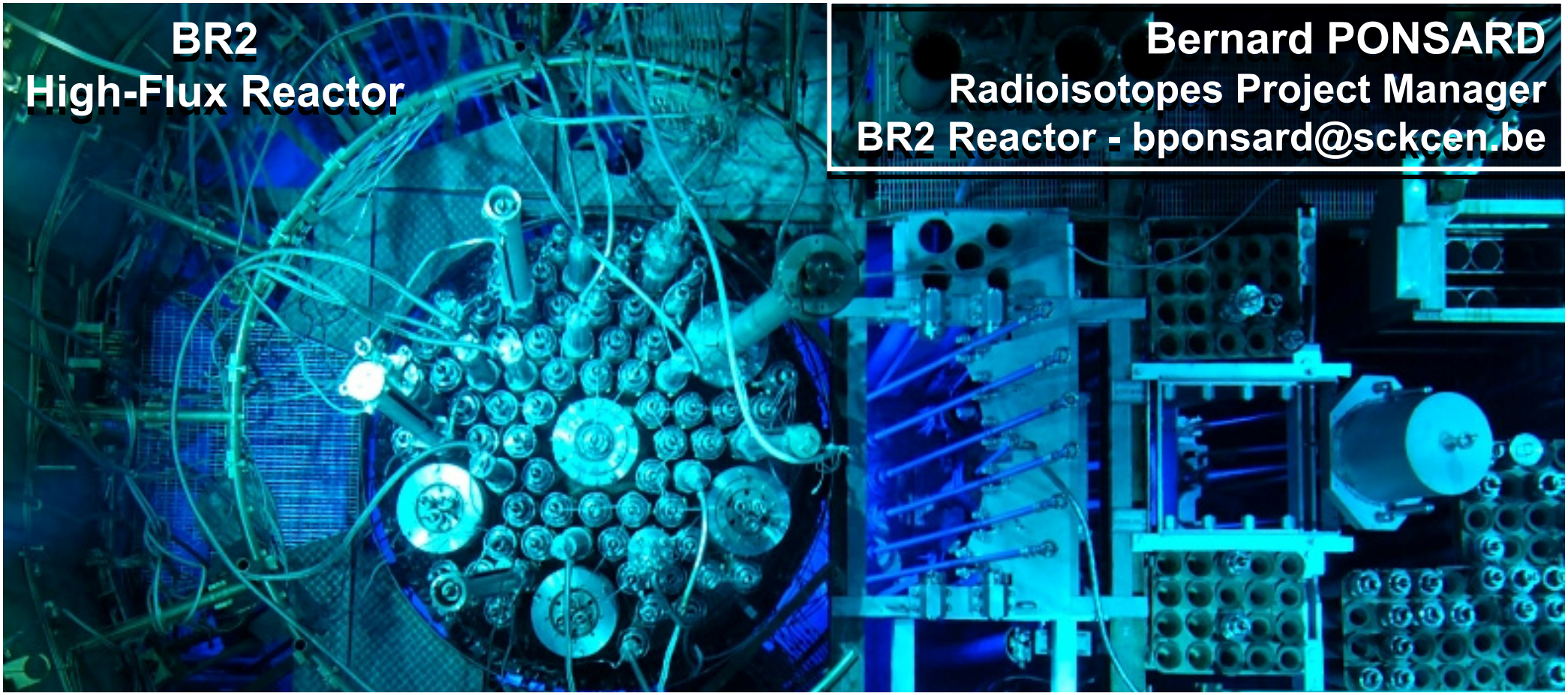
SCK•CEN

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

IRRADIATION OF LEU TARGETS IN THE BR2 REACTOR FOR MO-99 PRODUCTION



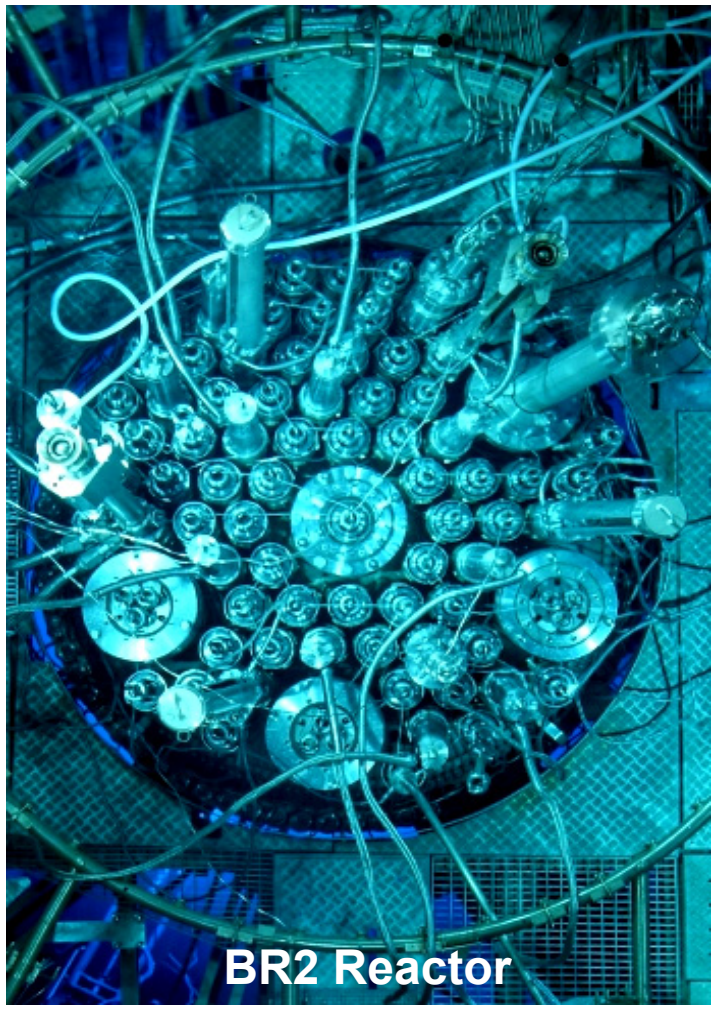
Bernard PONSARD
Radioisotopes Project Manager
BR2 Reactor - bponsard@sckcen.be

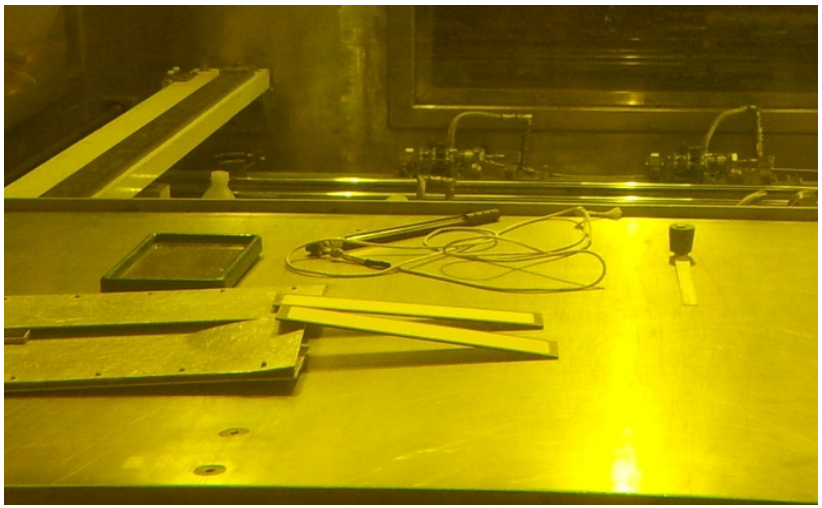
2015 MO-99 TOPICAL MEETING
MOLYBDENUM-99 TECHNOLOGICAL DEVELOPMENT
Boston, 01/09/2015

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Irradiation of LEU Targets in the BR2 Reactor for Mo-99 Production

- 1. Introduction : The BR2 Reactor
- 2. Current Mo-99 Production
- 3. Refurbishment of the BR2 Reactor
- 4. Future Mo-99 Production
- 5. Test Irradiations of LEU Targets
- 6. Conclusion


BR2 Reactor

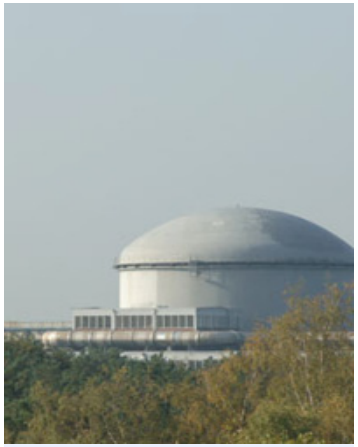


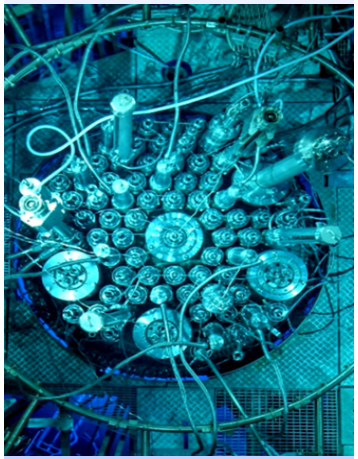
$^{99}Mo/^{99m}Tc$ Generator

PONSARD B.

