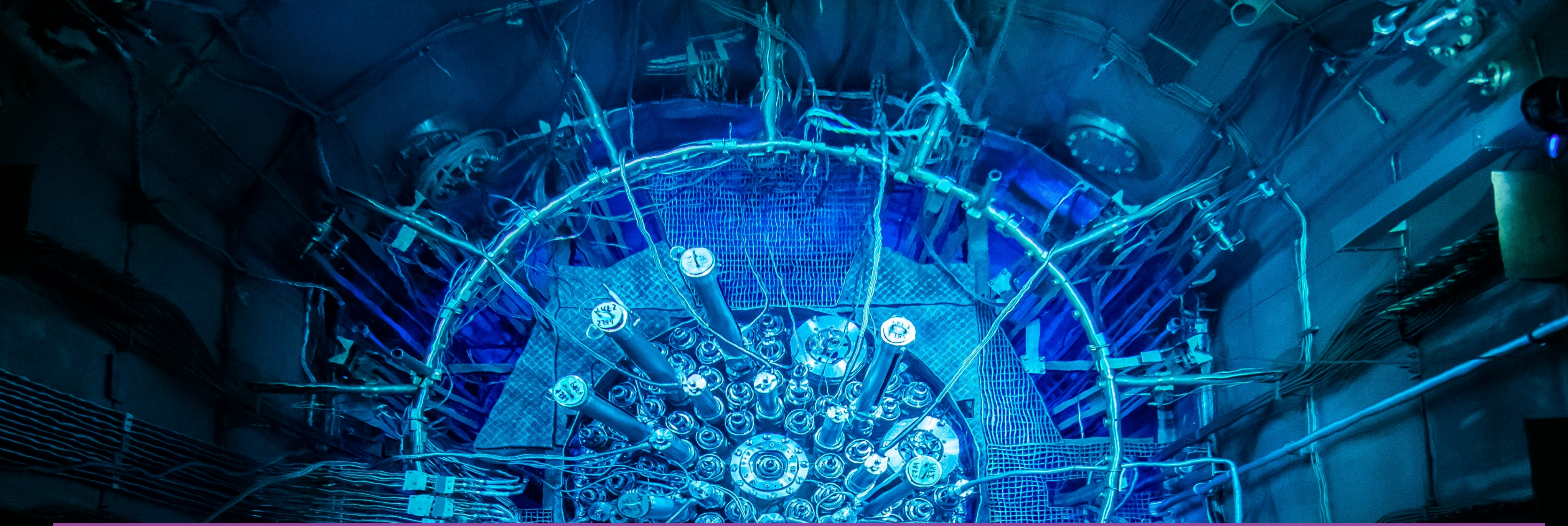


Irradiation of Material Test Reactor fuel in the BR2 reactor

Steven Van Dyck, Silva Kalcheva, Jared M. Wight, Bert Rossaert – TRTR-IGORR 2023 meeting

University of Maryland, June 18-22, 2023

sck cen
Belgian Nuclear Research Centre

SCKCEN

Our Belgian Nuclear Research Centre is based in Mol and Brussels. Our pioneering research is **internationally renowned**
Today this is reflected in our global lead on **Test Reactor Fuel** qualification

Home of the BR2

In 1952, we started to explore the possibilities of nuclear science and applications that could **significantly change the world**
In 1963, operation of the **BR2 high performance reactor** started

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.

Mission of the BR2

Enable SCK CEN to provide top level irradiation services

- High level of performance
  - *High flux available for irradiation, both thermalized and fast*
- Allow for ease of access to neutrons
  - *Access during operation, infrastructure for fast and safe handling*
- Provide flexibility in utilization
  - *Configuration and operation parameters can be varied, multiple irradiation devices can be installed*

General features of the BR2 reactor

Core characteristics

- Heterogeneous core
  - Fueled with HEU UAlx MTR fuel
  - Moderated by light water + metallic beryllium
- High flux available
  - Thermal flux up to 1 E15n/cm^2s
  - Fast flux up to 8 E14n/cm^2s
- Operation with shim rods
- Flexible configuration to achieve cycle length, flux levels and fuel economy

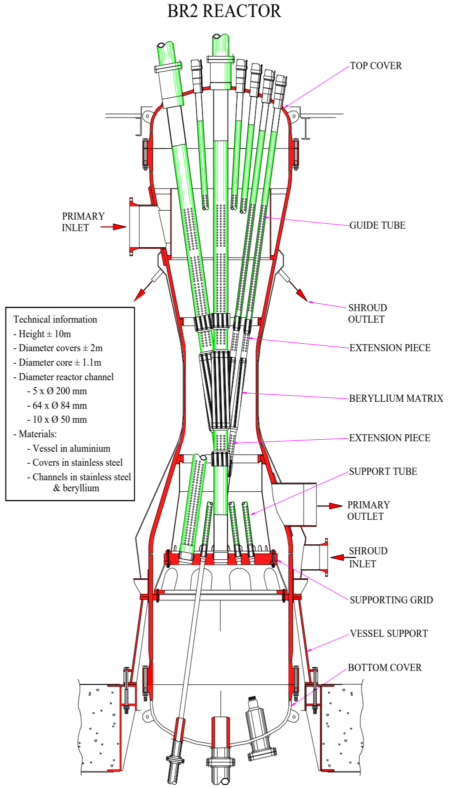
Reactor characteristics

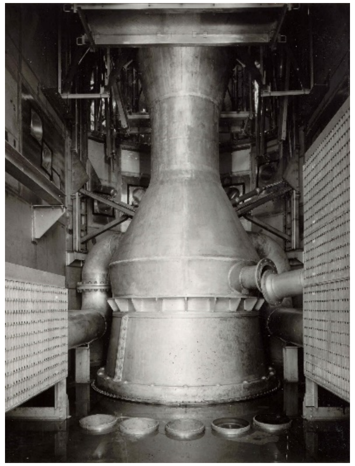
- Light water cooling in closed, pressurised loop
  - Heat flux up to 600W/cm^2 allowed, nominal 470W/cm^2
  - 1,2MPa pressure, 40-50°C, 7000m^3/h
- Open secondary loop with modular cooling tower
  - Thermal power up to 125MW
- Safe shut down in natural converction cooling mode
- Tank in pool with containment building which can be isolated from environment using electricity independent valves.

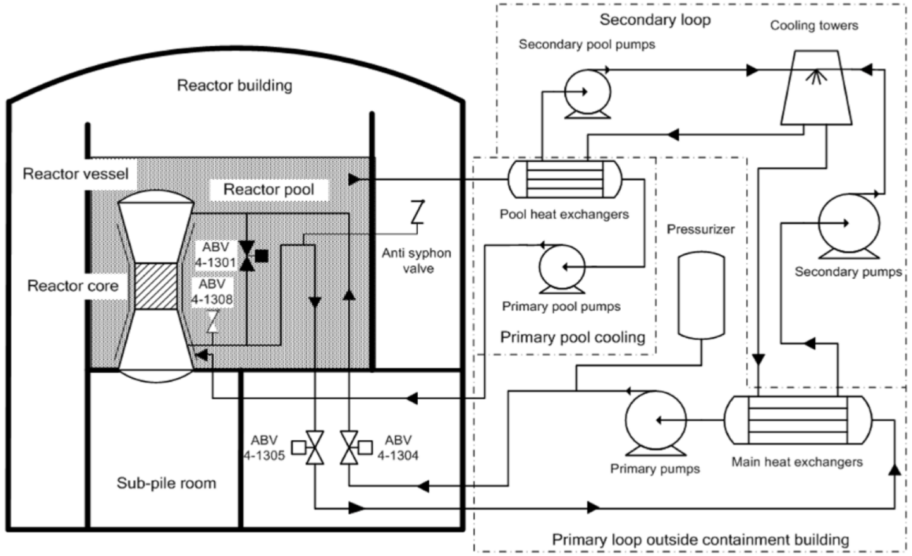
Reactor lay out

Cooling loops – irradiation environment and safety

- Primary loop:
  - high heat evacuation capacity
  - closed barrier for release of contamination
  - continuous operation for entire reactor cycle
- Pool cooling loop:
  - Reduced heat evacuation capacity
  - Open loop; large heat sink
- Secondary cooling:
  - No safety function; protected by activity monitoring



