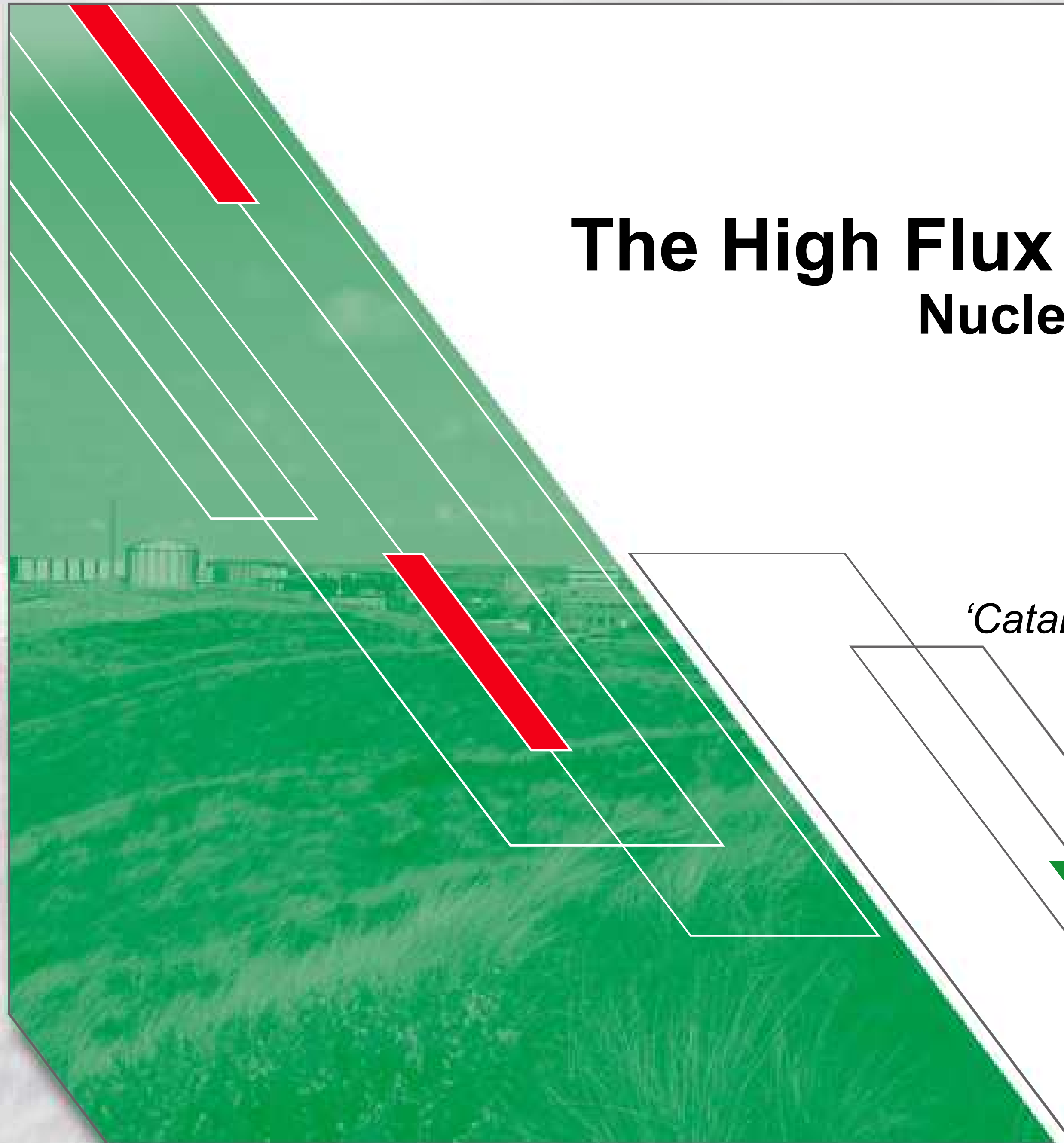


The High Flux Reactor (HFR)
Nuclear research at NRG

Geert-Jan de Haas

IAEA consultancy meeting
'Catalogue of research reactors'
Vienna
10-12 June 2013

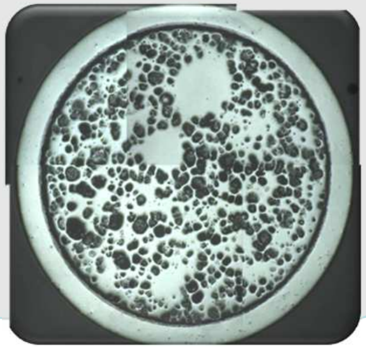
HFR
Hot Cells Laboratory
LFR

Department 'Irradiation & Development'
Irradiation business

MEDICAL ISOTOPES

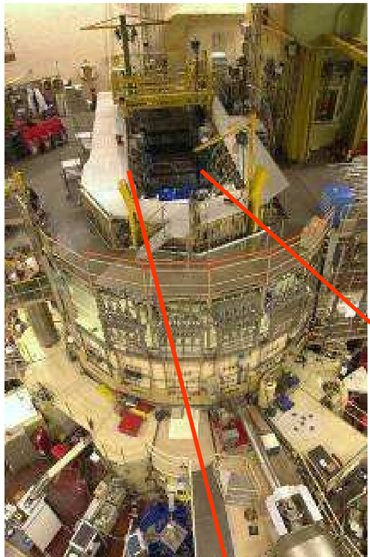
INDUSTRIAL ISOTOPES

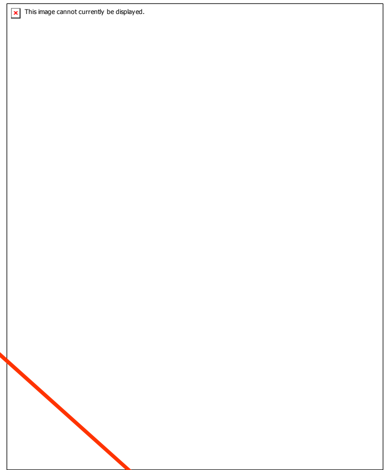
NUCLEAR INDUSTRY IRRADIATION SERVICES



NUCLEAR R&D

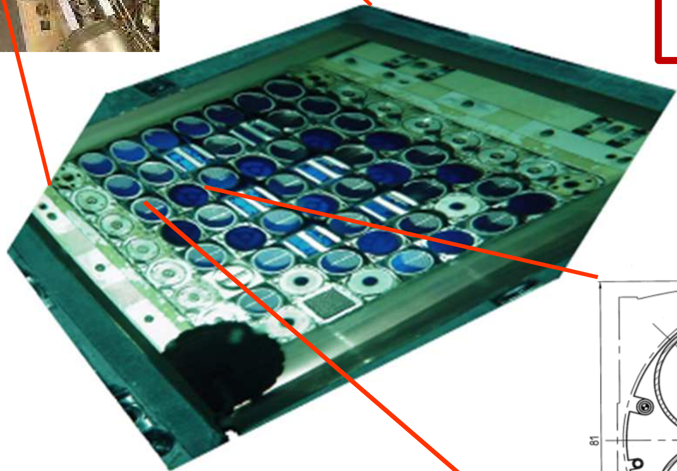
High Flux Reactor

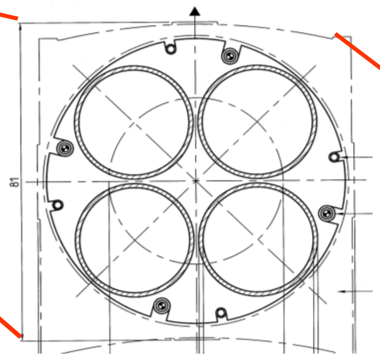




History:
- 1961 Start-up (first criticality)
- 1962 Reactor power = 20 MW
- 1966 Power increase to 30 MW
- 1970 Power increase to 45 MW
- 1984 Vessel replacement
- > 1985 Continuous improvements

Reactorprogram
- Ca. 290 days full power operation
- 11 cycles of 4 weeks per year
- 25 days full power operation
- 3 days stop;
- 2 maintenance periods per year



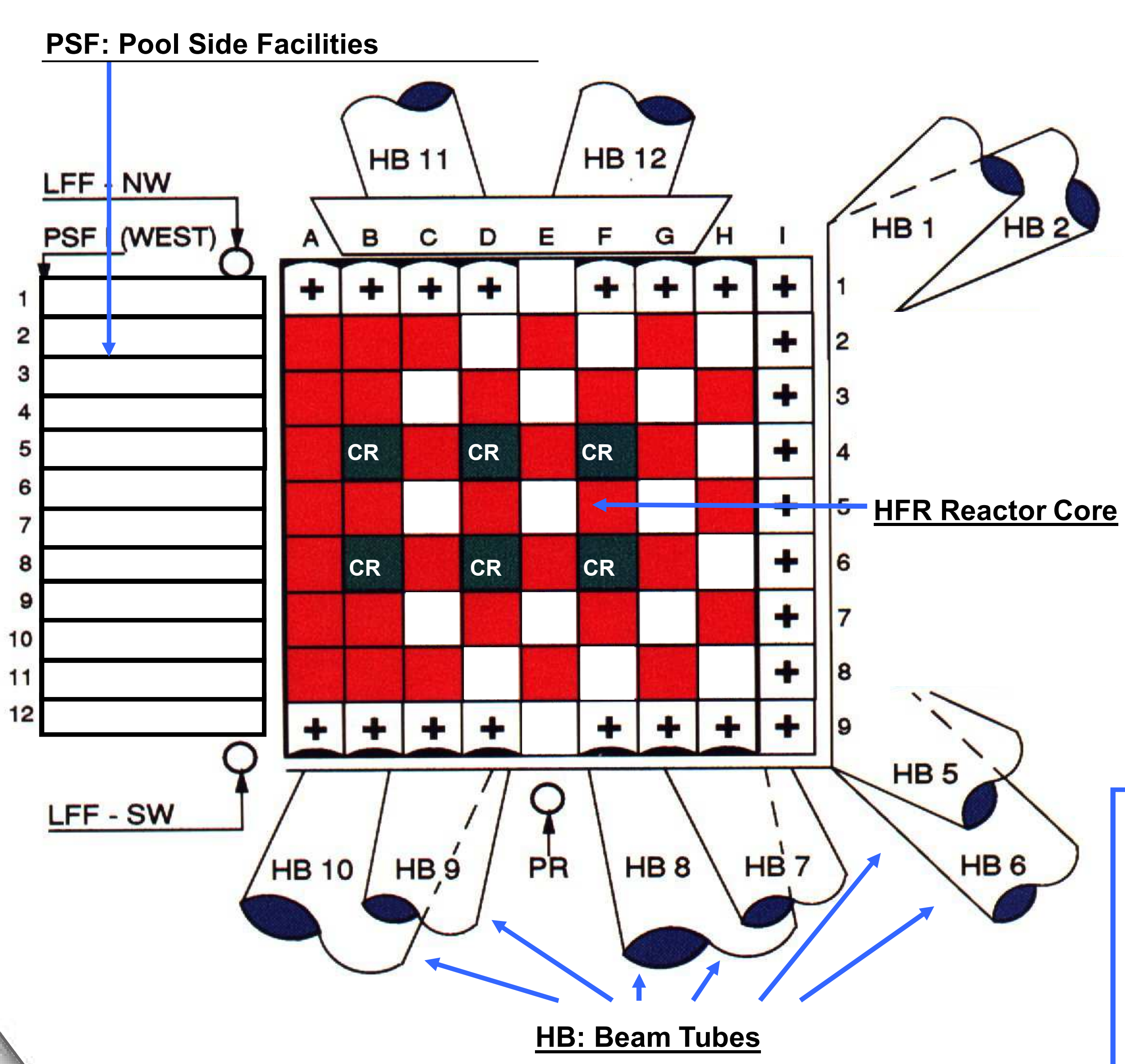


POOL SIDE FACILITY WEST

	A	B	C	D	E	F	G	H		I
1	Be	Be	Be	Be	Be	Be	Be	Be	1	Be
2	F	F	F	D2	F	F2	F	H2	2	Be
3	F	F	C3	F	E3	F	G3	F	3	Be
4	F	CR	F	CR	F	CR	F	H4	4	Be
5	F	F	C5	F	E5	F	G5	F	5	Be
6	F	CR	F	CR	F	CR	F	H6	6	Be
7	F	F	C7	F	E7	F	G7	F	7	Be
8	F	F	F	D8	F	F8	F	H8	8	Be
9	Be	Be	Be	Be	Be	Be	Be	Be	9	Be

