<table>
<thead>
<tr>
<th>Country</th>
<th>Research Reactor Scheduled and planned life- time Operation cycle</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator Reflector</th>
<th>Irradiation positions:</th>
<th>Test configuration</th>
<th>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</th>
<th>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</th>
<th>On-site PIE facilities (hot cells, glove boxes, tools for stress analysis, etc.)</th>
<th>Design, manufacturing, disposition, shipping, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>BR-2</td>
<td>50–120 MW Tank-in-pool HEU 72–93% U-235 Light water</td>
<td>With cosine flux profile – Standard 80 mm Ø, 900 mm height – Large 200 mm Ø, 900 mm height Thermal and fast neutron flux up to 10^{15} n·cm^{-2}·s^{-1}</td>
<td>PWR loop conditions Water pool conditions Stagnant water Stagnant inert gas Liquid metal Vacuum Air cooling flow</td>
<td>Heating, flux and temperature monitoring capabilities in various rig designs Temp range 50–600°C</td>
<td>Gamma irradiation facility on-site</td>
<td>On-site hot cells available</td>
<td>Full scale 3D heterogeneous MCNP model MCNP-4C with transmutation trajectory analysis code PIE facilities on-site</td>
<td>IPS design group and IPS manufacturing/assembly in-house Waste handling &amp; shipping possible</td>
<td>Via collaboration agreement Commercial</td>
<td>Long, proven experience with material testing research, high flux applications</td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>CEFR 2011</td>
<td>65 MW Pool type</td>
<td>UO₂ or MOX Sodium coolant and moderator Stainless steel and boron reflector</td>
<td>251 irradiation positions for special test subassemblies, to be put into: 81 fuel subassemblies, 1 neutron source subassembly and 169 steel shielding subassemblies Max neutron flux (F) 3.5 × 10^{15} n·cm^{-2}·s^{-1} Max 9.3 dpa/80EFPD</td>
<td>No special testing loop High temperature sodium static test facility (SSTF) – temperature 800°C – cover gas Argon – Oxygen in sodium: 10 ppm; Carbon in sodium: 10 ppm. High temperature sodium thermal convection test loop (STCTL) – Max. temperature: 550°C; Max. temperature C; Flow speed: 4-10 m/s-1 High temperature sodium mass transfer test loop (SMTTL)</td>
<td>Fuel-cladding chemical interaction out-of-pile test facility (FCCTF) – Max. test temperature 900°C</td>
<td>– electron microscopy lab – TEM operating at 200 kV, magnifications from 2000 X to 1 500 000 X. Equipped with a JEOL Instruments energy dispersive X-ray spectrometer. – mechanical test lab 300J pendulum impact machines, tensile test machines and creep testing machines. – hot cells – radiochemical laboratory</td>
<td>Wide range of material testing research applications</td>
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<tr>
<td>Country Research reactor</td>
<td>Power Type</td>
<td>Fuel</td>
<td>Coolant</td>
<td>Moderator Reflector</td>
<td>Irradiation positions:</td>
<td>Test configuration</td>
<td>Instrumentation and control</td>
<td>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</td>
<td>On-site PIE capabilities (hot cells, glove boxes, tools for stress analysis, etc.)</td>
<td>Design, manufacturing, disposition, shipping, waste handling and other capabilities</td>
<td>Method of access and degree of utilization</td>
<td>Miscellaneous and readiness for material testing research</td>
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<tr>
<td>China CARR 2013–2043 (planned) Each cycle of 25 days</td>
<td>60 MW Tank in pool type Plate type U3Si2, 19.75% enrichment (LEU) dispersed in Al matrix with a clad of Al-alloy Light water as coolant and moderator Heavy water reflector tank</td>
<td>23 irradiation positions Dia. 55–280 mm Length 1000 mm (available) Max neutron flux (T) 8 × 10¹⁴ n·cm⁻²·s⁻¹ Max neutron flux (F) 6 × 10¹⁴ n·cm⁻²·s⁻¹</td>
<td>HTHPTL: – pressure 17.2 MPa – temperature 350°C – cooling power 300 kW – volume flow 30 m³/h He-3 pressure control loop: – Range of pressure change 0.5–4.0 MPa – Design temperature of tritium trap 400°C – Power ramping rate 10 kW/m·min – Design volume flow 1–2 cm³/s</td>
<td>CIPITISE: – Maximum temperature for lithium breeder pebble bed 735°C – Maximum temperature for the RAFM structure steel 558°C</td>
<td></td>
<td>Temperature (thermocouple): Pressure of coolant Level of coolant (level-meters); Flow rate meters</td>
<td>9 beams Gamma spectrometry installation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Wide range of thermal spectrum material testing research applications</td>
<td></td>
</tr>
</tbody>
</table>
### Czech Republic

**LVR-15 REZ**

- **10 MW Tank**
  - HEU
  - IRT-2M
  - 36% U-235
- **Supercritical water loop**:
  - ID – 20 mm
  - Length – 500 mm
- **He loop**:
  - Space 30×570 mm
  - Sample size 4 × 40 mm
- **Irradiation rigs**:
  - CHOUCA – Charpy V, tensile, SRT, 0.5 CT
  - Flat rig – 1T-CT, 2T-CT specimens
  - Pb-Li in-pile rig
  - Gas doping system
  - Orbisphere H2/02 measurement
- **Dionex ion chromatography rigs**:
  - 1T-CT & 2T-CT specimens
  - 250 + 10 to 350 + 10 °C
  - Supercritical water loop: 600 °C
  - He loop: 900 °C
- **Heating, flux and temperature monitoring capabilities in various rig designs**
  - 6 to 8 heating sections
  - 20 – 30 thermocouples
- **Supercritical water loop**:
  - 600 °C
- **He loop**:
  - 900 °C

### France

**OSIRIS**

- **70 MW Light-water reactor, open-core pool type**
  - U, Si, Al fuel enriched to 19.75%:
  - In-core positions:
    - 4 water boxes (8.27 cm square, 60 cm height)
    - 4 locations within each water box (Ø 37 mm)
    - Max fast flux (E >0.1 MeV): 4 x 10¹⁴ n·cm⁻²·s⁻¹
    - Up to 7 dpa/year
  - Out-core positions:
    - Large number of water boxes (8.27 cm square, 60 cm height)
    - 2 locations with a displacement system
    - Thermal flux: 3x 10¹⁴ n·cm⁻²·s⁻¹
  - Test devices reproducing thermohydraulic, neutronic and chemical conditions of nuclear power plants (PWR, BWR)
  - Capsules (NaK, gas) for material testing (250–1000°C)
  - Test device dedicated to irradiate experimental reactors fuel plates Mo-99 rigs
  - Si doping facility
  - Neutron flux measurement: activation detectors, collectrons, fission chambers
  - Gamma heating by differential calorimeters with graphite samples
  - Thermocouples (250–1000°C)
  - LVDT type sensors to measure stress/strain characteristics
  - Sensors to measure the fission gas releases (pressure and composition)
  - Neutron radiography facility
  - Gamma spectrometry facility
- **LECI hot laboratory**: metallurgical and mechanical characterization of irradiated materials from power reactors, or experimental irradiations, manufacture of test specimens, samples and experimental fuel rods

<table>
<thead>
<tr>
<th>Czech Republic</th>
<th>France</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LVR-15 REZ</strong></td>
<td><strong>OSIRIS</strong></td>
</tr>
<tr>
<td><strong>10 MW</strong></td>
<td><strong>70 MW Light-water reactor, open-core pool type</strong></td>
</tr>
<tr>
<td><strong>Tank</strong></td>
<td><strong>U, Si, Al fuel enriched to 19.75%</strong></td>
</tr>
</tbody>
</table>
| **HEU** | **In-core positions**:
| **IRT-2M** | - 4 water boxes (8.27 cm square, 60 cm height)
| **36% U-235** | - 4 locations within each water box (Ø 37 mm)
| **Supercritical water loop** | - Max fast flux (E >0.1 MeV): 4 x 10¹⁴ n·cm⁻²·s⁻¹
| **He loop** | - Up to 7 dpa/year
| **Space 30×570 mm** | **Out-core positions**:
| **Sample size 4 × 40 mm** | - Large number of water boxes (8.27 cm square, 60 cm height)
| **4 water boxes (8.27 cm square, 60 cm height)** | - 2 locations with a displacement system
| **3x 10¹⁴ n·cm⁻²·s⁻¹** | - Thermal flux: 3x 10¹⁴ n·cm⁻²·s⁻¹

