Institutt for Energiteknikk

OECD Halden Reactor Project

Svein Novik
svein.novik@hrp.no

Senior Research Scientist
Reactor and fuel physics / Criticality Officer

- International research program to improve the safety and reliability of nuclear power, and to ensure Norway's national expertise in reactor technology.
Institutt for Energiteknikk

Budget IFE about 550 MNOK
Total 550 employees

- IFE - Kjeller
  - 330 employees

- OECD Halden Reactor Project
  - 264 employees
  - Budget ~ 170 MNOK (22 M€)

- Isotope production
- Tracers
- Industrial sources
- Radiopharmaceuticals
- Neutron Activation Analysis
- NTD - Neutron Transmutation Doping of silicon- silicon
- Fuel pellet fabrication

Injection of tracer  Production of tracer

Isotop- / hotlab
The Joint Programme is agreed upon and funded by the Halden Project participants. (~100 organisations: Utilities, vendors, licensing authorities & regulators, R&D centres)

In addition to the joint program, experiments are also carried out through Bilateral arrangements. The scope of the bilateral tests is comparable to the scope of the joint program in terms of number of tests and funding.
MTO – Man Technology Organization

- 76 employees
- Budget: 85 mill.kr.

- Surveillance systems for Operation and Maintenance
- Software systems Dependability
- Visualization technologies (VR-centre)

- Human Performance
- Design and Evaluation of Human System Interfaces and Control Rooms

Halden Boiling Water Reactor (HBWR)

- 150 employees
- Budget: MNOK 120

- Reactor site in solid rock
- Heavy water as moderator / primary coolant
- Two experimental periods by about 100 full power days each year
- By-product: 30 mt/h steam to paper mill (Norske Skog – Saugbrugs)

<table>
<thead>
<tr>
<th>Thermal power</th>
<th>20MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temp.(max)</td>
<td>240°C</td>
</tr>
<tr>
<td>Operating pressure (max.)</td>
<td>33.6 bar</td>
</tr>
<tr>
<td>Moderator</td>
<td>Heavy water (D₂O)</td>
</tr>
<tr>
<td>Heavy water volume</td>
<td>14m³ total</td>
</tr>
<tr>
<td>Type of fuel</td>
<td>Uranium oxide</td>
</tr>
<tr>
<td>Power adjustment</td>
<td>Control stations (30)</td>
</tr>
<tr>
<td>BWR/PWR conditions are simulated in 9 loop systems</td>
<td></td>
</tr>
</tbody>
</table>
IFEs research reactors vs. commercial power reactor (PWR)

Comparison of technical data

<table>
<thead>
<tr>
<th></th>
<th>JEEP II</th>
<th>HBWR</th>
<th>PWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Power:</td>
<td>2 MW</td>
<td>20 MW</td>
<td>3000 MW</td>
</tr>
<tr>
<td>Coolant Temperature:</td>
<td>50 - 56 C</td>
<td>240 C</td>
<td>290/330 C</td>
</tr>
<tr>
<td>Pressure:</td>
<td>1 bar</td>
<td>34 bar</td>
<td>155 bar</td>
</tr>
<tr>
<td>Moderator/Coolant:</td>
<td>D₂O</td>
<td>D₂O</td>
<td>H₂O</td>
</tr>
<tr>
<td>Fuel Elements:</td>
<td>19</td>
<td>~ 110 (max ~ 300)</td>
<td>160 (bundles)</td>
</tr>
<tr>
<td>Enrichment (U-235)</td>
<td>3.5 w%</td>
<td>max 20 w%</td>
<td>3-4 w%</td>
</tr>
<tr>
<td>Height of core</td>
<td>60 cm</td>
<td>80 cm</td>
<td>360 cm</td>
</tr>
<tr>
<td>UO2-amount</td>
<td>253 kg</td>
<td>500 kg</td>
<td>75 000 kg</td>
</tr>
<tr>
<td>Neutron flux:</td>
<td>3×10¹¹ n cm⁻² s⁻¹</td>
<td>5×10¹¹ n cm⁻² s⁻¹</td>
<td>~ 10¹² n cm⁻² s⁻¹</td>
</tr>
</tbody>
</table>

Objectives of the HRP
Fuels & Materials Programme

Address safety and economy of power generation in present and future nuclear power plants:

- Demonstrate reliability and operational flexibility of current and new fuel designs
- Show compliance with safety criteria and assess safety margins
- Assess measures for plant life extension and mitigation of core component ageing
HBWR Core Configuration

- ~ 300 positions individually accessible
- ~ 30 positions for experimental purposes
- Height of active core 80cm
- Experimental channel diameter 70 mm
- Loop systems to simulate thermal-hydraulic and chemistry for different reactor conditions.
What do we measure?