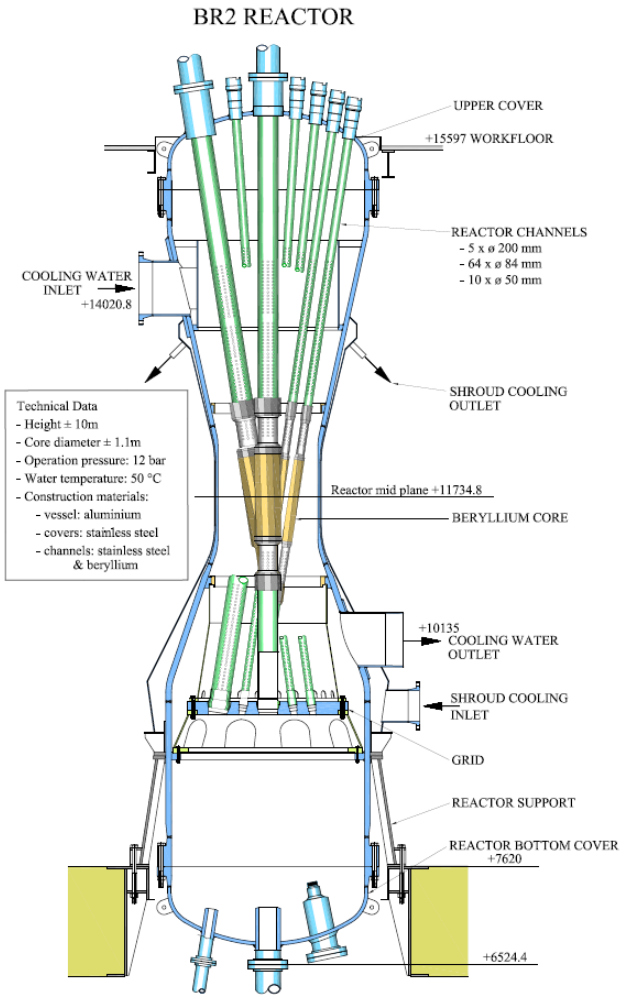
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

1. Introduction : The BR2 Reactor



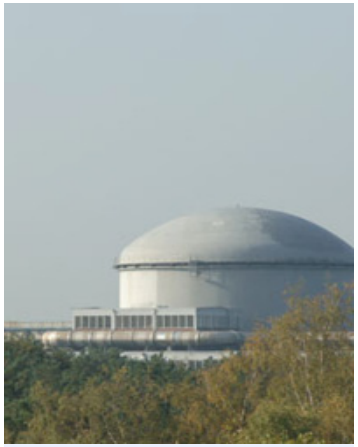


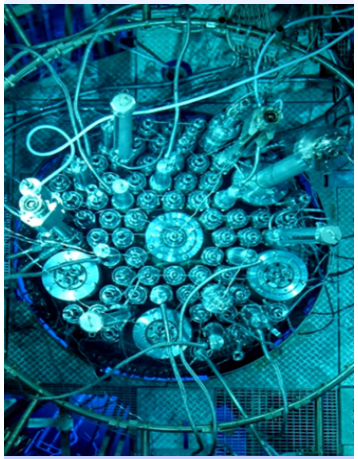
- The **BR2 reactor** is a multipurpose 100 MW_{th} High-Flux 'Materials Testing Reactor' operated by the Belgian Nuclear Research Centre (SCK•CEN).
- The availability of high thermal neutron fluxes up to **10^{15} $n \cdot cm^{-2} \cdot s^{-1}$** allows the production of a wide range of **radioisotopes** for various applications in **nuclear medicine**, **industry** and **research** such as Mo-99/Tc-99m, I-131, Xe-133, Sr-89, Lu-177, Re-186, Sm-153, Er-169, W-188/Re-188, Y-90, Sn-117m, P-32, Ir-192, Se-75, …



SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

1. Introduction : The BR2 Reactor

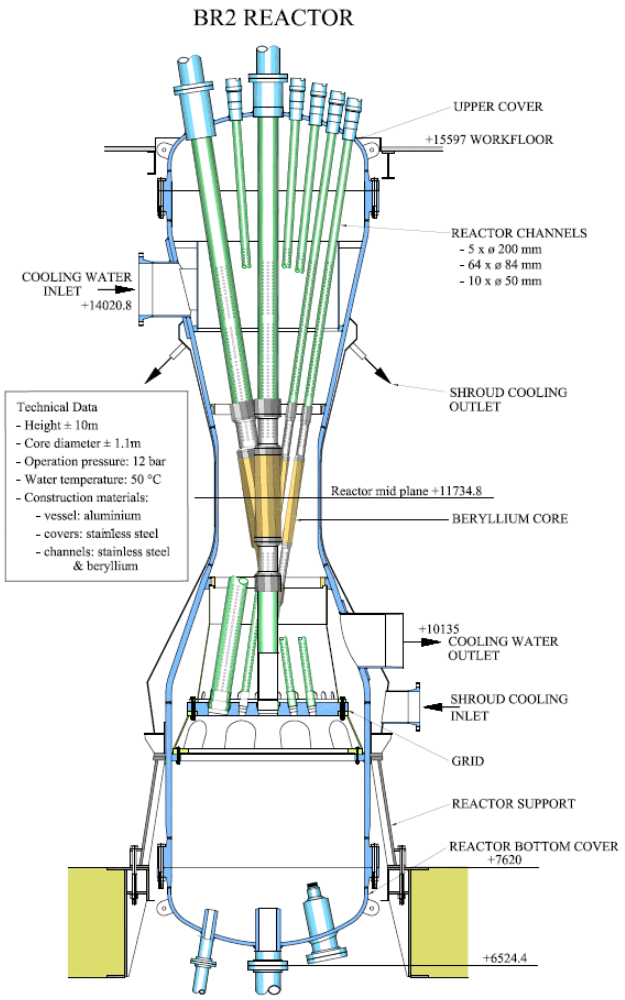




PONSARD B.

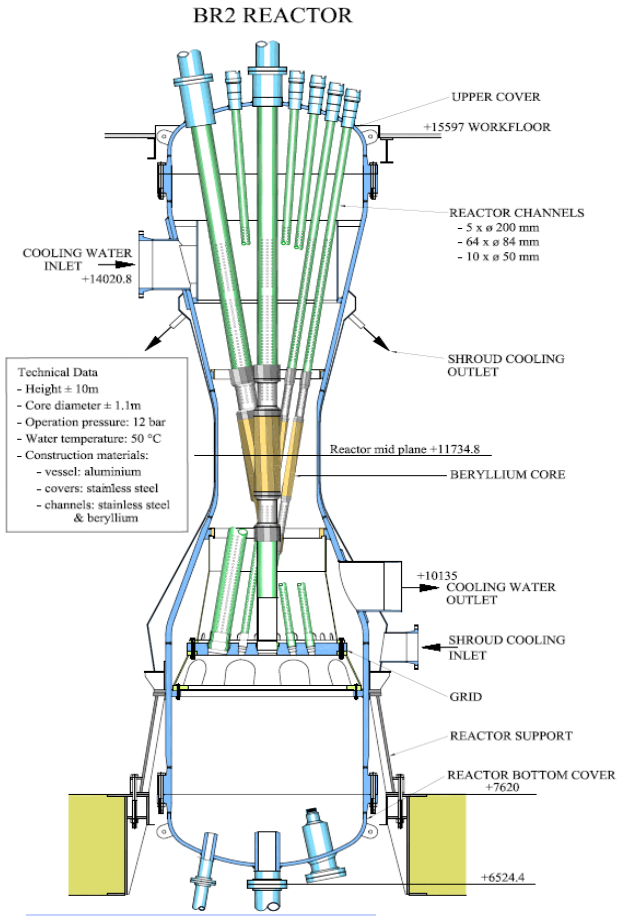
- **Reactor type**
  - High Flux **M**aterials **T**esting **R**eactor
  - Pressurized, light water
  - Be matrix, compact core
  - HEU fuel (93% ^{235}U)
  - LEU conversion project in place
  - In operation since 1963
  - Refurbishment : 1979-1980 & 1995-1997
    - Currently: February 2015 - June 2016
- **Aluminium pressure vessel**
  - Geometry : hyperboloid of revolution
  - Easy access to the top and bottom
  - Diameter : 1 to 2 m
  - Height : 8.6 m
- **Very compact core**
  - Diameter : 1.05 m
  - Height : 0.91 m