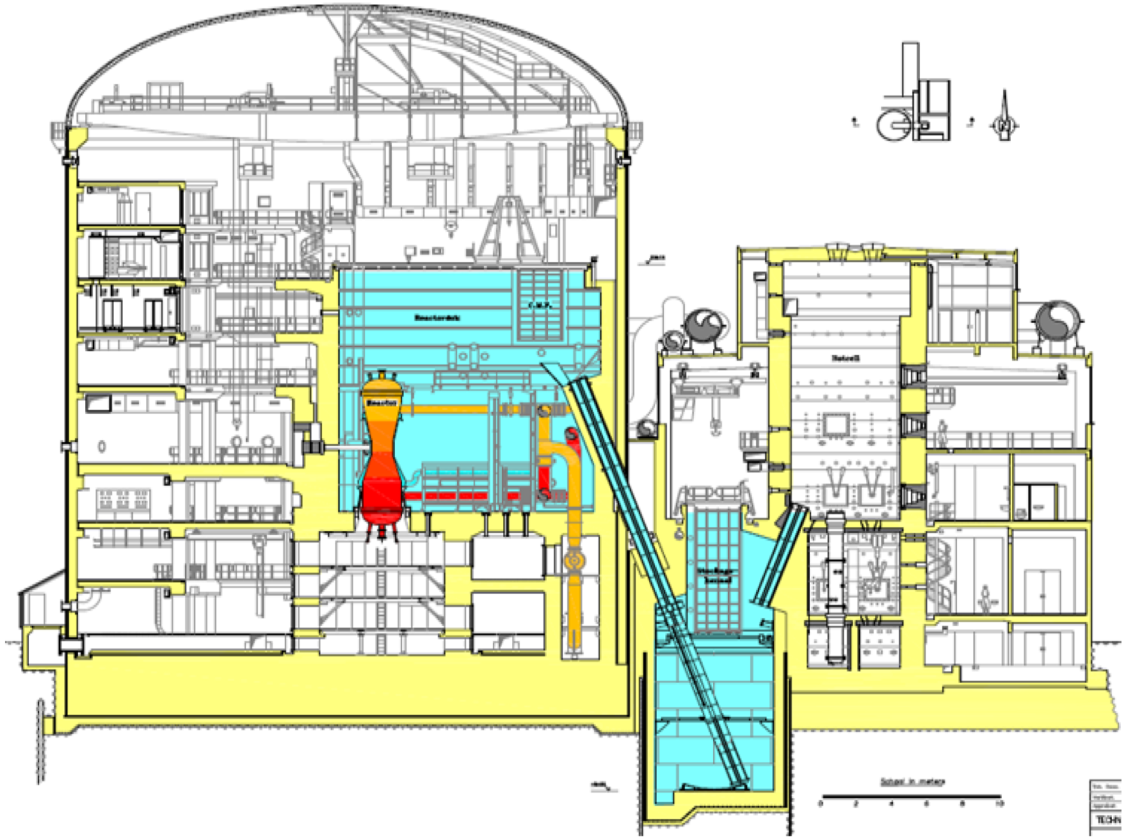




Reactor pool & building

Shielding and barrier against spreading of contamination

- Open pool: easy access for manipulations
- Transfer from reactor pool to hot cell or storage channel in shielded condition
- Access to reactor building through staff and vehicle locks
- Cranes with large capacity available



