Silicon doping at SCKCEN

Presented by **Karel sebrechts**– 16/06/2025

sck cen
Belgian Nuclear Research Centre

Exploring
a better tomorrow

At Europe's heart

Our Belgian Nuclear Research Centre is based in Mol and Brussels. Our pioneering research is **internationally renowned**

At the forefront of progress

In 1952, we started to explore the possibilities of nuclear science and applications that could **significantly change the world**

Mirroring societal needs

- Climate change
- Circular economy
- Fight against cancer

What does it take to explore a better tomorrow?

Infrastructure

Unique facilities are a decisive facilitator to perform pioneering research

Expertise

Over 900 employees dedicate themselves to developing peaceful nuclear applications

Partnerships

We join forces across the world to stimulate groundbreaking progress in society

Annual turnover

2022

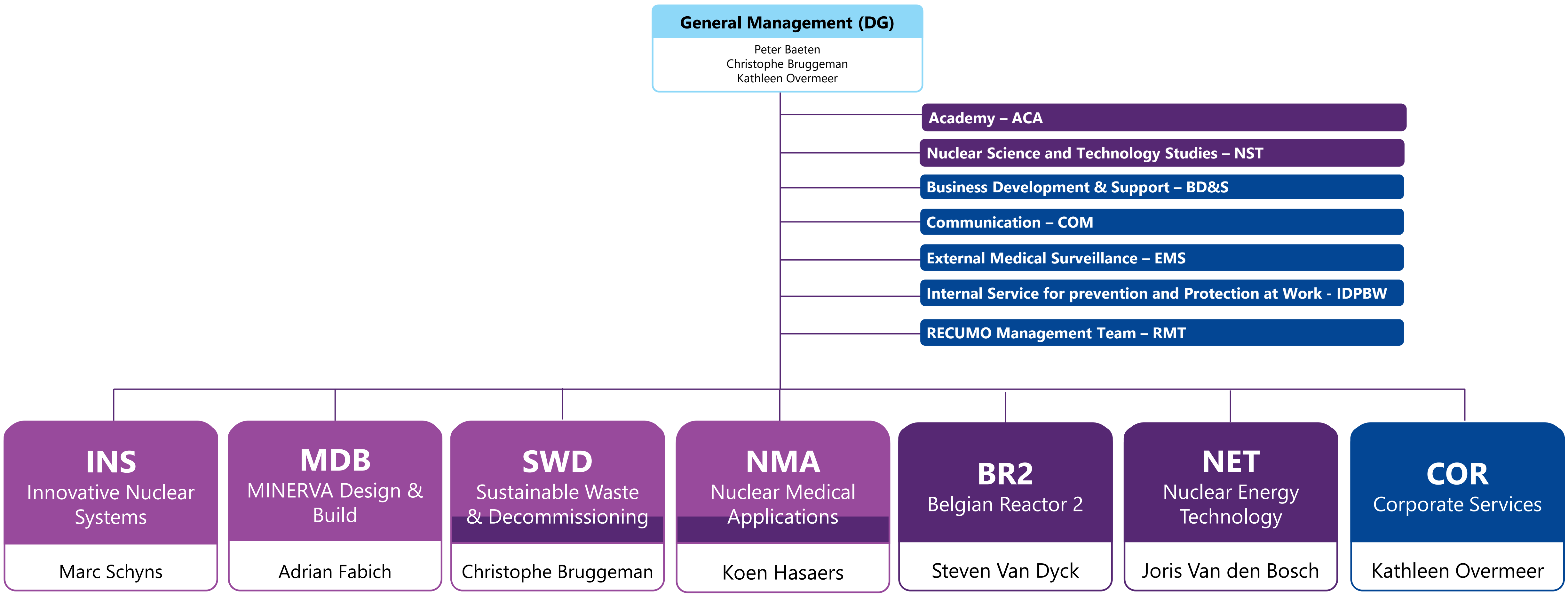
SCK CEN in figures
2021

966
EMPLOYEES

13 years
of service on average

39%
with an
academic degree

54
nationalities


General Management (DG)
Peter Baeten
Christophe Bruggeman
Kathleen Overmeer
Academy – ACA
Nuclear Science and Technology Studies – NST
Business Development & Support – BD&S
Communication – COM
External Medical Surveillance – EMS
Internal Service for prevention and Protection at Work - IDPBW
RECUMO Management Team – RMT
INS
Innovative Nuclear Systems
Marc Schyns
MDB
MINERVA Design & Build
Adrian Fabich
SWD
Sustainable Waste & Decommissioning
Christophe Bruggeman
NMA
Nuclear Medical Applications
Koen Hasaers
BR2
Belgian Reactor 2
Steven Van Dyck
NET
Nuclear Energy Technology
Joris Van den Bosch
COR
Corporate Services
Kathleen Overmeer

523
scientific publications and presentations

92
doctoral students

27
PhD's started

108
training courses for third parties

85
countries

It takes partnerships to explore a better tomorrow

Governmental organisations

On behalf of the Belgian government, we play an advisory role and participate in these organisations

OECD

Universities & schools

We ensure the transfer of all nuclear knowledge, skills and attitudes of students and professionals

BNEN

Research centres

Merging our expertise is a driving force to make progress in scientific research

IAEA designated ICERR

Industrial partners

These collaborations provide a strong stimulus for the way in which we move things forward

PANTERA

Fact

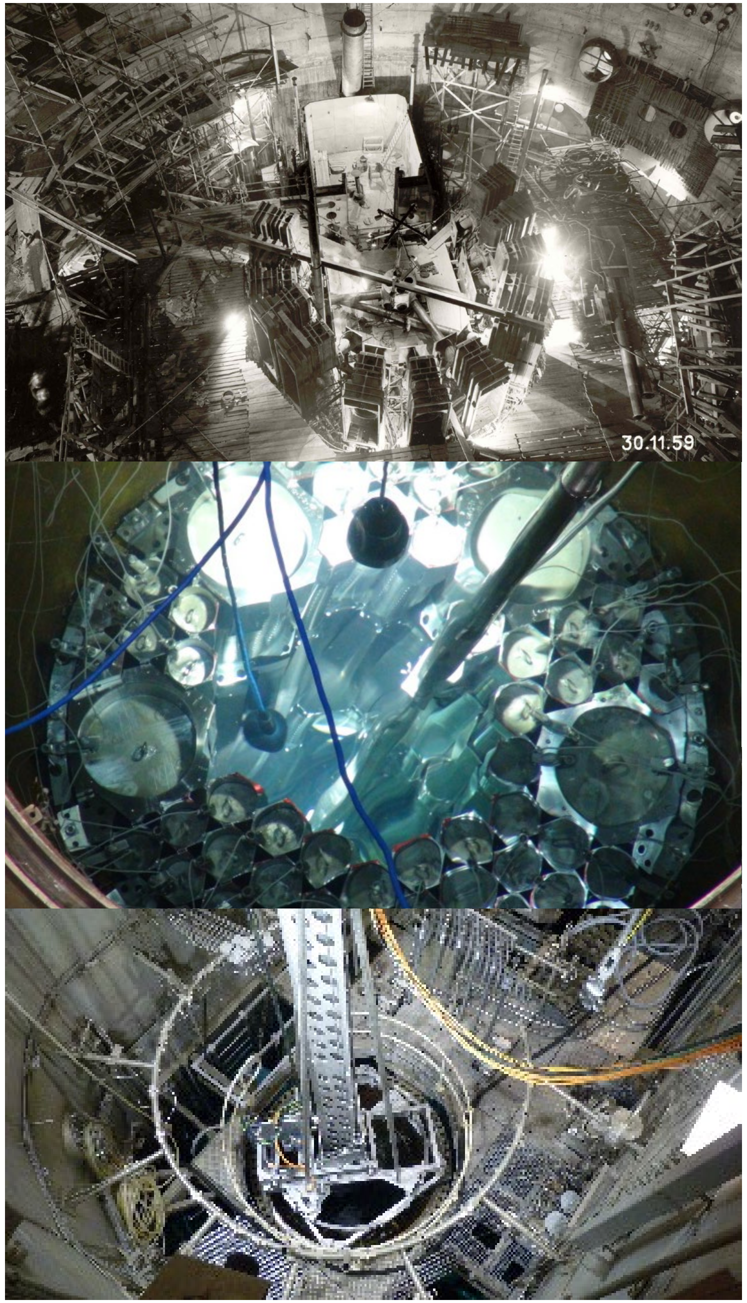
Infrastructure is crucially important
to perform pioneering research
and to contribute to societal development