### TABLE A-1 (cont.) OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)
<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
<th>Test configuration</th>
<th>Instrumentation and control</th>
<th>Other facilities</th>
<th>On-site PIE capabilities</th>
<th>Design, manufacturing, disposition, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>DHRUVA</td>
<td>100 MW</td>
<td>Tank type</td>
<td>Metalic nat. Ur</td>
<td>Heavy water (coolant, moderator &amp; reflector)</td>
<td>10 in-core vertical channels 3+3 for isotope production</td>
<td>2 × 1.6 MW in-pile loop</td>
<td>Flux (th) 1.8 × 10^{14} n·cm^{-2}·s^{-1} Fast</td>
<td>2.7 × 10^{12} n·cm^{-2}·s^{-1} 2 in-pile loop channels</td>
<td>In-pile loop of 1.6 MW Light water environment: Temperature 250–300°C Pressure-150 bar Irradiation of Th fuel bundle and AHWR, Th, Pu, MOX fuel, Zr-2.5,Nb, low carbon steel Controlled temperature irradiation facility for pressure tube 300±5°C</td>
<td>Irradiation chamber Self powered inconel neutron detectors (SPND) Noise analysis Creep and corrosion facilities Tensile strength, hardness</td>
<td>14 beam tubes NAA facility Cold source Hot source</td>
<td>One hot cell for isotope handling and experiments handling 2 × 10^5 Ci Shielding PIE Lab on-site</td>
<td>Necessary facilities and expertise exist for design and manufacturing of irradiation devices on-site</td>
</tr>
<tr>
<td>Japan</td>
<td>JMTR</td>
<td>50 MW</td>
<td>Tank type</td>
<td>MTR type</td>
<td>LEU fuel</td>
<td>Light water coolant and moderator Beryllium reflector</td>
<td>60 irradiation positions 60 capsules of diameter 30–110 mm Flux total 4 × 10^{14} n·cm^{-2}·s^{-1}, fast: 4 × 10^{14} n·cm^{-2}·s^{-1} 4 dpa in steel</td>
<td>Power ramp facility. Facility for studying SCC Controlled temperature irradiation facility, temperature 45–2000°C</td>
<td>Facility for temperature, chemistry and irradiation control</td>
<td>Water chemistry controlled irradiation facility</td>
<td>8 concrete cells, 7 lead cells and 5 steel cells</td>
<td>Yes</td>
<td>Long, proven experience with material testing research</td>
<td></td>
</tr>
</tbody>
</table>

<p>| India   | DHRUVA          | 100 MW     | Tank type | Metalic nat. Ur | Heavy water (coolant, moderator &amp; reflector) | 10 in-core vertical channels 3+3 for isotope production | 2 × 1.6 MW in-pile loop | Flux (th) 1.8 × 10^{14} n·cm^{-2}·s^{-1} Fast | 2.7 × 10^{12} n·cm^{-2}·s^{-1} 2 in-pile loop channels | In-pile loop of 1.6 MW Light water environment: Temperature 250–300°C Pressure-150 bar Irradiation of Th fuel bundle and AHWR, Th, Pu, MOX fuel, Zr-2.5,Nb, low carbon steel Controlled temperature irradiation facility for pressure tube 300±5°C | Irradiation chamber Self powered inconel neutron detectors (SPND) Noise analysis Creep and corrosion facilities Tensile strength, hardness | 14 beam tubes NAA facility Cold source Hot source | One hot cell for isotope handling and experiments handling 2 × 10^5 Ci Shielding PIE Lab on-site | Necessary facilities and expertise exist for design and manufacturing of irradiation devices on-site | Potential ageing management |
| Japan   | JMTR            | 50 MW      | Tank type | MTR type | LEU fuel | Light water coolant and moderator Beryllium reflector | 60 irradiation positions 60 capsules of diameter 30–110 mm Flux total 4 × 10^{14} n·cm^{-2}·s^{-1}, fast: 4 × 10^{14} n·cm^{-2}·s^{-1} 4 dpa in steel | Power ramp facility. Facility for studying SCC Controlled temperature irradiation facility, temperature 45–2000°C | Facility for temperature, chemistry and irradiation control | Water chemistry controlled irradiation facility | 8 concrete cells, 7 lead cells and 5 steel cells | Yes | Long, proven experience with material testing research |</p>
<table>
<thead>
<tr>
<th>Republic of Korea</th>
<th>30 MW Open-tank-in-pool LEU U3Si 19.75 w% U-235</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation cycle:</td>
<td>4 weeks/cycle operation 200 days/year</td>
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<tr>
<td>HANARO</td>
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<tr>
<td>Lifetime: NA</td>
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<tr>
<td>Operation cycle:</td>
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<td></td>
<td>Total of 32 test holes, 3 in-core, 4 in the</td>
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<tr>
<td></td>
<td>outer core and 25 in the reflector tank</td>
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<tr>
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<td>Height (all): 870 mm</td>
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<tr>
<td></td>
<td>Inside diameter (cm)</td>
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<tr>
<td></td>
<td>CT – 7.44</td>
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<tr>
<td></td>
<td>IR 1 &amp; 2 – 7.44</td>
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<td></td>
<td>OR – 6</td>
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<tr>
<td></td>
<td>LH – 15</td>
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<td>HTS – 10</td>
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<td>IP – 6</td>
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<td></td>
<td>NTD – 18 &amp; 22</td>
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<td></td>
<td>CNS – 16</td>
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<td>Materials test capsule:</td>
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<tr>
<td></td>
<td>– Total L – 6 m</td>
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<td></td>
<td>– Dia 60 mm</td>
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<td></td>
<td>– H 870 mm</td>
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<td>Fuel test capsule:</td>
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<tr>
<td></td>
<td>– Total L – 5 m</td>
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<tr>
<td></td>
<td>– Outer tube Ø 56 mm</td>
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<td></td>
<td>– Outer tube L 730 mm</td>
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<tr>
<td></td>
<td>Flux thermal</td>
</tr>
<tr>
<td></td>
<td>$4 \times 10^{11} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$</td>
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<tr>
<td></td>
<td>Fast (E&gt;0.82 MeV)</td>
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<td></td>
<td>$2 \times 10^{11} \text{ n}\cdot\text{cm}^{-2}\cdot\text{s}^{-1}$</td>
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<td></td>
<td>Estimated dpa/year</td>
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<td></td>
<td>in steel $\approx 2 \text{ dpa/year}$</td>
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<td></td>
<td>Core material/fuel test holes:</td>
</tr>
<tr>
<td></td>
<td>– CT</td>
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<td></td>
<td>– IR 1 &amp; 2</td>
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<td></td>
<td>– OR</td>
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<td></td>
<td>Reflector material/fuel test holes:</td>
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<td></td>
<td>– LH</td>
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<td>– HTS</td>
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<td>– IP</td>
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<td>Capsules:</td>
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<td></td>
<td>– Instrumented and non-instrumented for</td>
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<tr>
<td></td>
<td>materials testing (He atmosphere, 0 to 1 atm)</td>
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<tr>
<td></td>
<td>– Instrumented and non-instrumented for fuel</td>
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<tr>
<td></td>
<td>testing, water cooled (mixed gas environment</td>
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<td></td>
<td>He/Ne being developed)</td>
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<td></td>
<td>– Creep capsule (being developed)</td>
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<td></td>
<td>Materials test capsule:</td>
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<tr>
<td></td>
<td>– Max 950ºC</td>
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<td>– Min 50ºC</td>
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<td>Materials test capsule:</td>
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<tr>
<td></td>
<td>– 5 stages independent temperature control</td>
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<td></td>
<td>– 14 thermocouples</td>
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<td>– 5 micro heaters</td>
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<td>– 5 fluence monitors</td>
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<td>– Inside He 0 to 1 atm</td>
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<td>– to control temperature</td>
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<td>– Low to high temperature capsules:</td>
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<td>– $50$ to $950$ºC</td>
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<td></td>
<td>Fuel test capsule</td>
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<td>Control of irradiating temperature (all ranges</td>
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<td>from low to high)</td>
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<td></td>
<td>Instruments:</td>
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<td>– LVDT</td>
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<td>– SPND</td>
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<td>– Thermocouple</td>
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<td>– Micro-heater</td>
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<td></td>
<td>– Fluence monitor</td>
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<tr>
<td></td>
<td>Neutron beams</td>
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<td></td>
<td>(thermal &amp; cold)</td>
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<tr>
<td></td>
<td>NAA (thermal &amp; cold neutron)</td>
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<td></td>
<td>NTD (5 to 8 inch — 12.7 to 20.32 cm)</td>
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<tr>
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<td>RI production</td>
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<tr>
<td></td>
<td>2 PIE facilities</td>
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<td></td>
<td>IMEF</td>
</tr>
<tr>
<td></td>
<td>6 concrete hot cells</td>
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<td>2 lead hot cells</td>
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<td>1 pool PIE facility</td>
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<td>6 concrete cells</td>
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<td>mainly treat irradiated fuels</td>
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<td>Full engineering manpower and design capacity</td>
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<td>Manufacturing capacity for fuel handling tools,</td>
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<td>vessel, various experimental devices</td>
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<td>Waste management facility</td>
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<td>Facility for manufacturing new RR fuels</td>
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<td>Capability for shipping and transporting in</td>
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<td>the institute</td>
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<td></td>
<td>Can be accessed by contract or collaborative</td>
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<td>research agreement</td>
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<td></td>
<td>Users are accessed by applying in the internet</td>
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<tr>
<td></td>
<td>‘hanaro4u.kaeri.re.kr’</td>
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<tr>
<td></td>
<td>Irradiation, NAA, beams can be used by</td>
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<td></td>
<td>applying at HANARO4u NTD by contract</td>
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<tr>
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<td>Multi/purpose reactor with some potential for</td>
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<tr>
<td></td>
<td>material testing research</td>
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<tr>
<td>Country</td>
<td>Research reactor</td>
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<tr>
<td>The Netherlands</td>
<td>HFR</td>
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</table>