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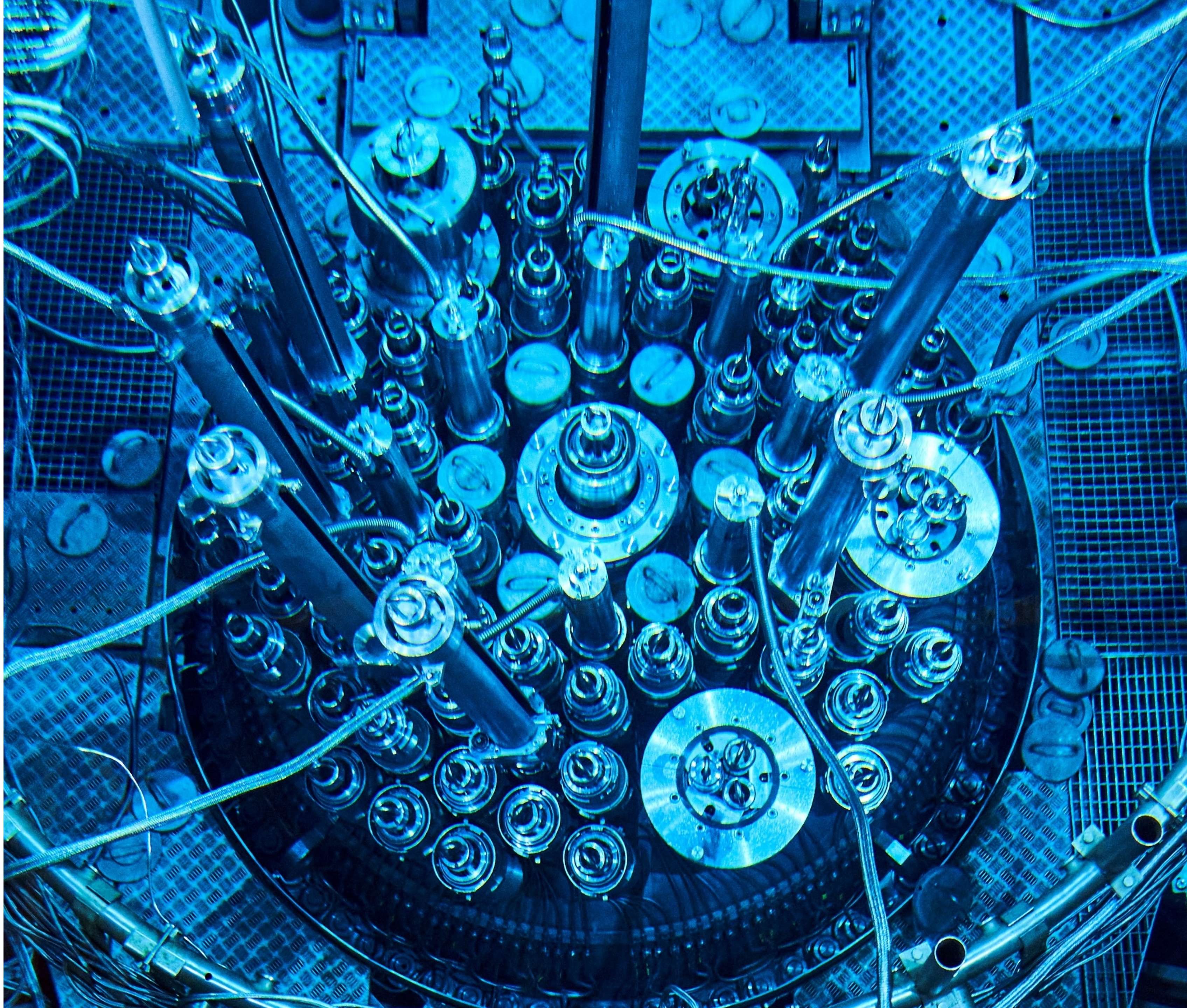
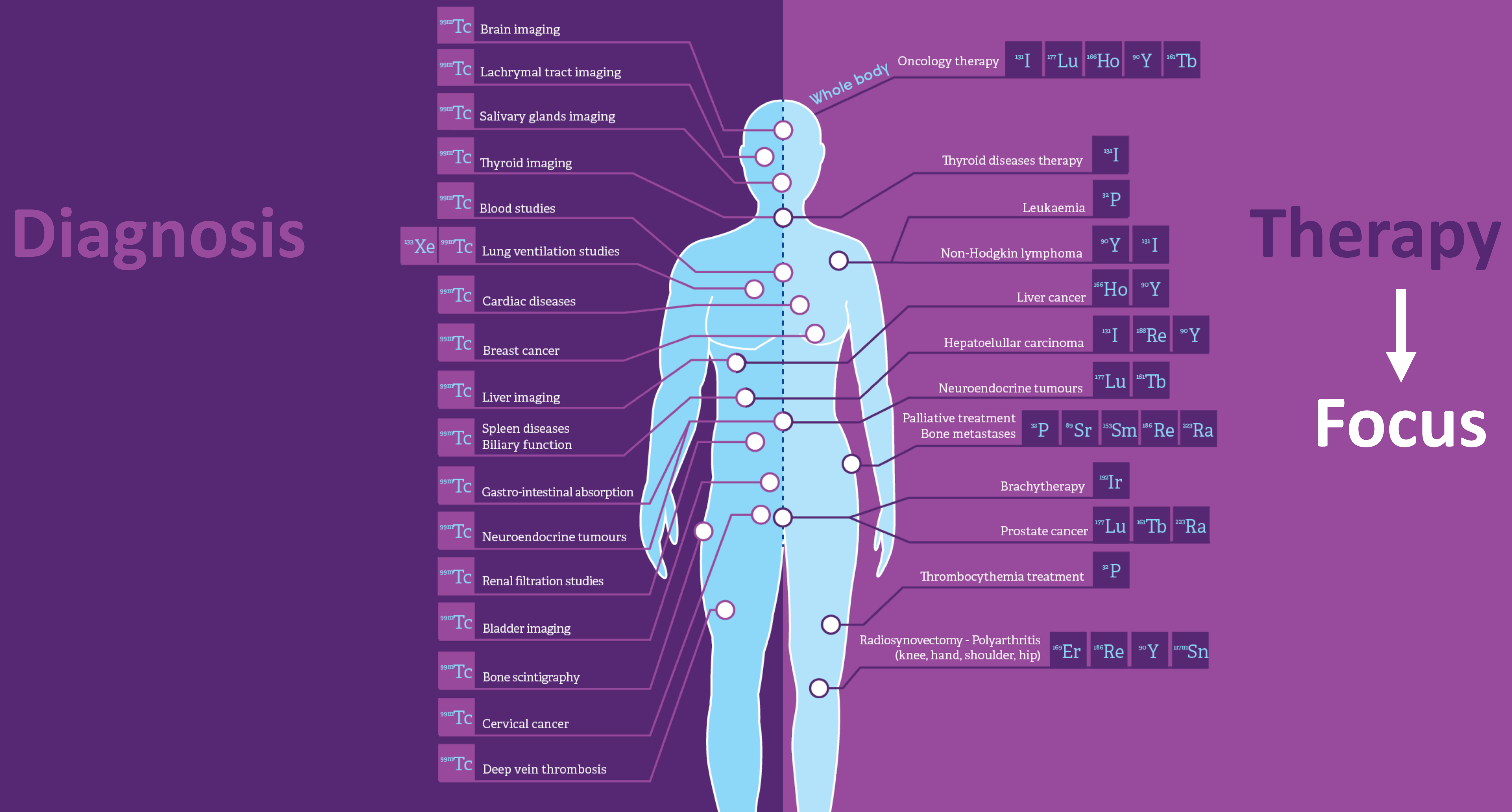
Life-saving production

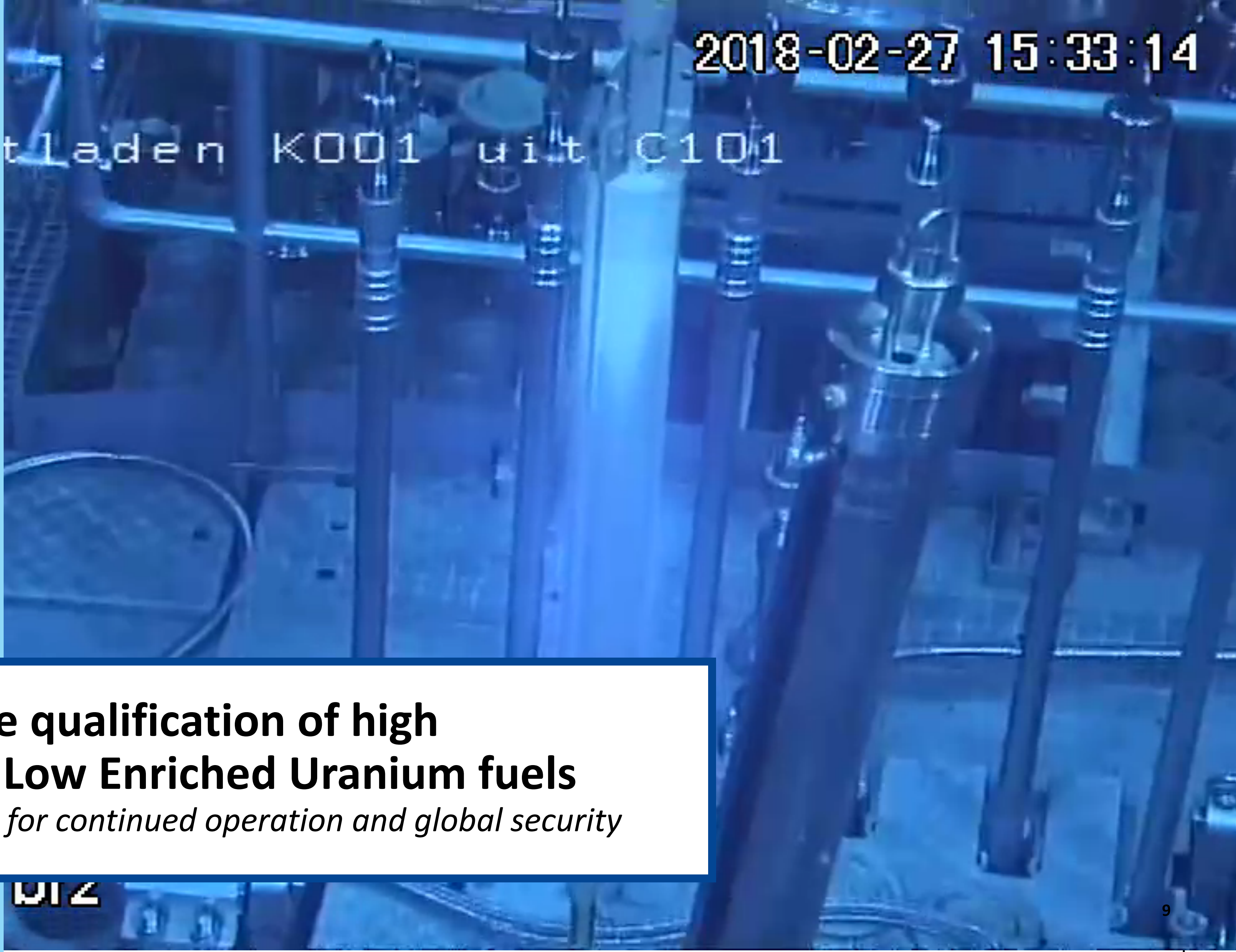
BR2 produces 25% of the global demand for the radioisotope molybdenum-99