The BR2 research reactor

Major historic milestones

Technical and regulatory changes

- Design & construction: 1956-1961
- Power upgrade from 75 to 125 MW: 1971
- 1^{st} Replacement of Be matrix: 1979
- Start of periodic safety reassessment: 1986
- First refurbishment (2^{nd} Be change) & reduction of operation: 1997
- Second refurbishment (3^{rd} Be change): 2016
- Enhancement of operational availability: 2020



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.

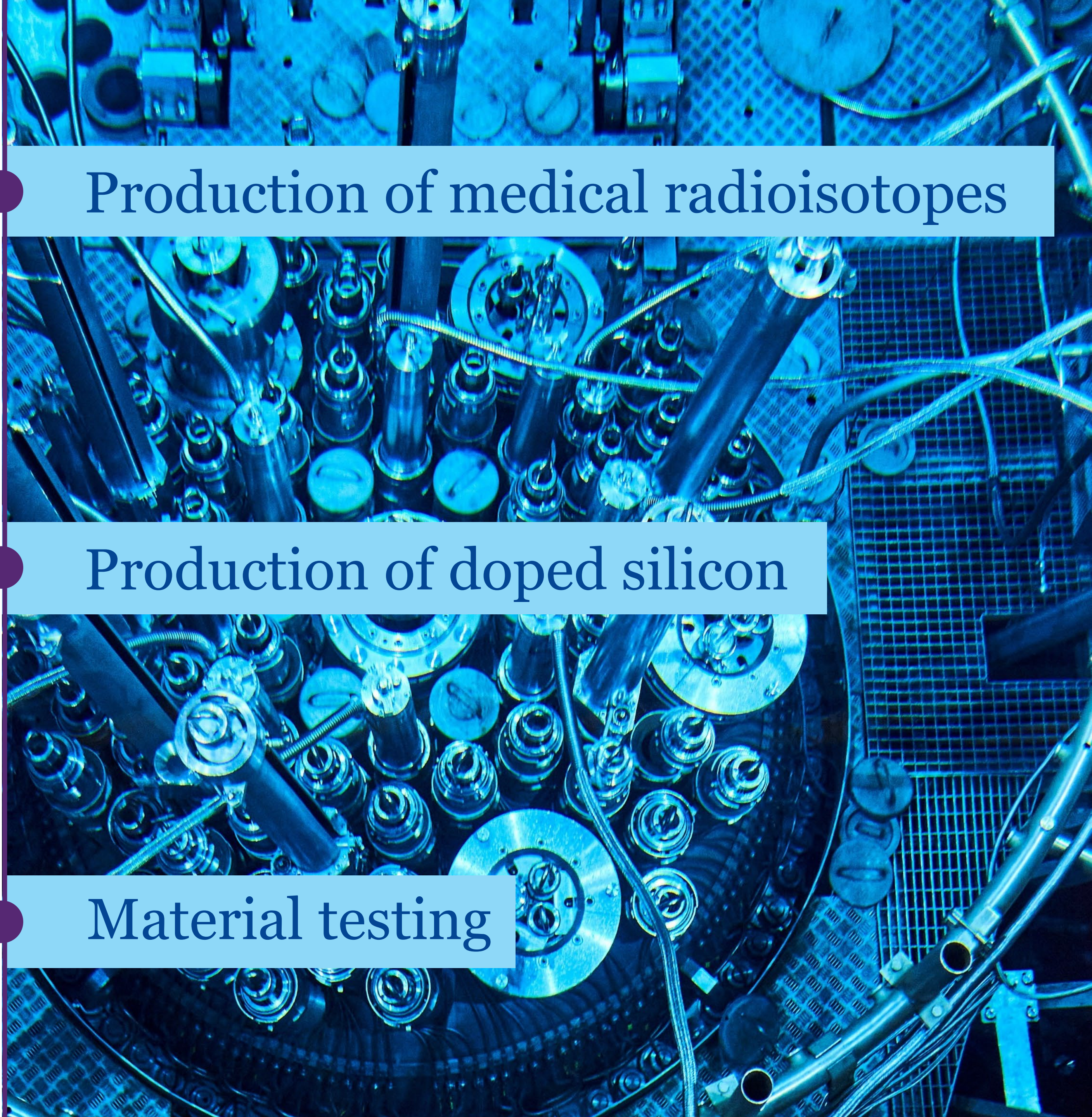
Mission of the BR2

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*

Belgian Reactor 2

SCK CEN is converting its Research Reactor from HEU to LEU Fuel. This is a major step to ensure the continuation of our production



General features of the BR2 reactor

Core characteristics

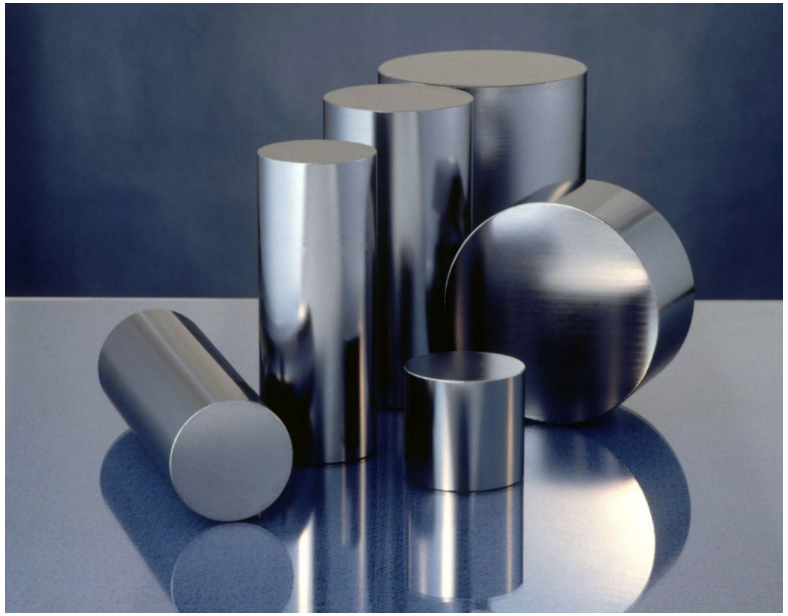
- Heterogeneous core
  - Fueled with HEU UAlx MTR fuel
  - Moderated by light water + metallic beryllium
- High flux available
  - Thermal flux up to 1 $E^{15} n/cm^2 s$
  - Fast flux up to 8 $E^{14} n/cm^2 s$
- Operation with shim rods
- Flexible configuration to achieve cycle length, flux levels and fuel economy

