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
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

Reactor program
- 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

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

- **HB**: Beam Tubes
- **PSF**: Pool Side Facilities
- **CR**: Control rod
- **Beryllium reflector**
- **Fuel**
- **Experimental or isotope production position**

**Legend**:
- + Beryllium reflector
- Red Fuel
- White Experimental or isotope production position
- CR Control rod
Schematic of the High Flux Reactor (HFR) Petten, The Netherlands

PSF: Pool Side Facilities

HB: Beam Tubes

PSF: Pool Side Facilities

LFF - NW

PSF (WEST)

1

11

12

LFF - SW

HB 10  HB 9  PR  HB 8  HB 7  HB 6

HB 1  HB 2

HB 11  HB 12

HFR Reactor Core

CR CR CR

CR

Beryllium reflector

Fuel

Experimental or isotope production position

Control rod

HFR Reactor Core
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):

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

12 pool side positions for example for ramp testing, flux control and safety tests with maximum position average (2.5 cm from core box):

- $0.5 \times 10^{14} \text{ cm}^{-2}\text{s}^{-1}$ fast
- $1.2 \times 10^{14} \text{ cm}^{-2}\text{s}^{-1}$ epithermal
- $1.5 \times 10^{14} \text{ cm}^{-2}\text{s}^{-1}$ 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

High burn-up HTR fuel structure

Ceramography
microstructure

JEOL 6490 LV SEM, placed in hot cell
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
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)

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

- Vacuum Vessel: qualification of alternative manufacturing methods
- Vacuum Vessel: qualification of repair welding
- Primary Wall & Shield: bolts for attachments of modules
- Primary Wall Modules: Pulsed Heat & Neutron Loads
- Primary Wall and Divertor: Tungsten cladding
- Alternative heat-sinks
- Specials: windows; diagnostics; feedthroughs; instrumentation

Upper Port Launcher:
Mirror Thermohydraulics & Remote Handling

Upper Port Viewer:
Mirror & Shielding

Test Blanket Modules:
- Eurofer qualification
- Li ceramics behaviour
- Beryllium behaviour
- LiPb behaviour
- Tritium transport
- Instrumentation

And:
- Prob. Safety Analyses
- Fitness for purpose
- Remote Handling
- Neutronics
- Training etc.

ITER, fusion reactor to demonstrate fusion viability, Cadarache, France
Large experience base: past 10 years and current HFR Irradiation Examples (fuels)

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<tr>
<td>OTTO:</td>
<td>Once through then out Pu-transmutation</td>
</tr>
<tr>
<td>THORIUM CYCLE:</td>
<td>Thorium fuel experiment</td>
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<tr>
<td>EFFTRA-T4, T4 bis, T4ter:</td>
<td>Transmutation experiments under EFFTRA</td>
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<tr>
<td>HELIOS:</td>
<td>Minor actinide fuels and targets</td>
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<tr>
<td>CONFIRM:</td>
<td>Nitride fuels for fast reactors</td>
</tr>
<tr>
<td>FUJI:</td>
<td>FBR innovative fuels, commercial</td>
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<td>MARIOS:</td>
<td>SFR minor actinide fuel irradiation</td>
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<tr>
<td>HFR-EU1, HFREU1bis:</td>
<td>HTR pebble irradiations</td>
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<td>SMART:</td>
<td>Nitride for advanced fuels</td>
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<td>TRABANT:</td>
<td>Fast reactor annular MOX fuel irradiation</td>
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<td>SPHERE:</td>
<td>Minor actinide bearing sphere-pac fuel</td>
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<tr>
<td>MARINE:</td>
<td>Fast reactor minor actinide bearing fuel</td>
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Production of medical isotopes
Molybdenum-99 Delivery Chain

U-235 targets

Reactor
"Target Irradiation"

Mo-99
bulk liquid

Mo-99/Tc-99m generators

Hospitals

HFR
BR2
Osiris
Safari
NRU

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

Europe (top 3):
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:
  o User Requirement Specifications – continuity of a financial sound irradiation business
  o Design & Construction according to “defense in depth” principle
  o Reliable, stable and easily manageable operation
  o 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
Reserve extra slides
Schematic of the High Flux Reactor (HFR) Petten, The Netherlands

PSF: Pool Side Facilities

LFF - NW
PSF (WEST)

HFR Reactor Core

HB: Beam Tubes

+ 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
• 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)
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.

![Graph showing temperature control](image)

- Decrease gas conductivity
- Increase gas conductivity

![Graph showing gap width control](image)

- Increasing gap width
- Decreasing gap width
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).