+-11M patients/year



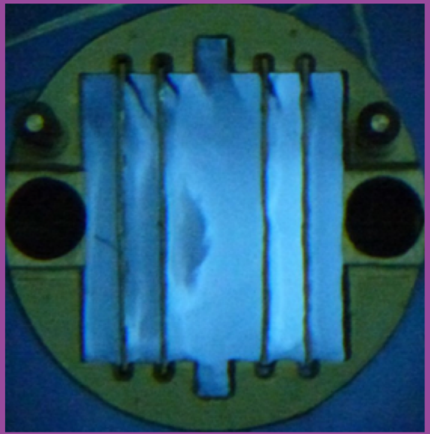
Secure the fuel supply



2

By leading the qualification of high performance Low Enriched Uranium fuels

An important asset for continued operation and global security



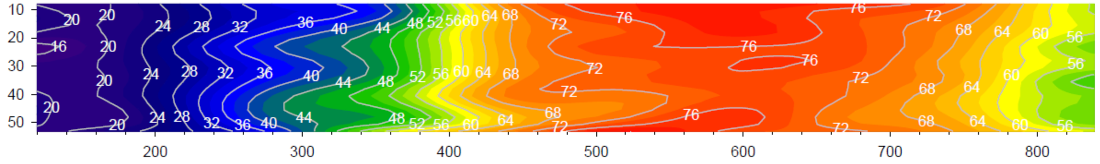
Qualification of a fuel system

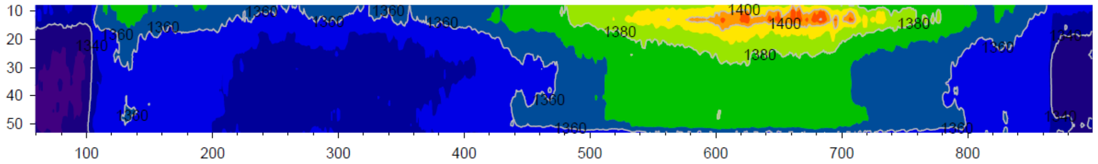
Irradiation of flat fuel plates

- FUTURE basket: up to 5 “full size” flat plates
- Minimal production effort
- Visual inspection between cycles + wet sipping test
- Up to 600W/cm² power density
- *Possible hydrodynamic instability*
- *Not representative fabrication*

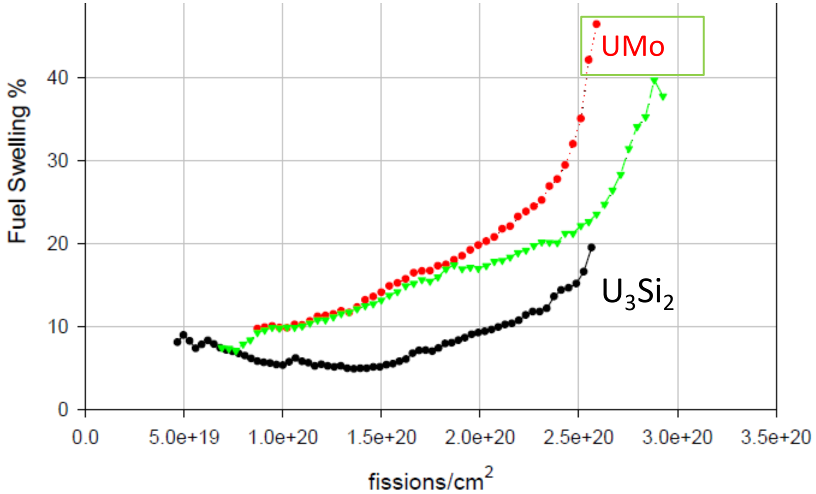
Irradiation conditions

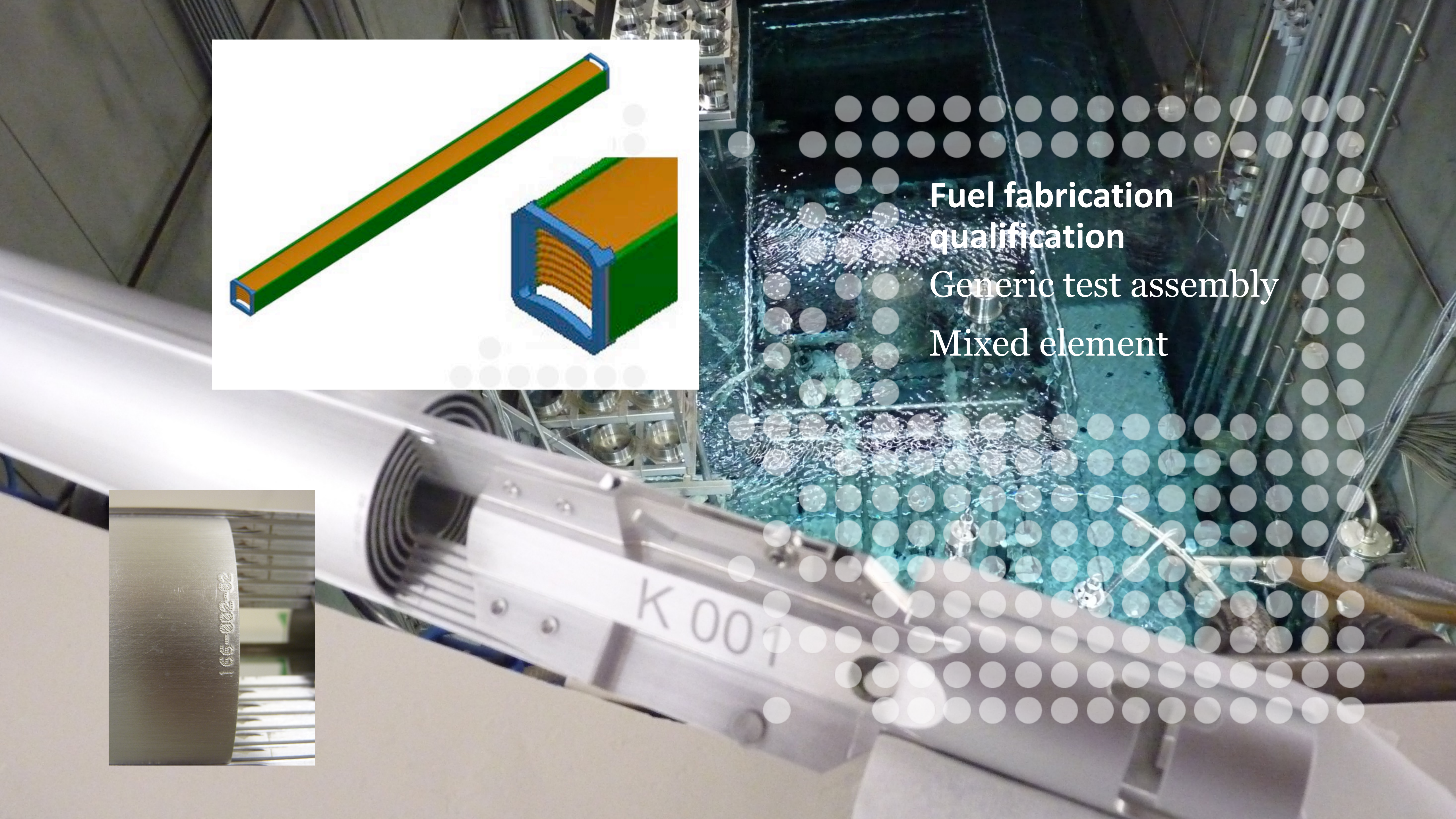
Neutronic & hydraulic





- Power distribution prediction
- Safety analysis
  - Margin versus DNB
- Integration of power distribution for burn-up calculation
- Correlation to Post Irradiation results
  - Swelling of HD silicide outperforms UMo at comparable power/BU