- **Pressure** in fuel rods.
- **Fuel temperature.**
- **Elongation** of cladding and fuel
- Change of **cladding diameter.**
- **Crack growth** in materials.
- Electrochemical potential, pH and other **water chemistry-related variables.**
- **Corrosion.**

‘On-line’ measurements providing direct insight into phenomena while they develop are the speciality of the experimental work at the Halden reactor. Reliable instrumentation has been developed since the sixties.

How do we measure?

**Instrumented Fuel Assemblies (IFA-rig)**

- Engineered and produced at own workshop in Halden
- Tailor-made hardware for each particular experiment.
- Know-how from years of experience and practice.
Fuel tests in HBWR

Capability to implement different modes of operation:

- Normal conditions / steady state
- Load follow (Local power control possible)
- Ramping
- Fast transients
- Abnormal conditions (e.g. RIA, LOCA)

Ability to simulate operation conditions of commercial nuclear power stations. Eg:

- BWR
- PWR
- CANDU
- Gen III+ / Gen IV
Fuel and cladding behavior during radiation

- PCI: Pellet Cladding Interaction
- PCMI: Pellet Cladding Mechanical Interaction
- FGR: Fission Gas Release
- Conductivity
- Fuel swelling
- Corrosion

- The standard data acquisition system allows sampling at 10ms intervals.
- More details through post irradiation examinations (PIE) in hot-lab facilities.

In-core material tests.

Example:
Crack growth measurement

Response of CT to the addition of H₂
Change in water chemistry give a clear picture of change in cracking behaviour.
Thorium fuel in HBWR

(IFA-652, 2001/2002)

- Fuel pellets fabricated at IFE-Kjeller:
  - IM - Inert Matrix
  - IMT - Inert Matrix Thorium-doped
  - T - Thorium
- Burnup history: 0 - 15 MWd/kg ox

✓ Fuel performance generated from in-core instrumentation.

✓ Working range for novel fuel can be determined.

<table>
<thead>
<tr>
<th>IM</th>
<th>IMT</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.637</td>
<td>6.01</td>
<td>5.97</td>
</tr>
<tr>
<td>81.49%</td>
<td>81.04%</td>
<td>81.04%</td>
</tr>
<tr>
<td>43.66%</td>
<td>43.66%</td>
<td>43.66%</td>
</tr>
<tr>
<td>93.2%</td>
<td>88.3%</td>
<td>88.3%</td>
</tr>
<tr>
<td>16.8%</td>
<td>11.7%</td>
<td>11.7%</td>
</tr>
<tr>
<td>10% U²³³</td>
<td>10% U²³³</td>
<td>10% U²³³</td>
</tr>
</tbody>
</table>

Fuel and material test for generation III+ and IV reactors

- Argentinean CAREM project
  - Small and Medium sized Reactors (SMR)
  - ~ 100 MW th.
  - Integrated control rods
- Super critical water Reactor (SCW)
  - Nordic Nuclear Materials Forum for Generation IV Reactors NOMAGE4 / GEN4FIN-VTT
  - Instrument development
  - SCW – loop i HBWR
  - European GETMAT (EU’s 7. rammeprogram)
  - Sustainable Nuclear Energy Technology Platform - SNETP
- Thorium fuel
  - Fuel test in HBWR for commercial and future reactors

- Temp. 510 °C - 625 °C
- Known turbine technology
- Fast or thermal neutrons

\[
\text{Th-232 + n} \rightarrow \text{Th-233} \\
\text{Pa-233 + β} \rightarrow \text{U-233 + β}
\]
To summarize: HBWR for future fuel and reactors

Closed fuel cycle.
(Pu for MOX or U-233 from Th-232)

Licensing of fuel for commercial reactors

Fuel test in HBWR - Halden
Fuel characteristics and behavior
- Pressure in fuel rods
- Fuel temperature
- Elongation of cladding and fuel
- Change of cladding diameter
- Crack growth in materials
- Electrochemical properties
- Corrosion

Lead Test Assembly (LTA) in commercial reactor

GIF