TABLE A-1. OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, (n·cm^{-2}·s^{-1}): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
Belgium *BR-2*	50–120 MW Tank-in-pool HEU 72–93% U-235 Light water	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}	PWR loop conditions Water pool conditions Stagnant water Stagnant inert gas Liquid metal Vacuum Air cooling flow	Heating, flux and temperature monitoring capabilities in various rig designs Temp range 50–600°C	Gamma irradiation facility on-site	On-site hot cells available Full scale 3D heterogeneous MCNP model MCNP-4C with transmutation trajectory analysis code PIE facilities on-site	IPS design group and IPS manufacturing/ assembly in-house Waste handling & shipping possible	Via collabo-ration agreement Commercial	Long, proven experience with material testing research, high flux applications
China *CEFR* *2011*	65 MW Pool type UO_2 or MOX Sodium coolant and moderator Stainless steel and boron reflector	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	No special testing loop High temperature sodium static test facility (SSTF) – temperature 800ºC – 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 □s-1 High temperature sodium mass transfer test loop (SMTTL) –		Fuel-cladding chemical interaction out-of-pile test facility (FCCITF) – Max. test temperature 900^0 C	– 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			Wide range of material testing research applications

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China *CARR* 2013–2043 (planned) Each cycle of 25 days	60 MW Tank in pool type Plate type U_3Si_2, 19.75% enrichment (LEU) dispersed in Al matrix with a clad of Al-alloy Light water as coolant and moderator Heavy water reflector tank	23 irradiation positions Dia. 55–280 mm Length 1000 mm (available) Max neutron flux (T) 8 × 10^{14} n·cm^{-2}·s^{-1} Max neutron flux (F) 6 × 10^{14} n·cm^{-2}·s^{-1}	*HTHPTL*: – pressure 17.2 MPa – temperature 350ºC – cooling power 300 kW – volume flow 30 m^3/h He-3 pressure control loop: – Range of pressure change 05–4.0 MPa – Design temperature of tritium trap 400ºC – Power ramping rate 10 kW/m·min – Design volume flow 1–2 cm^3/s *CIPITISE*: – Maximum temperature for lithium breeder pebble bed 735ºC – Maximum temperature for the RAFM structure steel 538ºC	Temperature (thermocouple); Pressure of coolant Level of coolant (level-meters); Flow rate meters	9 beams Gamma spectrometry installation	Hot cell: – 7 × 2.2 × 4.1 m – Cask for fuel rod and material transport – Video and camera for visual inspection of fuel assembly – Miller for dismantling of fuel assembly – Multi-function bench for NDT of full size fuel rod and CARR fuel plate			Wide range of thermal spectrum material testing research applications

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 250$\pm$10 to 350$\pm$10°C – Supercritical water loop – 600°C – He loop – 900°C	Heating, flux and temperature monitoring capabilities in various rig designs 1T-CT & 2T-CT – 6 to 8 heating sections and 20–30 thermocouples	HP loops: RVS-3 – 345°C BWR-1 –300°C BWR-2 –300°C ZINC – 320°C RVS-4 – 322°C	PIE facilities on-site in reactor hot cells or in hot or semi-hot cells located in nearby buildings			No paper available in this issue
France *OSIRIS* *1966-2015* *2018(?)* Average 200 days/year in cycles of varying lengths from 3 to 5 weeks	70 MW Light-water reactor, open-core pool type U_3Si_2 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 (∅ 37 mm) – Max fast flux (E >0.1 MeV): 4×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ – 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: 3×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$	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 dopping 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			Primary mission – material testing Limited capacity and access to the highest flux position No paper

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
India *DHRUVA* Scheduled life time 40 years 12 cycles in a year, each 27 days	100 MW Tank type Metallic nat. Ur Heavy water (coolant, moderator & reflector)	10 in-core vertical channels 3+3 for isotope production 2 × 1.6 MW in-pile loop Flux (th) $1.8 \times 10^{14}\ n \cdot cm^{-2} \cdot s^{-1}$ Fast $2.7 \times 10^{12} n \cdot cm^{-2} \cdot s^{-1}$ 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 PSA levels 1, 2, 3
Japan *JMTR* Currently (2015) shut down, but intention to restart 7 operation cycles/year with about 30 days operation in a month	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 $4 \times 10^{14}\ n \cdot cm^{-2} \cdot s^{-1}$, fast: $4 \times 10^{14}\ n \cdot cm^{-2} \cdot s^{-1}$ 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