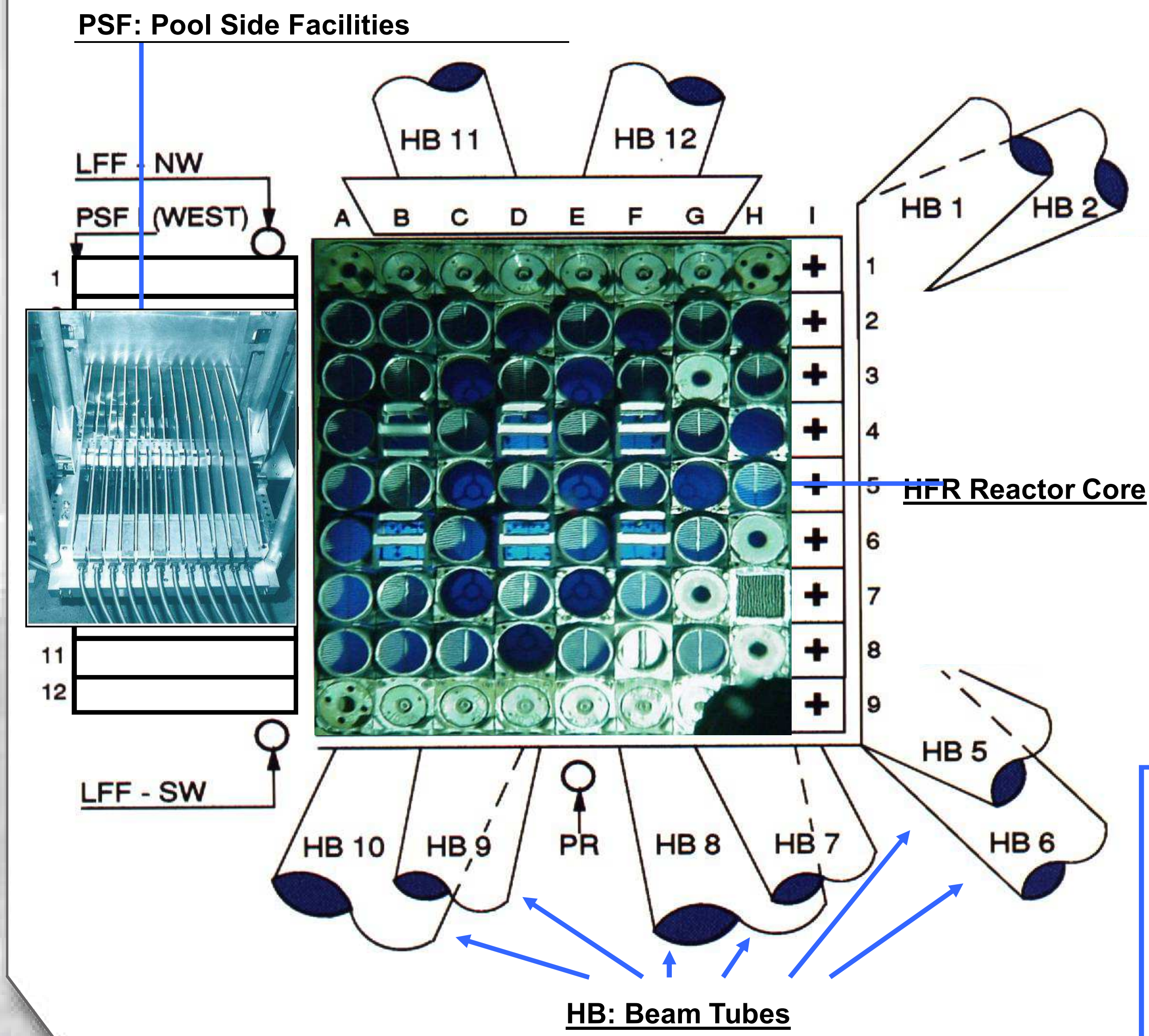
- F: Fuel element
- CR: Control rod
- Be: Reflectorelement
- C5: Experiment position

Schematic of the High Flux Reactor (HFR) Petten, The Netherlands



- + Beryllium reflector
- Fuel
- Experimental or isotope production position
- CR Control rod

Schematic of the High Flux Reactor (HFR) Petten, The Netherlands



+	Beryllium reflector
	Fuel
	Experimental or isotope production position
CR	Control rod

HFR Specifications

The HFR Petten is a 45 MW thermal tank-in-pool type material test reactor

Light water cooled and moderated with low enriched uranium plate-type fuel elements (conversion from high-enriched took place 6 years ago)

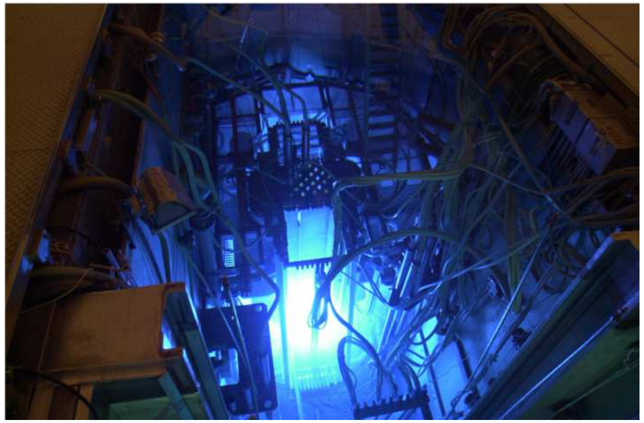
17 in core positions with maximum core position average (peak value is ± 25% higher) over 60 cm effective height (highest flux positions C3/C7):

- $1.8 \cdot 10^{14}$ $cm^{-2}s^{-1}$ fast
- $4.3 \cdot 10^{14}$ $cm^{-2}s^{-1}$ epithermal
- $2.6 \cdot 10^{14}$ $cm^{-2}s^{-1}$ thermal

Each irradiation position is different and the spectrum depends strongly on target material

12 pool side positions for example for ramp testing, flux control and safety tests with maximum position average (2,5 cm from core box):

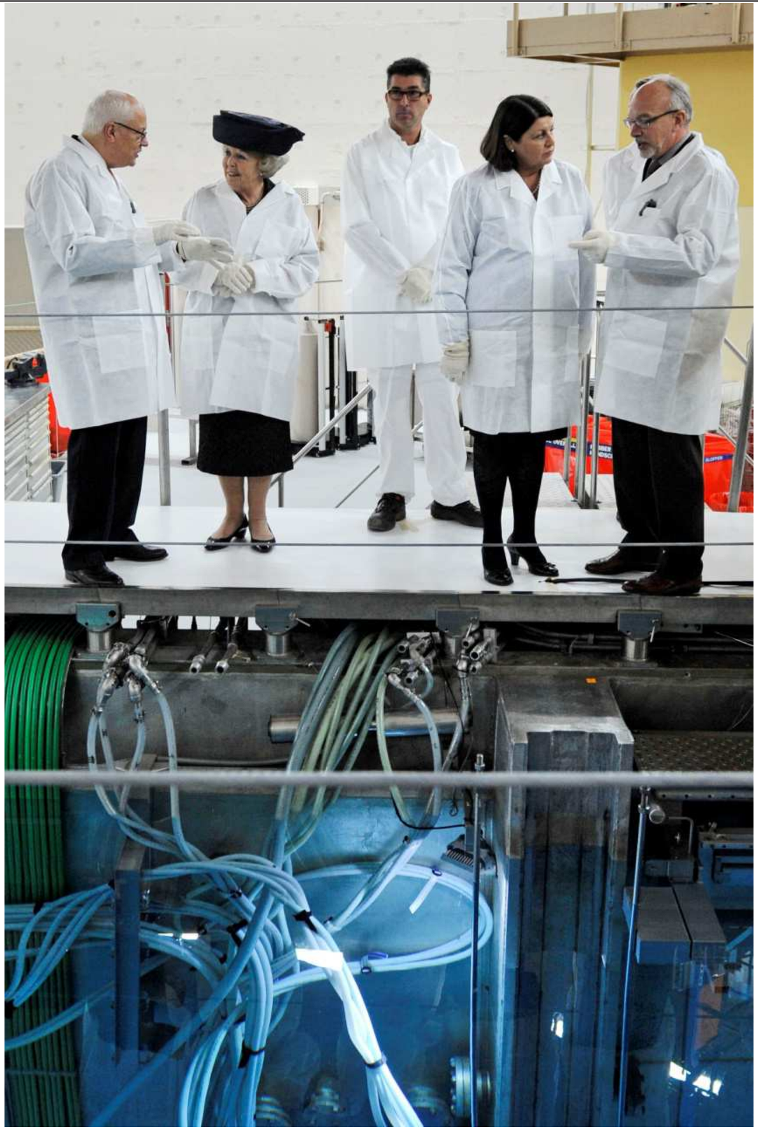
- $0.5.10^{14}$ $cm^{-2}s^{-1}$ fast
- $1.2.10^{14}$ $cm^{-2}s^{-1}$ epithermal
- $1.5.10^{14}$ $cm^{-2}s^{-1}$ thermal



