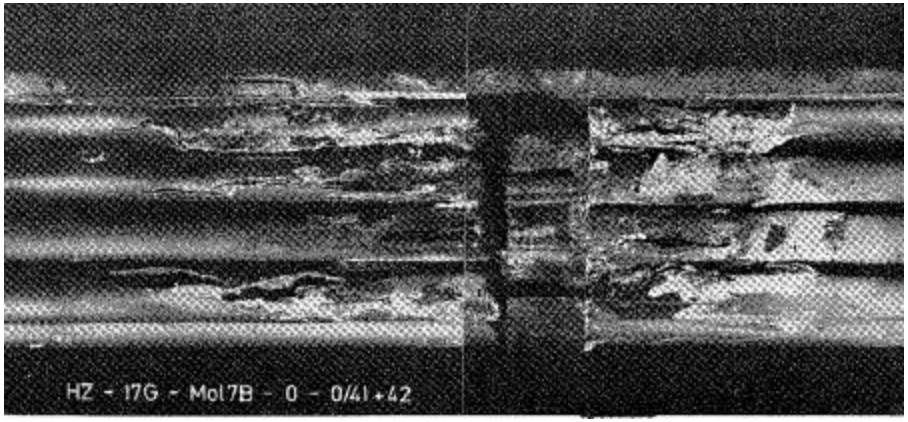
Under terms of a contract with the Centre d'Etudes pour les Applications de l'Energie Nucleaire (CEAN), the Nuclear Development Corporation of America (NDA) undertook the design of an engineering test reactor for Belgium. This reactor is intended to provide CEAN with a test facility of greatest overall usefulness in a future power reactor development program. Inasmuch as the present CEAN graphite reactor, BR 1, already provides low neutron flux facilities, a basic objective of this program was to provide high flux test facilities of ready accessibility.



First operation period 1963-1978

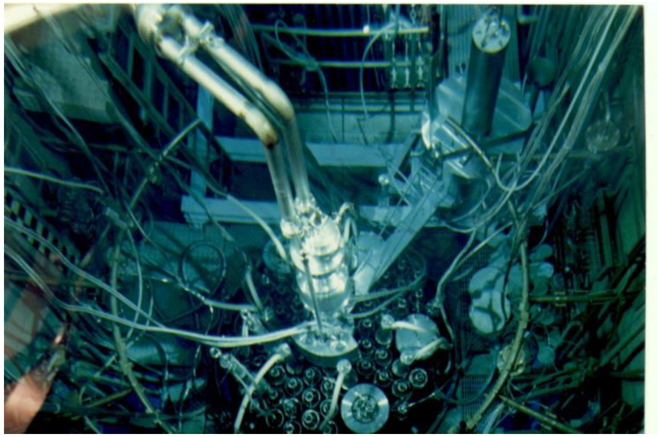


- Prototype experiments for
  - Light water reactor
  - Gas cooled reactor
  - Sodium cooled reactor
- First irradiations of MOX fuel
- Production of isotopes for energetic applications
- 1978-1980: replacement of Be matrix

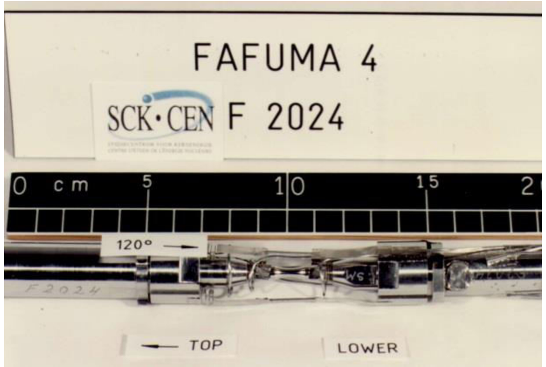


Second operational period (1980-1995)

- Legislation change in 1984: no operational limit in license, periodic safety re-assessment (10 year periods)



- Safety experiments Na cooled reactors
  - Loss of Flow accident
  - Post Accident Heat Removal
- BR3 shut-down (1987)
  - PWR loop in BR2
  - LWR MOX studies



- Material irradiations
- Second Be replacement 1995-1997

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Essential characteristics

- Geometry: tank in pool
  - 78 channels in hyperboloid arrangement inside vessel
  - Core diameter: 1m - Top & bottom cover: 2m
  - Vessel height: 14m
  - Cilindric fuel elements, fueled zone 800mm
- Materials
  - Be prisms in core, stainless steel extension tubes
  - Aluminum 5052 vessel
  - High enriched uranium (Ualx fuel disperion)
- Cooling
  - Light water cooling: nominal power 100 MW + 25 MW
  - 35-50°C, 120MPa pressure, 10m/s
  - Maximum heat flux 470W/cm² (600W/cm² in experiments)