100 MW



SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

1. Introduction : The BR2 Reactor



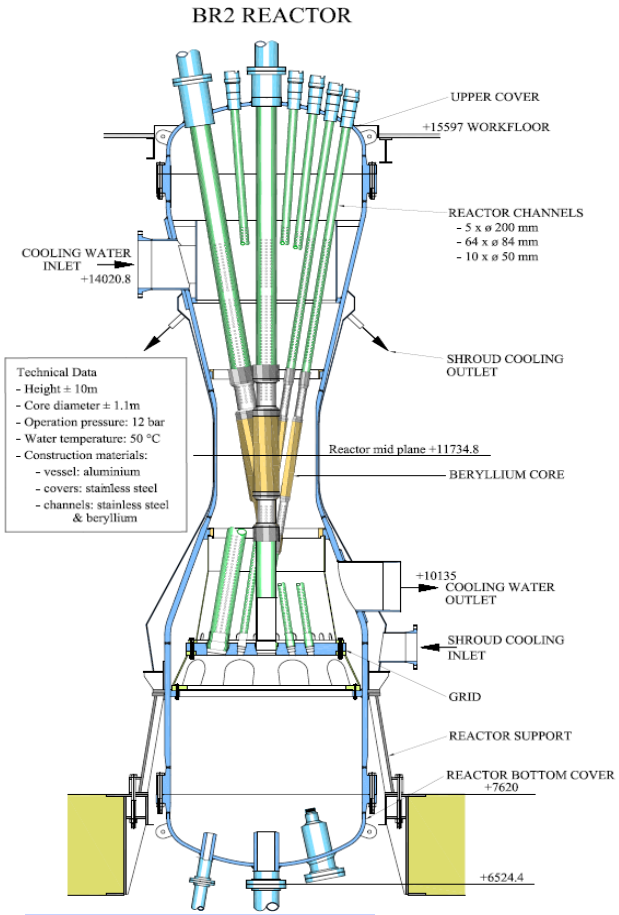
- **Operating parameters**
  - Operating power: 50 – 100 MW
  - Operating cycle: 21 or 28 days
  - Operating regime before refurbishment : 5 or 6 cycles per year
  - Operating days before refurbishment : 120 – 140 days per year
- **Moderators**
  - Light water
  - Beryllium
- **Primary coolant**
  - Light water
  - Pressure : 12 bars
  - Temperature : 40 - 45 °C
  - Flow-rate : 6 500 m³/h
- **Control rods**
  - Hafnium since 2010 (previously, cadmium)

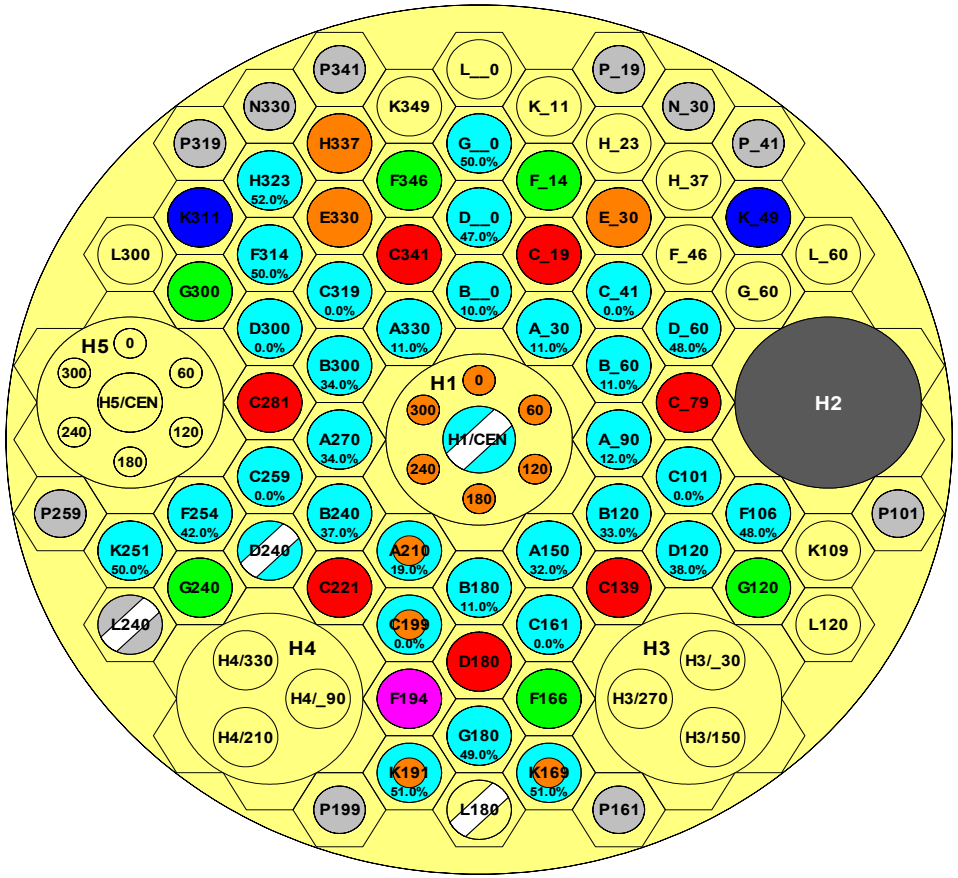
100 MW

SCK•CEN

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

1. Introduction : The BR2 Reactor

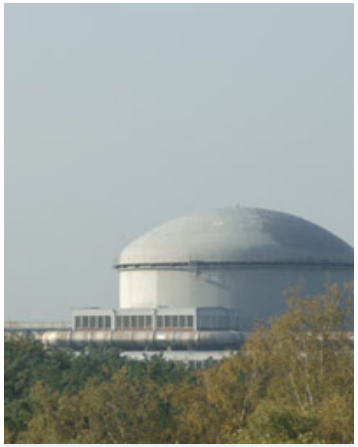


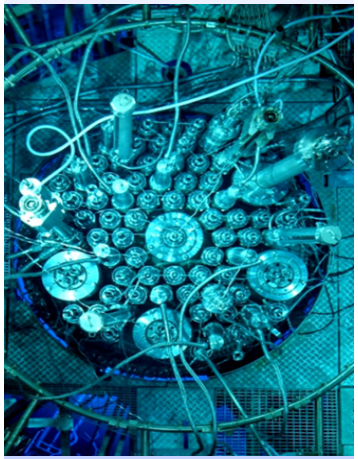


100 MW

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

2. Current Mo-99 Production at BR2





- The BR2 reactor has currently with **7.800 six-day curies** per week the **largest** installed irradiation capacity worldwide for the production of Mo-99.

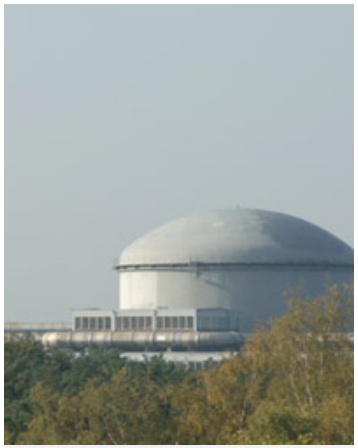
Reactors	Countries	Targets	Weekly Irradiation Capacities [six-day curies]
BR2	Belgium	HEU	**7.800**
HFR	The Netherlands	HEU	4.680
NRU	Canada	HEU	4.680
SAFARI	South Africa	HEU/LEU	3.000
LVR-15	Czech Republic	HEU	2.800
OSIRIS	France	HEU	2.400
MARIA	Poland	HEU	2.200
OPAL	Australia	LEU	1.000
RA-3	Argentina	LEU	400

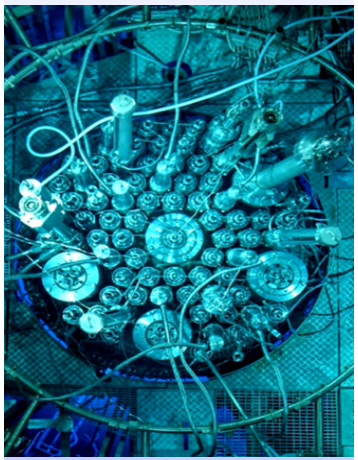
Reference: *NEA/SEN/HLGMR (2014) 2, "The Supply of Medical Radioisotopes – Medical Isotope Supply in the Future: Production Capacity and Demand Forecast for the Mo-99/Tc-99m Market, 2015-2020", OECD/NEA, www.oecd-nea.org, April 2014.*

PONSARD B.