All numbers provided are approximate

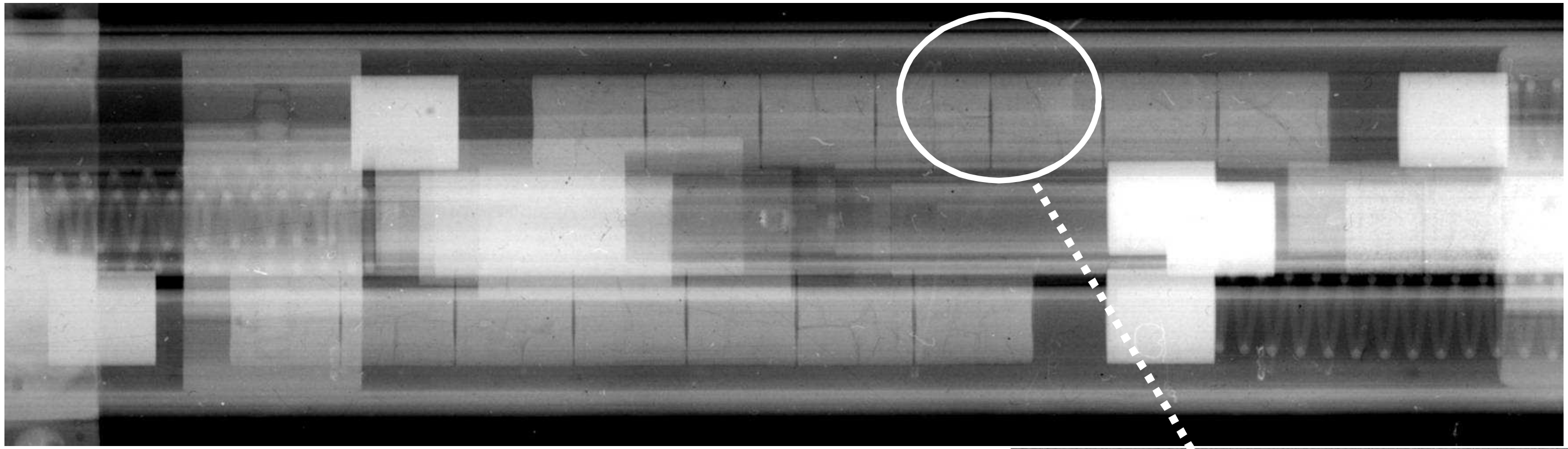
280 days of operation per year (approaching 300) in 10 cycles

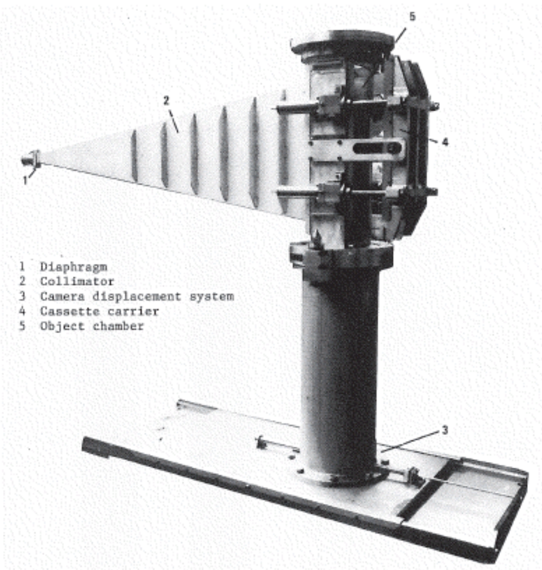
Max 5-8 dpa per year for steel achievable

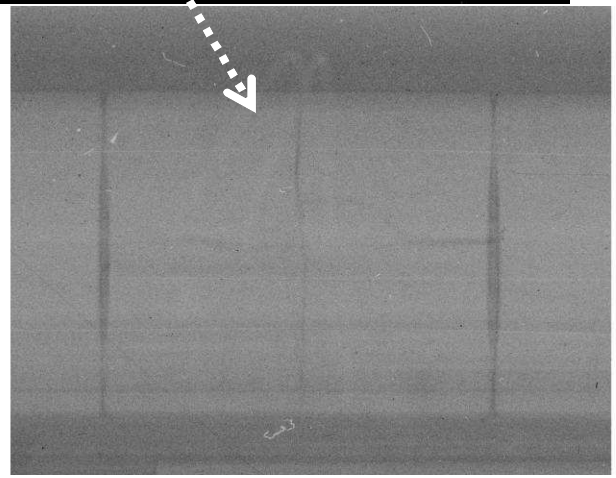


Visit of H.M. Queen Beatrix of the Netherlands and Eurocommissioner Máire Geoghegan–Quinn on the occasion of 50 years HFR, November 22, 2011

Neutron radiography

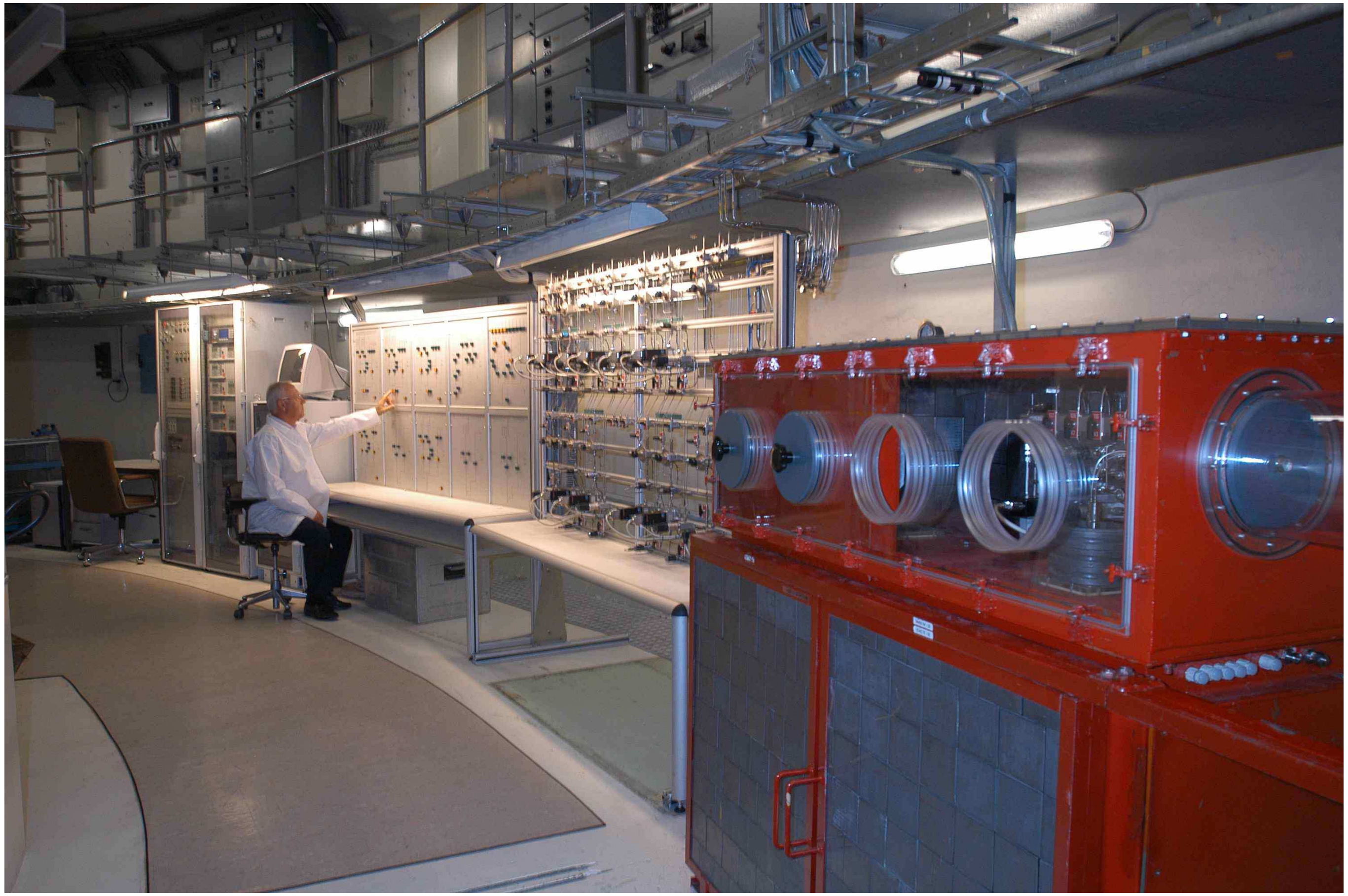






Detail, scan resolution 5 μm

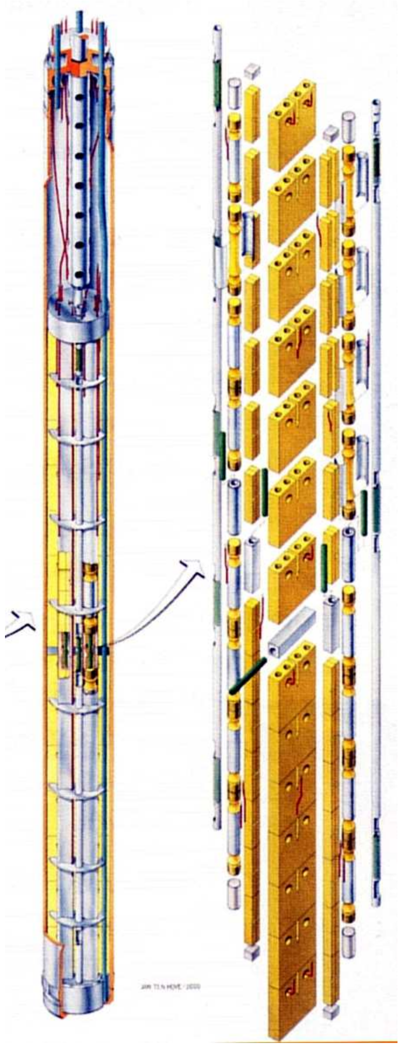
Out-of-pile measurements



Fission-gas release HTR fuel: sweep loop measurement and control system

Materials

- Metals
- Graphite
- Composites
- Ceramics
- Fuel



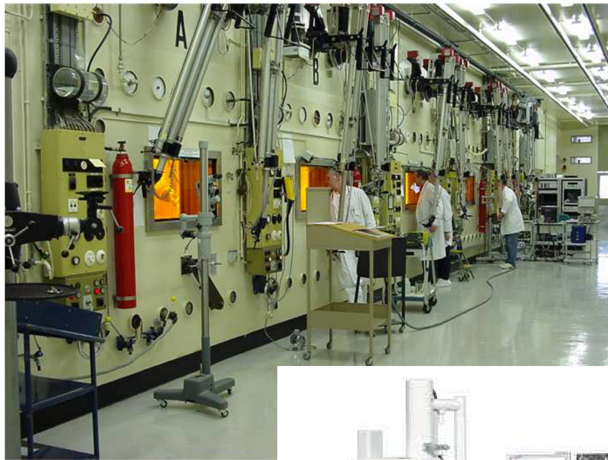
Hot Cell laboratories (1)

Concrete Cells:

- Dismantling of experiments
- Gamma scanning (tomography)
- X-ray
- Puncture tests (gas mass spectrometer)

F-cells:

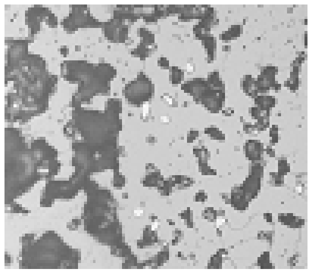
- Destructive examination preparation line
- Ion etching
- Pressure/tensile testing of small specimens
- Microscopy/ceramography
- SEM, with EDS, WDS and EBSD systems



JEOL 6490 LV SEM, placed in hot cell

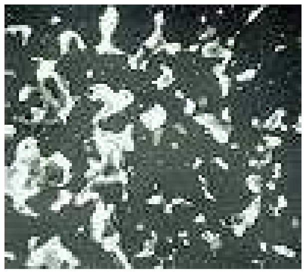
High burn-up HTR fuel structure

Ceramography

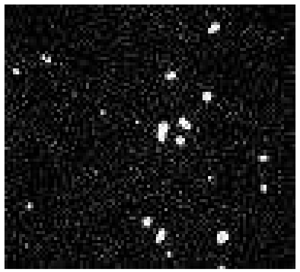


microstructure

EPMA



e-image



ruthenium

molybdenum

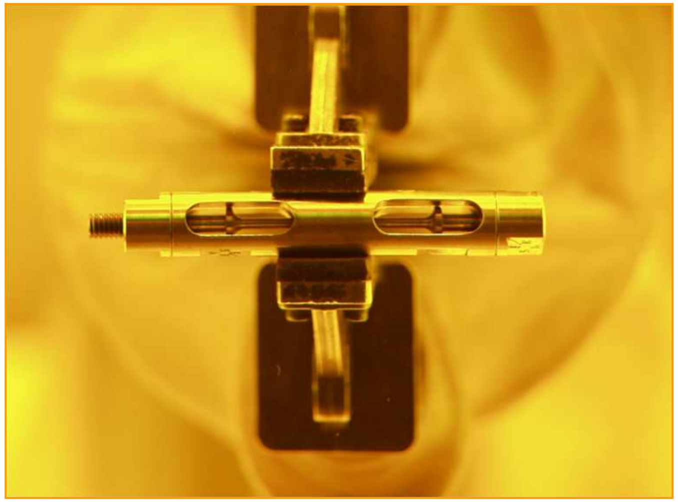
Hot Cell laboratories (2)

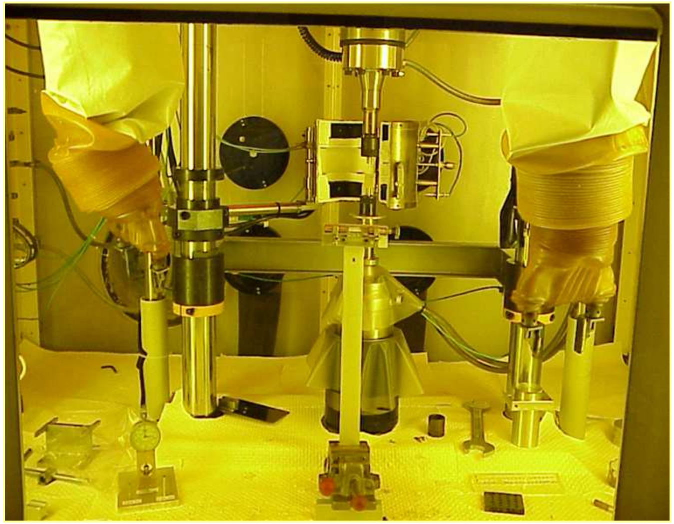
G-cells

- Material testing: (high T) tensile testing, thermal conductivity/diffusivity (laser flash), thermal expansion, creep
- Dedicated graphite testing glove boxed and measurement equipment

Actinide laboratory

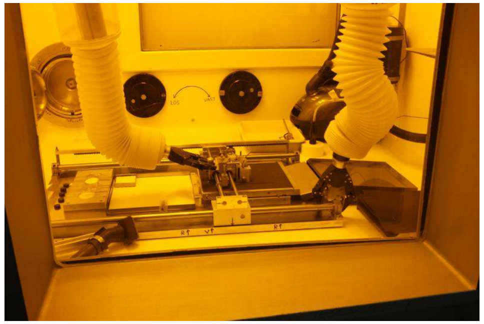
- Fabrication and characterization of actinide bearing fuels





Flexible facilities

- Development of new set-ups
- Regular decontamination of facilities allows easy access to:
  - upgrade set-ups
  - develop new set-up
  - install new set-ups.

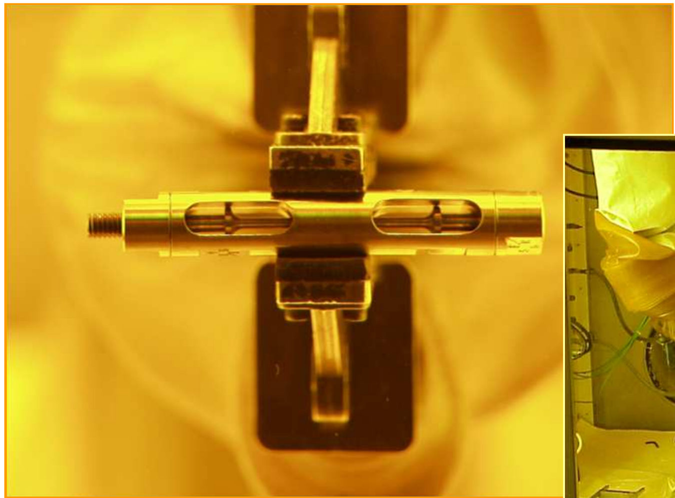


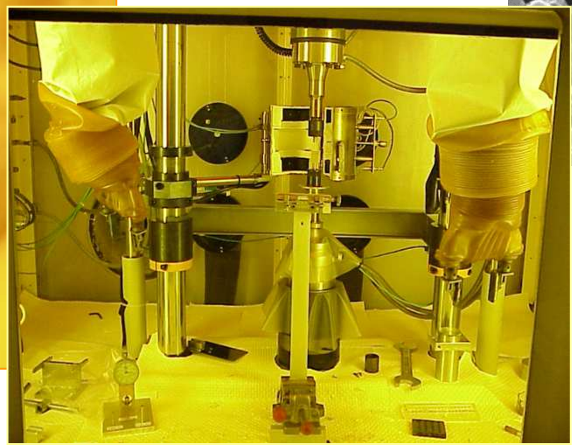
Characterization techniques - overview

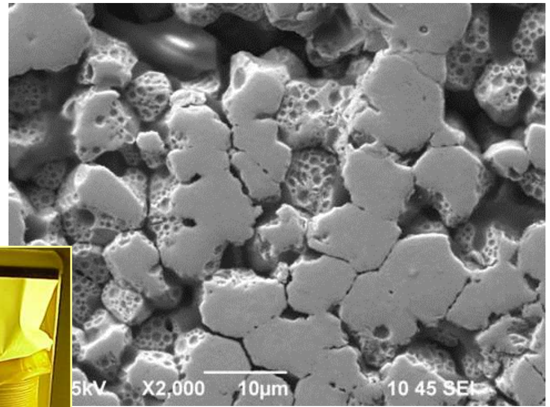
- Tensile testing
- Bending testing
- Compressive testing
- Fatigue crack Propagation
- Fracture toughness
- Charpy impact testing
- Creep

- Dimensions
- Mass
- Dynamic Young's modules (ToF and Resonance)
- Thermal conductivity
- Thermal expansion
- Electrical resistivity
- Photography

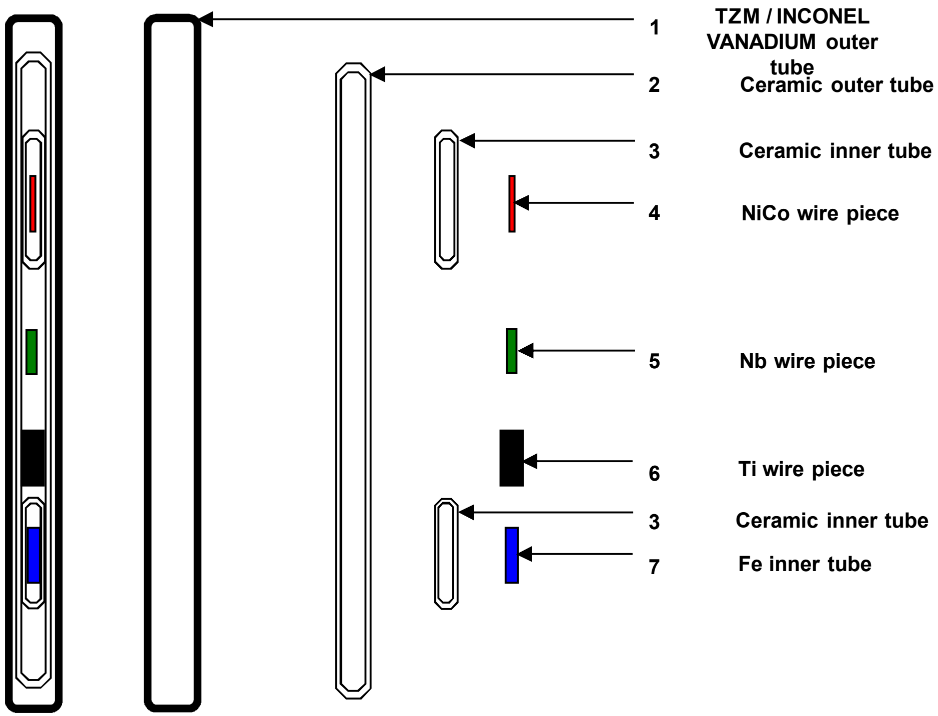
- Light microscopy (in hotcell)
- SEM + EDS/WDS/EBSD (in hotcell)
- TEM + EDS
- X-Ray diffraction
- XR tomography