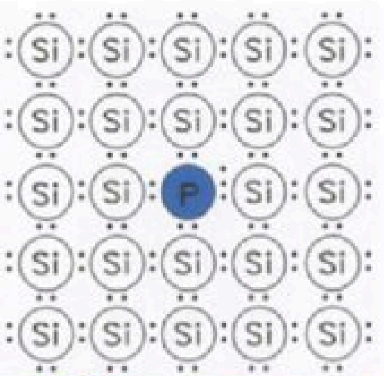
Reactor characteristics

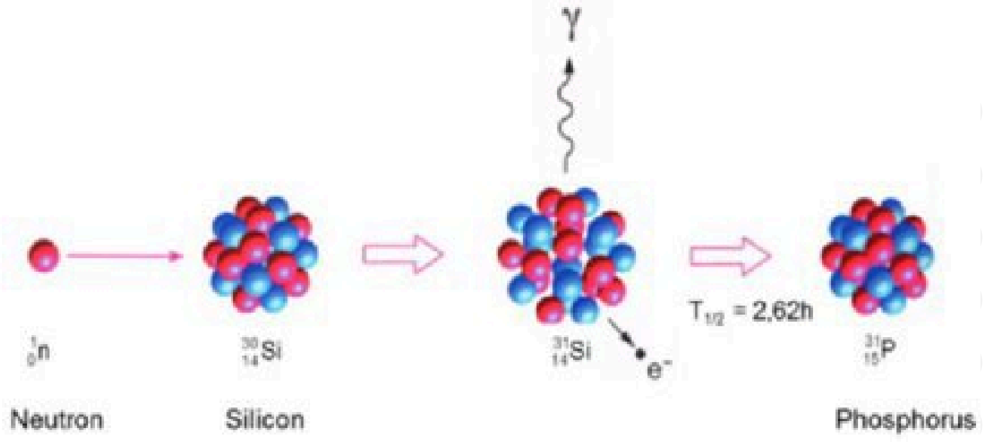
- Light water cooling in closed, pressurised loop
  - Heat flux up to $600 W/cm^2$ allowed, nominal $470 W/cm^2$
  - 1,2MPa pressure, 40-50°C, $7000 m^3/h$
- Open secondary loop with modular cooling tower
  - Thermal power up to 125MW
- Safe shut down in natural converction cooling mode
- Tank in pool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