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

2. Current Mo-99 Production at BR2

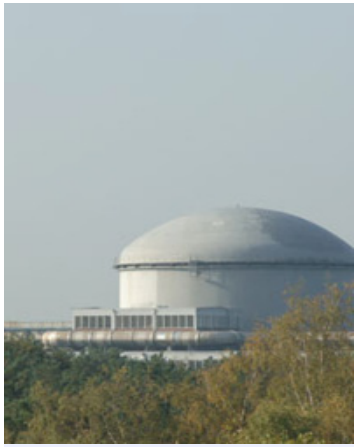


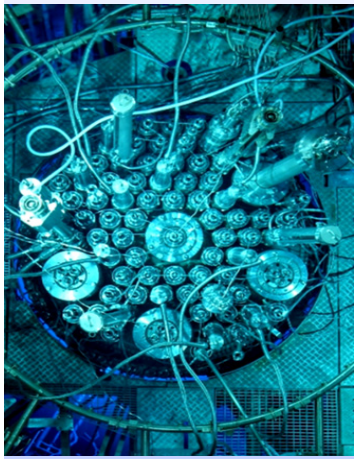


- This **production level** is currently achieved :
  - by the irradiation of highly enriched uranium (**HEU**; 93% U-235) targets in dedicated "PRF" irradiation devices
  - **6 PRF** (Primary Water Cooled Device for Reloadable Fissile Targets) dedicated irradiation devices
  - total irradiation capacity of **75 HEU targets per week**
  - according to an annual operating regime of 6 reactor cycles (20 operating weeks per year), i.e. **140 operating days per year**
- These PRF irradiation devices are designed to allow loading/unloading of the 4 to 5 g U-235 **HEU targets** during reactor operation.
- A typical irradiation of 150 hours in a thermal neutron flux of 2.5 x 10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ yields up to 1.000 Ci per target at "EOI" (End Of Irradiation), i.e. **120 six-day curies per target**.

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

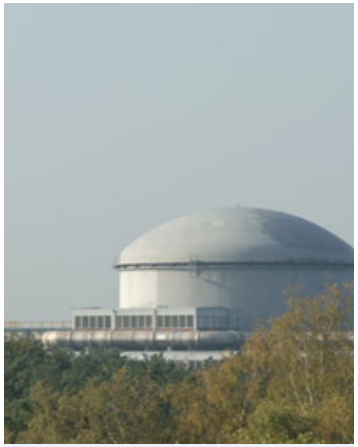
3. Refurbishment of the BR2 Reactor

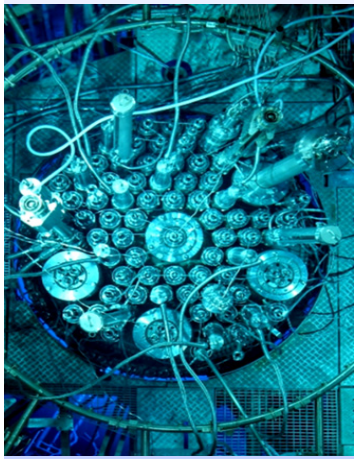


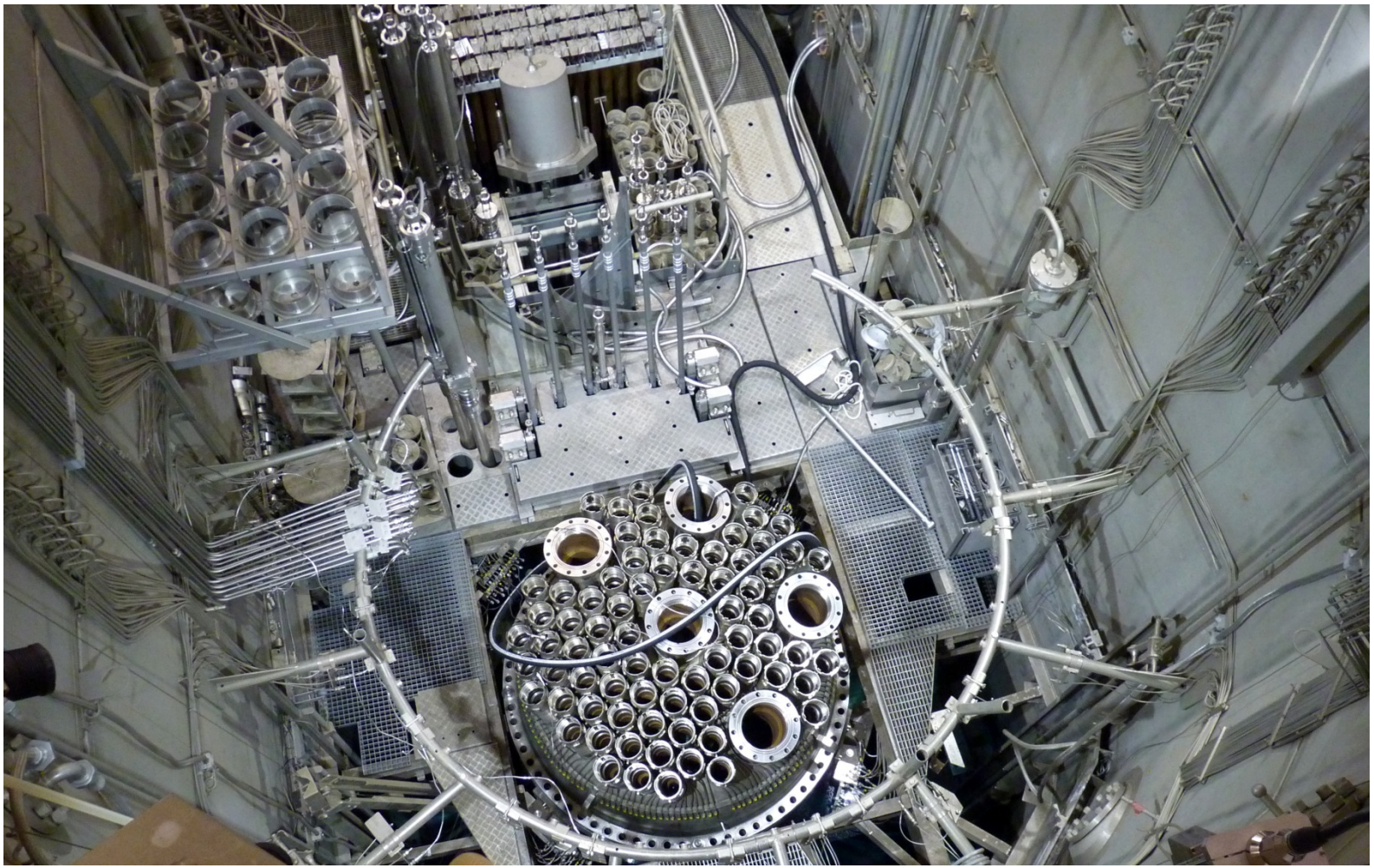


- The BR2 reactor reached its first criticality in **June 1961** and routine operation started in **January 1963**.
- The compact core is composed of a **beryllium matrix** providing **79 irradiation channels** in which fuel elements, control rods, experimental and production devices are loaded.
- The BR2 reactor is **currently temporarily shutdown** for a period of **16 months** (February 2015 – June 2016) for major refurbishment.
- The preventive replacement of the beryllium matrix will allow **safe and reliable reactor operation** for another period of at least 10 years.
- Taking into account the upgrade that took place in the late 1960s, the current refurbishment is the 4th major maintenance of the BR2 reactor and the **3rd replacement of the Be matrix**.