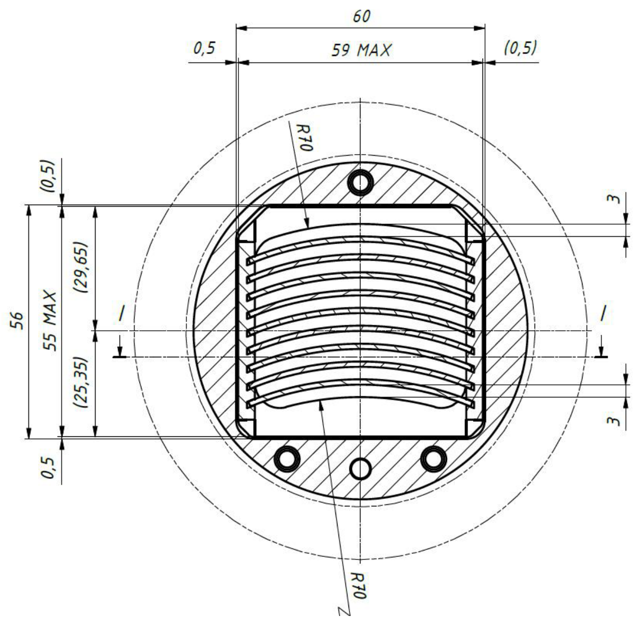
Fuel fabrication qualification

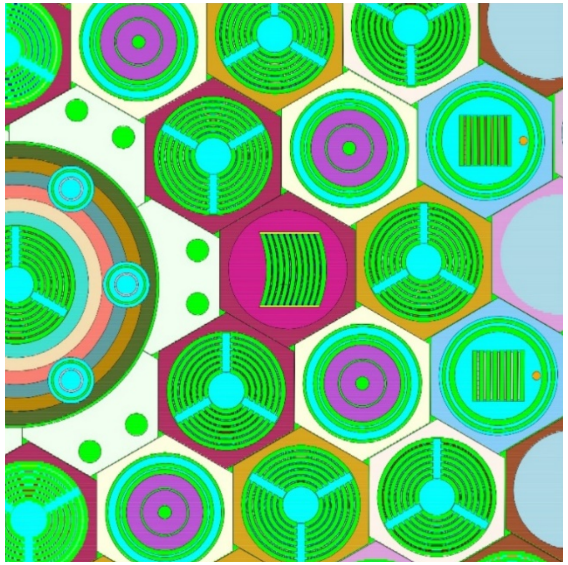
Generic test assembly

Mixed element

Generic Test Assembly

- Assembly of “typical” MTR geometry
  - Curved plates (radius 14.5-145mm)
  - Swaged into rails
  - Dimensions corresponding to FUTURE flat plate specification
  - Nominal plate spacing : 3mm (= BR2 driver fuel)
  - 9 plates in square box
- Safety file covers testing up to 470W/cm²
- Higher relevance for production technology
- Higher hydraulic stability
- MCNP optimization of core to obtain max heat flux on minimum 3 plates



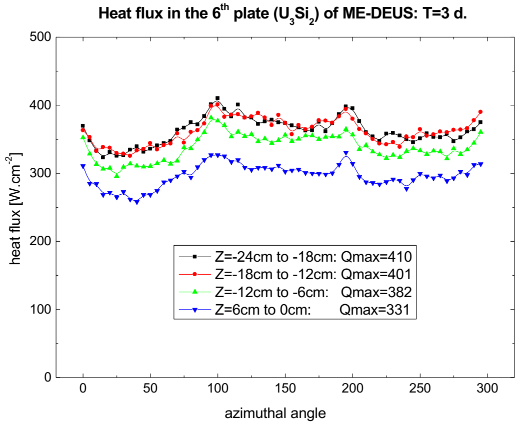


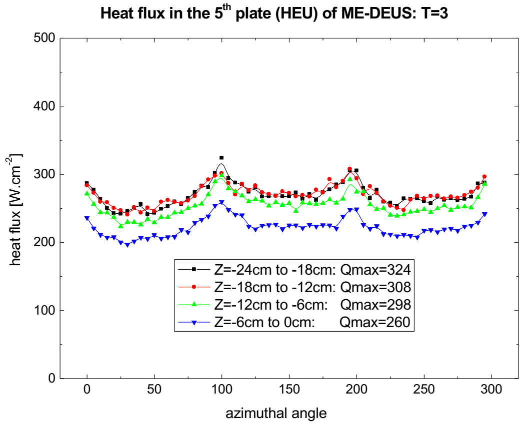
Mixed elements

- Standard assembly of BR2 driver fuel element
  - Currently HEU, UAlx (1.04gU/cm^3) with Gd burnable absorber (2.5g/element)
- Outer 3 plates replaced by experimental plates
  - Inner radius of curvature 37.61mm
  - Thickness 1.33mm, cladding 0.35mm average
  - Water gap 3mm (inside) and 3.16mm (outside)
- Fabrication: BR2 specific
  - Maximum allowable heat flux: 470W/cm^2 (600W/cm^2 if other plates remain below 470W/cm^2)

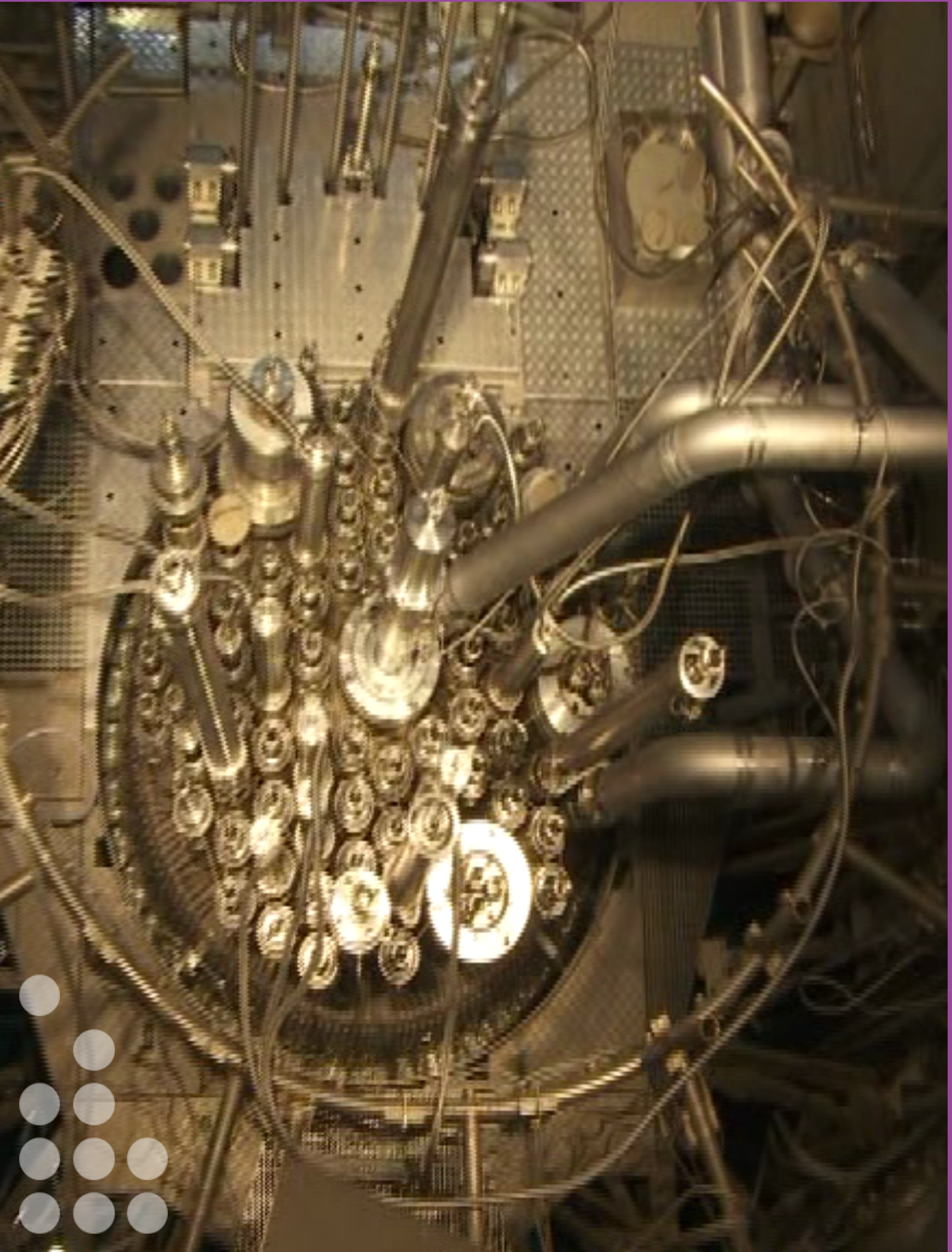
Typical irradiation conditions for mixed element