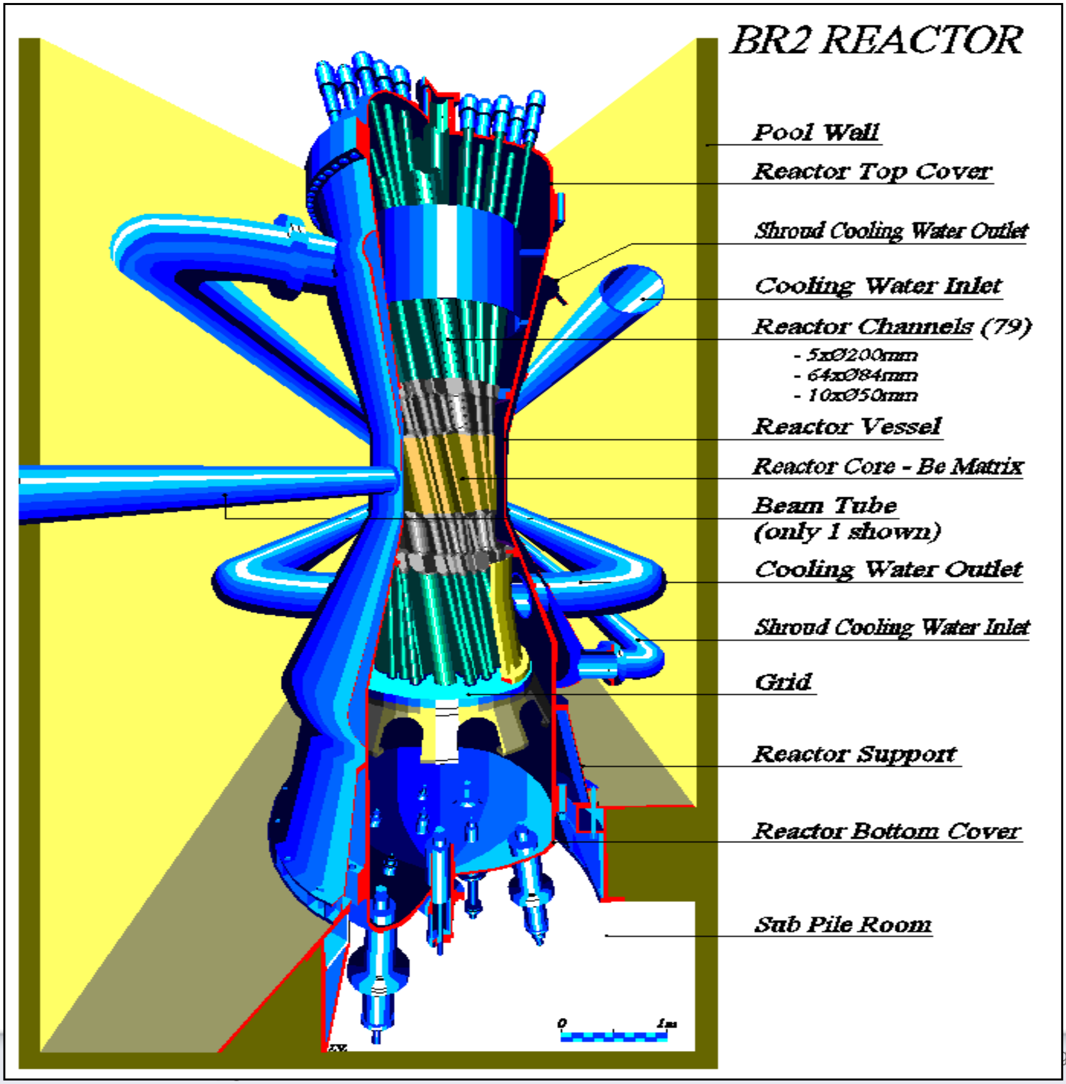
The essential chracteristics

Light water cooled, water+ Be moderated MTR

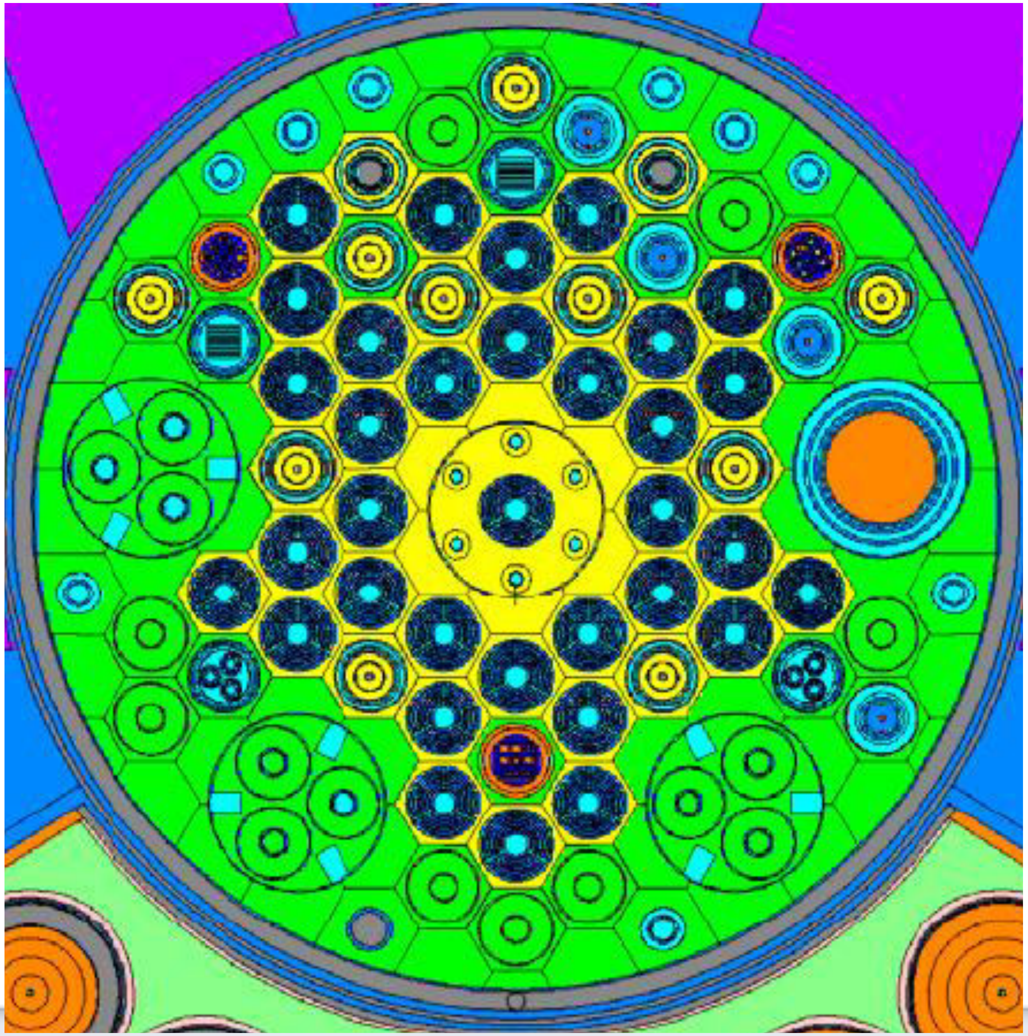
Maximum thermal power level 100MW

Typical flux levels
1E15 n/cm²s thermal
6E14 n/cm²s fast
(E>0.1MeV)

Irradiation inside rigs in reactor channel or in axis of fuel element



Flexibility in applications: variable core configuration



- Fuel elements
- Control rods
- Regulating rod
- beryllium matrix
- beryllium plugs
- PRF (isotope production)
- DG (isotope production)
- CALLISTO (PWR simulation)
- SIDONIE (irradiation of Si 5”)
- POSEIDON (irradiation of Si 6”-8”)