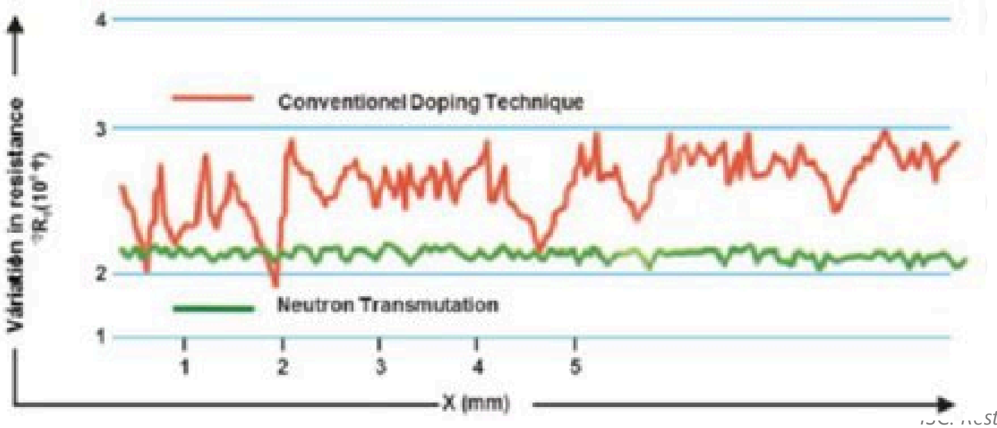
Neutrons for high power electronics

Renewables through neutrons

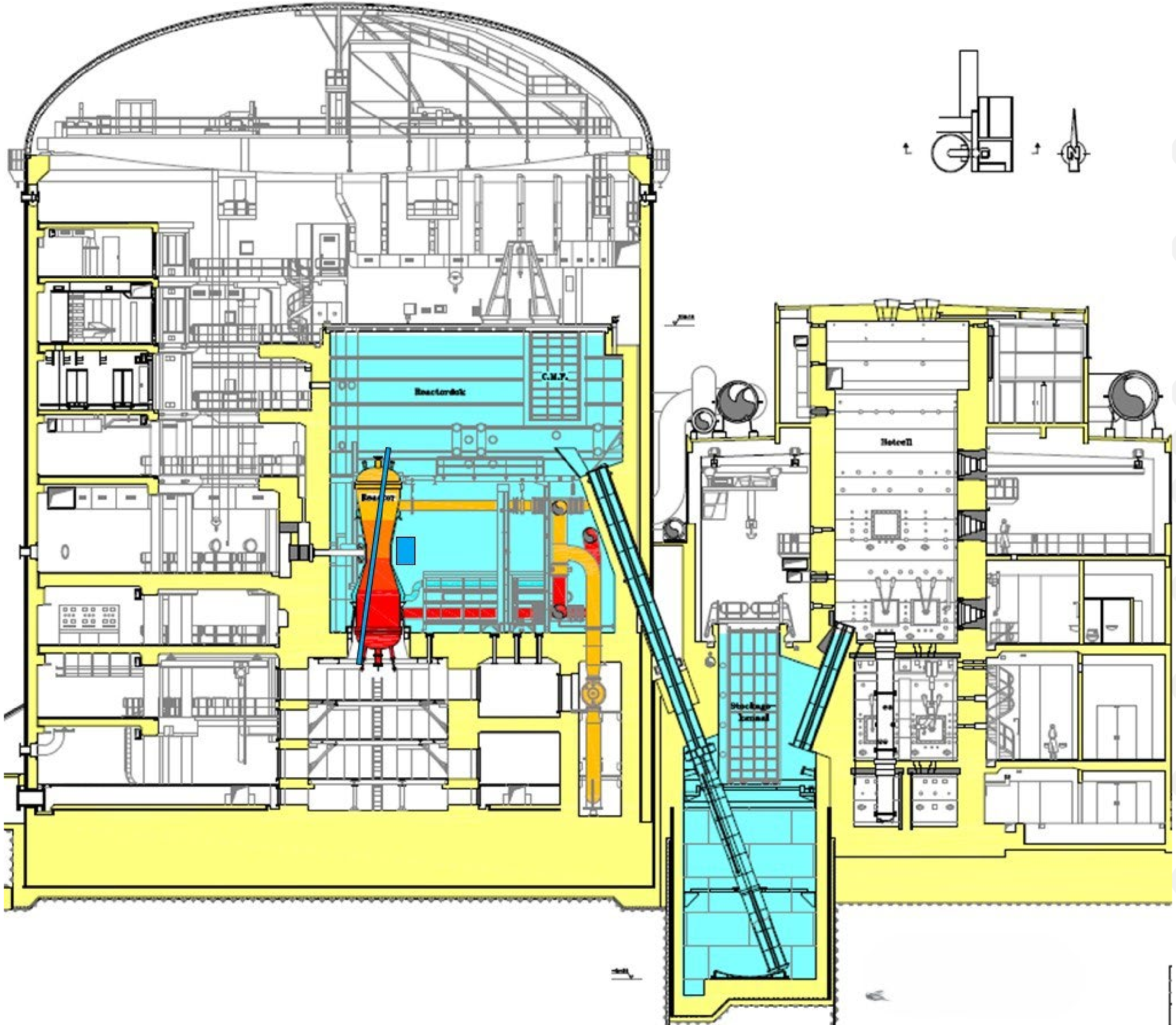






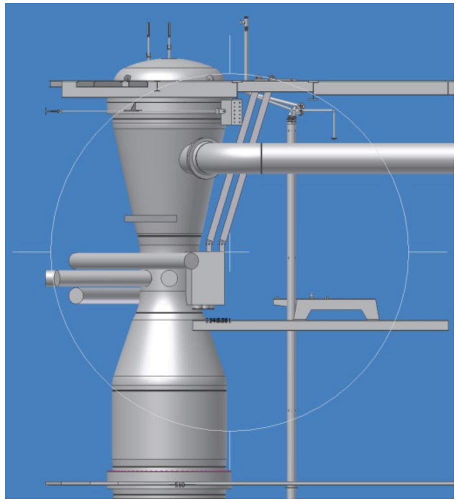


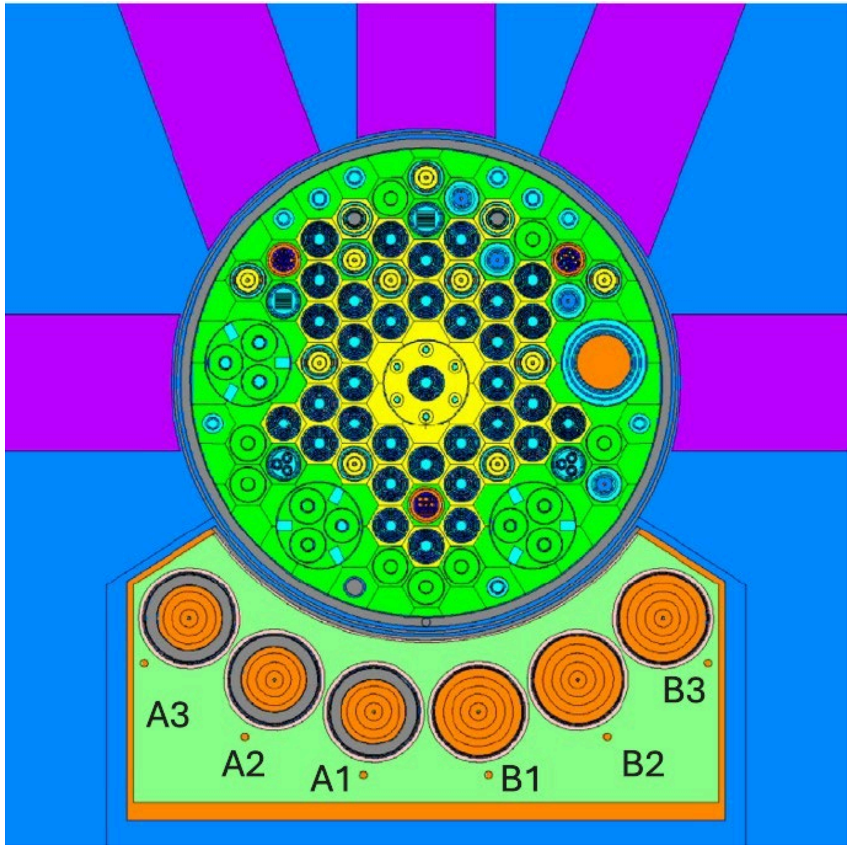
The reactor pool and building

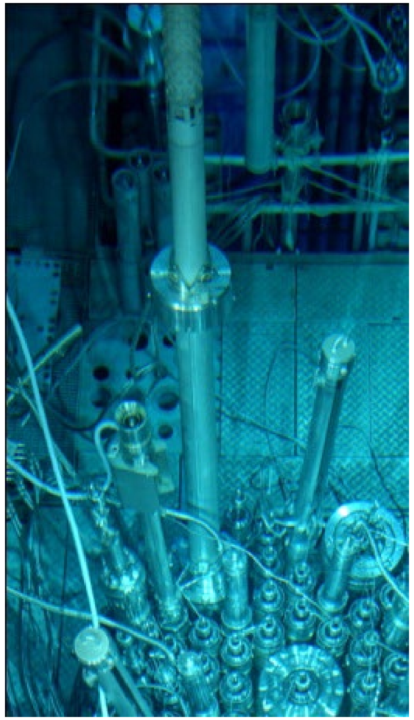


NTD Silicon production at BR2

- Start of Neutron Transmutation Doping of Silicon in 1992
  - SIDONIE facility
  - Installation of pool side facility for 6″ and 8″ ingots POSEIDON in 2008 with 6 channels



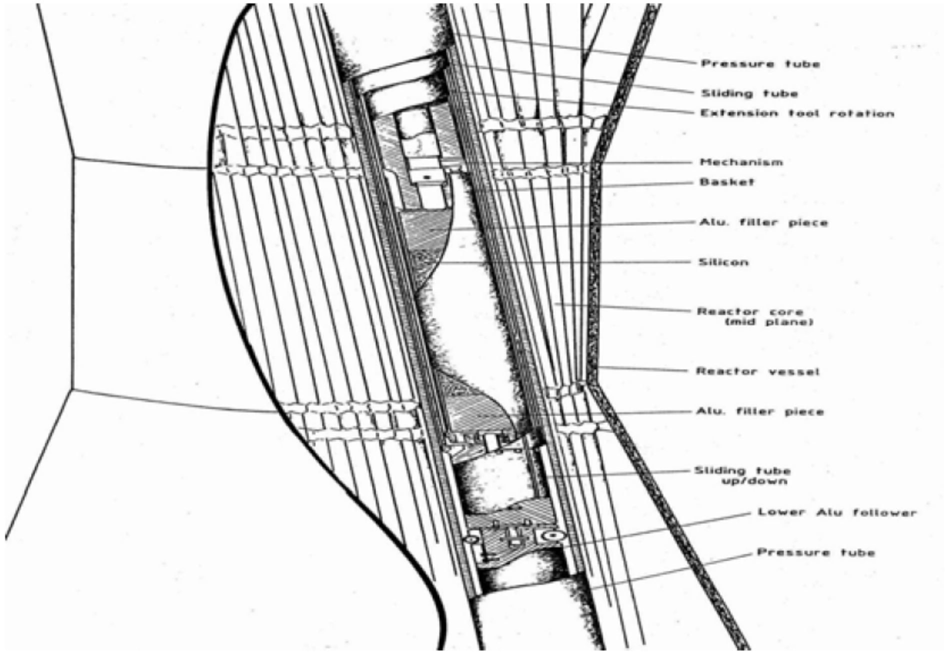




Pool Side Equipment for the Irradiation and Doping Of silicon by Neutrons
Silicon Doping by Neutron Irradiation Experiment

SIDONIE

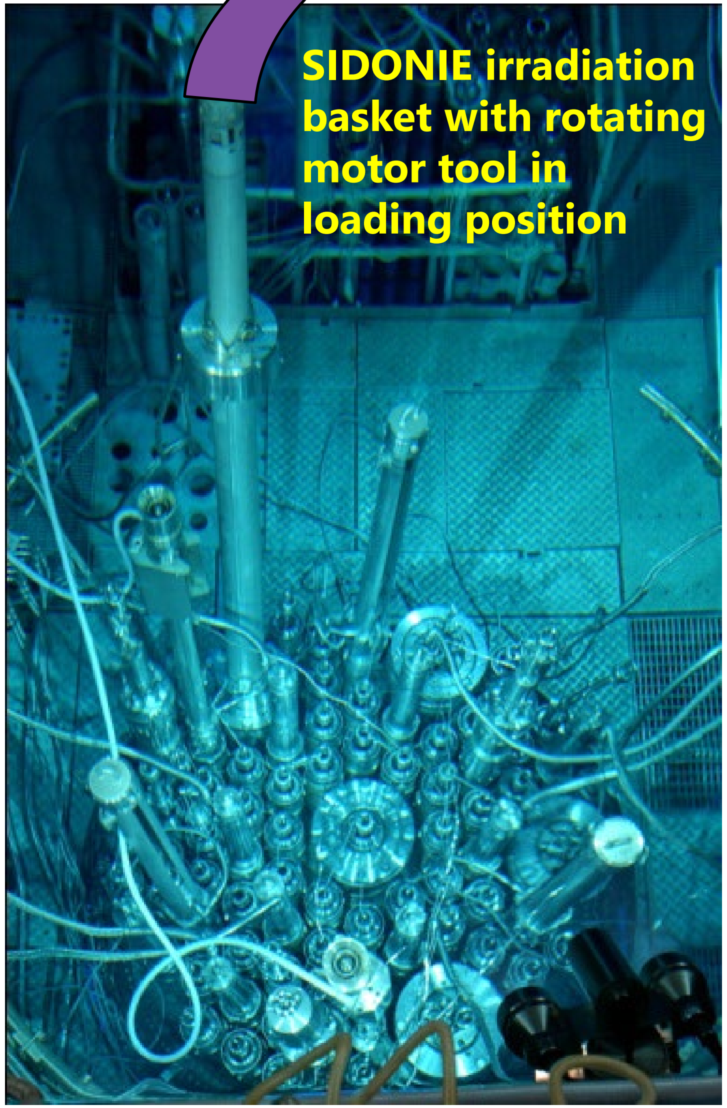
- In vessel irradiation device
  - Inserted in 200mm channel, through core displacement during operation
  - Moderation by Beryllium
  - Cooling by light water from reactor pool
  - Accessible on-line, rotation tool connected to irradiation basket