- Outer plate: U_3Si_2 LEU dispersion, 5.3g/cm³
- Irradiation in central channel: symmetric power distribution
- Evolution of hot zone with time forecast





Axial mesh	T=0		T=3 days		T=5 days		T=8 days	
	6th plate (LEU)	5th plate (HEU)	6th plate (LEU)	5th plate (HEU)	6th plate (LEU)	5th plate (HEU)	6th plate (LEU)	5th plate (HEU)
Z=-24cm to -18cm	481	363	410	324	403	311	385	309
Z=-18cm to -12cm	475	357	401	308	397	306	398	303
Z=-12cm to -6cm	454	332	382	298	386	294	363	289
Z=-6cm to 0cm	393	292	331	260	332	293	331	261



Devices for prototypes

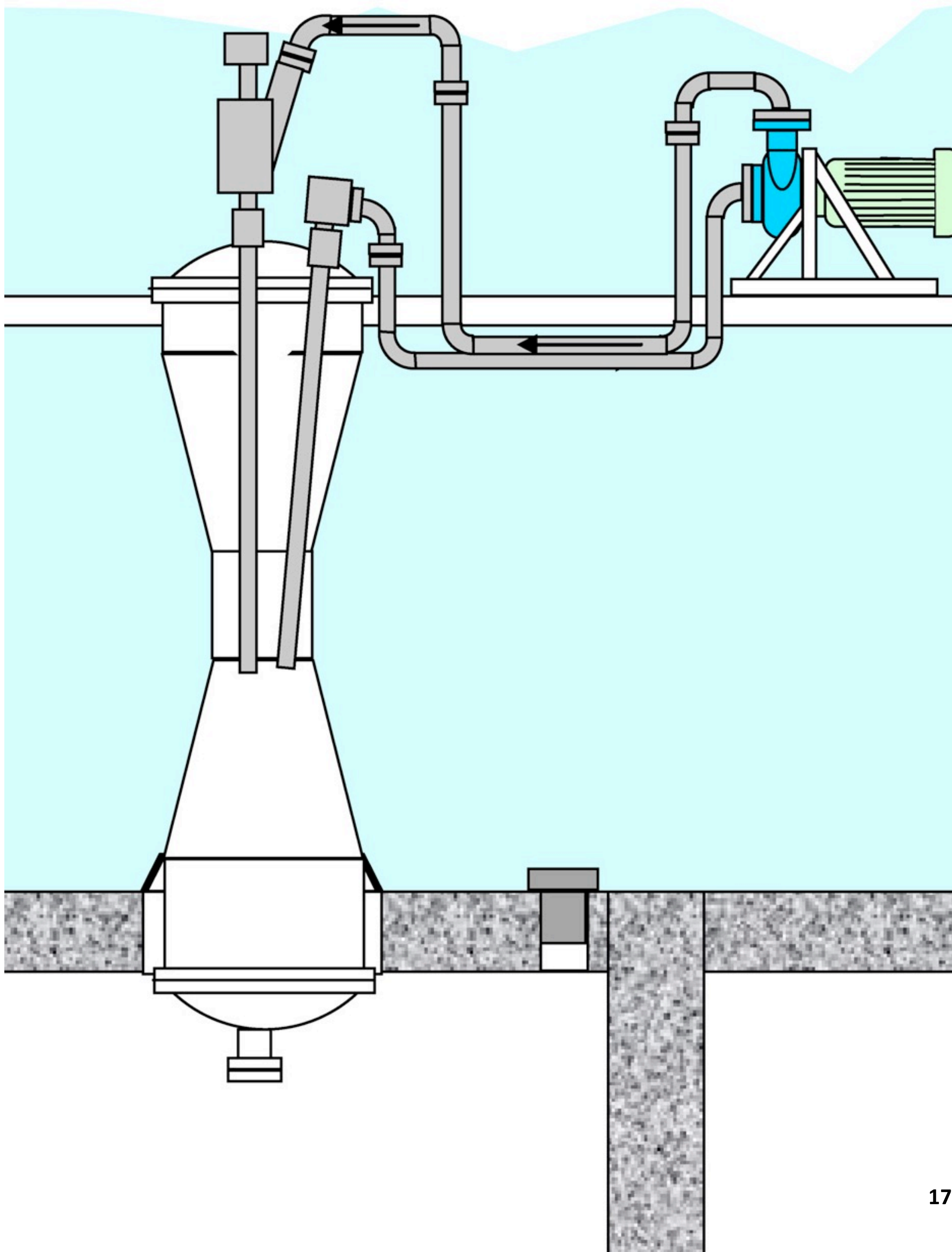
Adaptaion of hydraulic conditions

- Enhanced velocity test loop EVITA
  - Testing of fuel element with enhanced flow
- Restricted flow device MUSTANG-R
  - Testing of elements with reduced flow

Enhanced flow loop concept

Safe irradiation of fuel beyond standard BR2 capability

- Fuel with smaller spacing between plates and higher power density
  - Enhanced pressure drop
  - Active cooling after SCRAM for 1 hour
- Higher fissile content with no burnable absorbers in fuel
  - High reactivity effect of fresh element
  - Compensation of burn up during multi-cycle campaign