**Test configuration**
- **Test environment temperature and pressure range**
- **Instrumentation and control**
  - (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)
- **Other facilities**
  - (beams, neutron activation analysis, gamma-ray, etc.)
- **On-site PIE capabilities**
  - (hot cells, glove boxes, tools for stress analysis, etc.)
- **Design, manufacturing, disposition, shipping, waste handling and other capabilities**
- **Method of access and degree of utilization**
- **Miscellaneous and readiness for material testing research (MTR)**
- **Synthesis/fabrication of (nuclear) materials**
- **Loops for testing components of reactor core**
- **Facilities for investigation of corrosion of reactor materials**
- **Experimental facilities for investigation of accidental conditions**
  - LOCA, LOFT, RIA, etc.
- **Devices for capsule/ampule tests of materials in different environment, at wide range temperature and dose rates etc.**
<table>
<thead>
<tr>
<th>Norway</th>
<th>HBWR</th>
<th>18–20 MW (thermal) heavy water moderated and cooled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test fuel rod length up to 100 cm</td>
<td>Loop systems for simulation of BWR/PWR/WWER/CANDU conditions</td>
<td></td>
</tr>
<tr>
<td>More than 300 positions individually accessible</td>
<td>Heat removal capacity 200 kW</td>
<td></td>
</tr>
<tr>
<td>About 110 positions in central core of which 20–30 positions can be used for experimental purposes at the same time</td>
<td>Pressurization system for imposing up to 500 bar pressure on fuel rods under operating conditions</td>
<td></td>
</tr>
<tr>
<td>Experimental channel diameter is 70 mm in HBWR moderator and 35–45 mm in pressure flask</td>
<td>Rig for fuel and material testing: pressure 165 bar, temperature 340°C</td>
<td></td>
</tr>
<tr>
<td>Height of active core 80 cm</td>
<td>Water chemistry, purification during operation, conductivity, mass spectrometry (ICP MS)</td>
<td></td>
</tr>
<tr>
<td>Usable length within moderator about 160 cm</td>
<td>LOCA in-situ with temperature control</td>
<td></td>
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<tr>
<td>Max fast (0.8 \times 10^{14} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} ) (&gt;1 \text{ MeV})</td>
<td>Cladding creep under variable loading conditions (600 bar)</td>
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<tr>
<td>Max thermal flux (1.6 \times 10^{14} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1})</td>
<td>Rod overpressure and clad lift-off (auxiliary gas 600 bar)</td>
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<tr>
<td>2 dpa per year</td>
<td>Fuel creep, gas flow and fission gas analysis</td>
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<td></td>
<td>For fuel testing:</td>
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<tr>
<td></td>
<td>– Fuel thermocouple</td>
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<td></td>
<td>– Rod pressure transducer</td>
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<td></td>
<td>– Cladding extensometer</td>
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<td></td>
<td>– Fuel stack elongation detector</td>
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<td>– Moveable diameter gauge</td>
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<td>For materials testing:</td>
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<td></td>
<td>– DC potential drop measurement</td>
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<td>– Electrochemical potential sensor</td>
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<td>– Water conductivity cell</td>
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<td></td>
<td>– Electrochemical impedance measurement</td>
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<td>Gas flow system</td>
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<td>Gas analysis system</td>
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<td></td>
<td>Hydraulic drive system 240°C–340°C up to 250 bar, 600–700°C</td>
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<td>Neutron beam facilities at JEEP-II reactor IFE-Kjeller site</td>
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<td>Hot laboratory for fuel fabrication and re-fabrication, post irradiation examination</td>
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<td></td>
<td>Workshop for design and fabrication of irradiation devices</td>
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<tr>
<td></td>
<td>Instrument development, testing and qualification</td>
<td></td>
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<td></td>
<td>Neutron radiography</td>
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<td></td>
<td>Storage space for spent fuel</td>
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<tr>
<td></td>
<td>Transportation of radioactive fuels and materials</td>
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<td></td>
<td>Fresh and irradiated logistic</td>
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<tr>
<td></td>
<td>Long, proven experience with MTR including instrumentation</td>
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<tr>
<td></td>
<td>Planned: supercritical water facility (250 bar, 600°C)</td>
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</table>

Member-ship in Halden Reactor Project (HRP)
<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Romania</td>
<td>TRIGA II PITESTI SS CORE</td>
<td>14 MW Reactor pool type</td>
<td>UZrEr</td>
<td>Hydride</td>
<td>Water + Be blocks</td>
<td>Example illustrated with 2 active positions for experiment and 5 more positions plugged (total 7 in-pile positions to allow flexibility) Dia 54 mm for fuel experiments 90 × 90 mm slots for in-pile rigs 3.80 m long pressure tube 300/500mm active exp length, samples Useful diameter of capsules 29.5 mm Flux 4.22 × 10^{14} n·cm^{-2}·s^{-1} Extrapolated: 3000/6000 hours average operation in position C5 results in about 2 dpa/year for steel/3dpa at 12 MW</td>
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<tr>
<td>Schedule and planned life-time</td>
<td>Operation cycle</td>
<td>Test configuration</td>
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<tr>
<td>Romania</td>
<td>2030</td>
<td>Temperature and pressure range</td>
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<tr>
<td>Romania</td>
<td>Operation lifetime:</td>
<td>Power</td>
<td>14 MW</td>
<td>Reactor pool type</td>
<td>UZrEr</td>
<td>Hydride</td>
<td>Water + Be blocks</td>
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<tr>
<td>Romania</td>
<td>2030</td>
<td>Total flux</td>
<td>Extrapolated:</td>
<td>3000/6000 hours average operation in position C5 results in about 2 dpa/year for steel/3dpa at 12 MW</td>
<td>Test environment</td>
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<tr>
<td>Romania</td>
<td>2030</td>
<td>fast flux (≥0.1 MeV)</td>
<td>Estimated dpa/year</td>
<td>in steel</td>
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<td>2030</td>
<td>Flux, (n·cm^{-2}·s^{-1}):</td>
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<td>Romania</td>
<td>2030</td>
<td>– total flux</td>
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<td></td>
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<td>Romania</td>
<td>2030</td>
<td>– fast flux (≥0.1 MeV)</td>
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<td>2030</td>
<td>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</td>
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<td>Romania</td>
<td>2030</td>
<td>On-site PIE capabilities (hot cells, glove boxes, tools for stress analysis, etc.)</td>
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<td>Romania</td>
<td>2030</td>
<td>Design, manufacturing, shipping, waste handling and other capabilities</td>
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<td>Romania</td>
<td>2030</td>
<td>Method of access and degree of utilization</td>
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<td>2030</td>
<td>Miscellaneous and readiness for material testing research (MTR)</td>
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<td>Loop for testing nuclear fuel and materials (loop A):</td>
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<td>– Total power 100 kW</td>
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<td>– Water flow rate at the samples 3–7 m³/h</td>
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<td>– Max. pressure 135 bar</td>
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<td>2030</td>
<td>– Temp: 310–330°C</td>
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<td>2030</td>
<td>– Over power &amp; ramp test In-pile assembly for high temperature materials (rig C5) with temp up to about 600°C under inert atmosphere</td>
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<td>Instrumented irradiation capsules 35kW each:</td>
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<td>– C1 fission gas on line composition analysis</td>
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<td>2030</td>
<td>– C2 pressure of fission products and central temperature in experimental fuel rods</td>
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<td>The capsules parameters are 110 bar/310°C</td>
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<td>– beam tube for fresh fuel</td>
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<td>– Two large heavy concrete hot cells</td>
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<td>– Tight designed for works in inert atmosphere</td>
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<td>Fuel and sample holder instrumentation</td>
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<td>LL&amp;ML-RW management</td>
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<td>Licensed shipping cask</td>
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<tr>
<td>Romania</td>
<td>2030</td>
<td>– INR-RR – testing facility for capsules irradiation</td>
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<tr>
<td>Romania</td>
<td>2030</td>
<td>– Isotope production</td>
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<td>– INR-RR – testing facility for capsules irradiation</td>
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<td>Romania</td>
<td>2030</td>
<td>Commercial contract</td>
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<td>Romania</td>
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<td>Suitable for high temperature testing of structural materials</td>
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<td>Russian Federation</td>
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<td>Scheduled/ planned life time: 2017/2030</td>
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<td>Operating time at power – 250 days/year</td>
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<td>Fuel cycle – 10–14 days</td>
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<td>Outage period – 2–6 days</td>
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<td>Maintenance period – 40 days</td>
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<table>
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<tr>
<th>90–100 MW (thermal)</th>
<th>2017/2030 time planned life</th>
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<tr>
<td>High flux, vessel-type reactor</td>
<td>Operating time</td>
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<tr>
<td>Fuel: 90% HEU UO2 dispersed in Cu-Be matrix</td>
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<tr>
<td>Pin type elements in SS cladding Light water as coolant and moderator</td>
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<tr>
<td>Beryllium reflector</td>
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</tbody>
</table>

| Total irradiation positions (IP) – 81, height of IP 350–400 mm |
| Trap positions: 27 IP with Ø 12 mm | |
| Neutron flux: total – ≤5.4 × 10^{15} n·cm^{-2}·s^{-1} | |
| fast (E>0.1 MeV) | ≤1.5 × 10^{15} n·cm^{-2}·s^{-1} | |
| dpa/year | ≤11–16 | |
| Core positions: 24 IP with Ø 12 mm, 4 IP with Ø 24.5 mm | |
| Neutron flux: total | ≤4.3 × 10^{15} n·cm^{-2}·s^{-1} | |
| fast (E>0.1 MeV) | 2.3 × 10^{15} n·cm^{-2}·s^{-1} | |
| dpa/year | ≤16–25 | |
| Reflector positions: 30 IP with Ø 68 mm | |
| Neutron flux: total | ≤1.6 × 10^{15} n·cm^{-2}·s^{-1} | |
| fast (E>0.1 MeV) | ≤5.3 × 10^{14} n·cm^{-2}·s^{-1} | |
| dpa/year | ≤0.1–6.0 | |