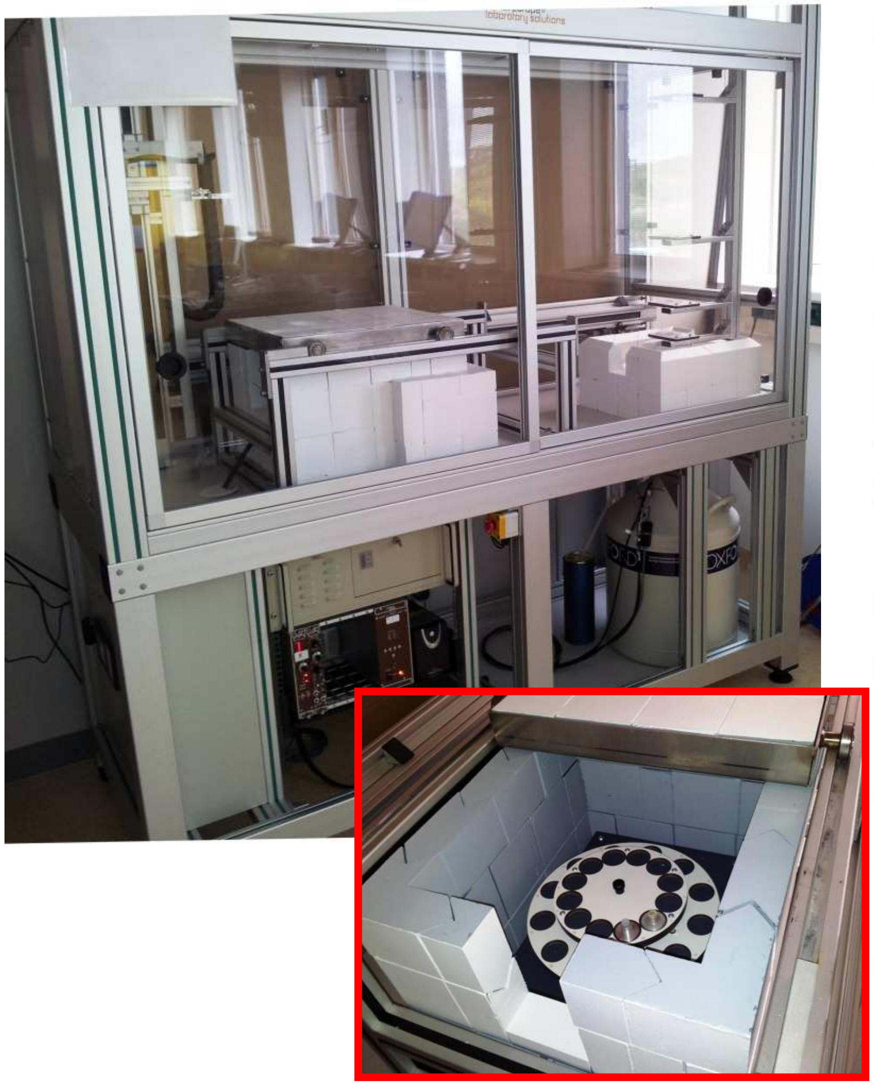






Neutron dosimetry



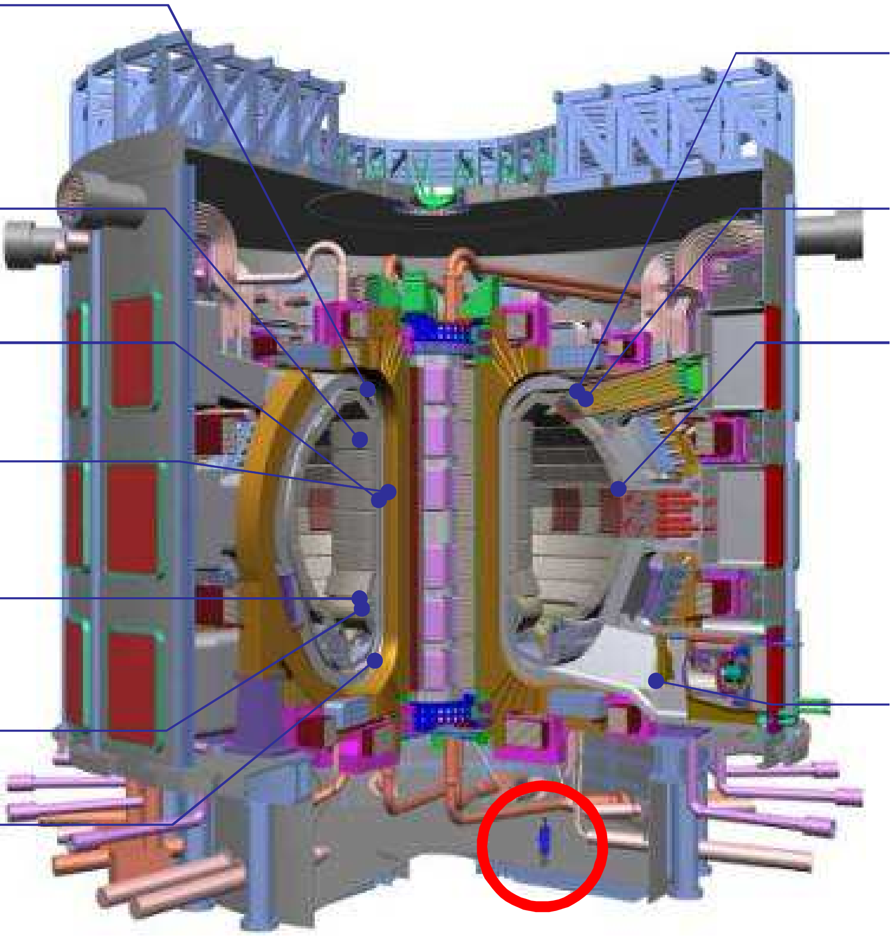


Activated materials are measured with a HPGe detector with broad resolution coupled to a sample changer

Large Experience Base: Past 10 Years and current HFR Irradiation Examples (Materials)

NRG Name	Application Area
SUMO-1 to -12:	9Cr steels & joints for fission/fusion
STROBO-1 to -7:	Stress-relaxation of bolt materials
CIWI:	BWR core shroud welds
SOSIA-1 to -5:	Creep & creep fatigue of 9Cr steels
IBIS:	Structural material in lead-bismuth
INNOGRAPH-1A, -1B, -2A, -2B:	HTR graphite irradiations
EXTREMAT-1, -2:	High temperature materials
BODEX:	Transmutation targets
POSITIVE:	ITER first wall components
LYRA-1 to -10:	RPV steel irradiations
PYCASSO-I, -II:	HTR surrogate particles
HICU:	Breeder material for fusion
EXOTIC-1 to 9:	Solid tritium breeder materials
LIBRETTO-1 to -5:	Liquid tritium breeder materials
HIDOBE-1, -2:	High dose beryllium irradiation
PebbleBedAssembly:	Integrated fusion blanket experiment

Fusion Technology at NRG

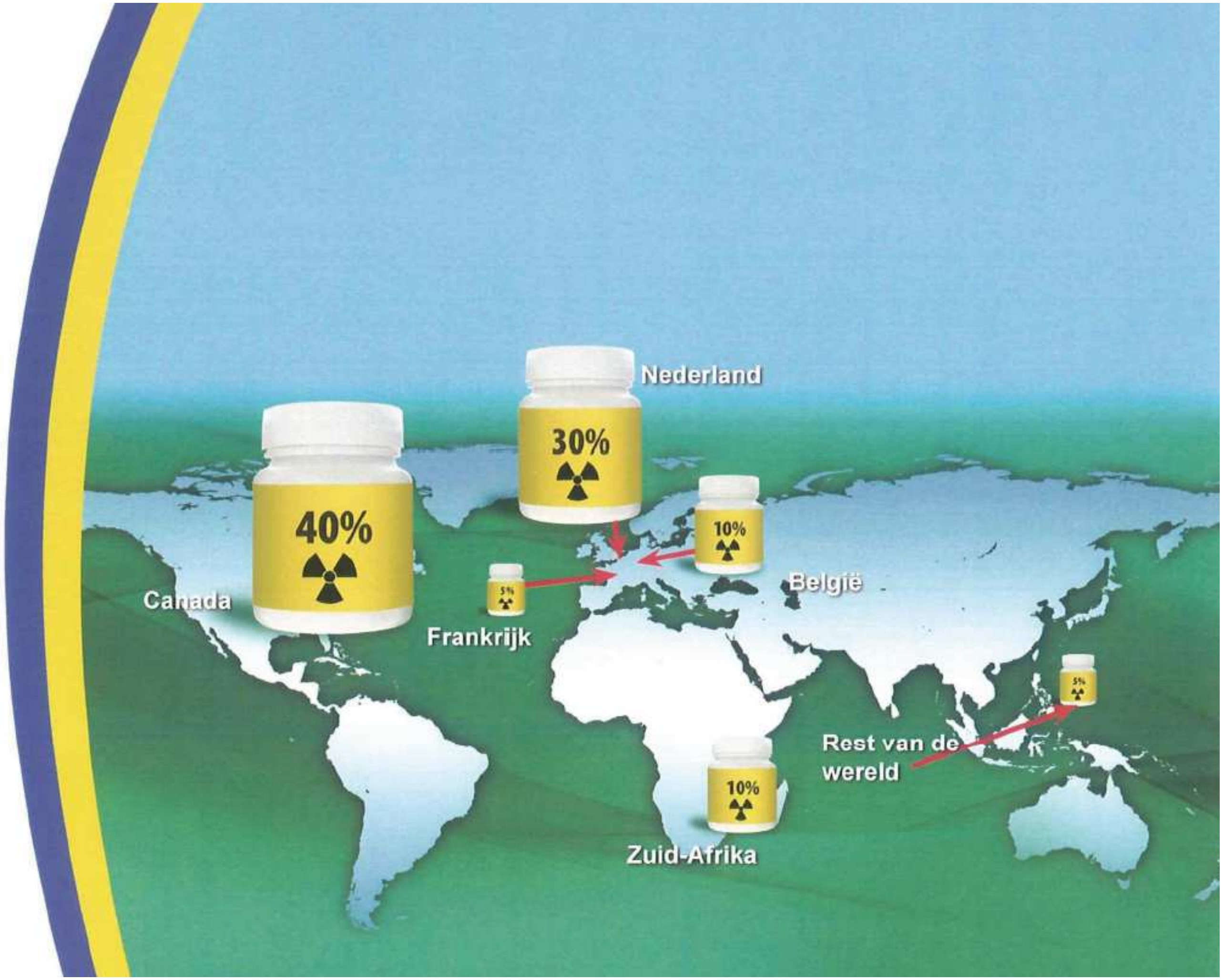


ITER, fusion reactor to demonstrate fusion viability, Cadarache, France

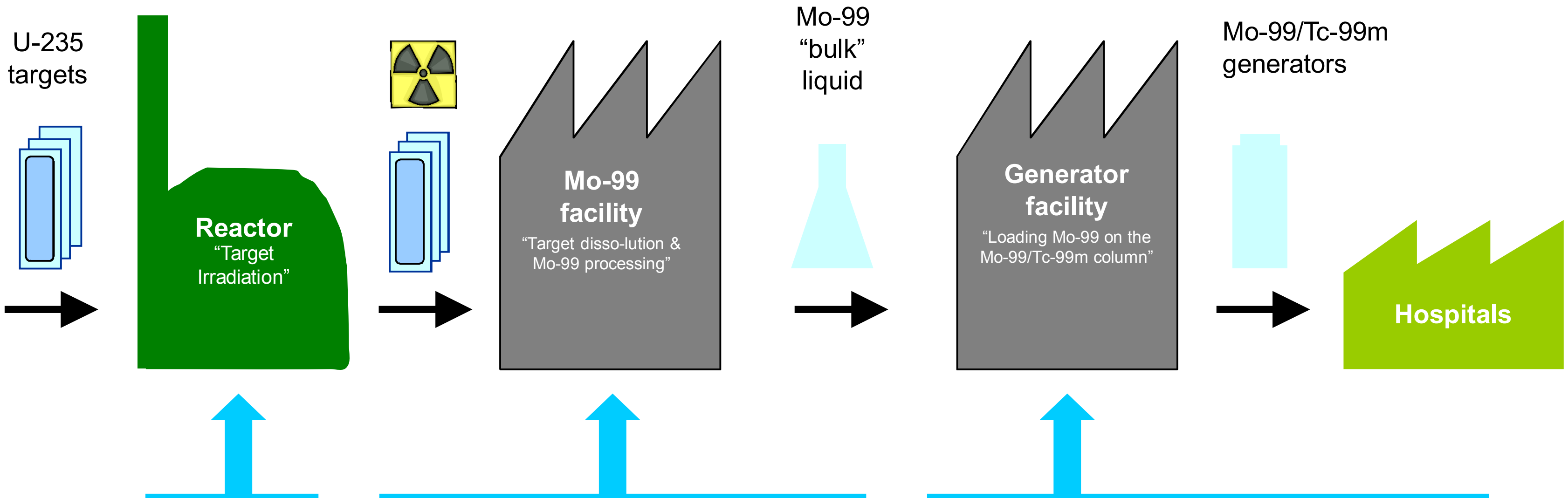
Large experience base: past 10 years and current HFR Irradiation Examples (fuels)