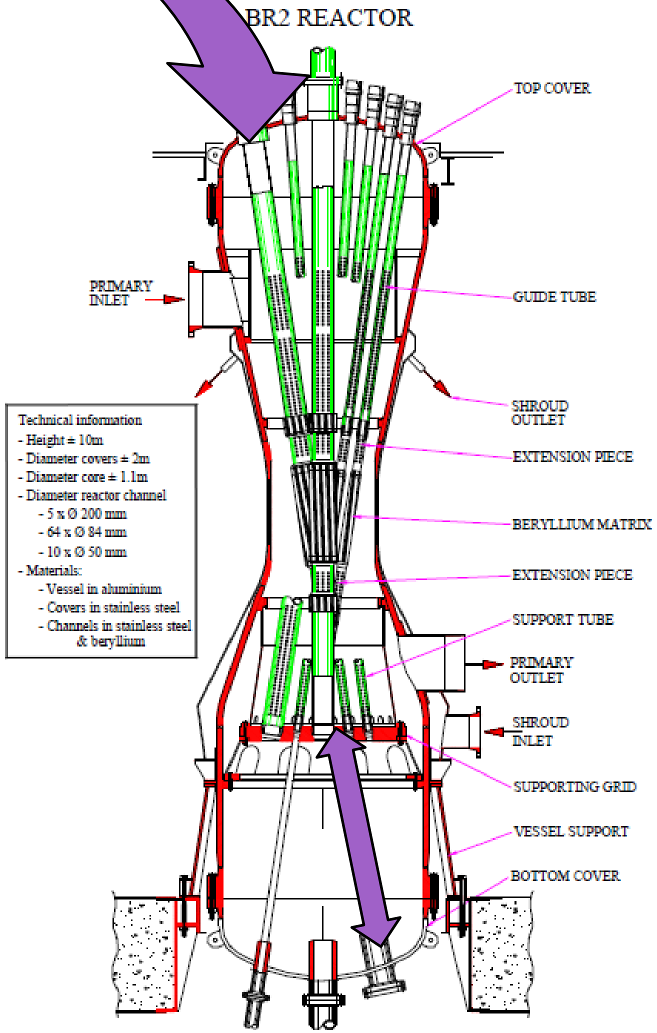


SIDONIE characteristics

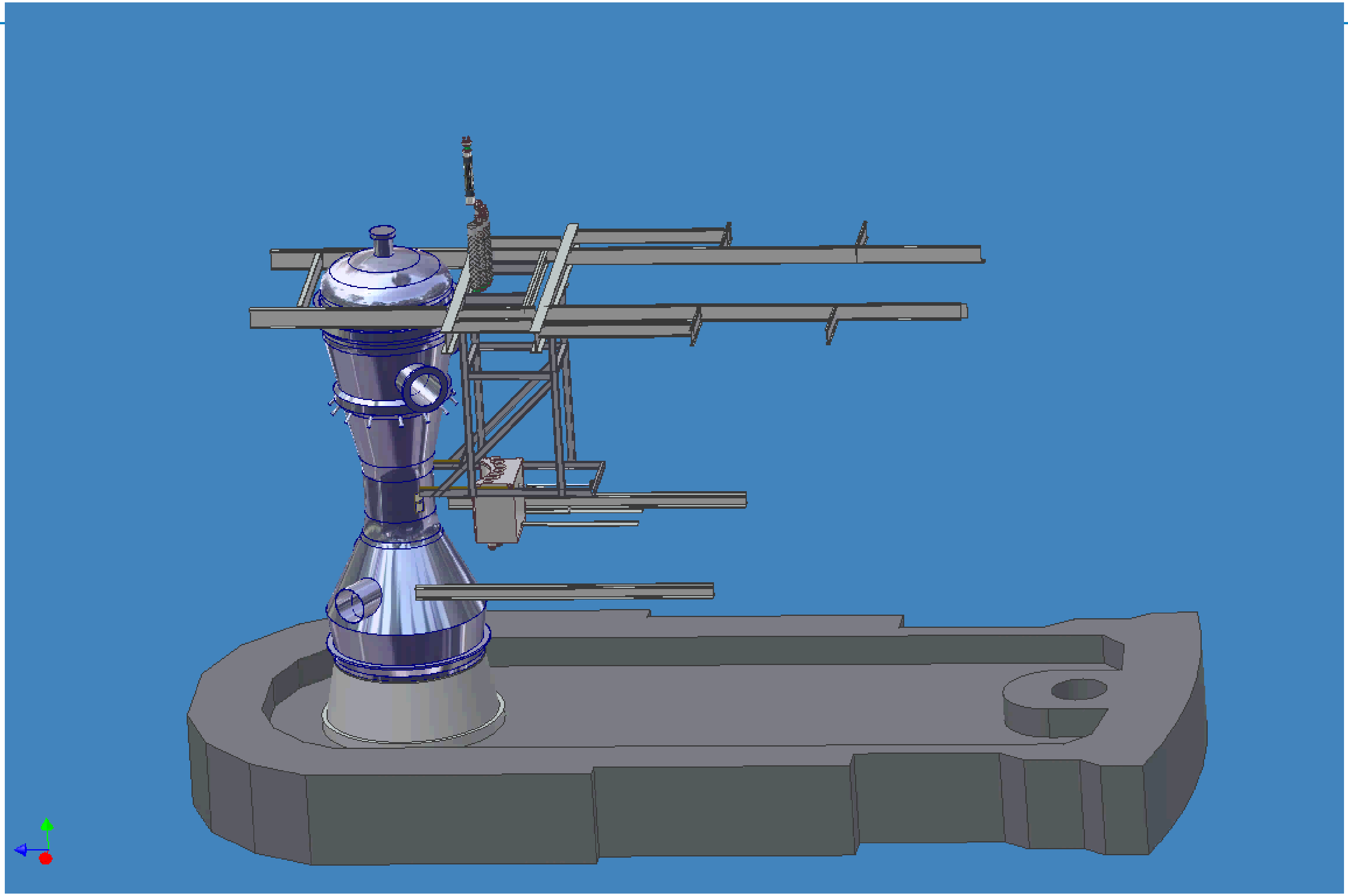
- Typical thermal flux 2,8 10^{13}n/cm^{2}s
- Cadmium ratio 25:1
- Target resistivity 5 to 500Ωcm
- Axial gradient <3%
- Radial gradient <3%
- Capacity in full-time operation
  - 15 tonnes/year 50 Ωcm
  - Irradiation time typical 3,6h
- Standard load: single 5″ diameter crystal stack of 800mm long (individual length up to 300mm)
- Option for 4″ diameter crystals available