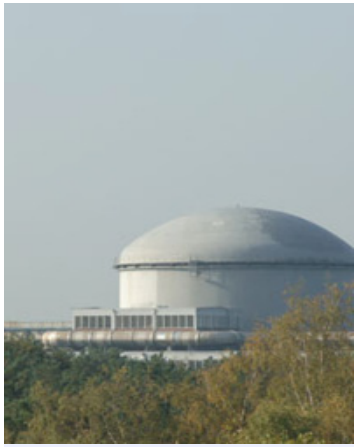
3. Refurbishment of the BR2 Reactor

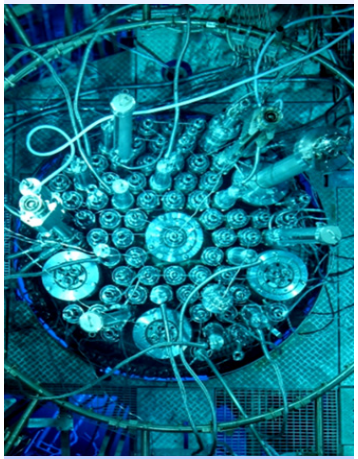


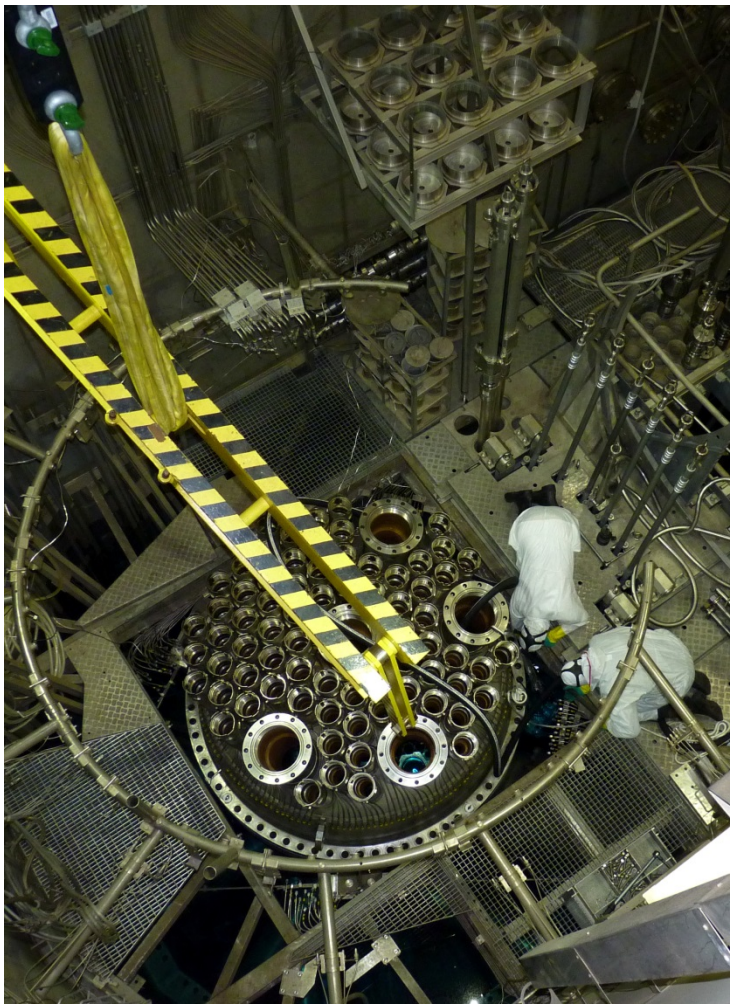


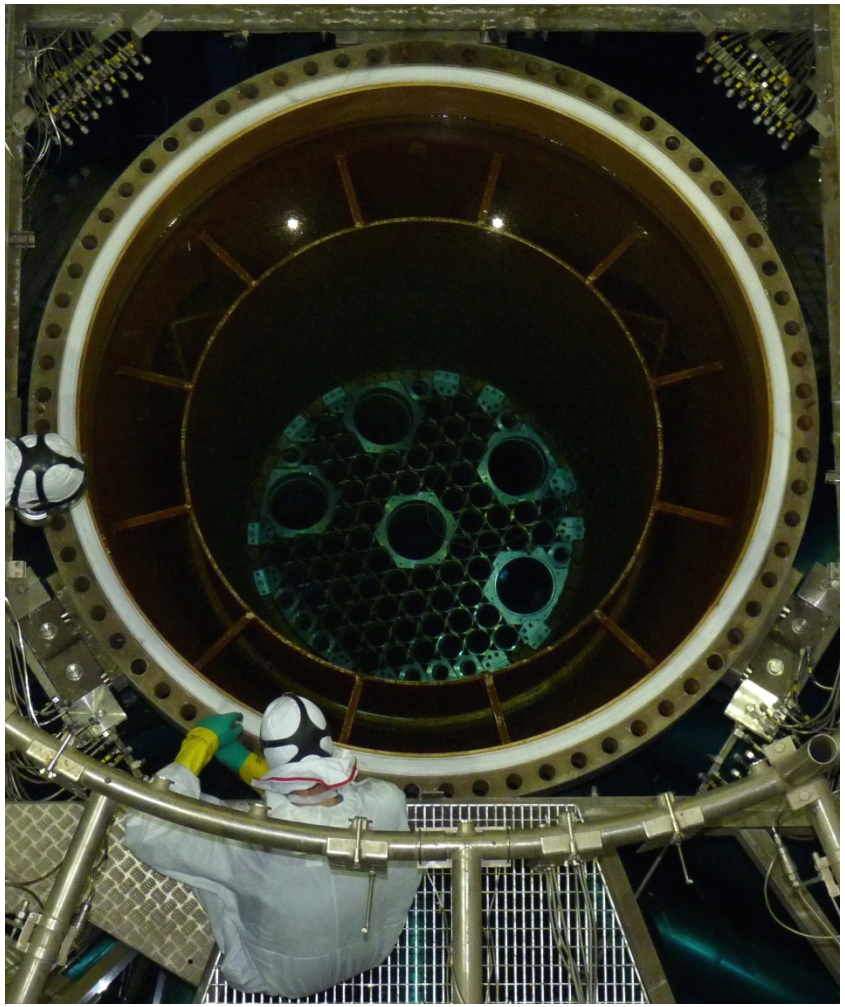


3. Refurbishment of the BR2 Reactor



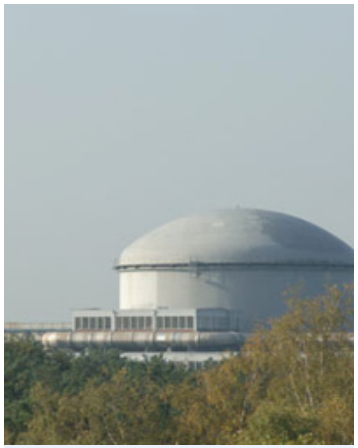


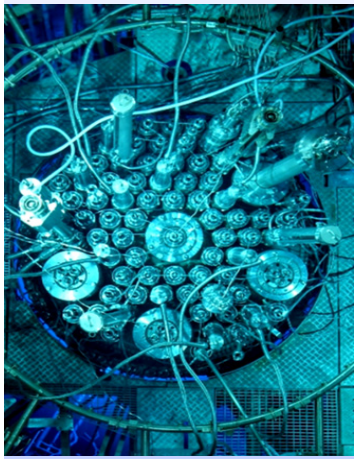


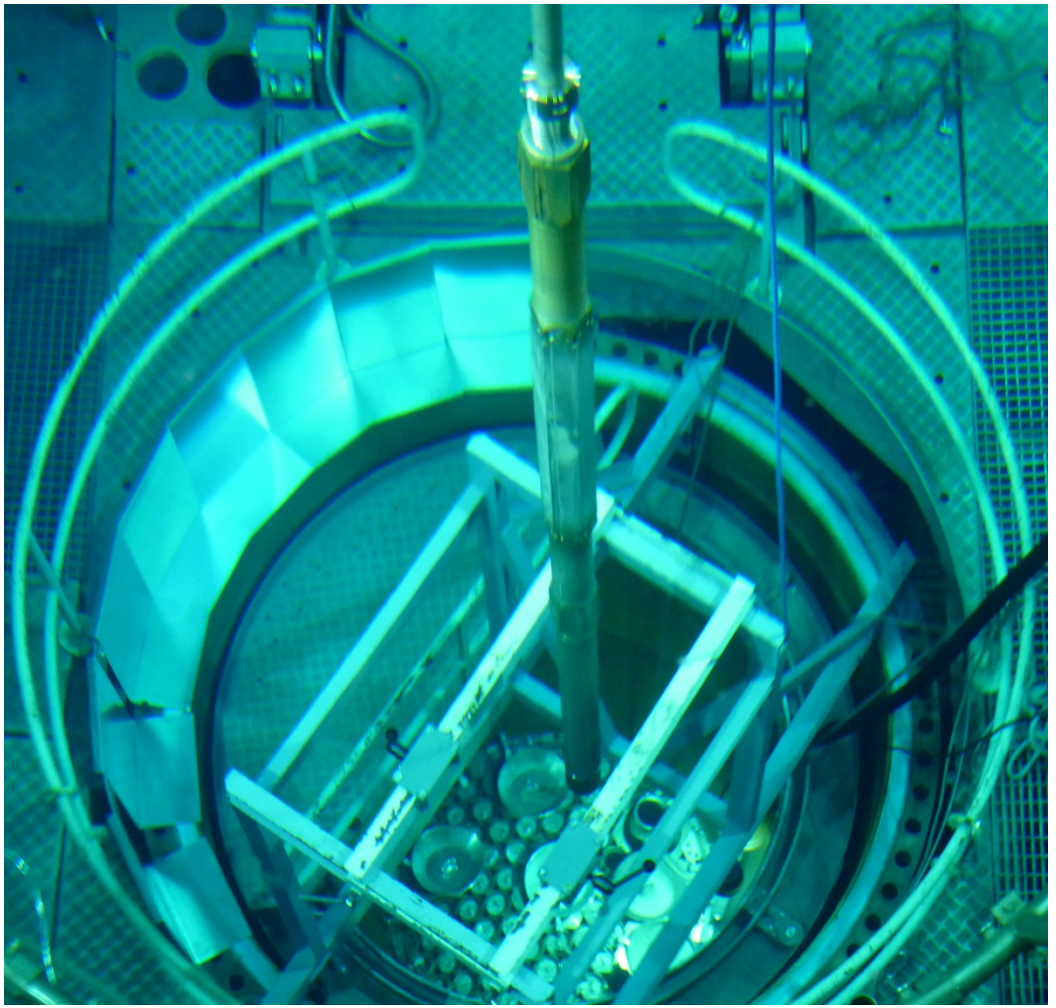


SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

3. Refurbishment of the BR2 Reactor

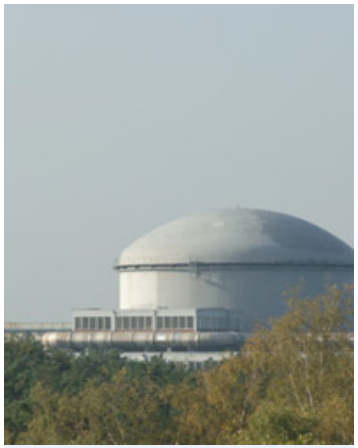


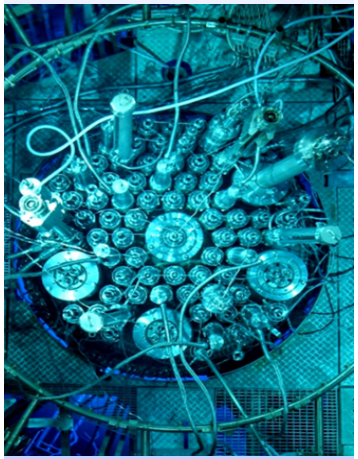




SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

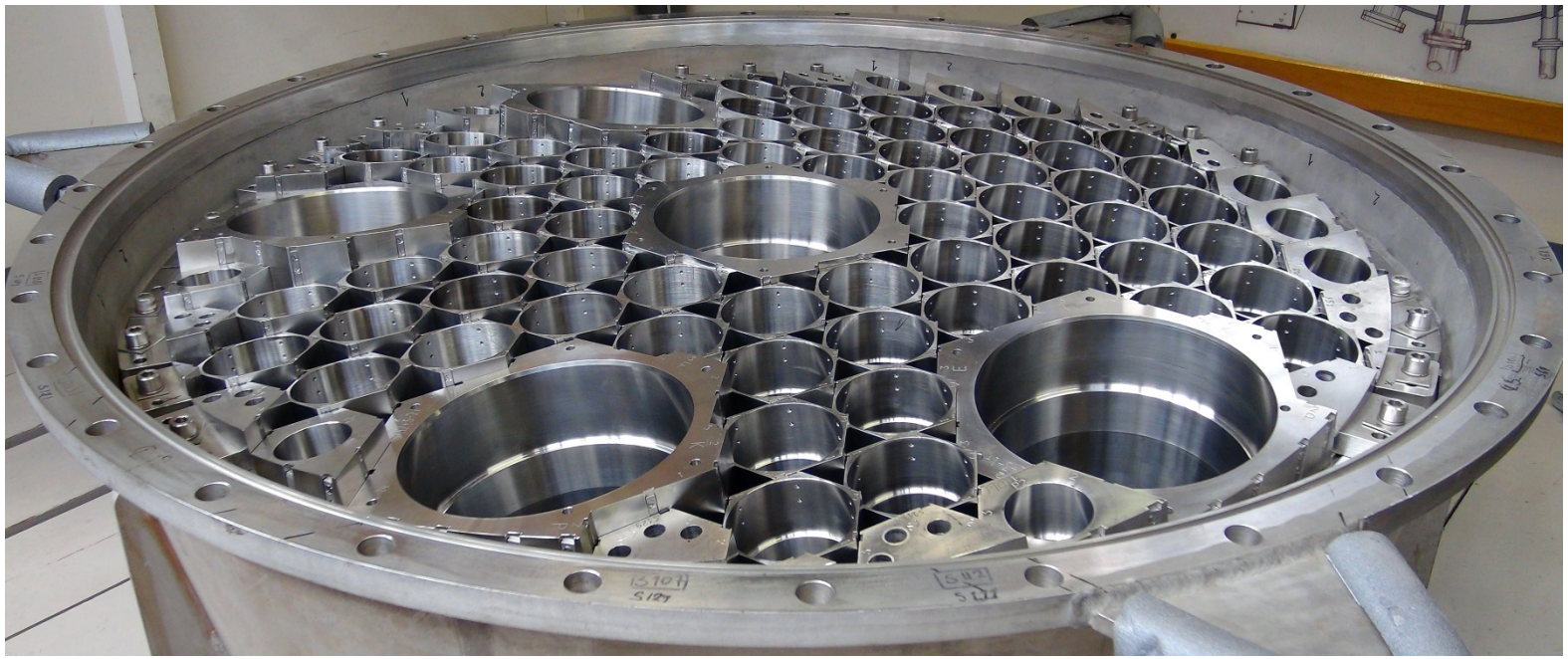
3. Refurbishment of the BR2 Reactor





BR2's refurbishment is "on track" !!!

New beryllium matrix installed in BR2's mock-up pressure vessel in August 2015

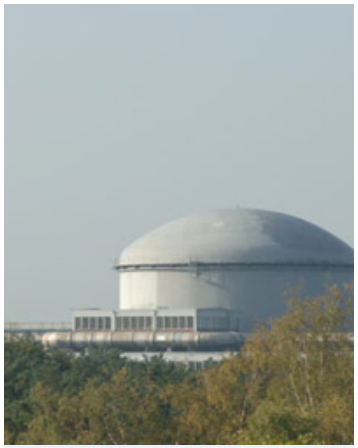


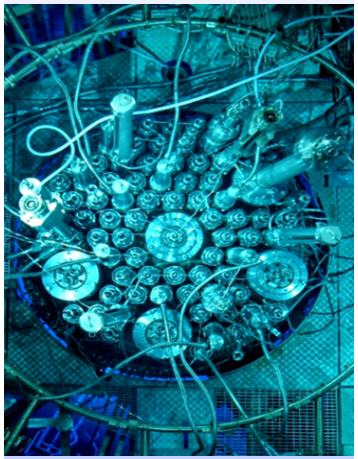
The new beryllium matrix will be installed in BR2's pressure vessel begin of 2016 after the pressure vessel inspection programme scheduled in September – October 2015.