NRG Name	Application Area
OTTO:	Once through then out Pu-transmutation
THORIUM CYCLE:	Thorium fuel experiment
EFFTRA-T4, T4 bis, T4ter:	Transmutation experiments under EFFTRA
HELIOS:	Minor actinide fuels and targets
CONFIRM:	Nitride fuels for fast reactors
FUJI:	FBR innovative fuels, commercial
MARIOS:	SFR minor actinide fuel irradiation
HFR-EU1, HFREU1bis:	HTR pebble irradiations
SMART:	Nitride for advanced fuels
TRABANT:	Fast reactor annular MOX fuel irradiation
SPHERE:	Minor actinide bearing sphere-pac fuel
MARINE:	Fast reactor minor actinide bearing fuel

Production of medical isotopes



Molybdenum-99 Delivery Chain



HFR
BR2
Osiris
Safari
NRU

Covidien Petten (NL)
IRE Fleurus (Belgium)
NTP (South Africa)
Nordion (Canada)

<u>Europe (top 3):</u>
Covidien Petten
CIS / IBA Saclay, France
GE Healthcare, UK

Investing in future energy solutions

NRG is preparing the infrastructure for developing nuclear power solutions for future generations

Mission: *'Pallas aims to become world leader in the development and production of (new) medical isotopes and to increase the knowledge and turnover of nuclear technology'*

Pallas

Pallas project

1. Nuclear Island; deliverables:
   - Nuclear reactor, isotope-rigs and experimental loops
   - Auxiliary and EI&C systems
   - Building and building related
2. Off-plot scope; deliverables:
   - Office Building, roads and landscaping
   - E-distibution including 10 kV systems
   - Security systems
   - Cooling Water System,
   - Water inlet & outlet, pumps and piping
   - Etcetera
3. Licensing

Pallas reactor

- Tank-in-pool type for simple handling of experimental rigs and logistics for isotope production
- Light water reactor
- Maximum capacity 55 MW (HFR: 45 MW)

The road to Pallas

2006-2011

- Preparations, negotiations with stakeholders
- URS:
  - User Requirement Specifications – continuity of a financial sound irradiation business
  - Design & Construction according to “defense in depth” principle
  - Reliable, stable and easily manageable operation
  - Taking into account the *lessons learned* from Fukushima

2012

- Decision of Dutch government and province of North Holland to fund the first, critical phase: 80 M€
- Appointment of a quartermaster by the ministry of Economic Affairs to scrutinise the project, set up a professional organisation and draw up a plan for private or other financing of the construction.

2013

- Positive advice from quartermaster
- Preparations for the establishment of a foundation for the preparation of the PALLAS reactor (June 2013)

2013-2017: licensable design phase (first phase)

- Licensing, preparations
- Tendering, review process of designs, contracts
- Completion of business case; funding in place

2017-2024: realisation phase (second phase)

- Building, construction
- Commissioning
- Start of Pallas

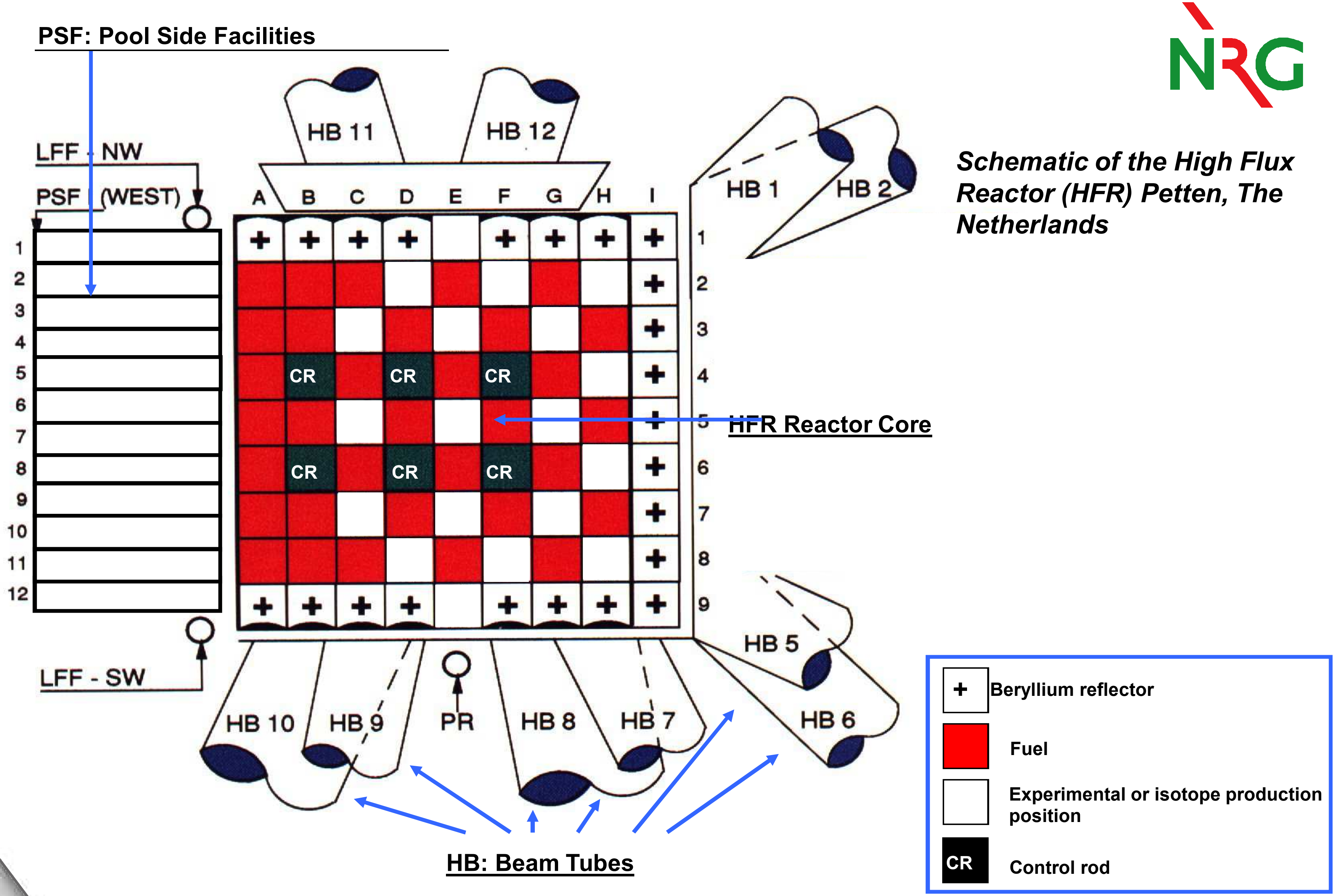
Thank You

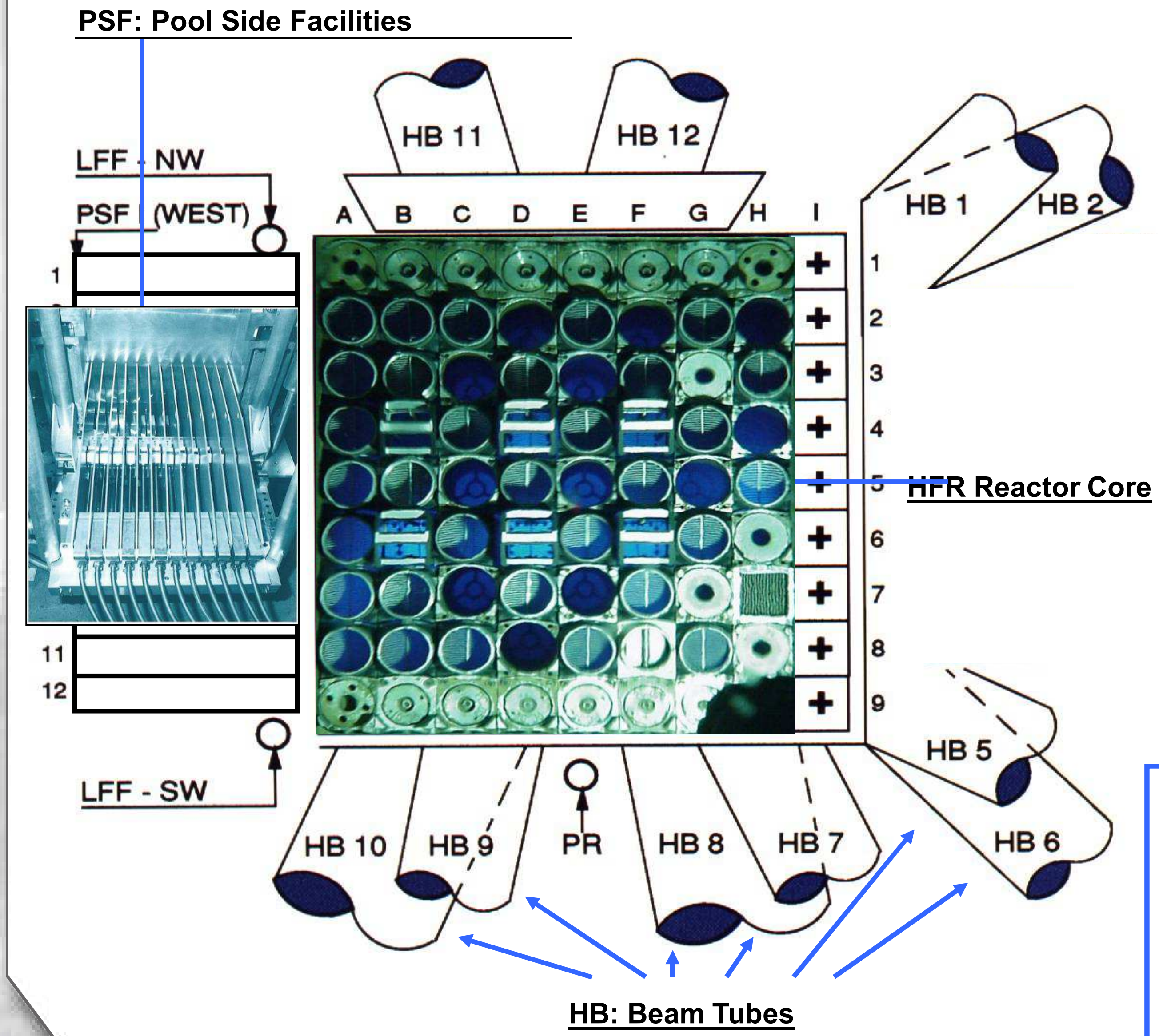
NRG committed to
Worldwide Healthcare
and Energy Supply