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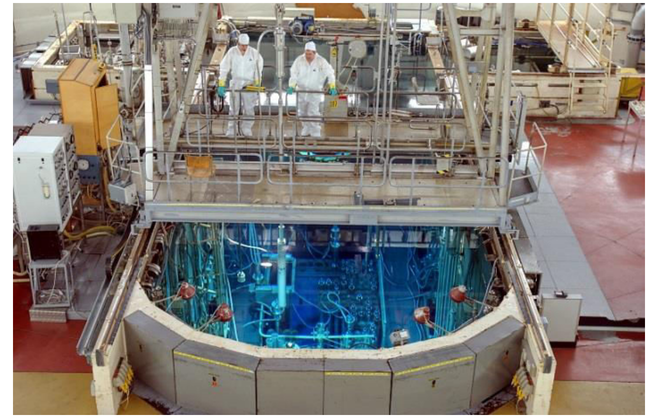
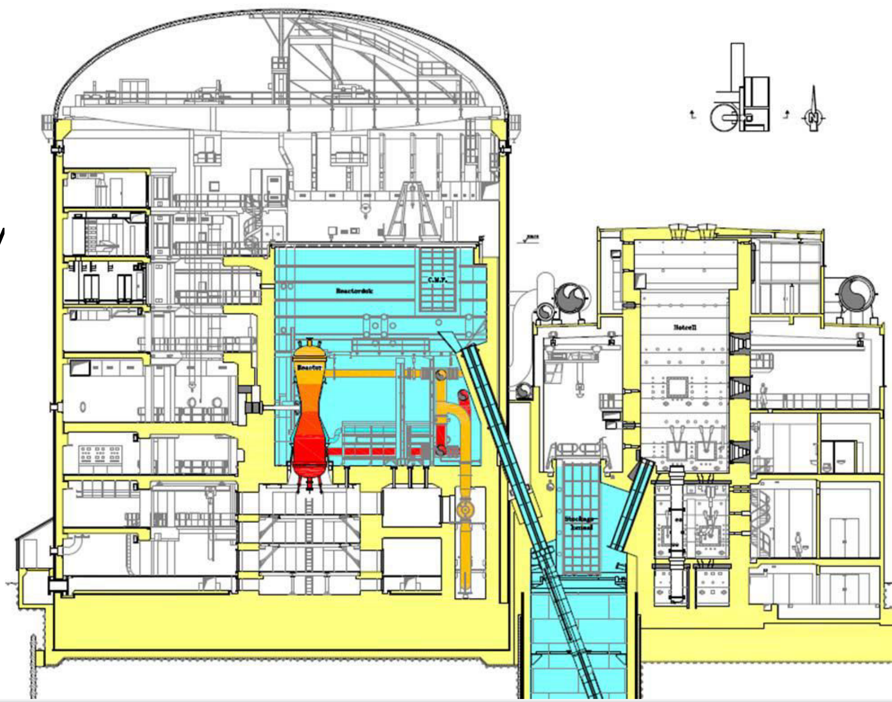
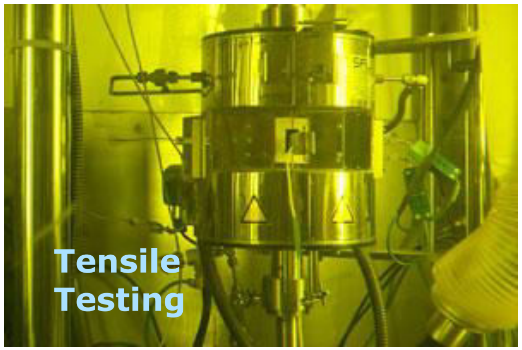
Supporting facilities inside BR2

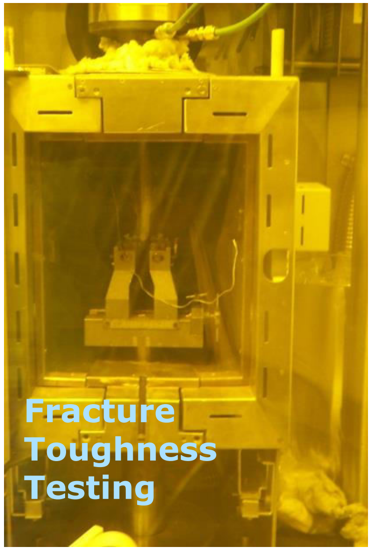
- Secondary cooling
  - Reactor
  - Pool
  - Experiments
- Containment building
  - Reactor pool
  - Irradiated fuel and experiment storage pools
  - Transfer tube to storage channel / hot cell
- Hot cell
  - Dismantling of experiments
- Gamma irradiation facilities
  - ^{60}Co and ^{137}Cs sources