The programme is progressing very well according the established schedule which expects BR2 resuming routine operation from July 2016.

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

4. Future Mo-99 Production at BR2

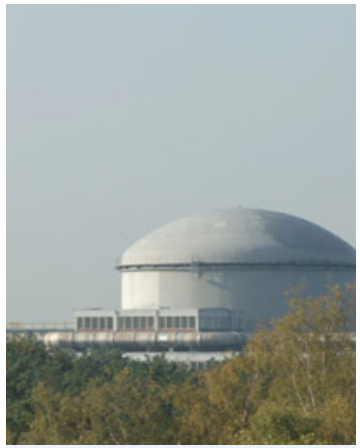


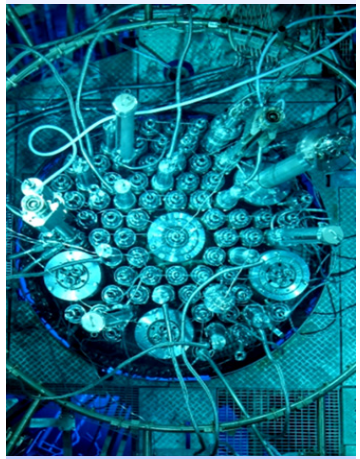


- SCK•CEN is considering **upgrading** BR2's operating regime and **increasing** its yearly irradiation capacity for Mo-99 production if compatible with the full-cost recovery principle defined by the OECD/NEA High-Level Group on the Security of Supply of Medical Radioisotopes (HLG-MR):
  - up to 8 reactor cycles per year (27 operating weeks per year)
  - 190 operating days per year
  - potential production capacity increase from 156.000 up to 210.600 six-day curies per year (i.e. **+35%)**
  - irradiation of HEU targets in a first phase
  - irradiation of **LEU targets** after their qualification in 2016 - 2017

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

5. Test irradiations of LEU targets for Mo-99 Production



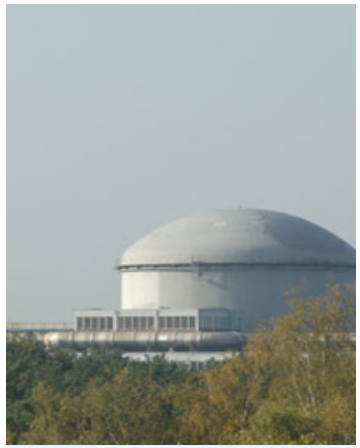


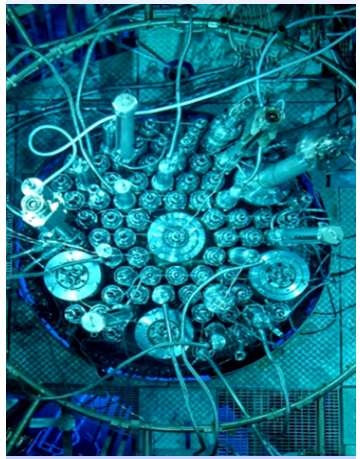
PONSARD B.