| Test environment of ampoule rigs in the core and reflector: water, boiling water – ≤350°C, ≤16 MPa; Pb, Pb - Bi -650°C, ≤1 MPa; supercritical water ≤650°C, ≤23 MPa; gas (He, Ne, N2) – 400–2500°C, ≤10 MPa | |
| High temperature water loop in the core and reflector ≤350°C, ≤18 MPa | |
| Low temperature water loop ≤100°C, ≤5 MPa | |
| Instrumented irradiation devices for in-pile investigation creep, stress relaxation, stress corrosion cracking etc. | |

| Temperature: chromel-alumel thermocouples up to 1100°C | |
| W-Re thermocouples up to 2300°C | |
| Geometry change: linear differential inductosyn transducer (LDIT) | |
| Pressure, stress and strains: bellows rolling diaphragm + LDIT | |
| Neutron flux: Rb-, V-, Hf – direct charge detectors | |
| Neutron fluence: activation monitors | |

| Chemistry control and measurement systems of water and gas environment for ampoule rigs | |
| Fission products monitoring and measurement facilities | |
| Loop systems for simulation of PWR, WWER conditions | |
| 1 hot cell in the reactor building | |

| More than 110 equipment in the material testing complex | |
| Burn-up; fission products release; metallographic and ceramographic, micro-hardness; density and porosity; thermal conductivity and electric resistance; X-ray analysis; TEM, SEM, EPMA, AES, SIMS; mechanical testing (tensile, compression, bending, impact etc.) | |

| Department for design of reactor components and experimental facilities | |
| Plant for manufacturing reactor components and experimental facilities | |
| Facilities and technologies for investigation and production of nuclear fuel | |
| Radiochemical complex to study and produce transplutonics, radioisotopes and sources for industrial and medical purposes | |
| Facilities to dispose radwaste and spent nuclear fuel and materials | |

| Bi- and multilateral contracts between laboratories and institutions | |
| Degree of utilization: 80–90% | |