Implemented solutions

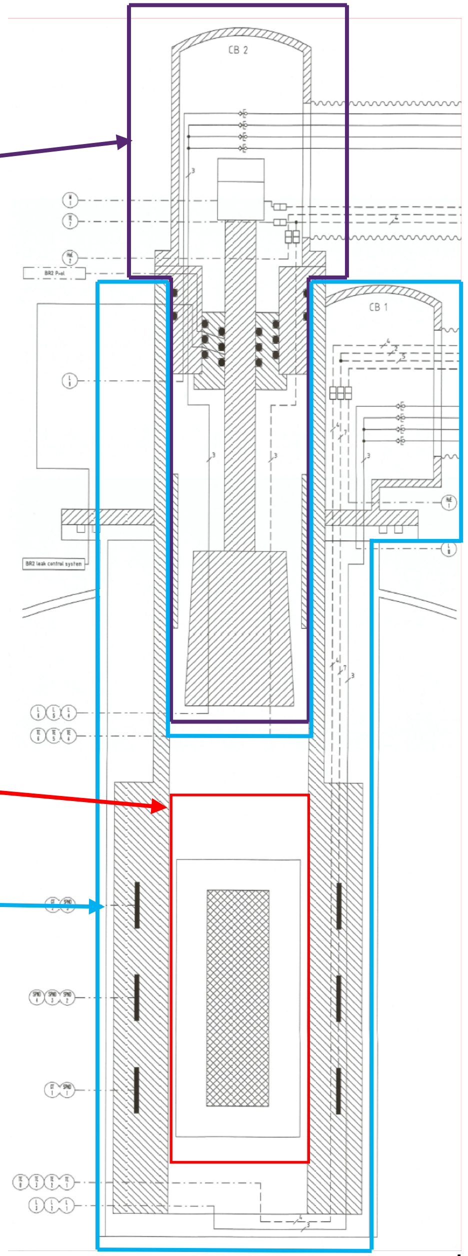
- Submerged booster pump in semi-open loop
  - Reduced LOCA risk
  - Redundant shut down cooling by loop pump and primary pumps
  - UPS to support loop pump
- Variable environment for reactivity control
  - Al+water plug -> Be plug
  - Dedicated zero power measurements and loading procedure
- On-line power measurement in complement to modelling
  - Total power up to 5MW, power density 550W/cm^2

Reduced flow aparatus

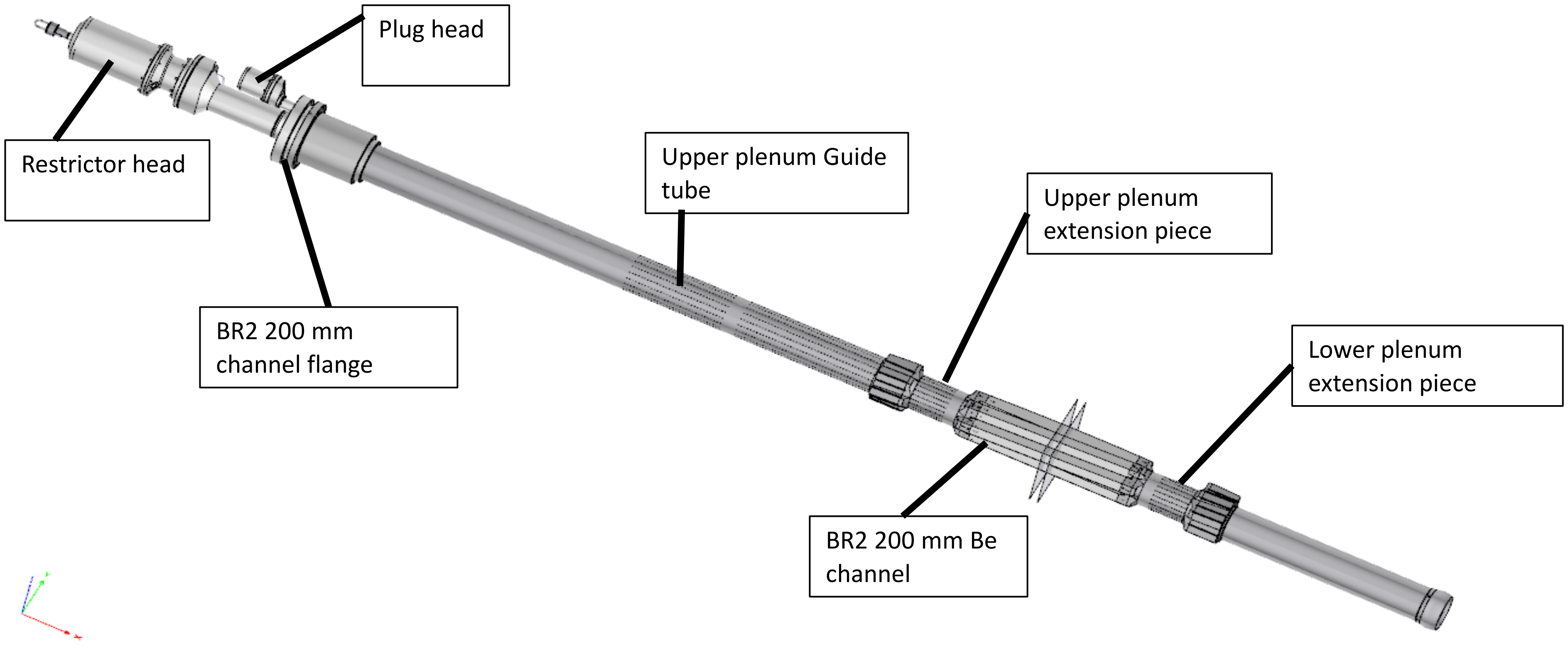
- Qualification of prototype elements in reactor specific conditions
  - Reduced flow rate
  - Specific geometry accommodation
  - Adapted neutronic conditions
- Basket in plug rig
  - Adaptive irradiation volume for various fuel type
  - Plug design allows for low or high flux as function of selected materials

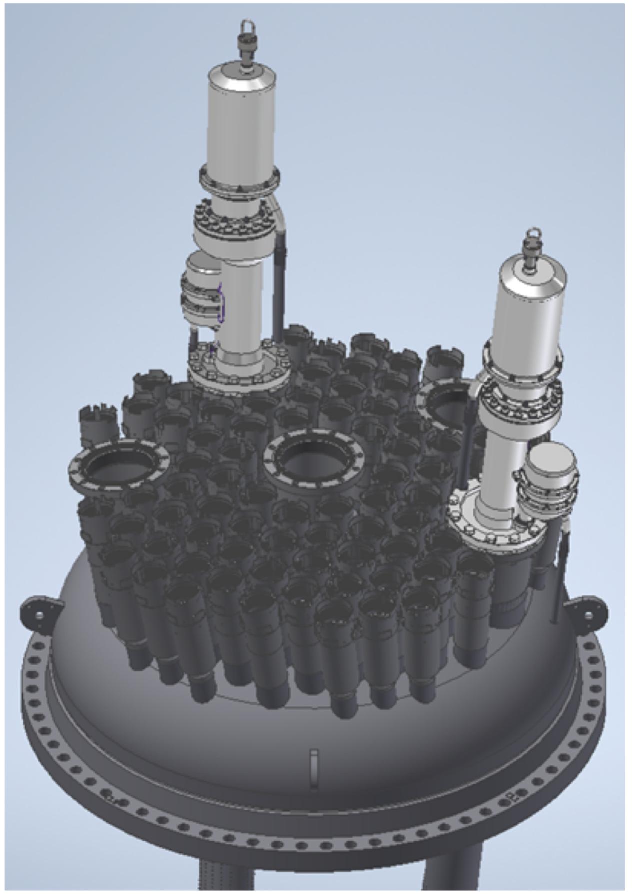
Device Overview

- **Restrictor**
  - Flow restrictor (adjustable orifice)
  - Sits above the basket assembly inside the top of the plug
- **Basket assembly**
  - Full-size fuel assembly inside an Al basket
- **Plug**
  - Hangs from top cover (200 mm flange)
  - Basket assembly sits inside bottom of plug