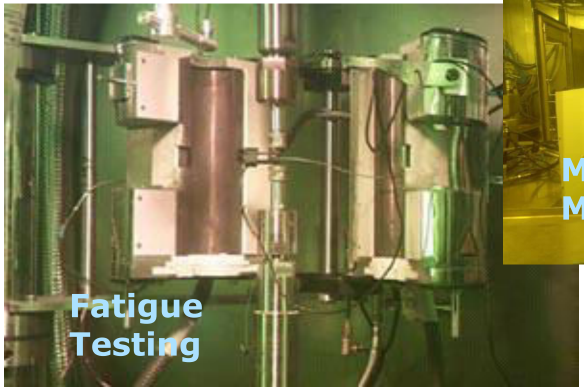


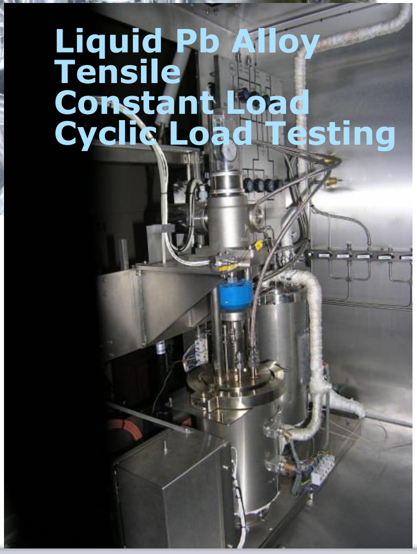


Supporting facilities outside BR2
Mechanical testing







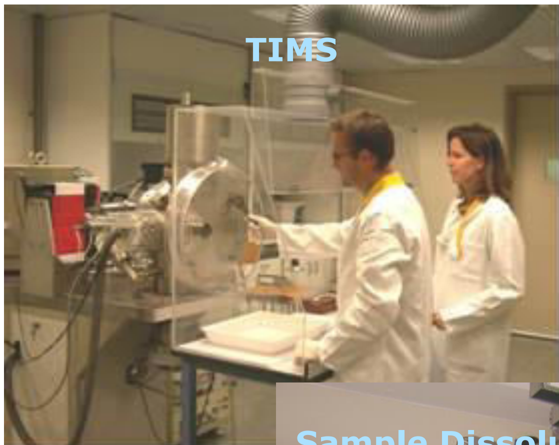


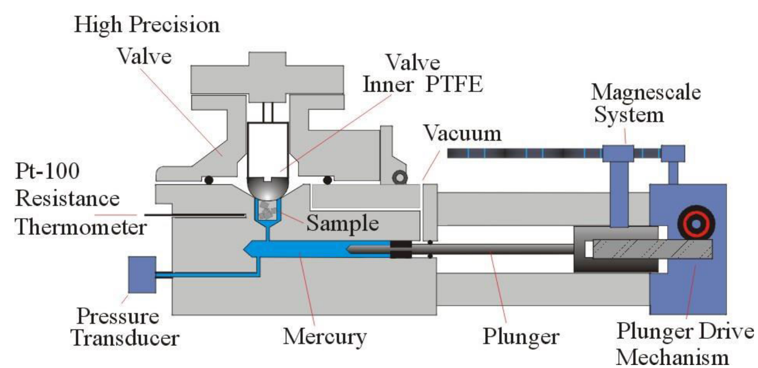
µStructure & Non-destructive Analyses hot laboratory (LHMA)

masters and runs the microscopes with associated preparative equipments
and physical infrastructures (NDT, fuel refab./instr.)

Radio-Chemical Analyses Laboratory

α,β,γ-Spectrometry / TI-MS, ICP-MS, AES, ICP-AES, IC, TOC, ISE, G-MS / RGA / Pycnometry





Mercury Pycnometry

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Radio-isotopes from fission

- Irradiation of (HE) Uranium metallic (dispersed) targets
  - Irradiation capacity: 75 targets, 6 irradiation facilities
  - Maximum production rate ^{99}Mo: 7800Cie/week (6 day calibrated)
  - Annual production: 20% of global demand

- Major assets of irradiation devices
  - Heat flux limit $350 W/cm^2$
  - Loadable during operation
  - In-pile cooling and underwater loading for shipment

Radio-isotopes from activation

- Irradiation in thimble tubes:
  - ^{177}Lu, ^{186}Re, ^{153}Sm, ^{169}Er, ^{90}Y, ^{32}P, ^{125}I,…
  - "Small" quantities and low heat generation
  - Flexible loading/unloading
  - Low to medium flux ($4\ 10^{14} n/cm^2s$)
- Irradiation in baskets (primary water flow)
  - ^{192}Ir, ^{84}Sr, ^{188}W, ^{117m}Sn, ^{67}Cu, ^{14}C,…
  - "Large" quantities, high heat generation
  - Full cycle irradiation
  - Up to maximum neutron flux available in BR2
- Decanning and packaging in BR2 hot-cell

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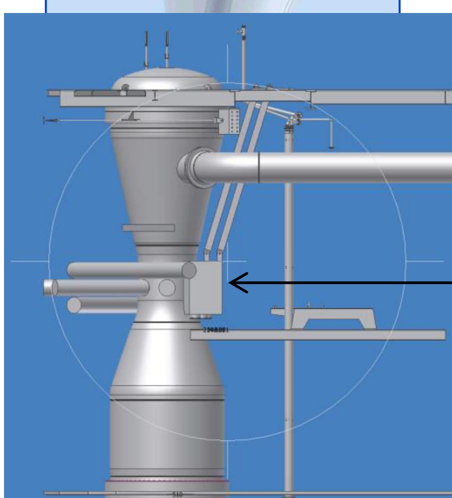
Production of high grade semiconductors by neutron transmutation



- **$^{30}Si(n,\gamma)^{31}Si\beta\text{-}^{31}P$** creates semiconduction silicon crystals with high quality.
- 2 installation in BR2:
  - SIDONIE: inside vessel for 4-5" diameter crystals
  - POSEIDON pool side facility for 6-8" crystals
- Total capacity of 15 and 18 tonnes/year respectively
- Application of NTD Si: transport (electric-hybrid vehicles), energy (solar & wind)

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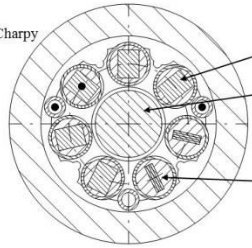
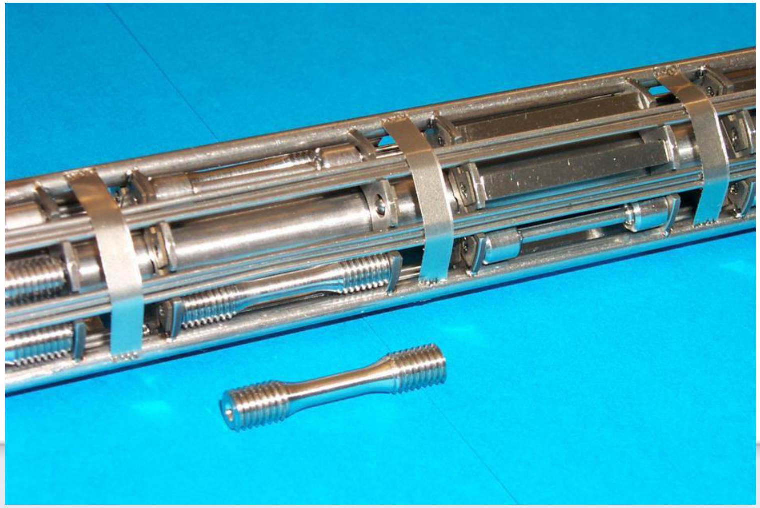
Irradiation rigs for structural materials

- Standard capsules in primary water
  - High flexibility in nuclear conditions (reflector or fuel element)
  - Irradiation temperature determined by design
  - Full cycle(s) irtradiation
  - Environment: gas or (primary) water
- Capsules in thimble tube ("ROBIN")
  - Limited flux levels (0.5 to 5 10^{13} n/cm^{2}s E>1MeV)
  - Temperature control by design and cooling flow adjustment (+/-30°C)
  - Irradiation time flexible
- Dedicated rigs: boiling water capsule ("MISTRAL") / pressurised water loop ("CALLISTO")
  - Stable temperature, accurate control
  - Full cycle irradiation
  - Variable flux levels

Boiling water capsule irradiation "MISTRAL"



- 200-300°C irradiation temperature
- Boiling water environment
- High Fast Flux level
- Irradiation temperature monitoring and control by water pressure and heating element
- Reloadable with standard specimens



Designed for:

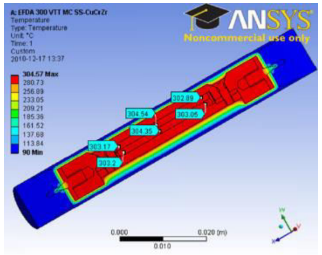
Tensile specimens 5 mm Φ x 27 mm

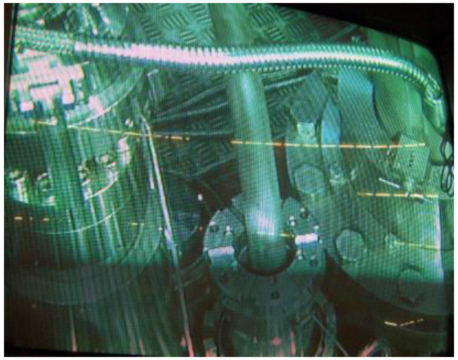
Mini Charpy specimens 3 x 4 x 27 mm³

Encapsulated specimens must fit into similar volume

Thimble tube capsule holder “ROBIN”

- Specimen holder geometry with gas gap and metal matrix sample holder
- Incoporation in closed needle
- Monitoring by measurement of temperature in dummy specimen
- Temperature control by water flow adjustment





Content

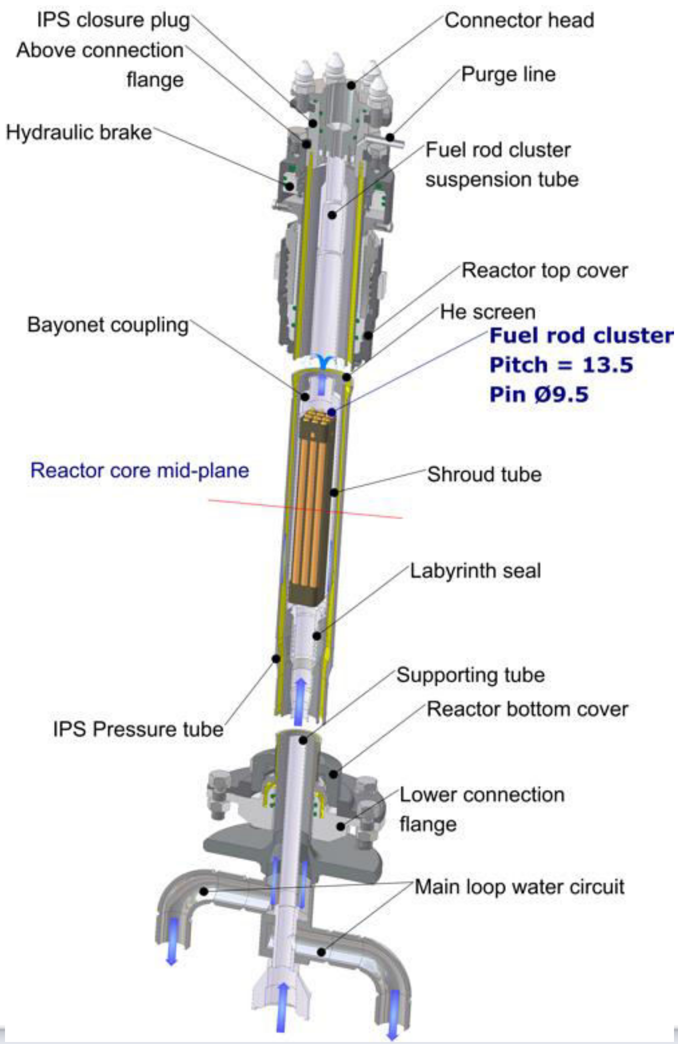
Nuclear fuel irradiation experiments

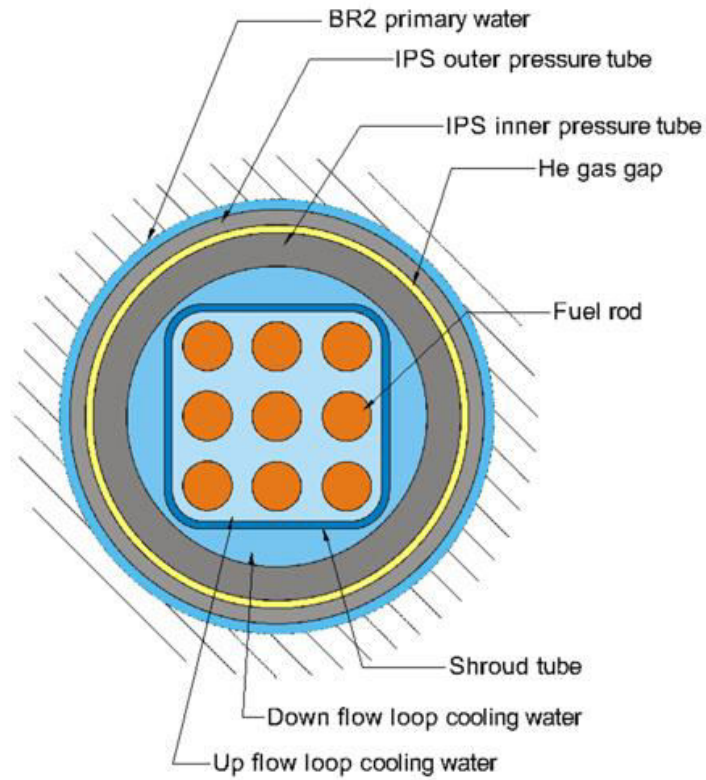
- Objectives
  - Determine safe operational conditions for fuel in representative conditions (power, environment, dimensions)
  - Steady state irradiation: power and burn-up limits
  - Transient irradiation: safety margin
  - *Accident studies: DBA and beyond DBA*

- Tools
  - Irradiation loops: CALLISTO, EVITA
  - Irradiation baskets: PWC, FUTURE
  - *Dedicated rigs (MOL7C, PAHR-PYRAMID…)*

Simulation of PWR in BR2: the CALLISTO loop

- Full thermal-hydraulic simulation of PWR conditions
- Independent cooling system
- Fuel: 3x3 assembly 1m rods
- Structure materials