<p>| Suitable for high flux instrumented tests of new materials and fuels of innovative reactors | |</p>
<table>
<thead>
<tr>
<th>Country Research reactor Scheduled and planned life-time Operation cycle</th>
<th>Power Type Fuel Coolant Moderator Reflector</th>
<th>Irradiation positions: number, height, diameter Flux, (n·cm⁻²·s⁻¹): total flux, fast flux (≥0.1 MeV) Estimated dpa/year in steel</th>
<th>Test configuration Test environment temperature and pressure range</th>
<th>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</th>
<th>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</th>
<th>On-site PIE capabilities (hot cells, glove boxes, tools for stress analysis, etc.)</th>
<th>Design, manufacturing, disposition, shipping, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research (MTR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian Federation BOR-60</td>
<td>Experimental fast sodium reactor Fuel: MOX (75% HEU UO₂ + 23 wt% PuO₂), and 75% HEU UO₂ Coolant: primary and secondary circuits – sodium, third circuit – water Radial reflector – SS Axial reflector – natural UO₂</td>
<td>Irradiation positions (IP) in the core up to 25 (depends on core configuration), height of IP 450–500 mm, flat to flat size of hexagonal cell – 44 mm Neutron flux: total [3.6 \times 10^{13} \text{n·cm}^{-2} \text{s}^{-1}] fast (E &gt; 0.1 MeV) [3.0 \times 10^{13} \text{n·cm}^{-2} \text{s}^{-1}] dpa/year [10–25] IP in the radial reflector – unlimited, height of IP 450–500 mm, flat to flat size of hexagonal cell – 44 mm Neutron flux: total [1.8 \times 10^{15} \text{n·cm}^{-2} \text{s}^{-1}], fast (E &gt; 0.1 MeV) [1.1 \times 10^{15} \text{n·cm}^{-2} \text{s}^{-1}], dpa/year [5–10]</td>
<td>Test environment of ampoule rigs in the core and reflector: Na, Pb, Pb-Bi – 320–720°C, ≤1 MPa Gas (Ar, He, Ne and mixture) 330–1100°C, ≤1 MPa Na, Pb, Pb–Bi in-vessel loop facilities – 330–720°C, ≤1 MPa</td>
<td>Temperature: chromel-alumel thermocouples up to 1100°C Melting monitors, SiC monitors Pressure, stress and strains: bellows rolling diaphragm, spring Neutron fluence activation monitors</td>
<td>Chemistry control and measurement systems of gas environment for ampoule rigs Fission product monitoring and measurement facilities 1 hot cell in the reactor building 9 vertical channels located outside the reactor vessel with Ø 90–230 mm Neutron flux: total [1.8 \times 10^{13} \text{n·cm}^{-2} \text{s}^{-1}] fast (E &gt; 0.1 MeV) [8 \times 10^{12} \text{n·cm}^{-2} \text{s}^{-1}] 2 horizontal beams Neutron flux: total [1 \times 10^{9} \text{n·cm}^{-2} \text{s}^{-1}] fast (E &gt; 0.1 MeV) [3 \times 10^{8} \text{n·cm}^{-2} \text{s}^{-1}]</td>
<td>More than 110 equipment in the material testing complex Burn-up; fission products release; metallographic and ceramographic, micro-hardness; density and porosity; thermal conductivity and electric resistance; X-ray analysis; TEM, SEM, EPMA, AES, SIMS; mechanical testing (tensile, compression)</td>
<td>Department for design of reactor components and experimental facilities Plant for manufacturing of reactor components and experimental facilities Facilities and technologies for investigation and production of nuclear fuel Radiochemical complex to study and produce transplutonics, radioisotopes and sources for industrial and medical purposes Facilities to dispose radwaste and spent nuclear fuel and material</td>
<td>Bi- and multilateral contracts between laboratories and institutions Degree of utilization: 80–90%</td>
<td>Suitable for high flux instrumented tests of new materials and fuels of innovative reactors</td>
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<tr>
<td>Russian Federation</td>
<td>6 MW Open pool HEU, UO2 H2O Fuel: spent fuel of SM-3 reactor (90% HEU UO2 dispersed in Cu-Be matrix) Pin type elements in SS cladding Light water as coolant, moderator and reflector</td>
<td>Total irradiation positions (IP) – 16, height of IP 350–400 mm Core positions: 8 IP with Ø ≤69 mm Neutron flux: total ≤2.2 × 10^{14} n·cm^{-2}·s^{-1} fast (E&gt;0.1 MeV) ≤5.6×10^{13} n·cm^{-2}·s^{-1} dpa/year ≤0.6 Reflector positions 8 IP with Ø ≤160 mm Neutron flux: total – ≤3.2 × 10^{13} n·cm^{-2}·s^{-1} fast (E&gt; 0.1 MeV) ≤1.2 × 10^{13} n·cm^{-2}·s^{-1} dpa/year ≤0.1 Capsules only Test environment of ampoule rigs in the core and reflector: – water, boiling water – ≤350°C, ≤16 MPa; – supercritical water – ≤650°C, ≤23 MPa; – gas (He, Ne, N2) – 400–2500°C, ≤10 MPa Instrumented irradiation devices for in-pile investigation creep, stress relaxation, stress corrosion cracking etc.</td>
<td>Temperature: chromel-alumel thermocouples up to 1100°C, W-Re thermocouples up to 2300°C Geometry change: linear differential inductosyn transducer (LDIT) Pressure, stress and strains: bellows rolling diaphragm + LDIT Neutron flux: Rh-, V-, Hf – direct charge detectors Neutron fluence: activation monitors</td>
<td>Chemistry control and measurement systems of gas environment for ampoule rigs Fission products monitoring and measurement facilities 1 hot cell in the reactor building</td>
<td>The material testing complex houses more than 110 equipment Burn-up; fission products release; metallographic and ceramographic, micro-hardness; density and porosity; thermal conductivity and electric resistance; X ray analysis; TEM, SEM, EPMA, AES, SIMS; mechanical testing (tensile, compression)</td>
<td>Department for design of reactor components and experimental facilities Plant for manufacturing of reactor components and experimental facilities</td>
<td>Bi- and multilateral contracts between laboratories and institutions Degree of utilization: 40–50%</td>
<td>Suitable for in-pile instrumented tests under medium and low fluxes of new materials, testing for pressure vessels possible</td>
<td></td>
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<tr>
<td>Country</td>
<td>Research reactor</td>
<td>Scheduled and planned life-time</td>
<td>Power Type</td>
<td>Fuel</td>
<td>Coolant</td>
<td>Moderator</td>
<td>Reflector</td>
<td>Irradiation positions:</td>
<td>Test configuration</td>
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<tr>
<td>Russian Federation</td>
<td><strong>MIR.M1</strong></td>
<td>Scheduled/ planned life time – 2027/2035</td>
<td>100 MW(th) channel-type in water pool</td>
<td>Fuel: 90% HEU UO2 dispersed in Al-matrix</td>
<td>Tube-type elements in Al cladding</td>
<td>Light water as coolant</td>
<td>Beryllium as moderator and reflector</td>
<td>Total irradiation positions (IP) – 49, height of IP 1100 mm Core positions: 11 cells for loop channels, with Ø ≤148.5 mm Neutron flux: total ≤6.0 × 10^{14} n·cm^{-2}·s^{-1} fast (E&gt;0.1 MeV) ≤2.0×10^{14} n·cm^{-2}·s^{-1} Dpa/year ≤1.5; 38 IP with Ø ≤34mm Neutron flux: total ≤6.0×10^{14} n·cm^{-2}·s^{-1} fast (E&gt;0.1 MeV) ≤3.0×10^{14} n·cm^{-2}·s^{-1} Dpa/year ≤5</td>
<td>Test environment in the water loop facilities: water – temperature ≤350°C, pressure ≤17MPa (2 facilities with 2 channels each) Test environment in the boiling water loop facilities: water – temperature ≤350°C, pressure ≤17 MPa, volume vapour content (2 facilities with 2 channels each) Test environment in the vapour loop facilities: superheating steam-temperature ≤1100°C, pressure ≤20 MPa (one facility, with one channel) Test environment in the gas loop facility: N, He, Ne, Xe – temperature ≤1100°C, pressure ≤4 MPa (one facility, with one channel)</td>
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</table>
| Russian Federation | 8 MW(th) Pool-type Reactor
IR-8
Scheduled/planned life time – 2016/2025
Operating time at nominal power – 120 days/year |
|-------------------|--------------------------------------------------|
| Fuel: 90% HEU UO2 dispersed in Al-matrix
Tube-type elements in Al cladding
Light water as coolant and moderator
Beryllium as reflector |
| Total irradiation positions (IP) – 42, height – 580 mm, diameter – 45 mm
Core positions – 29 IP
Flux total – \( \leq 2.1 \times 10^{14} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \)
Flux fast (\( \text{E} > 0.1 \text{MeV} \)) \( \leq 0.6 \times 10^{14} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \)
dpa/year \( \leq 0.6 \) Reflector positions – 13 IP with Ø \( \leq 160 \text{mm} \)
F total – \( \leq 3.1 \times 10^{14} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \)
F (\( \text{E} > 0.1 \text{MeV} \)) \( \leq 1.7 \times 10^{13} \text{n} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \)
dpa/year \( \leq 0.2 \) |
| Capsules only
Test environment of ampoule rigs in the core and reflector:
– water, boiling water – \( \leq 350^\circ \text{C}, \leq 16 \text{MPa} \)
Neutron flux: Rh-, V-, Hf – direct charge detectors
Neutron fluence: activation monitors |
| 12 neutron beams instrumented:
– five-circle neutron diffractometer MOND
– triaxial crystal spectrometer ATOS
– polycrystal multidetector circular diffractometer DISK
– triaxial perfect crystal-based spectrometer STOIK
– complex of hardware for neutron and gamma introscopy of materials and products (turbine blades, welded joints, fuel assemblies, etc.) |
| Hot cells for PIE of non-fuel materials by (metallographic and ceramographic, micro-hardness; density and porosity; thermal conductivity and electric resistance; X ray analysis; TEM, SEM, EPMA, AES, SIMS; mechanical testing) |
| Department for design experimental facilities
Facilities to dispose radioactive waste and spent nuclear fuel and materials |
| Bi- and multilateral contracts between laboratories and institution
Degree of utilization: N/A |
| Multipurpose, also suitable for tests with low fluxes, material testing for pressure vessels possible
Beam studies of irradiated materials |
### TABLE A-1 (cont.) OPERATIONAL RESEARCH REACTORS: OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Scheduled and planned life-time Operation cycle</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
<th>Test configuration</th>
<th>Instrumentation and control</th>
<th>Other facilities</th>
<th>On-site PIE capabilities</th>
<th>Design, manufacturing, disposition, shipping, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research (MTR)</th>
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</thead>
<tbody>
<tr>
<td>Russian Federation</td>
<td>IVV-2M</td>
<td>Scheduled/planned life time – 2018/2025 Operating time at nominal power – 290 days/year</td>
<td>15 MW(th) Pool-type Fuel: 36% HEU UO$_2$ dispersed in Al-matrix Tube-type elements in Al cladding Light water as coolant and moderator Beryllium as reflector</td>
<td>Total irradiation positions (IP) – 45, height – 500 mm 40 IP with Ø ≤60 mm 2 IP with Ø ≤120 mm 1 IP with Ø ≤130 mm 1 IP with Ø ≤190 mm 1 IP with Ø ≤400 mm Neutron flux: total: ≤7 \times 10^{14} \text{n-cm}^{-2}\text{s}^{-1} fast (E&gt;0.1 \text{MeV}) ≤2 \times 10^{14} \text{n-cm}^{-2}\text{s}^{-1} Dpa/year ≤2.0</td>
<td>Test environment of ampoule rigs in the core and reflector: water, boiling water – ≤350°C, ≤16 MPa; Pb, Pb – 650°C, ≤1 MPa; supercritical water – ≤650°C, ≤23 MPa; gas (He, Ne, N$_2$) – 400–1500°C, ≤1 MPa Instrumented irradiation devices for in-pile investigation creep, stress relaxation, stress corrosion cracking etc.</td>
<td>Temperature: chromel-alumel thermocouples up to 1100°C Neutron flux: Rb, V, Hf – direct charge detectors Neutron fluence: activation monitors</td>
<td>Low temperature water loop (≤100°C, ≤5 MPa) Lead-coolant loop for investigation a corrosion of structural materials under in-pile and out-of-pile conditions at different temperatures 420–540°C 6 neutron beams</td>
<td>Hot cells for PIE of non-fuel materials (metallographic and ceramographic, micro-hardness; density and porosity; thermal conductivity and electric resistance; X-ray analysis; TEM, SEM, EPMA, AES, SIMS; mechanical testing)</td>
<td>Department for design of experimental facilities Facilities to dispose radwaste and spent nuclear fuel and materials</td>
<td>Bi – and multilateral contracts between laboratories and institutions Degree of utilization: 70–80%</td>
<td>Suitable for in-pile instrumented tests of new materials, under medium and low fluxes Beam studies of irradiated materials</td>
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<td>USA</td>
<td>ATR</td>
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<td>Licenced to 250 MW</td>
<td>Operating cycles 1–59 days average – 49 days</td>
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<td>Operates at power levels (~ 110 MWth)</td>
<td>Refuelling 14 days long 6 weeks outage per year</td>
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<td>Aluminium plate fuel</td>
<td>No end of life planned</td>
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<tr>
<td>Light water cooled</td>
<td>Typical refuelling (and experiment change out) outages are 14 days long, with one long (about 6 weeks) outage per year for major maintenance / equipment replacement</td>
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<td>Light water moderated</td>
<td>No end of life planned due to constant refurbishment and beryllium reflector replacement every ~ 10 years</td>
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<td>Beryllium reflected</td>
<td>Can be accessed via a bilateral agreement at full cost recovery</td>
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<td>77 testing positions in reactor tank: 9 flux traps, large power variations</td>
<td>Can be accessed at reduced or no cost through the ATR national scientific user facility peer reviewed proposal system</td>
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<td>Power tilt capability (4 independent lobe powers) 9 high-intensity neutron flux traps</td>
<td>Much of the reactor is full of experiments, however, there are some positions available, and other plans change to enable new experiments</td>
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<td>68 additional irradiation positions inside the reactor core reflector tank, each of which can contain multiple experiments</td>
<td>Full engineering staff available to design and build ATR experiments, arrange for shipment of irradiated experiments, and preparation of specimens for PIE work. No experiments are allowed that would require a new waste stream, but if there is already an approved waste stream within INL’s waste disposal system, the material can be allowed</td>
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<td>2 capsule irradiation tanks outside the core with 34 additional low-flux irradiation positions In-pile tubes (loops) Can have tests in water loops at prototypical (and beyond) PWR environment (pressure, temperature, flow rate, chemistry), gas-cooled tests up to 1300°C</td>
<td>Can be accessed at reduced or no cost through the ATR national scientific user facility peer reviewed proposal system</td>
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<td>4 test configurations: static capsule (with passive instrumentation), instrumented lead experiment (with instrument lines leading to detectors outside reactor vessel), pressurized water loop experiment, and hydraulic shuttle irradiation system (HSIS) Instrumentation available to measure temperature, flux and fluence, fission product release, compression creep, tritium release, moisture inside experiment, oxidation of specimens</td>
<td>The high temperature test laboratory (HTTL) contains specialized equipment to conduct high-temperature testing and develop in-pile test instrumentation</td>
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<td>Thermal neutron fluxes range from $1.7 \times 10^{13} - 4.4 \times 10^{14}$ n·cm$^{-2}$·s$^{-1}$ Fast flux ($E&gt;1$ MeV) $1.3 \times 10^{12} - 2.2 \times 10^{14}$ n·cm$^{-2}$·s$^{-1}$ dpa/year estimated to be $\approx 7$, depending on axial location of specimen in test position</td>
<td>None at the ATR site, but many at the INL site: hot fuel examination facility (HFEF), the analytical laboratory (AL), and the electronic microscopy laboratory (EML), and microscopy and characterization suite for PIE work</td>
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<td>77 testing positions in reactor tank: 9 flux traps, large power variations Power tilt capability (4 independent lobe powers) 9 high-intensity neutron flux traps 68 additional irradiation positions inside the reactor core reflector tank, each of which can contain multiple experiments 2 capsule irradiation tanks outside the core with 34 additional low-flux irradiation positions In-pile tubes (loops) Can have tests in water loops at prototypical (and beyond) PWR environment (pressure, temperature, flow rate, chemistry), gas-cooled tests up to 1300°C</td>
<td>No beams No NAA facilities No gamma tubes</td>
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### Table A-1 (cont.)  Operational Research Reactors: Overview of Current Capabilities for Material Testing Research (MTR)