50 YEARS
PETTEN

Reserve/extra slides

Schematic of the High Flux Reactor (HFR) Petten, The Netherlands





Schematic of the High Flux Reactor (HFR) Petten, The Netherlands

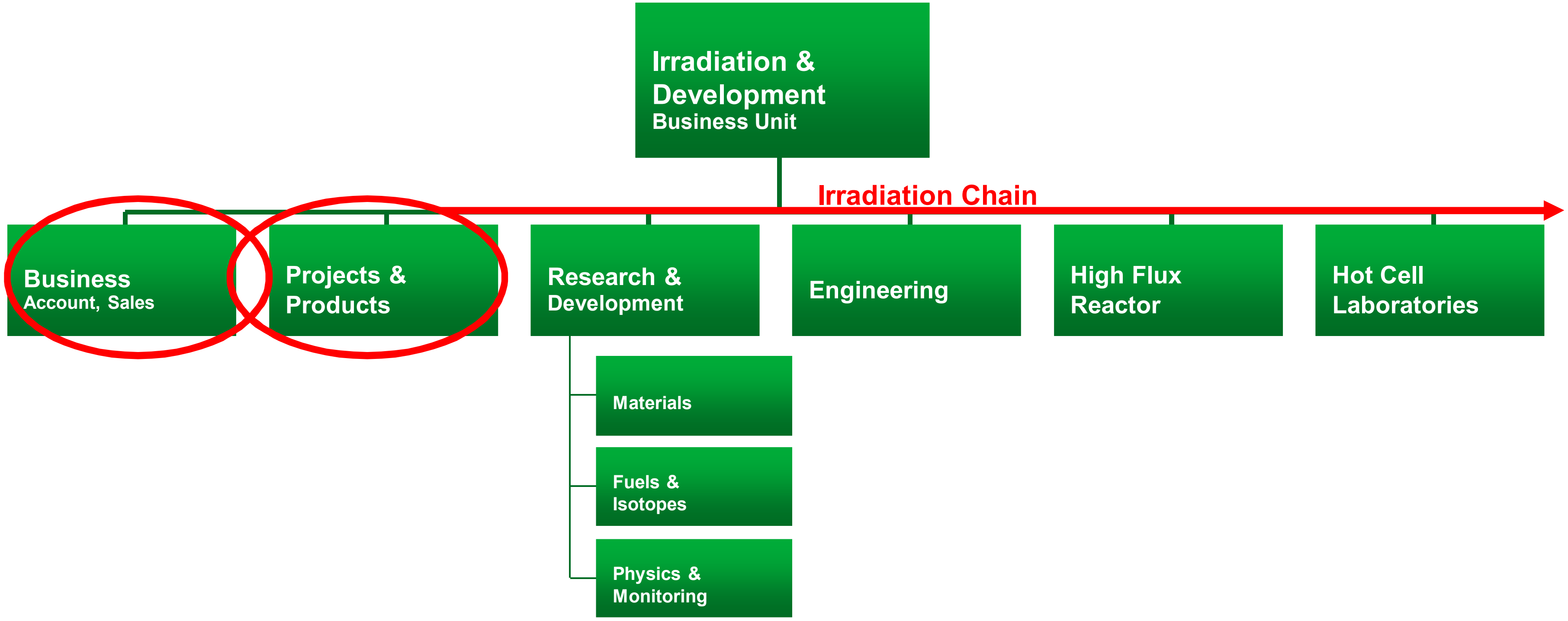
+ Beryllium reflector

Fuel

Experimental or isotope production position

CR Control rod

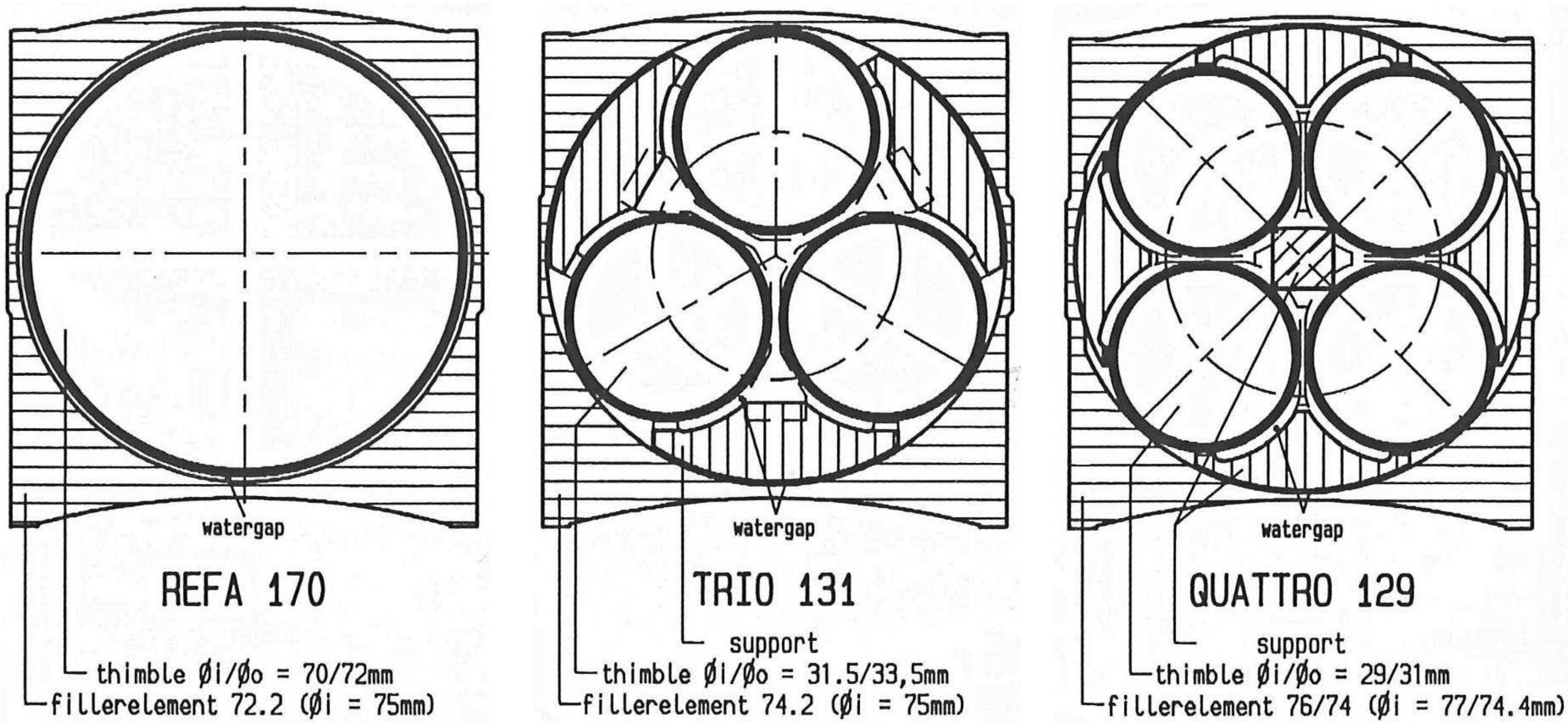
NRG I&D Organisational Structure: Irradiation Chain



- Resource management via line management
- Process and project execution under dedicate P&PM team responsibility
- Financial control of the chain and front end activities in team business

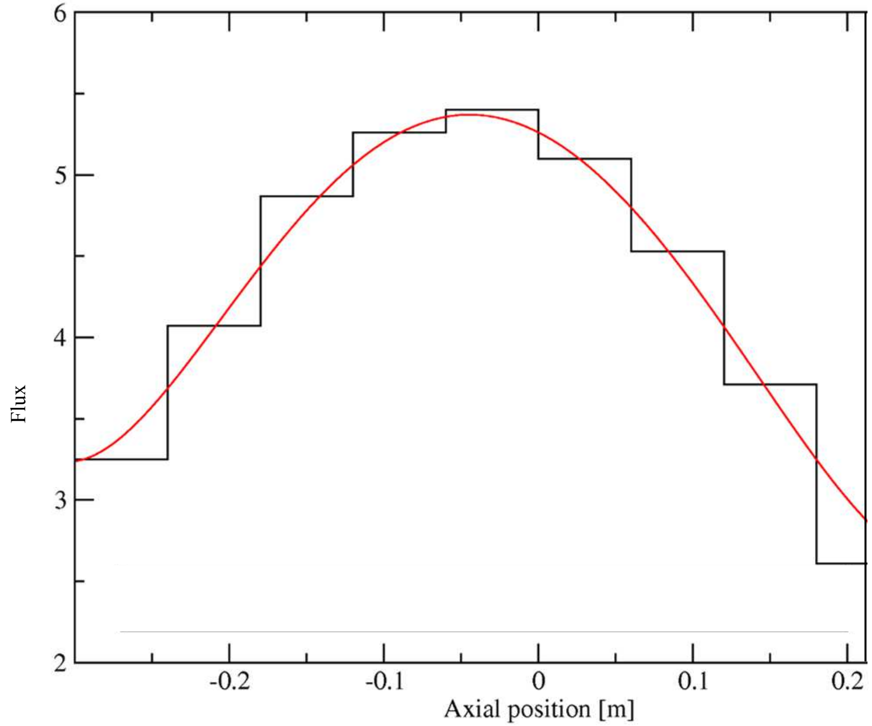
HFR Irradiation Facilities

Irradiation Rigs



- Standard irradiation rigs (TETRA and TRIO 129 not shown)
- Outside water cooled, inside gas swept (mixtures of helium, neon, nitrogen)
- Customisation possible (CONFIRM irradiation example later on)