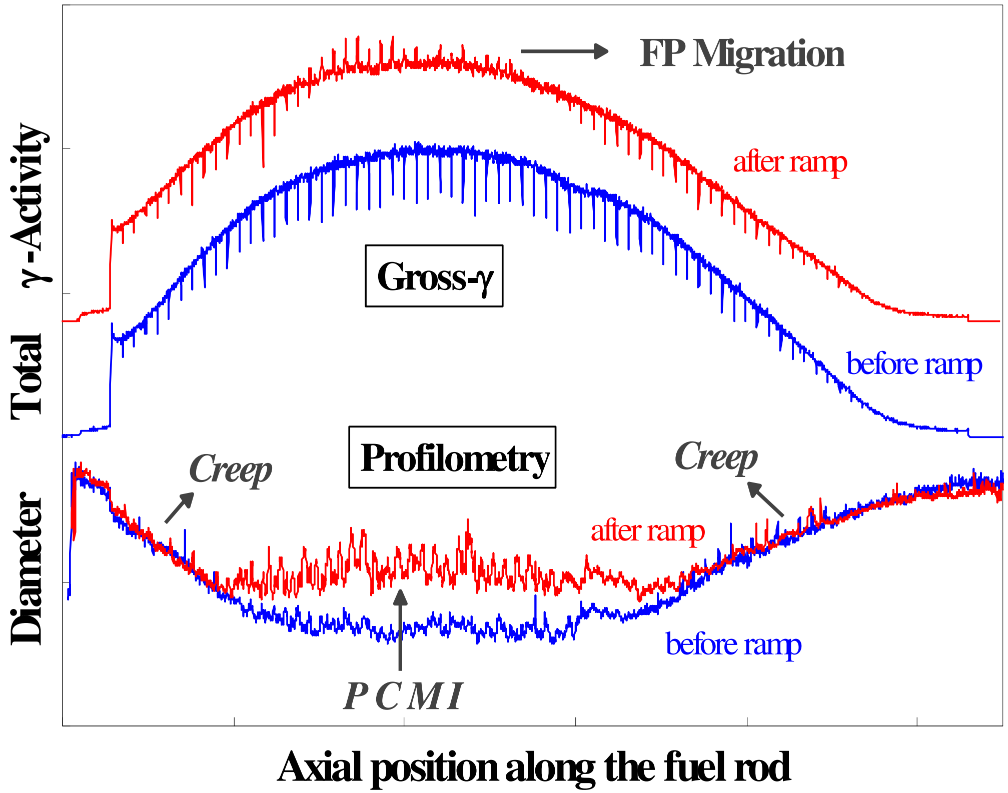
Irradiation conditions

BR2 Configuration **20**
Nominal Power: **55 MW**

Channel	Neutron flux [10^{14} n/cm².s]		γ heating
	Thermal	Fast (>1 Mev)	[W/gr_{Al}]
K49	1,2	0,1	1,0
K311	1,5	0,2	1,3

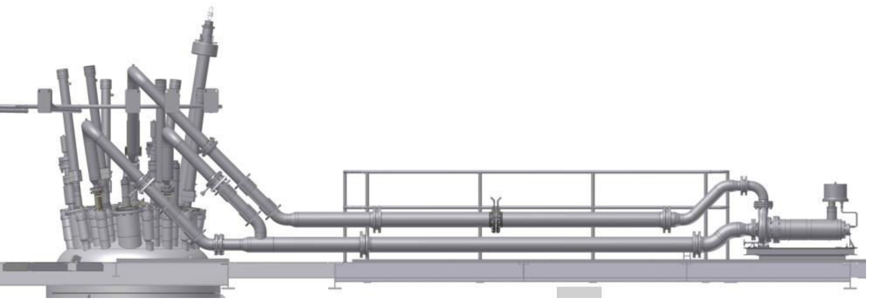
Parameter	Typical value	
Linear power at hot plane	350	W/cm
Axial shape factor (max/avg)	1.6	
Coolant pressure	155	bar
Coolant mass flow rate (in IPS)	2.1	kg/s
Av. coolant velocity along rods	3	m/s
Coolant temperature		
at fuel bundle inlet	294	°C
at fuel bundle outlet	313	°C

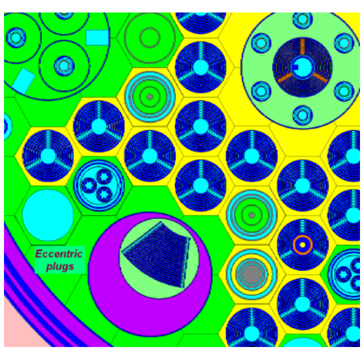
Example of PIE on LWR Fuel: Geometrical and FP response to power transients

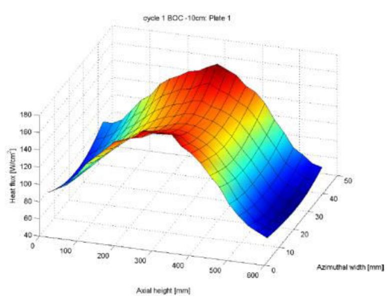


- Gross-γ
  - Power profile
  - Interpellet
    - Pits (dishes, chamfers)
    - Peaks (FP migration)
- Profilometry
  - Creep
    - Reflecting power profile
  - PCMI
    - Reflecting power profile
    - + interpellet pits/peaks

MTR fuel irradiation







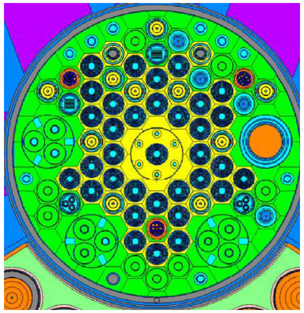
- Applications:
  - Qualification of high density Low Enriched Uranium fuel for high performance MTRs
  - Qualification of new fuel elemnt designs

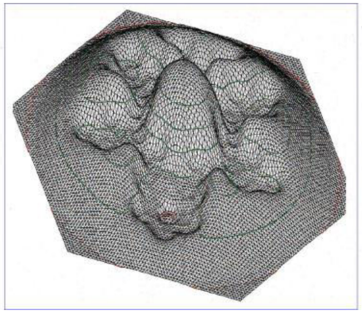
Tools:
  - Test baskets for plate irradiation
  - Test loops for full element irradiations

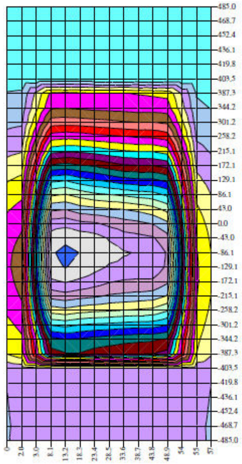
- Support:
  - Advanced modelling of irradiation conditions
  - Inter cycle inspections
  - Non-destructive + destructive PIE