<table>
<thead>
<tr>
<th>Country Research reactor</th>
<th>Power Type</th>
<th>Fuel Coolant</th>
<th>Moderator Reflector</th>
<th>Irradiation positions:</th>
<th>Test configuration</th>
<th>Instrumentation and control</th>
<th>Other facilities</th>
<th>On-site PIE capabilities</th>
<th>Design, manufacturing, shipping, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research (MTR)</th>
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</thead>
<tbody>
<tr>
<td>USA HFIR</td>
<td>85 MW</td>
<td>High flux, pressure vessel-type Light water as coolant and moderator</td>
<td>Beryllium reflector</td>
<td>Primary inlet coolant temperature: 120°F (48.89°C)</td>
<td>Irradiation positions (IP) – 83 IP in flux trap: Ø13 mm (can also provide Ø22 mm positions), Ftotal – 2.3×10⁹ n·cm⁻²·s⁻¹, F(E &gt;0.1 MeV) Max 14 dpa/year in flux trap 24 IP in Be-reflector: 8 RB Ø 38–70 mm, Flux total – 4.5×10⁸ n·cm⁻²·s⁻¹, F(E &gt;0.1 MeV) 2.5×10¹⁴ n·cm⁻²·s⁻¹</td>
<td>37 full-length positions in the flux trap Hydraulic tube irradiation facility in flux trap for on-line insertion and removal (irradiations shorter than one cycle) Pneumatic tube facilities in the beryllium reflector for online insertion and removal (emanate from shielded cave in NAA lab) Materials test temperature range from 60°C to 1000°C Online monitoring of effluent gas production, temperatures and pressures. Online monitoring of deformation possible On-line control of temperatures via in-pile heaters or sweep gas blending as well as pressures Neutron activation analysis (NAA) to examine trace elements and identify the composition of materials Gamma irradiation capability that uses spent fuel assemblies and is capable of accommodating high gamma dose experiments for infrastructure materials qualifications 4 beam lines with 12 world-class instruments for condensed matter research 1. Irradiated material examination and testing (IMET) facility. Hot cells for materials testing 2. Irradiated fuels examination laboratory (IFEL), hot cells for fuels examination 3. Low activation materials development and analysis laboratory (LAMDA). Facility for materials testing of small or low activity material samples Experiment capsule design and fabrication including passive gas-gap temperature controls, active gas loop temperature controls Fabrication including complex geometries, additive manufacturing, most welding technologies, as well as fabrication and assembly of irradiated targets (hot cell fabrication facilities) Shipping of irradiated samples is available Waste handling is required for each experiment prior to irradiation</td>
<td>Design, manufacturing, shipping, waste handling and other capabilities</td>
<td>Method of access and degree of utilization</td>
<td>Miscellaneous and readiness for material testing research (MTR)</td>
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<tr>
<td>USA HFIR</td>
<td>Scheduled and planned life-time 1965–2040 Operating time at nominal power – 140 days/year Fuel cycle – 23–25 days, outage period 18–50 days</td>
<td>USA HFIR</td>
<td>USA HFIR</td>
<td>USA HFIR</td>
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<tr>
<th>USA</th>
<th>MITR</th>
<th>9 weeks operation per cycle, 24 h/day, 7 days/week</th>
<th>Two weeks refuelling and maintenance outage</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MW Tank Light water cooled Heavy water moderated</td>
<td>Fast flux (1.2 \times 10^{14} \text{n}\cdot \text{cm}^{-2}\cdot \text{s}^{-1}) Thermal flux (5 \times 10^{13} \text{n}\cdot \text{cm}^{-2}\cdot \text{s}^{-1}) 3 in-core facilities, up to 1.8” ID x 24” length (4.572 cm x 60.96 cm)</td>
<td>Pressurized water loops: – Can simulate typical PWR and BWR flow and chemistry conditions</td>
<td>High temperature irradiation facility: – Able to control (and dynamically adjust) flux and temperature independently of each other. Maximum temperature 1600°C Inert gas irradiation facility: – Can accommodate materials, optic sensors, static fluoride salt, graphite, SiC cladding material</td>
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<td>Thermocouples</td>
<td>Experiment residual gas monitoring Fission gas monitoring Electrochemical corrosion potential DC potential drop strain Crack growth measurement</td>
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<td>NAA (both prompt and delayed)</td>
<td>Hot cells mainly used for disassembly and experiment re-packaging Standard metallurgical sample preparation (epoxy mounting, sectioning, polishing) Photography and macro-photography Can access some microscopy instruments in MIT’s material science labs, but subject to dose limits</td>
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<td>All experiments to be performed in MITR can be designed by MITR staff Most experiments can be assembled at MITR, but if need to encapsulate previously irradiated material, may not have the hot cell capability Experiments can be wet-loaded or dry-loaded Can use the GE-2000 shipping container</td>
<td>Access to MITR is through contracts directly with MITR Access can also be gained through the ATR NSUF peer-review proposal selection process, since MITR is one of the ATR NSUF partner facilities Suitable for tests with low fluencies, fluxes, material testing for pressure vessels possible</td>
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# TABLE A-2. PLANNED RESEARCH REACTORS. OVERVIEW OF FUTURE CAPACITIES FOR MATERIAL TESTING RESEARCH

<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Power Type</th>
<th>Fuel Type</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina</td>
<td>RA-10 (planned 2018)</td>
<td>Open-pool</td>
<td>LEU fuel</td>
<td>Light water as coolant and moderator</td>
<td>Heavy water reflector</td>
<td>6 in-core irradiation channels 12–65 cm long Ø 5–8 cm</td>
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<td>Total flux: ( \leq 6 \times 10^{14} ) n·cm(^{-2})·s(^{-1}); fast flux (max): ( \leq 5 \times 10^{14} ) n·cm(^{-2})·s(^{-1}); 8 dpa/year</td>
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<td>Loop facility for testing PHWR and PWR fuels, linear power 500 W/cm and a maximum heat flux of 130 W/cm(^2) in steady state conditions (3 rods) and 600 W/cm and 150 W/cm(^2) in ramp conditions (1 rod)</td>
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<td>Temperature 320ºC (max.) Pressure 15bar (max.)</td>
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<td>In pile temp, pressure, stress, strain</td>
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<td>Pneumatic system for NAA and long irradiation capsules, cold source and beams guides (cold and thermal), Isotope production, neutron transmutation doping (NTD)</td>
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<td>Hot cell for fresh and irradiated experimental material in-pool neutron radiography facility for irradiated devices inspection</td>
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<td>Method of access and degree of utilization</td>
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<td>Miscellaneous and readiness for material testing research (MTR)</td>
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<tr>
<td>Belgium</td>
<td>MYRRHA Planned to be operational by 2024</td>
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<tr>
<td>65–100 MW ADS system capable of operating in critical mode Max 35 wt% enriched MOX fuel Pb-Bi eutectic (LBE) coolant 2 layers dummy FA (LBE and YZrO)</td>
<td>6+1 instrumented In-pile-sections (IPS) positions, 21 additional positions for inserts from top available Core height 600 mm, irradiation space: hexagonal, ID 101.5 mm Total flux $10^{19}$ n·cm⁻²·s⁻¹ Fast flux (&gt;0.75 MeV) $4.2 \times 10^{14}$ n·cm⁻²·s⁻¹ dpa/year: 23 in IPS, up to 30 dpa/year below target zone in ADS mode</td>
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<td>Test configuration is IPS design dependent Sample surface temperature range 100–650°C Temperature gradient ΔT over sample &lt;30°C IPS coolant possibilities: inert gas (He, Ar, CO₂…), water, liquid metal (LBE, Pb, Na) Possibilities for material testing, fuel tests, instrumentation tests, etc.</td>
<td>Instrumentation &amp; control is IPS dependent</td>
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<tr>
<td>On-site hot cells available On site PIE facilities</td>
<td>IPS design group and IPS manufacturing/assembly in-house Waste handling &amp; shipping possible Via MYRRHA consortium Commercial access Scientific merit (via PAC)</td>
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<td>Primary mission: demonstration No paper</td>
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<td>Country Research reactor</td>
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<td>Fuel</td>
<td>Coolant</td>
<td>Moderator</td>
<td>Reflector</td>
<td>Irradiation positions:</td>
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<td>Flux, ((n\cdot \text{cm}^{-2}\cdot \text{s}^{-1})):</td>
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<td>– fast flux (&gt;0.1 MeV)</td>
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<td>Test environment</td>
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<td>gamma-ray, etc.)</td>
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<td>stress strain, etc.)</td>
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<td>analysis, etc.)</td>
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<td>and other capabilities</td>
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**India**