SIDONIE


SIDONIE irradiation basket with rotating motor tool in loading position


BR2 REACTOR
TOP COVER
PRIMARY INLET
GUIDE TUBE
SHROUD OUTLET
EXTENSION PIECE
BERYLLIUM MATRIX
EXTENSION PIECE
SUPPORT TUBE
PRIMARY OUTLET
SHROUD INLET
SUPPORTING GRID
VESSEL SUPPORT
BOTTOM COVER
Technical information
- Height ± 10m
- Diameter covers ± 2m
- Diameter core ± 1.1m
- Diameter reactor channel
- 5 x Ø 200 mm
- 64 x Ø 84 mm
- 10 x Ø 50 mm
- Materials:
- Vessel in aluminium
- Covers in stainless steel
- Channels in stainless steel & beryllium

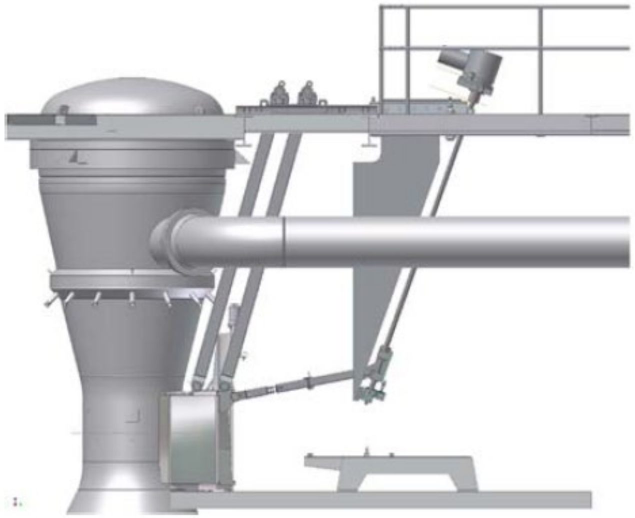
Animation: *P*ool *S*ide *E*quipment for the *I*rradiation and *D*oping *O*f silicon by *N*eutrons

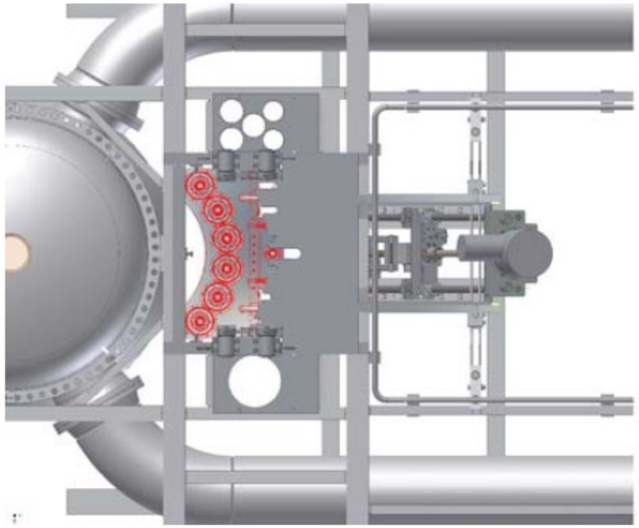


POSEIDON

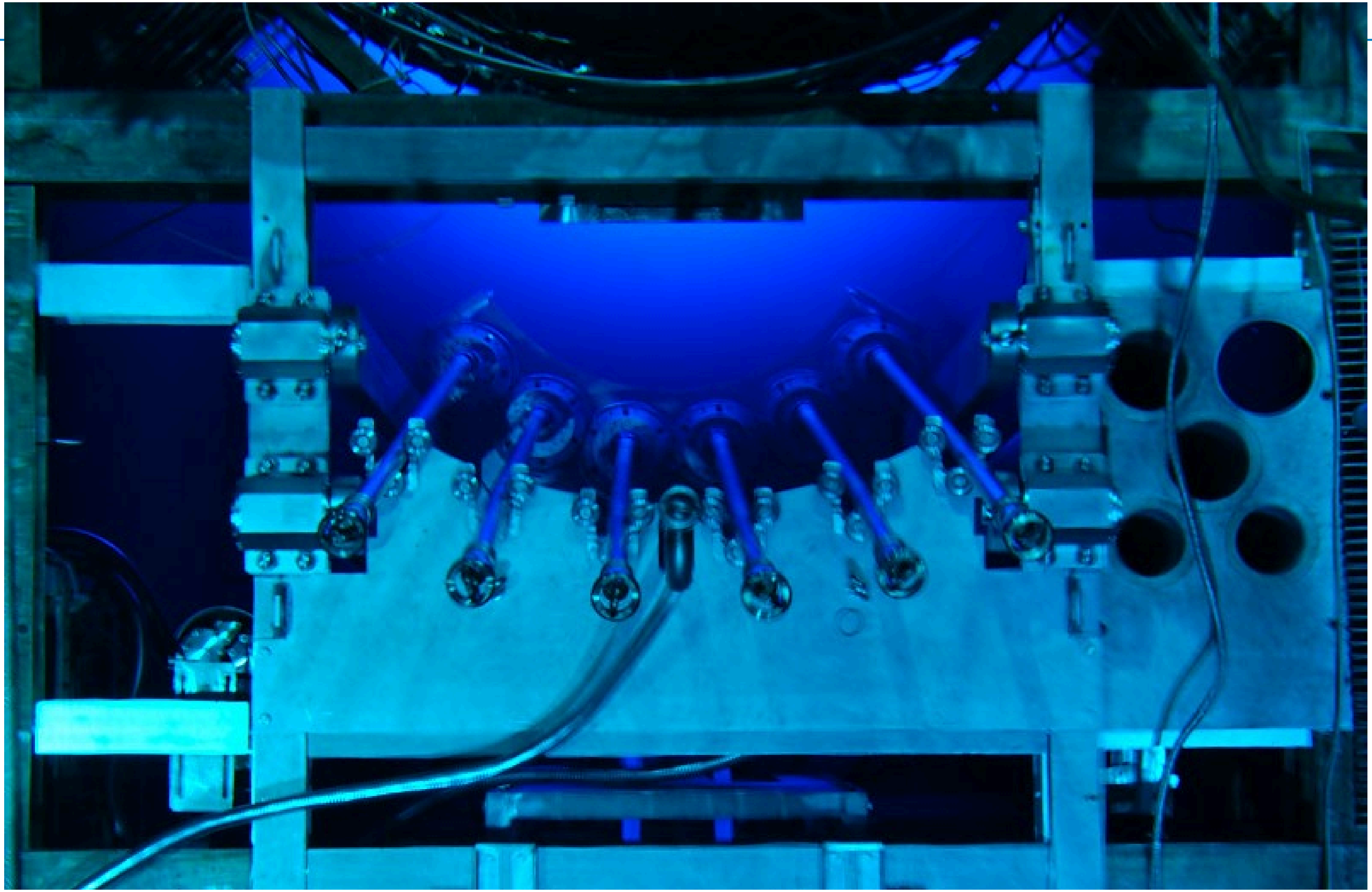
- pool side irradiation device
  - Suspended in reactor pool at core level
  - Graphite reflector box
  - Loading/unloading position in zero flux position
  - Irradiation position at reactor vessel

- 6 irradiation positions (5 available)
  - Stack of 2 crystals with up to 8" diameter per position
  - Total stack length 500mm; individual crystals 250 +/-5mm
  - Rotating baskets to limit radial resitivity gradient
  - Crystal shuffling after 25% irradiation time to limit axial resistivity gradient