HFR Flux Buckling

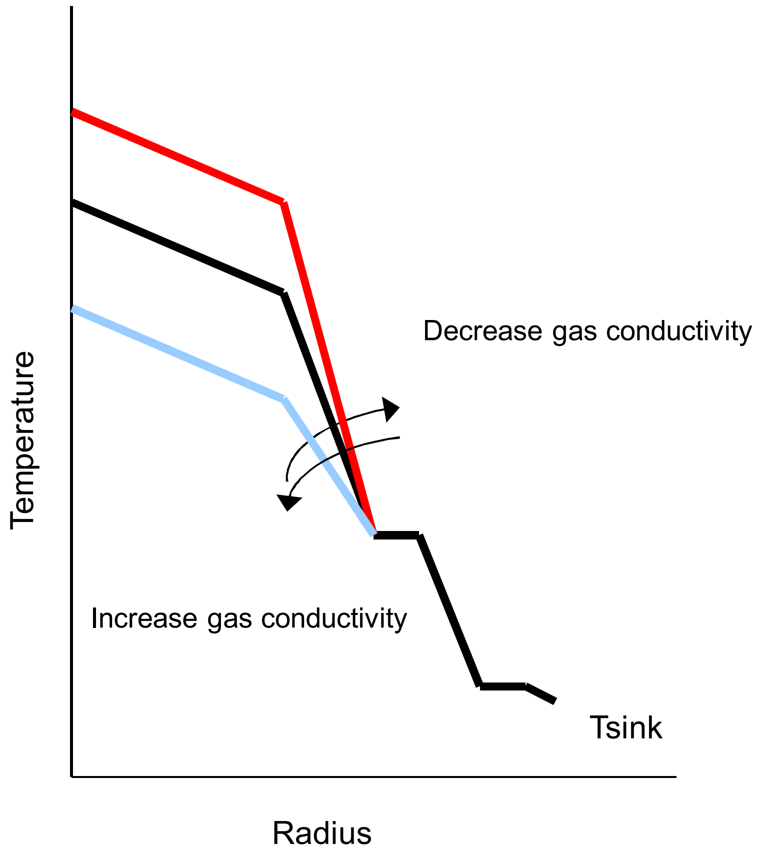


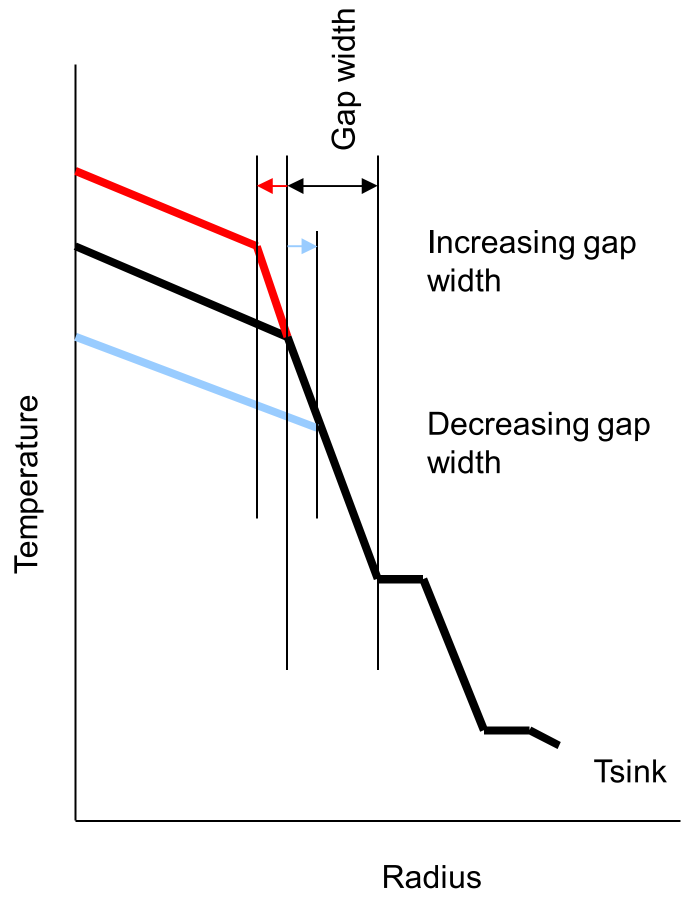
Flux and nuclear heating in the HFR core depend on the axial location in the core: the HFR flux buckling

The flux buckling hardly changes within a cycle, but moves slightly, which is accommodated by the ‘Vertical Displacement Unit’ or (VDU), generally adopted for irradiation experiments

Temperature Control

Besides the possibility to apply heaters, the temperatures of most HFR irradiations are determined and controlled by gas gaps.

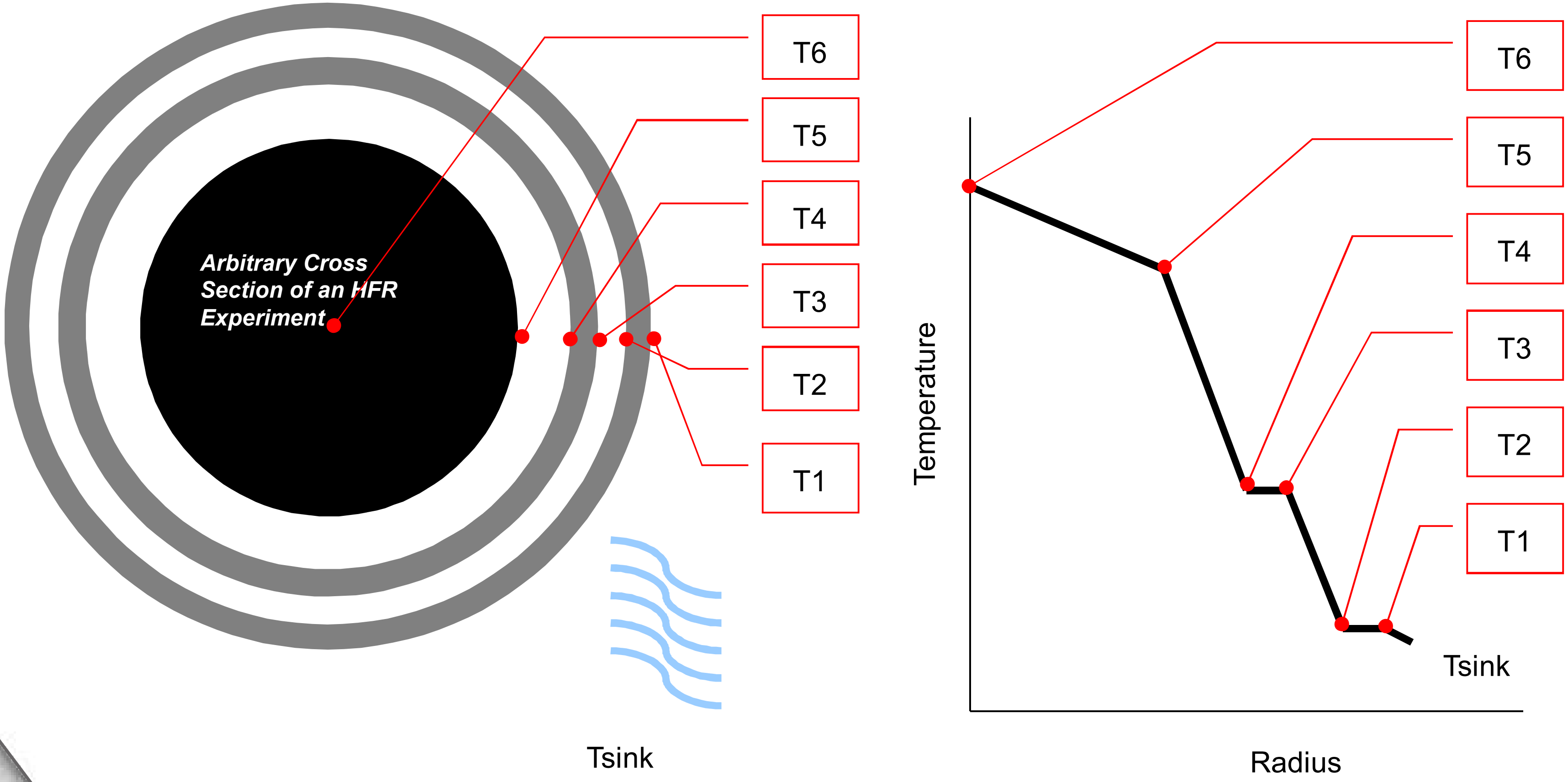




Temperature Control

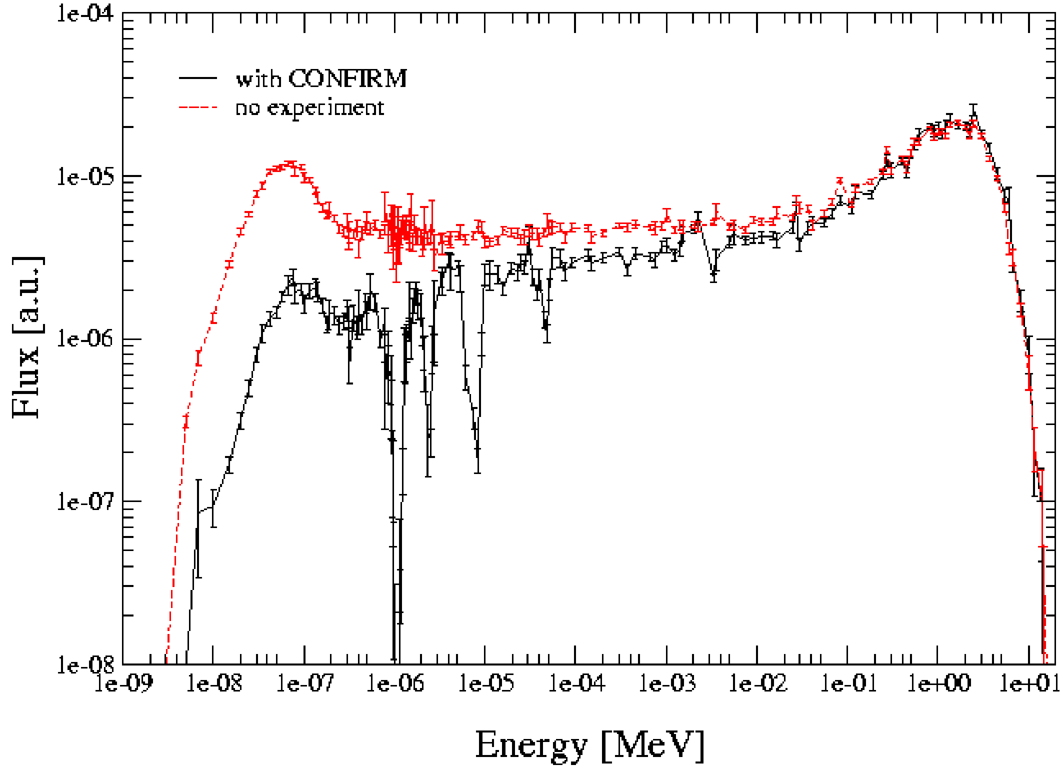
Gas gaps, and gas mixtures are adjusted to achieve the temperatures desired

In this way for example the flux buckling profile can be compensated to achieve constant temperatures over the axial length of the experiment



Neutron shielding

Neutron shields can be adopted to adjust the spectrum in the irradiation position



Significant experience has been gained in applying neutron shields, and the introduction of strong (thermal) neutron absorbing materials in the HFR core (SIRIO, HICU, CONFIRM)