**HFRR**

**Planned – 2022 start-up**

12 cycles in a year, each 25 days

<table>
<thead>
<tr>
<th>Country Research reactor</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation position, thermal neutron (&lt;0.621 eV), Epithermal (0.625 eV–821 keV), Fast neutron (&gt;821 keV) In-core water hole, 6.7 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 3.4 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 1.8 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} In-core peripheral water holes, 4.4 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 2.4 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 1.3 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} Irradiation holes in D₂O, 7 cm away from core edge, 3.7 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 6.0 × 10¹³ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 1.2 × 10¹³ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} Irradiation holes in D₂O, 20 cm away from core edge, 2.9 × 10¹⁴ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 5.0 × 10¹³ n\cdot \text{cm}^{-2}\cdot \text{s}^{-1} 1.7 × 10¹² n\cdot \text{cm}^{-2}\cdot \text{s}^{-1}</th>
<th>Test configuration</th>
<th>Test environment temperature and pressure range</th>
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<td>Materials irradiation facility planned: temperatures up to 1000°C Planned 200–450°C with inert gas environment such as helium 450–1000°C with molten salt environment Fuel test loop facility: temperatures up to 350°C, pressure 17.5 MPa Facility for changing water chemistry</td>
<td>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</td>
<td>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</td>
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<td></td>
<td>Hot cells</td>
<td>Necessary in-house expertise exists</td>
<td>Material irradiation facility planned</td>
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</tbody>
</table>
| **France**<br>JULES HOROWITZ REACTOR (JHR) | **High performances material testing reactor**<br>100 MW Light-water reactor, slightly pressurized core U3Si2 Al fuel (19.75% or 27%)<br>10 cycle per year 25 days cycle | **20 irradiation positions** (about 10 for fuel experiments; 10 for material experiments)<br>Fast flux (E >0.1 MeV): 5.5 E14 n·cm⁻²·s⁻¹<br>Thermal flux 5.5 × 10¹⁴ n·cm⁻²·s⁻¹<br>Material ageing: up to 16 dpa/year – max value in specific location<br>Diameter available in the core: 30 mm (3 possibility to 80 mm)<br>Outside the core in displacement system (6 available) | **Experimental loops** under developments allowing to represent thermo-hydraulic conditions of PWR, BWR and WWER (nominal, incidental-ramps and accidental scenario – LOCA – are considered)<br>For material corrosion loop to address irradiated assisted stress corrosion cracking (IASCC)<br>Sodium loop under feasibility for GENIV support | **Many up to date modern on-line instrumentation** to measure: thermal and fast neutron flux, gamma heating, elongation mono and bi-axial, stress strain, temperature, pressure…<br>On-line fission gas release analysis | **Non-destructive equipment** to perform X and Gamma analysis (tomography) on fuel in the reactor pool, in the storage pools and in hot cells <br>No neutron beam available | **Non-destructive analysis:** X and Gamma measurement (tomography) – elongation via LCDT…<br>4 hot cells to perform first level of PIE before sending sample to Cadarache Hot Labs (or others) | **Modern facility with all support activities such as:**<br>design of new experimental device, transport, waste management | **JHR is an advanced material testing research steer and fund by an International Consortium (12 members at the end of 2013)**<br>According to the Consortium agreement, possibility for non-member to have access to JHR experimental capacity | **Advanced**<br>Under construction<br>Plan to be in full operation by the end of this decade<br>Multi purpose with primary mission – material testing
<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Egypt</td>
<td><em>ETRR-2</em></td>
<td>Thermal</td>
<td>22</td>
<td>light water</td>
<td>light water and beryllium</td>
<td>One cobalt irradiation device (CID) in the core centre position with neutron flux of $2.7 \times 10^{14} \text{ n-cm}^{-2}\text{s}^{-1}$</td>
<td>Neutron transmutation doping (NTD) irradiation rigs</td>
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<td></td>
<td></td>
<td>pool</td>
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<td>Two positions in the core with neutron flux of $2 \times 10^{14} \text{ n-cm}^{-2}\text{s}^{-1}$</td>
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<td>23 irradiation boxes at the irradiation grids with neutron flux $10^{13} - 10^{14} \text{ n-cm}^{-2}\text{s}^{-1}$ and two rigs in thermal column with flux $10^{13} \text{ n-cm}^{-2}\text{s}^{-1}$</td>
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<td>Max thermal flux: $2.8 \times 10^{14} \text{ n-cm}^{-2}\text{s}^{-1}$ Max fast flux: $7.6 \times 10^{13} \text{ n-cm}^{-2}\text{s}^{-1}$</td>
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<thead>
<tr>
<th>Scheduled and planned life-time Operation cycle</th>
<th>Irradiation positions: number height diameter Flux, ($\text{n-cm}^{-2}\text{s}^{-1}$): total flux fast flux ($\geq 0.1 \text{ MeV}$) Estimated dpa/year in steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997–2020 30 years of operation 10 cycles per year Each cycle of 15 days</td>
<td>2 pneumatic tubes for fast irradiation for use in neutron activation analysis applications</td>
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</tbody>
</table>

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<thead>
<tr>
<th>Test configuration</th>
<th>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</th>
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<tbody>
<tr>
<td></td>
<td>Neutron transmutation doping (NTD) irradiation rigs NAA labs Large sample neutron activation analysis (LSNAA)</td>
</tr>
</tbody>
</table>

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<tr>
<th>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</th>
<th>On-site PIE capabilities (hot cells, glove boxes, tools for stress analysis, etc.)</th>
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</thead>
<tbody>
<tr>
<td>Radio isotope production cells</td>
<td>Design, manufacturing, disposition, shipping, waste handling and other capabilities</td>
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</table>

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<thead>
<tr>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research (MTR)</th>
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<tbody>
<tr>
<td>Limited capability for in-core material testing research</td>
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<tr>
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<td>Reactor Name</td>
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<td>Power Type</td>
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</table>
| France  | CABRI      |      |         |           |           | 25 MW at steady state  | In pile pressurized water loop reproducing thermohydraulic, neutronic and chemical conditions of PWR power reactors (300°C, 155 bars) | Neutron flux measurements by activation detectors and ionization chambers (online during transients) Inside the test device:  
- LVDT type sensors to measure axial strain on test fuel pin  
- Turbine and pitot tube flowmeters: 0–10 m³/h  
- Pressure sensors: 0–350 bars  
- Thermocouples (250–1000°C)  
- LVDT type sensors for measuring water level in the cell  
- Microphone for acoustic measurements | Hodoscope: on-line measurement of the pin test power profile IRIS: post-irradiation X ray tomography and gamma-spectrometry device for pin test | LECA hot laboratory: mechanical and metallurgical characterization on test fuel pins before and after transients in the CABRI reactor | Shipping cask for irradiated test fuel pins | Long experience with transient testing (RIA), to be expanded to LOCA No paper |
|         | lifetime: 1964 to NA |      |         |           |           | 30 GW during power transient (10 ms half width pulse) Light-water reactor, open-core pool type UO2 fuel enriched at 6% |          | Steady power at 25 MW:  
- Thermal flux (max): 9 × 10¹³ n·cm⁻²·s⁻¹  
- Epithermal flux (max): 7 × 10¹³ n·cm⁻²·s⁻¹  
- Fast flux (max): 2 × 10¹³ n·cm⁻²·s⁻¹ |          |          |              |                                      |                                | 250 m³/h, 155 bars | 200 m³/h, 155 bars | 200 m³/h, 155 bars |
|         | Pulsed research reactor |      |         |           |           |            |                   | Test environment temperature and pressure range | | | | |

*) n = neutron, cm⁻² = centimeter squared, s⁻¹ = second inverse, dpa = displacement per atom per year, m³/h = cubic meter per hour, bars = bar, °C = degree Celsius.
<table>
<thead>
<tr>
<th>Kazakhstan</th>
<th>( {\text{IGR}} )</th>
<th>Life-time is not specified</th>
<th>Operation cycle is not specified</th>
<th>Two main reactor operation modes: aperiodic pulse (neutron flash) and programmed pulse (pulse with different predetermined shape)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperiodic pulse max 10000 MW, programmed pulse max 1000 MW</td>
<td>Thermal impulse graphite reactor</td>
<td>Fuel – ( \text{U}_2\text{O}_4 ), dispersion in graphite, 90% U-235</td>
<td>Heat capacity type (without coolant)</td>
<td>Moderator &amp; reflector – graphite</td>
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<tr>
<td>Two vertical experimental channels:</td>
<td>– Central one with ( \Omega \text{ 228 mm and 3825 mm total height and active height 1400 mm} )</td>
<td>– Lateral one with ( \Omega \text{ 82 mm and 3440 mm total height and active height 1400 mm} )</td>
<td>Thermal flux up to ( 7 \times 10^{15} \text{ n cm}^{-2} \text{s}^{-1} ) (neutron flash with minimal half width 0.12 s), up to ( 7 \times 10^{14} \text{ n cm}^{-2} \text{s}^{-1} ) (programmed pulse)</td>
<td>Fast flux up to ( 10^{15} \text{ n cm}^{-2} \text{s}^{-1} ) and ( 10^{14} \text{ n cm}^{-2} \text{s}^{-1} ) respectively</td>
</tr>
<tr>
<td>Environment in the experimental rigs: hydrogen, nitrogen, carbon dioxide, helium, water, sodium and others during different diagrams of flow, pressure and temperature</td>
<td>Temperature (thermocouples, infrared method)</td>
<td>Acoustic signals</td>
<td>Pressure of the gaseous and liquid medium</td>
<td>Pressure impulse (e.g. in the liquid sodium)</td>
</tr>
<tr>
<td>Level of liquids (level-meters)</td>
<td>Voids in boiling liquid (void meters)</td>
<td>Local neutron flux (small scale neutron detectors)</td>
<td>Gas fission product release</td>
<td>Energy release in the fuel using spectrometry and by thermal method</td>
</tr>
<tr>
<td>Speed of the tested fuel movement inside IGR</td>
<td>The pneumohydraulic test bench is an extensive system with open loops for test object coolant</td>
<td>Number of gas paths – 11</td>
<td>Number of liquid paths – 7</td>
<td>Liquid discharge system – 950 m³</td>
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<tr>
<td>Level of liquids (level-meters)</td>
<td>Gas discharge system – 25 m³</td>
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<td>Voids in boiling liquid (void meters)</td>
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<td>Energy release in the fuel using spectrometry and by thermal method</td>
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<tr>
<td>Speed of the tested fuel movement inside IGR</td>
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**Note:** In order to keep uniformity of data presentation through the document the relevant institutions of pulsed research reactors provided estimated fluxes according to their available methods, usually calculated taking into account the values at half width of a pulse peak. For details the reader should address the full papers presented on the attached CD-ROM.
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**Romania**

**TRIGA II PITESTI**

Pulsed (ACPR)

Operation lifetime: 2030

- Steady state mode: max power 500 kW
- Pulsed mode: max power 20 GW
- Annular core pulsed, open pool
- Type reactor: Metal alloy U-ZrH 19.75% enriched fuel