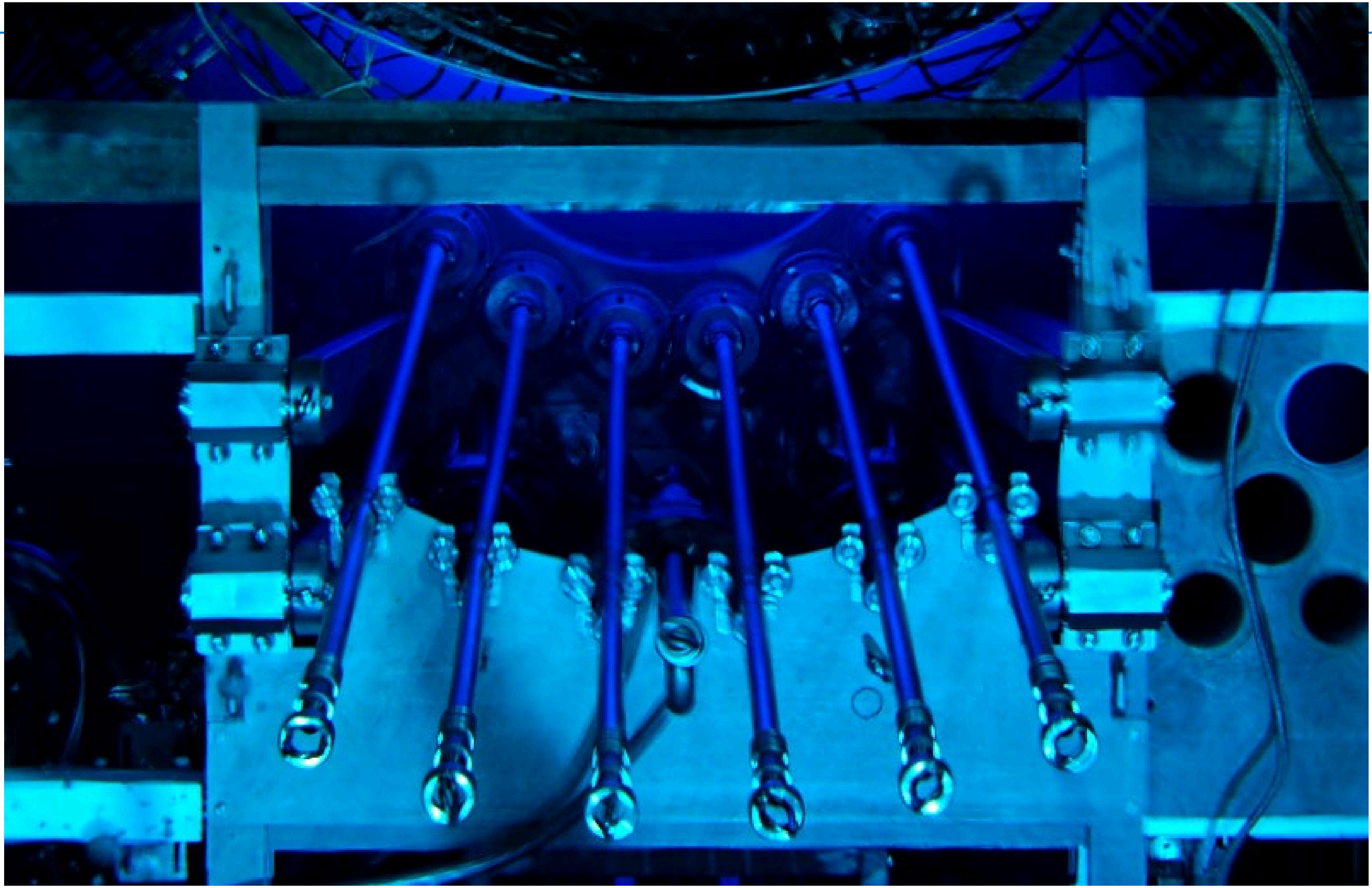




POSEIDON: Loading position

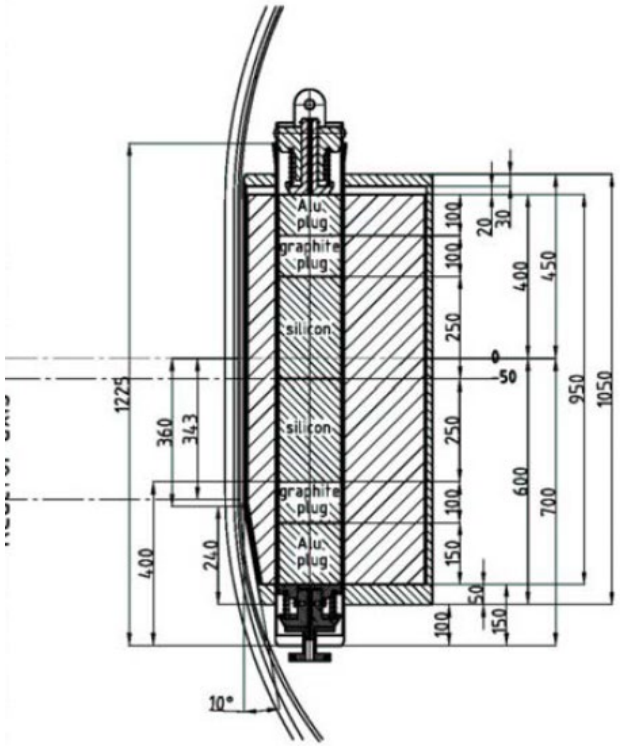


POSEIDON: Irradiation position



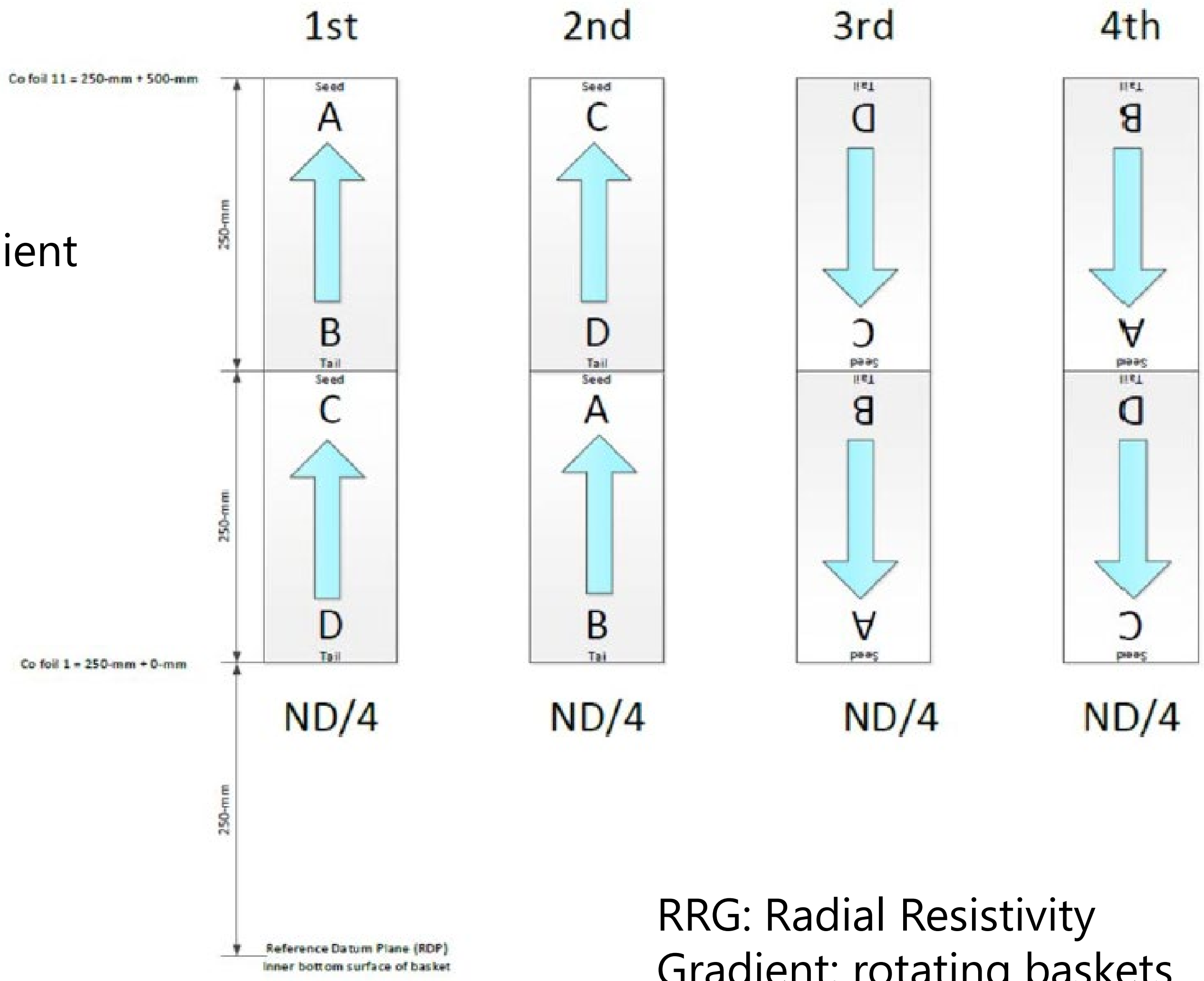
POSEIDON characteristics

- Typical thermal flux 0,5 10^{13}n/cm^{2}s
- Cadmium ratio >50:1
- Target resistivity 20 to 1000Ωcm
- Axial gradient <8%
- Radial gradient <5%
- Capacity in full-time operation
  - 20 tonnes/year 50Ωcm
  - Irradiation time typical 24h
- Standard load: single 8″ diameter crystal stack of 500mm long (individual length up to 255mm)
- Option for 6″ diameter crystals available



POSEIDON irradiation scheme

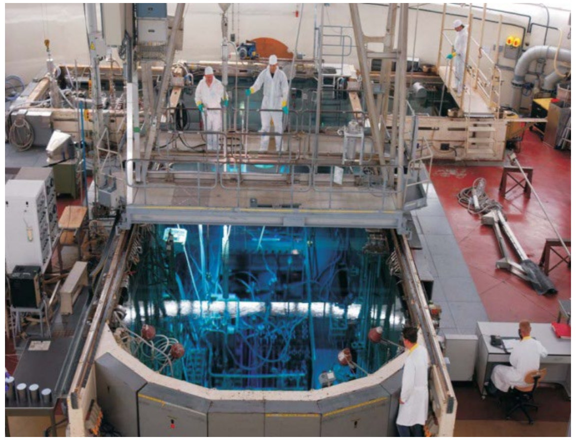
ARG: Axial Resistivity Gradient



RRG: Radial Resistivity Gradient: rotating baskets

Operational aspects of NTD-Si production

- Full capacity NTD-Si production requires handling of hundreds of batches/crystals
  - SIDONIE: one manipulation for each batch loading and unloading
  - POSEIDON: 4 manipulations for each batch loading and unloading
- Loading of NTD-Si crystals cannot be done during handling of radio-isotope productions
  - Access to reactor loading crane limited
  - Availability of crane varies during 3 shifts (1<2<3)
- Staff availability
  - Staffing was increased in 2019: irradiation performed over 3 shifts during the reactor cycle.
  - Silicon doping is responsible for 75 % of the workload. This activity is a buffer for other BR2 commercial activities

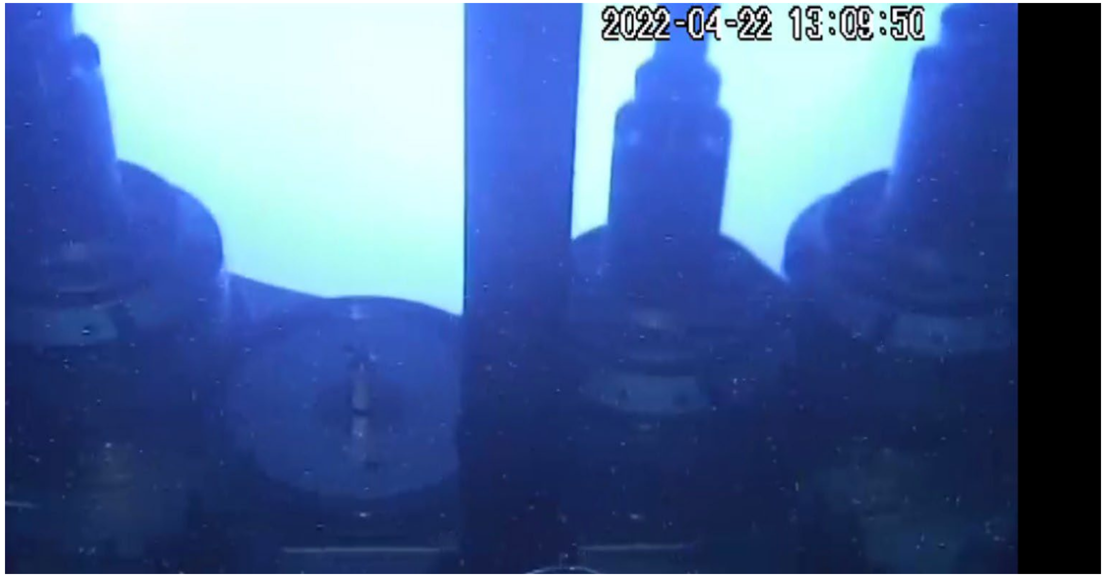


Silicon Ntd @ BR2
Production quantities
Time
C01 2020
C02
C03
C04
C05
C06
C07
C01 2021
C02
C03
C04
C05
C06
C07
C01 2022
C02
C03
C04
C05
C06
C07
C01 2023
C02
C03
C04
C05
C06
C01 2024
C02
C03
C04
C05
C06
C07
C01 2025
C02
Sidonie
Poseidon

Challenges at BR2 for Si-ntd