- In support of **non-proliferation objectives** and global reliability of supply, two separate and independent projects have been initiated in 2012 with the processors (MALLINCKRODT and IRE) and the target manufacturer (CERCA) to develop low enriched uranium (**LEU; 19,75% U-235**) targets for the production of Mo-99 without the use of HEU.
- The higher-density LEU targets specifications and geometries – **confidential matter** – have been determined in a consensus between the target manufacturer, the involved reactors and the processors taking all parameters into account as safety aspects, manufacturing constraints, impurities in the target material, irradiation positions, irradiation conditions, chemical processing, waste management, transportation issues, …

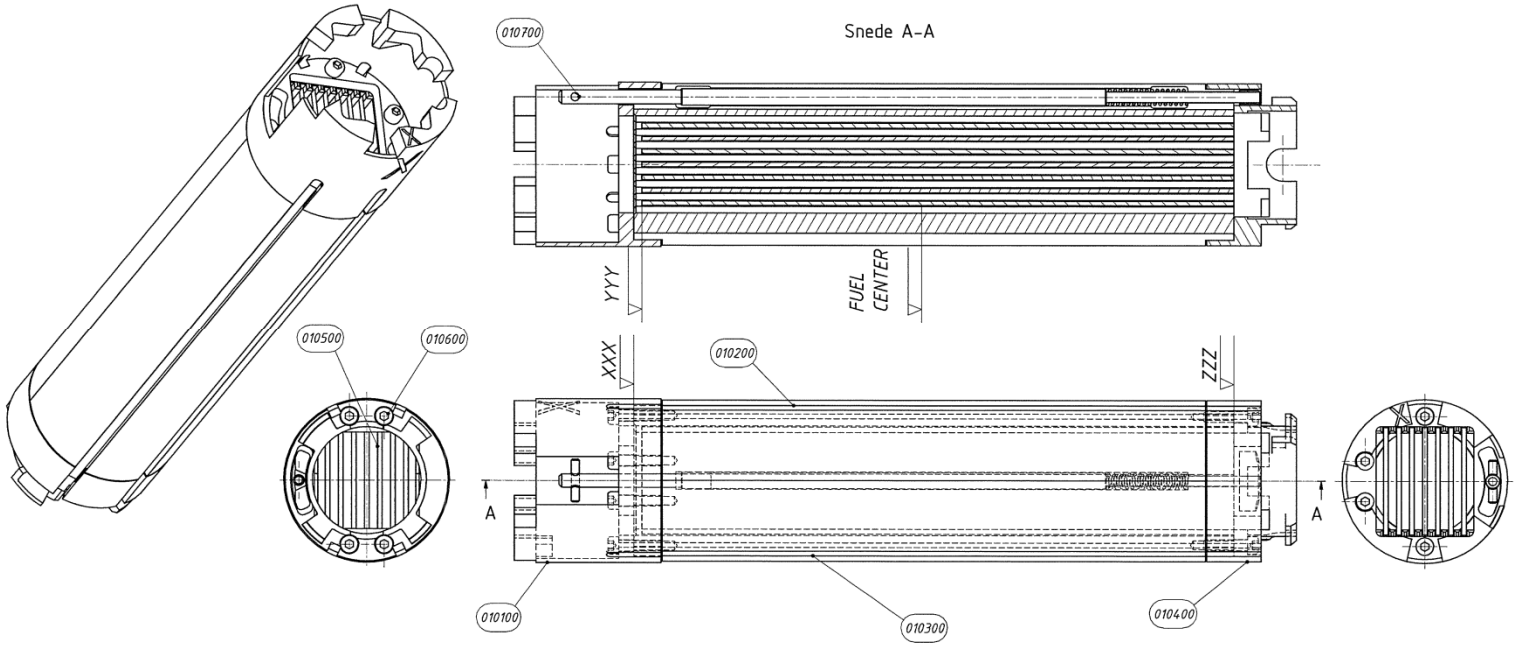
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

5. Test irradiations of LEU targets for Mo-99 Production





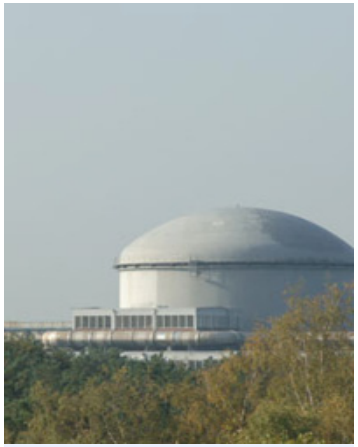
- **New irradiation baskets** have been designed by SCK•CEN and manufactured to accommodate the **LEU targets** in BR2's existing PRF irradiation devices without too significant irradiation capacity loss.

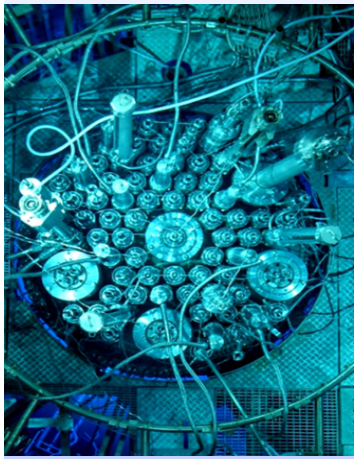


PONSARD B.

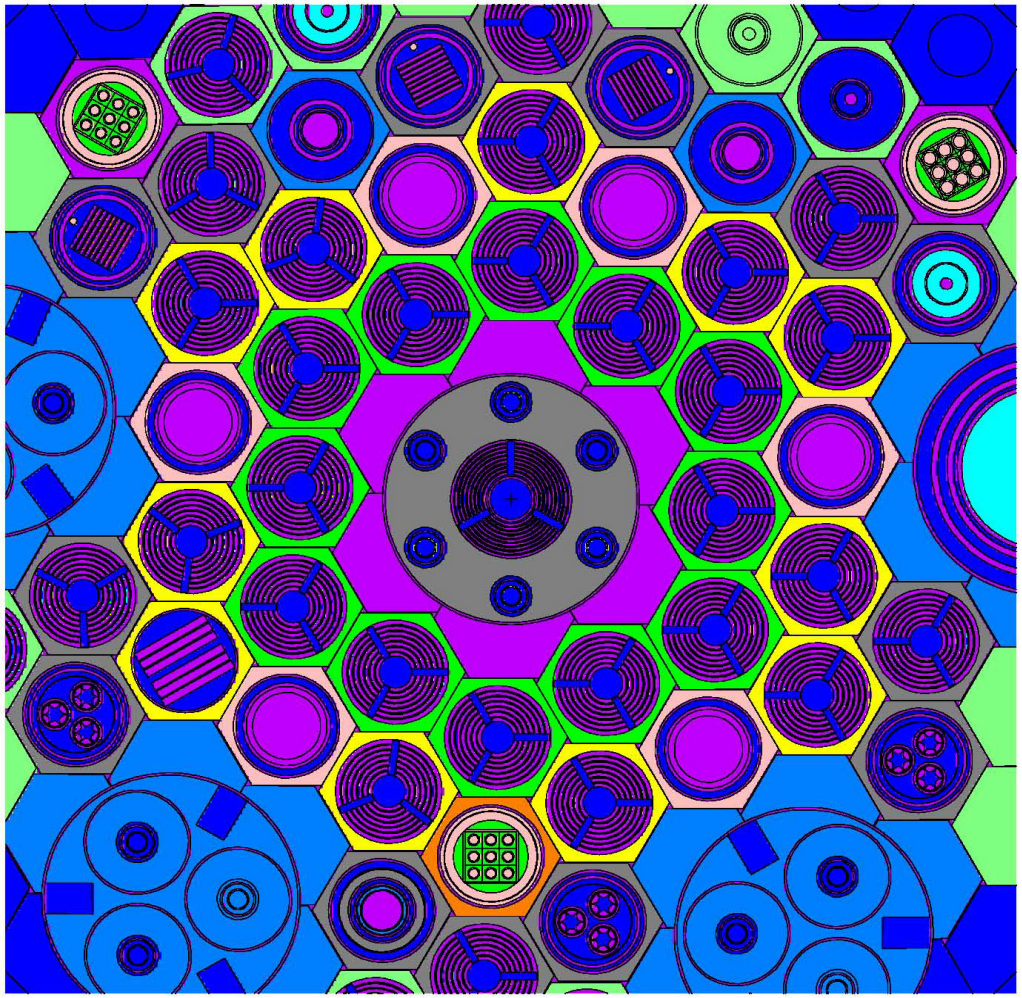
SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