The annular core by design accommodate 245 mm in diameter vertical tube for experiments

Capsule C6 designed for RIA type experiment for a single experimental instrumented fuel rod

Another designed capsule with PbBi will be fabricated and used for three fuel rods

A high speed data acquisition system is in use for this type of test

Fuel clad temperature measurement and internal pressure are recorded during the pulse

A pneumatic transfer system is used for NAA when annular core pulsed reactor (ACPR) is in low power steady operation

Facility for capsules irradiation

Isotope production facility

PIE lab:

- 2 large heavy concrete hot cells tight designed for works in inert atmosphere
- 3 steel shielded hot cells
- one lead shielded hot cell

Destructive PIE

Non-destructive PIE

SEM

Mechanical testing

Burnup determination by mass spectrometry

- Oxide layer thickness measurement by eddy current

Fission gas analysis

Design and manufacturing of in-pile equipment

Neutron and thermal hydraulic analysis of in-core experiments

Collaborative research agreement

Commercial contract

Experience with RIA testing of CANDU reactor type fuel

Planned: testing of MYRRHA fuel

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<th>Country</th>
<th>Research reactor</th>
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**Table A-4. (cont.). PULSED RESEARCH REACTORS. OVERVIEW OF CAPABILITIES AND CAPACITIES**
**Russian Federation**

**BIGR**

Fast pulse graphite reactor

Operational life time not specified

Material life time more than 3000 pulses about half of which is performed

<table>
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<tr>
<th>Fast pulse graphite reactor with ceramic UO$_2$ 0.5 MW power at steady-state operation</th>
<th>Cylindrical core with Ø 76 cm and 67 cm height</th>
<th>Dimensions available for samples 55 cm height and Ø 10 cm</th>
</tr>
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<tbody>
<tr>
<td>Energy release 280 MJ</td>
<td>Total fluence $1 \times 10^{16}$ n·cm$^{-2}$·s$^{-1}$ and in central channel $8.5 \times 10^{15}$ n·cm$^{-2}$·s$^{-1}$</td>
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<td>Minimum pulse half-width 2 ms 0.5 s quasi pulse half-width 1 pulse per day</td>
<td>The facility is equipped with additional equipment which makes it possible to vary $n \cdot \gamma$-radiations in a greater range, namely: different $n \cdot \gamma$-converter modifications, large-sized reflectors made of steel, graphite, polyethylene and beryllium</td>
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<tr>
<td>Peak power in quasi-pulse peak up to 75 GW Power in a quasi-pulse peak 1.5 GW</td>
<td>1 pulse per day and then the facility is left to cool down (i.e. no steady state conditions)</td>
<td>Tests can be performed in water varied pressure up to 17 MPa or in air at atmospheric pressure</td>
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<td></td>
<td>Measuring of temperatures of fuel element and ampoule elements, medium pressure in the ampoule</td>
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<td></td>
<td>Facilities are mentioned to be equipped for PIE but not listed</td>
<td>Gas filling and laser welding available</td>
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<td></td>
<td>The neutronic code CMK, 1D and 3D thermo-mechanical codes for numerical analyses of experiments</td>
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<td></td>
<td>Collaborative research agreement Commercial contract</td>
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</tbody>
</table>

**Note:** In order to keep uniformity of data presentation through the document the relevant institutions of pulsed research reactors provided estimated fluxes according to their available methods, usually calculated taking into account the values at half width of a pulse peak. For details the reader should address the full papers presented on the attached CD-ROM.
### TABLE A-5. LOW POWER RESEARCH REACTORS (LPRR). SOME EXAMPLES OF COMPLEMENTARY ROLE TO MATERIAL TESTING RESEARCH

<table>
<thead>
<tr>
<th>Country</th>
<th>Research reactor</th>
<th>Power Type</th>
<th>Fuel</th>
<th>Coolant</th>
<th>Moderator</th>
<th>Reflector</th>
<th>Irradiation positions:</th>
<th>Test configuration</th>
<th>Instrumentation and control (in-pile temperature, pressure, fission gas monitoring, stress strain, etc.)</th>
<th>Other facilities (beams, neutron activation analysis, gamma-ray, etc.)</th>
<th>On-site PIE capabilities (hot cells, glove boxes, tools for stress analysis, etc.)</th>
<th>Design, manufacturing, disposition, shipping, waste handling and other capabilities</th>
<th>Method of access and degree of utilization</th>
<th>Miscellaneous and readiness for material testing research</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slovenia</td>
<td>TRIGA Mark II</td>
<td>250kW</td>
<td>1MW in pulse operation (possible)</td>
<td>20% U mixed by ZrH (standard TRIGA fuel)</td>
<td>Water coolant</td>
<td>Graphite reflector</td>
<td>Max thermal flux in central channels: $7.6 \times 10^{12}$ n·cm$^{-2}$·s$^{-1}$</td>
<td>– Central vertical aluminium irradiation channels Ø int.=2.5cm</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– DT converter: irradiation by 14 MeV neutrons</td>
<td>– Rotating grooves: 40 irradiation positions for ampoules Ø int.=5cm Height 10cm</td>
<td>– Hot cell facility 2 cells: connected with reactor by pneumatic transfer system, equipped by master-slave manipulators</td>
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<td></td>
<td>Operating cycle: 800 working days per year</td>
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<td>– Triangular channel Ø int.=5cm</td>
<td>– 2 radial beam ports Ø int.=15cm</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– DT converter: irradiation by 14 MeV neutrons</td>
<td>– Rotating groove: 40 irradiation positions for ampoules Ø int.=5cm Height 10cm</td>
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<td>Lifetime: 1966, reconstructed in 1991</td>
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<td></td>
<td>– 2 tangential ports Ø int.=15cm</td>
<td>– 2 graphite blocks leading to irradiation facilities 10 cm x 10cm (Thermal column and thermalizing column)</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm</td>
<td>– DT converter: irradiation by 14 MeV neutrons</td>
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<td>Power Type</td>
<td>Fuel</td>
<td>Coolant</td>
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<td>Reflector</td>
<td>Irradiation positions:</td>
<td>Test configuration</td>
<td>Instrumentation and control</td>
<td>Other facilities</td>
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<tr>
<td>Italy</td>
<td>TRIGA RC-1</td>
<td>1MW</td>
<td>Natural</td>
<td>demineralized water</td>
<td>convection cooling</td>
<td>Uranium–ZrH alloy (8.5% Wt U)</td>
<td>20% U-235 H₂O, ZrH moderator</td>
<td>Experimental facility, thermal flux ((n\cdot cm^{-2}\cdot s^{-1})), (R_{\text{Cd}}^a*), shape, dimensions (mm) A radial channel, (4.8 \times 10^{12}, \approx 2.2), cylinder, Ø int.=152 B radial channel, (4.3 \times 10^{10}, \approx 3), cylinder, Ø int.= 152 C radial channel, (4.3 \times 10^{10}, \approx 3), cylinder, Ø int.= 152 D radial channel, (5.4 \times 10^{10}, 10.4), cylinder, Ø int.= 152 tangential channel, (1.1 \times 10^{6}, 2.2), cylinder, Ø int.= 152 piercing tangential channel, (1.1 \times 10^{6}, 1.24), cylinder, Ø int. = 180 Thermal column horizontal channel, (2.2 \times 10^{6}, 3.2), cylinder, Ø int. = 40</td>
<td>Liquid sample irradiation facility (LOOP)</td>
<td>Neutron radiography/tomography</td>
<td></td>
<td>Design and manufacture of experimental devices and measurement systems Including neutron collimators, shutters, irradiation devices, hydraulic loops, etc.)</td>
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<td></td>
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</tbody>
</table>

\(R_{\text{Cd}} = \text{Cadmium ratio.}\)
<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal column vertical channel (with plug of graphite)</td>
<td>$1.9 \times 10^{10}$, 4.3, square, side = 100</td>
</tr>
<tr>
<td>Thermal column vertical channel (without cap of graphite)</td>
<td>$4.2 \times 10^{9}$, $\approx 4$, square, side = 100</td>
</tr>
<tr>
<td>Central thimble</td>
<td>$2.68 \times 10^{13} \text{n cm}^{-2} \text{s}^{-1}$, 1.73, cylinder 'S' shaped, $\Omega \text{int.}=34.04$</td>
</tr>
<tr>
<td>Thermalizing column</td>
<td>$1.3 \times 10^{9}$, $&gt;100$</td>
</tr>
<tr>
<td>Parallelepiped</td>
<td>$608 \times 608 \times 155$</td>
</tr>
<tr>
<td>Rotary specimen rack</td>
<td>$2.0 \times 10^{12}$, 2.7, cylinder 'S' shaped, $\Omega \text{int.}=32$</td>
</tr>
<tr>
<td>Removable grid cavity</td>
<td>$1.25 \times 10^{13}$, 2.21, triangular prism, $l \approx 75, h = 650$</td>
</tr>
<tr>
<td>Rabbit (Pneumatic transfer tube)</td>
<td>$5.1 \times 10^{12}$, 2.00, cylinder, $\Omega \text{int.}=14 \Omega \text{int.}$ tube = 27</td>
</tr>
<tr>
<td>Loop for irradiation of liquids</td>
<td>$\approx 5.0 \times 10^{12}$, cylinder, $V \approx 150 \text{ml}$</td>
</tr>
<tr>
<td>Country</td>
<td>Research reactor</td>
</tr>
<tr>
<td>--------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>Italy</td>
<td>TAPIRO (Fast pile calibration at 0 power)</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>BFS-1 &amp; BFS-2</td>
</tr>
</tbody>
</table>