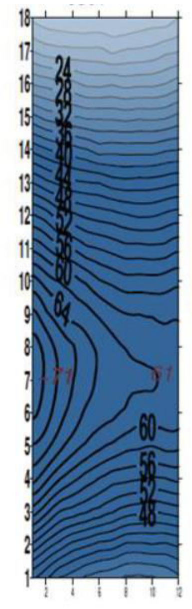
Modelling and experimental characterisation

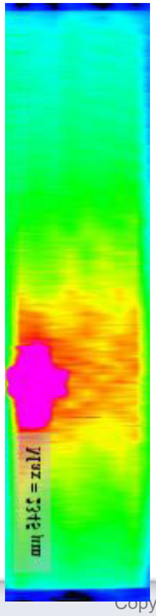
- Irradiation condition modelling
  - Neutronics: fluxes and fission density
  - Thermal hydraulics: temperature and power distribution
- Characterisation
  - Oxide thickness
  - Swelling
  - Microstructure en FP distribution



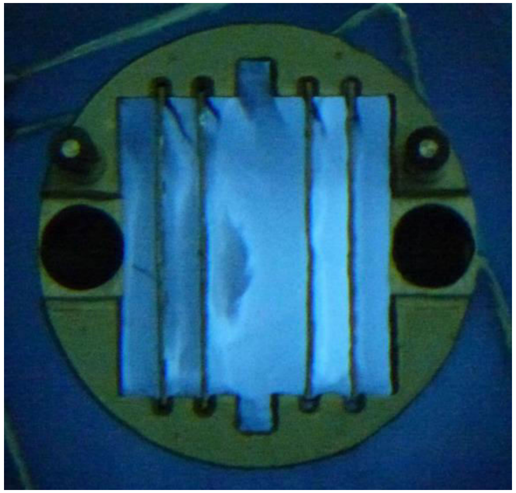


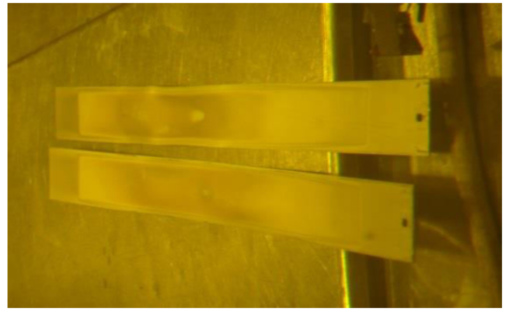


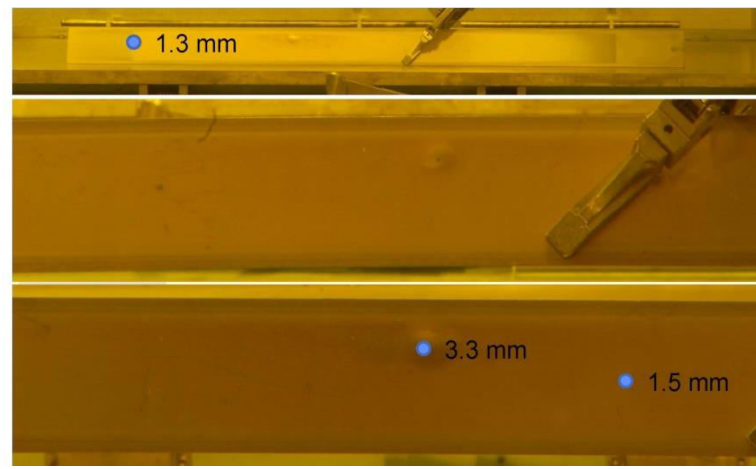




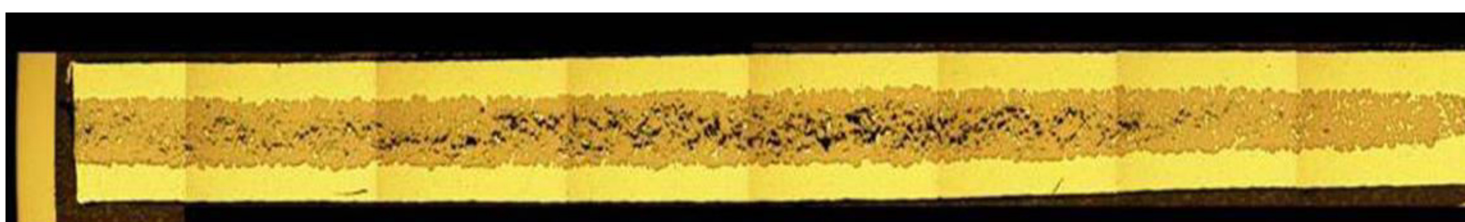
Dispersed Umo characterisation





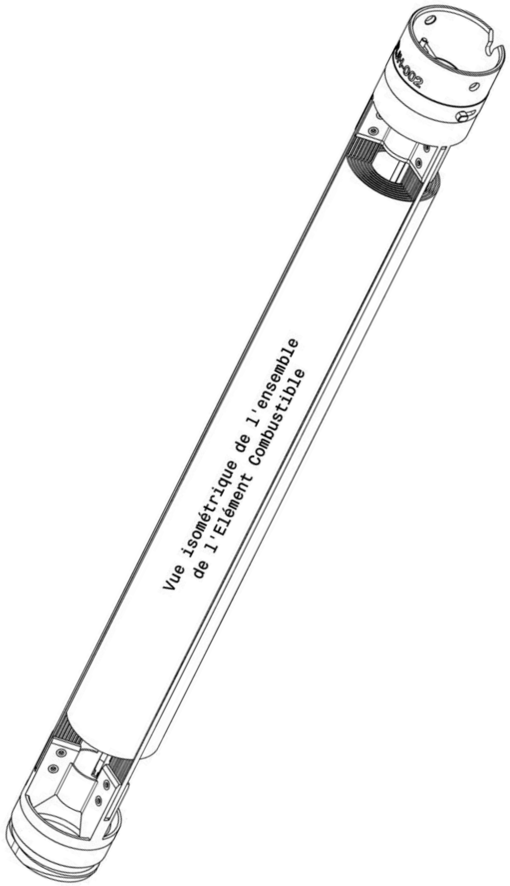


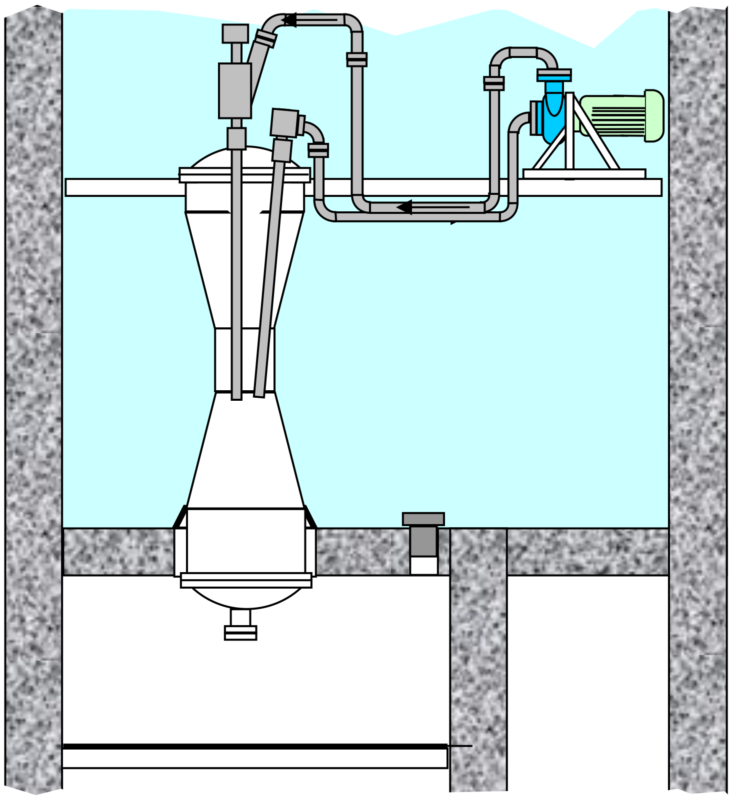
Failure modes:
Buckling
Blistering



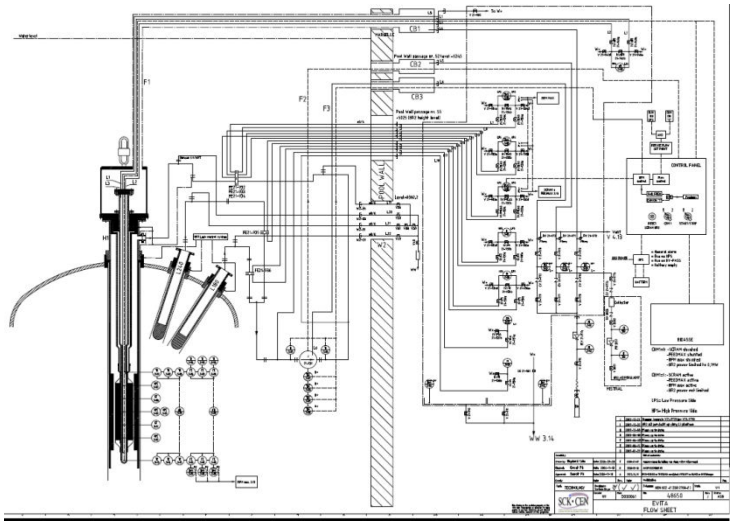
Simulation of Jules Horowitz Reactor: the EVITA loop

- Full scale RJH element qualification
- Representative thermal hydraulic simulation
- Open cooling system

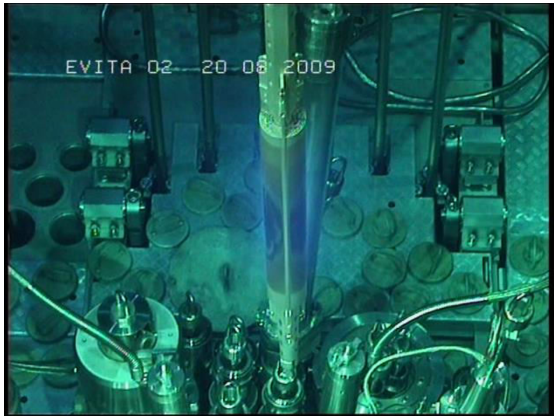


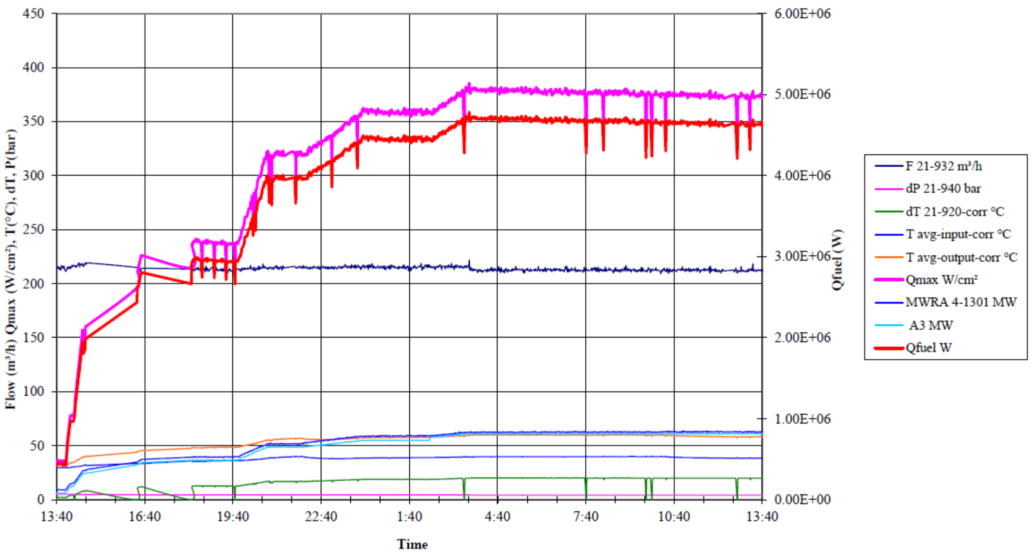


On-line power and flux monitoring



Silicide fuel was qualified up to nominal power and burn-up of the Jules Horowitz Reactor!





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BR2 provides SCK•CEN with

- A powerfull and flexible tool for
  - Production of radio-isotopes and semi-condutors
  - Studies of irradiation induced ageing of reactor construction materials
  - Performance studies and qualification of nuclear fuel in normal and abnormal conditions

- In order to do so it needs
  - High performance and efficient irradiation rigs, supported by an in-house design and construction capability
  - Top level pre- and post irradiation testing facilities
  - Efficient logistics
  - An effective maintenance and renewal programme

The future of BR2

- Although the facility celebrated its 50th aniversary in 2013
  - It is permanently kept in good shape
  - It is being prepared for the future periodic safety reassessment period (2016-2026)
- The BR2 reactor will undergo an extensive overhaul in 2015
  - To replace its Be core
  - To perform major maintence operations and inspections
  - To be upgraded to conform to the future’s challenges