5. Test irradiations of LEU targets for Mo-99 Production



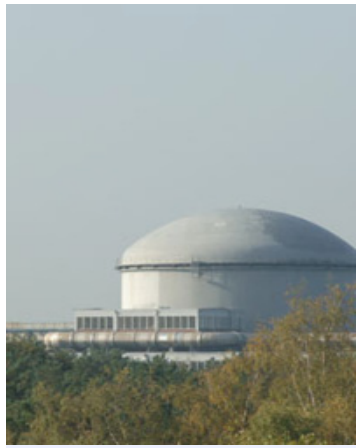


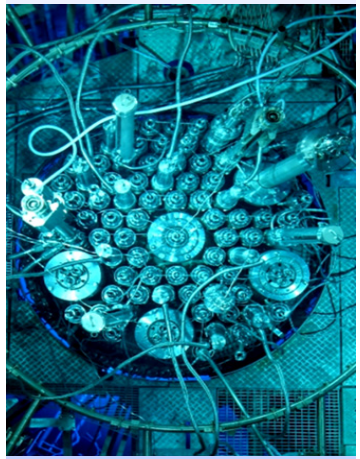
- Detailed neutronic calculations have been performed by the **MCNPX 2.7.0** full core 3-D model of the BR2 reactor to compare the **isotopic vectors** from the irradiation of **HEU** and **LEU** targets in representative conditions for future **Mo-99** production.



SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

5. Test irradiations of LEU targets for Mo-99 Production





- The **conversion of HEU into LEU targets** would lead to:
  - decrease the **Mo-99 activity** produced per target by 20% to 25% at "EOI" (End Of Irradiation)
  - increase the **target consumption** by the same factor to maintain an equivalent level of Mo-99 production
- However, the six PRF irradiation devices will offer an increased **weekly irradiation capacity** of 78 LEU targets instead of 75 HEU targets currently:
  - the **global loss of irradiation capacity** for Mo-99 production in the BR2 reactor associated to the **full conversion** from HEU into LEU targets would be limited to approximately 15% to 20%

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

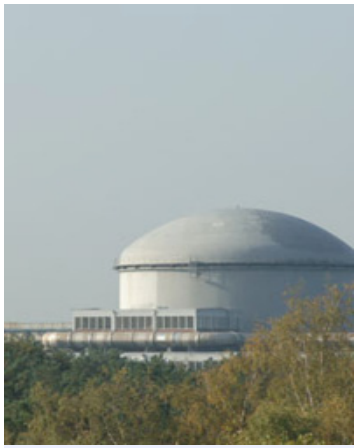
5. Test irradiations of LEU targets for Mo-99 Production

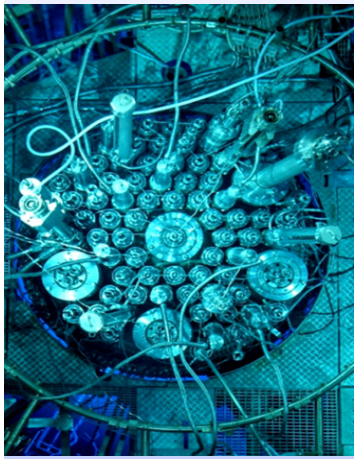
- **Five test irradiation campaigns of LEU targets** (34 targets in total) have been successfully performed in the BR2 reactor in 2014 before its refurbishment.
- The LEU targets have been irradiated for **up to 200 hours**.
- The **maximum heat flux** on the targets has been increased gradually to reach a level close to the **current safety limit** fixed by the Safety Committee for the irradiation of targets in a PRF device.
- The **analysis of water samples** taken during the unloading of the LEU targets from the PRF irradiation devices demonstrated that there was **no fission products release**.

PONSARD B.

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

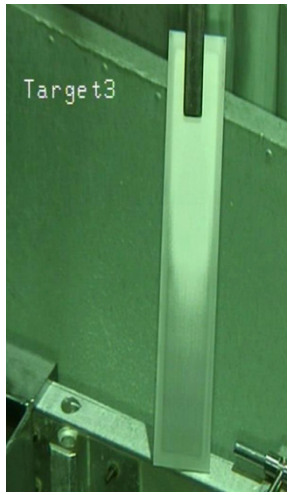
5. Test irradiations of LEU targets for Mo-99 Production

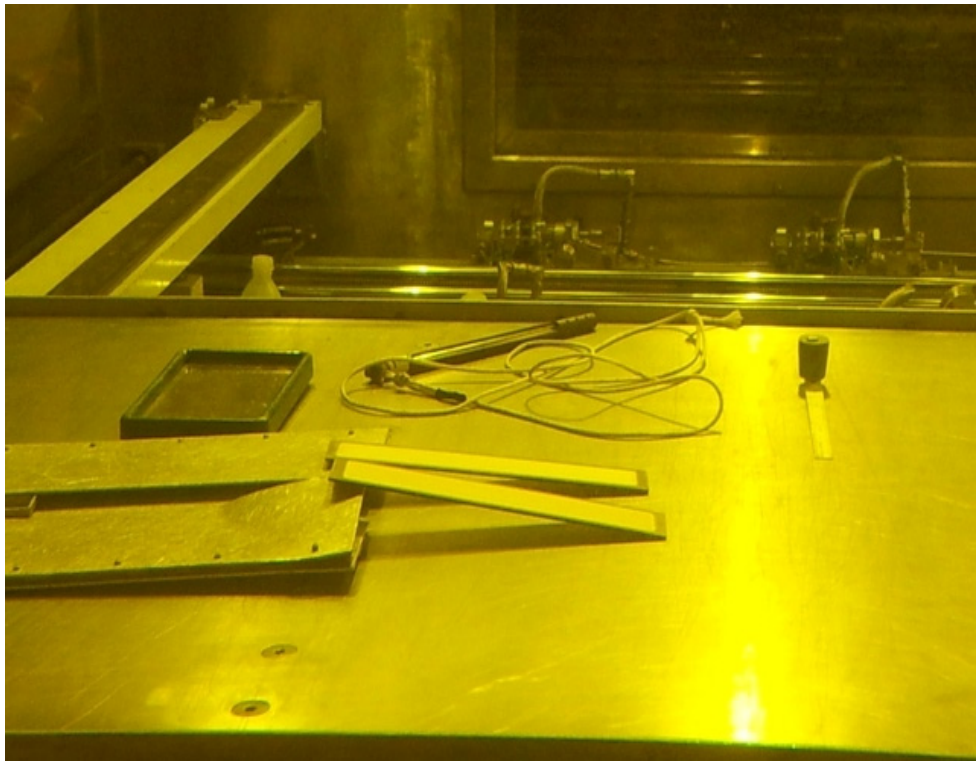




PONSARD B.

The **visual inspection** showed that there was no issue related to the irradiation and handling procedures.

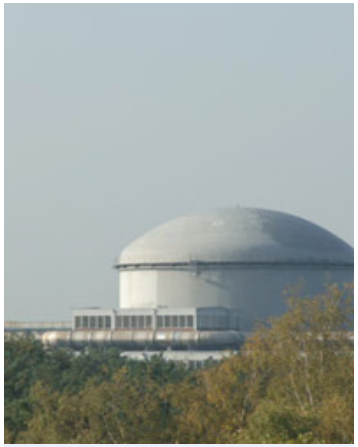


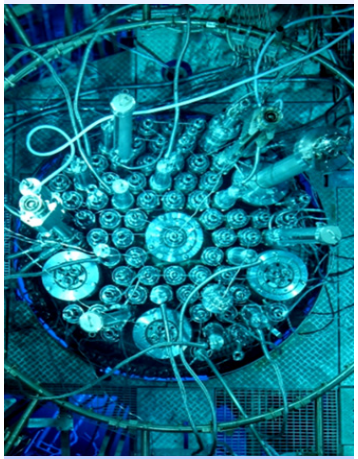


The **non-destructive "PIE"** (Post Irradiation Examination) showed no swelling and only minor oxide growth.

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

6. Conclusion





- Five irradiation campaigns have been **successfully** performed in the BR2 reactor in 2014 for the qualification of LEU targets.
- The **full conversion from HEU into LEU targets** for Mo-99 production will be gradually achieved in agreement with the processors MALLINCKRODT and IRE in the period 2016 - 2017.
- The **loss of irradiation capacity** for Mo-99 production in the BR2 reactor would be limited to approximately 15% to 20% by the conversion process.
- However, the **refurbishment of the BR2 reactor** currently performed during 16 months in 2015-2016 will contribute substantially to the **long-term** and **reliable supply** of Mo-99 until **2026 at least**.

Thank You For Your Attention …

PONSARD B.

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

Copyright notice

SCK•CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSEL
Operational Office: Boeretang 200 – BE-2400 MOL