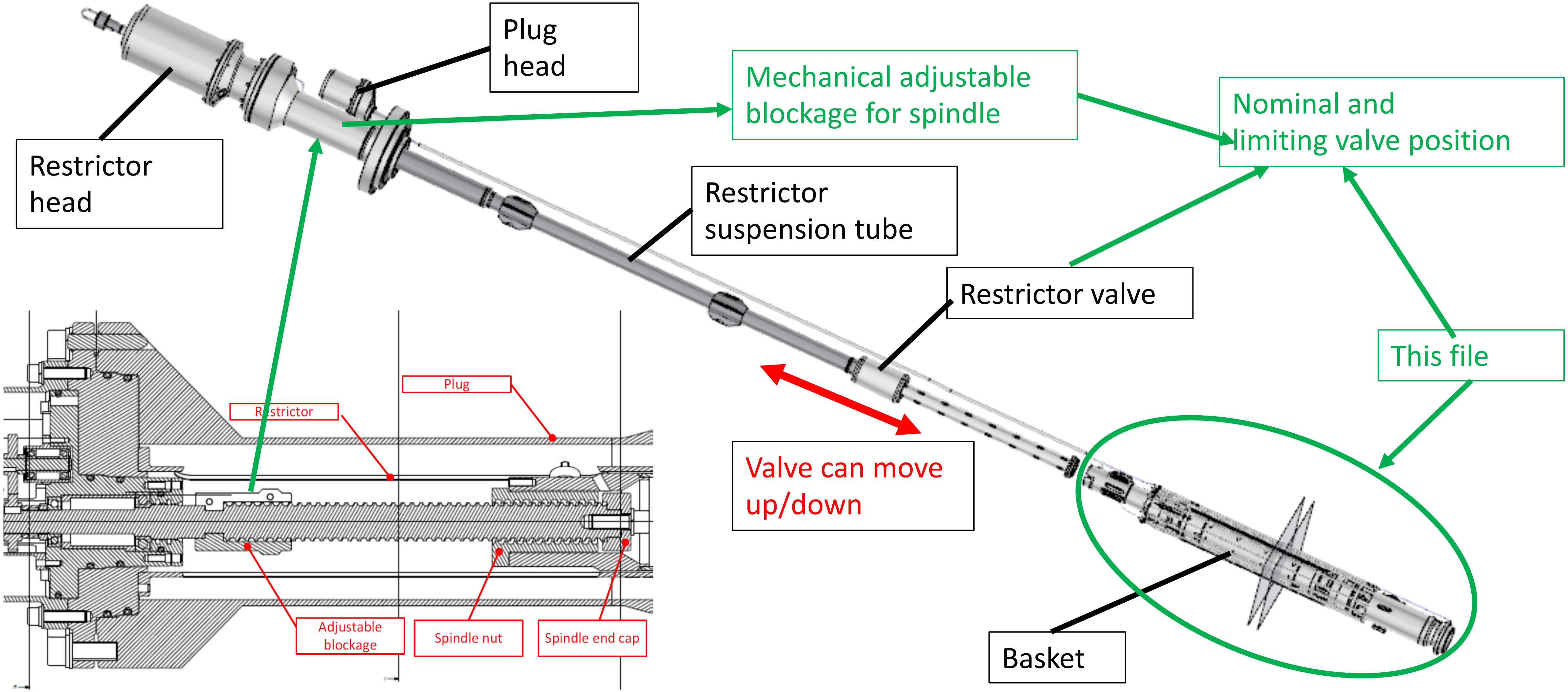


Equipment design – In Pile Section in 200mm channel

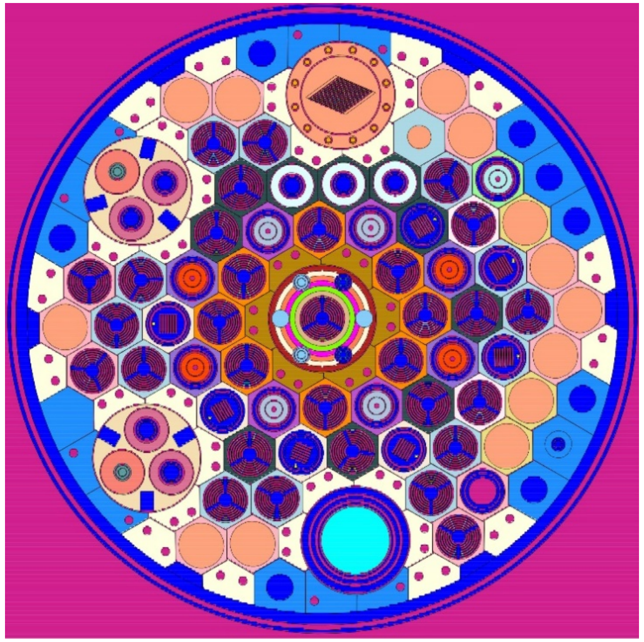


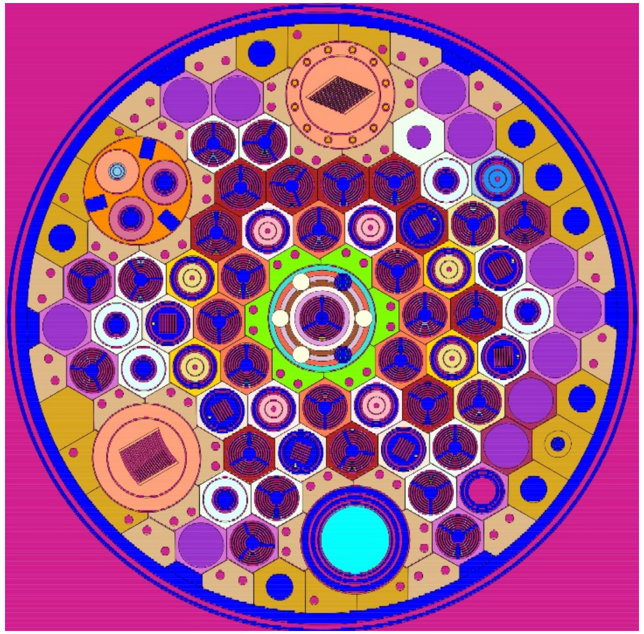


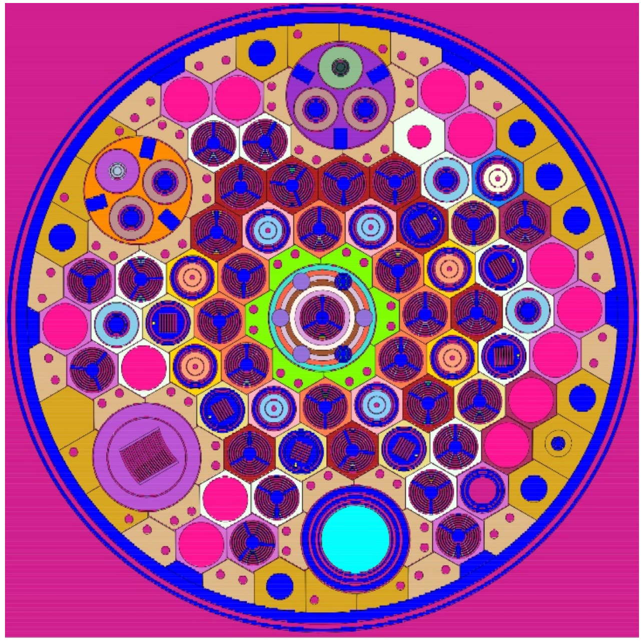
Equipment design - IPS



Selection of configuration for prototypic irradiation of 2 elements







Conclusions

- Qualification of MTR fuel can be addressed by generic to prototypic devices
  - Low lead time – small production development effort for fuel system studies in flat plates / generic test assembly
  - High lead time – prototype testing in dedicated rigs or as standard elements
- High performance levels can be qualified
- Flexibility of the BR2 core design and operation allows combination of several rigs while maintaining its core mission