- Sidonie: well maintained and controlled
- Poseidon
  - 1 channel never used due to malfunction of the SPND.
  - BR2 lost 2 channels because they are leaking.
  - SCKCEN fixed the channels but they are lost for production

Maintenance of Poseidon is needed to secure Production of Silicon in the future.



Operational outlook

- Silicon Irradiation demand in BR2 is increasing/booming
  - BR2 installation is technically fit for increased availability while maintaining life-time up to 2036
  - Availability up to 30 weeks per year in 3 shifts is standard since 2020
  - Tendency for longer operation cycles: new fuel type available
    - Higher fraction of cycle available for NTD-Si production
      - 76% of time for 3 weeks cycle to 86% in 5 week cycle
      - Cycles are 28-31 days in 2025
  - Refurbishing NTD-Si (Neutron Transmutation Doped Silicon) infrastructure is essential to meet this growing demand BR2 is experiencing

Ageing concerns

- BR2 reactor is well maintained and exhibits a remarkable track record of reliable operation thanks to an effective ageing management and investment program
- Investment in dedicated NTD-Si irradiation is also required for sustaining production with ageing instruments
  - Silicon doping is not part of strategic mission of SCK CEN but BR2 experience an increased irradiation demand.
  - The BR2 institute has a mandate to pursue commercial irradiation activities at a financially balanced condition and within the capacity to fulfill its strategic mission priorities

It is not easy to be a pioneer - but oh, it is fascinating!

Elizabeth Blackwell

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Foundation of Public Utility

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