Republic of Korea *HANARO* Lifetime: NA Operation cycle: 4 weeks/cycle operation 200 days/ year	30 MW Open-tank-in-pool LEU U_3Si 19.75 w% U-235 Coolant: light water Moderator: heavy water & light water Reflector: heavy water	Total of 32 test holes, 3 in-core, 4 in the outer core and 25 in the reflector tank Height (all): 870 mm Inside diameter (cm) – CT – 7.44 – IR 1&2 – 7.44 – OR – 6 – LH – 15 – HTS – 10 – IP – 6 – NTD – 18 & 22 – CNS – 16 Materials test capsule: – Total L ~ 6 m – Dia 60 mm – H 870 mm Fuel test capsule: – Total L ~ 5 m – Outer tube Ø 56 mm – Outer tube L 730 mm Flux thermal 4×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Fast (E>0.82 MeV) 2×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Estimated dpa/year in steel ≈ 2 dpa/year	Core material/fuel test holes: – CT – IR 1 & 2 – OR Reflector material/fuel test holes: – LH – HTS – IP Capsules: – Instrumented and non-instrumented for materials testing (He atmosphere, 0 to 1 atm) – Instrumented and non-instrumented for fuel testing, water cooled (mixed gas environment He/Ne being developed) – Creep capsule (being developed) Materials test capsule: – Max 950°C – Min 50°C	Materials test capsule: – 5 stages independent temperature control – 14 thermocouples – 5 micro heaters – 5 fluence monitors – Inside He 0 to 1 atm to control temperature – Low to high temperature capsules: 50 to 950°C Fuel test capsule Control of irradiating temperature (all ranges from low to high) Instruments: – LVDT – SPND – Thermocouple – Micro-heater – Fluence monitor	Neutron beams (thermal & cold) NAA (thermal & cold neutron) NTD (5 to 8 inch — 12.7 to 20.32 cm) RI production	2 PIE facilities IMEF 6 concrete hot cells 2 lead hot cells 1 pool PIE facility 6 concrete cells mainly treat irradiated fuels	Full engineering manpower and design capacity Manufacturing capacity for fuel handling tools, vessel, various experimental devices Waste management facility Facility for manufacturing new RR fuels Capability for shipping and transporting in the institute	Can be accessed by contract or collaborative research agreement Users are accessed by applying in the internet 'hanaro4u. kaeri.re.kr' Irradiation, NAA, beams can be used by applying at HANARO4u NTD by contract	Multi/ purpose reactor with some potential for material testing research

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
The Netherlands *HFR* High flux reactor	45 MW low-enriched uranium U_3Si_2 fuel Tank in pool type with a rectangular aluminium vessel Beryllium reflector	60 cm effective height is available (typical diameter 70 mm) PSF width 65 mm 17 in-core irradiation positions 12 pool side facility (PSF) irradiation positions Flux thermal 2.6×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Fast 1.8×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$	1000–1100°C Ampule tests		Neutron beam facilities Neutron tomography	Hot cells Radiochemistry facilities, SEM, TEM, X-Ray installations, gamma scanning, neutron beams facilities, etc. Labs for radiochemistry, solid source mass spectrometry (TIMS), XRD, XRT, mechanical testing, tritium release measurement	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.		

Norway *HBWR*	18–20 MW (thermal) heavy water moderated and cooled	Test fuel rod length up to 100 cm More than 300 positions individually accessible About 110 positions in central core of which 20–30 positions can be used for experimental purposes at the same time Experimental channel diameter is 70 mm in HBWR moderator and 35–45 mm in pressure flask Height of active core 80 cm Usable length within moderator about 160 cm Max fast 0.8×10^{14} n·cm^{-2}·s^{-1} n·cm^{-2}·s^{-1} (>1 MeV) Max thermal flux 1.6×10^{14} n·cm^{-2}·s^{-1} 2 dpa per year	Loop systems for simulation of BWR/PWR/WWER/ CANDU conditions Heat removal capacity 200 kW Pressurization system for imposing up to 500 bar pressure on fuel rods under operating conditions Rig for fuel and material testing: pressure 165 bar, temperature 340°C Water chemistry, purification during operation, conductivity, mass spectrometry (ICP MS) LOCA in-situ with temperature control Cladding creep under variable loading conditions (600 bar) Rod overpressure and clad lift-off (auxiliary gas 600 bar) Fuel creep, gas flow and fission gas analysis	For fuel testing: – Fuel thermocouple – Rod pressure transducer – Cladding extensometer – Fuel stack elongation detector – Moveable diameter gauge For materials testing: – DC potential drop measurement – Electrochemical potential sensor – Water conductivity cell – Electrochemical impedance measurement	Gas flow system Gas analysis system Hydraulic drive system 240°C–340°C up to 250 bar, 600–700°C Neutron beam facilities at JEEP-II reactor IFE-Kjeller site	Hot laboratory for fuel fabrication and re-fabrication, post irradiation examination	Workshop for design and fabrication of irradiation devices Instrument development, testing and qualification Neutron radiography Storage space for spent fuel Transportation of radioactive fuels and materials Fresh and irradiated logistic	Member-ship in Halden Reactor Project (HRP)	Long, proven experience with MTR including instrumenta tion Planned: supercritical water facility (250 bar, 600°C)

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Romania *TRIGA II PITESTI* SS CORE Operation lifetime: 2030	14 MW Reactor pool type UZrEr Hydride Water + Hydride Be blocks	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} $n \cdot cm^{-2} \cdot s^{-1}$ Extrapolated: 3000/6000 hours average operation in position C5 results in about 2 dpa/year for steel/3dpa at 12 MW	Loop for testing nuclear fuel and materials (loop A): – Total power 100 kW – Water flow rate at the samples 3–7 m^3/h – Max. pressure 135 bar – Temp: 310–330°C – Over power & ramp test In-pile assembly for high temperature materials (rig C5) with temp up to about 600°C under inert atmosphere Instrumented irradiation capsules 35kW each: C1 fission gas on line composition analysis C2 pressure of fission products and central temperature in experimental fuel rods C9 power cycling The capsules parameters are 110 bar/310°C	In-pile temperature up to about 600°C; for metallic alloys samples irradiation Axial temperature in exp fuel 1800°C In-situ data acquisition; Pressure, temperature, flow, neutron flux water quality & delayed neutrons, on line gamma spectrometer	Neutron radiography: – in pool for irradiated fuel – beam tube for fresh fuel Pool side gamma scanning	PIEL: – Two large heavy concrete hot cells – Tight designed for works in inert atmosphere – Three steel shielded hot cells – One lead shielded hot cell Destructive PIE Non-destructive PIE SEM Mechanical testing Sample preparation high quality metallography/ ceramography Burn-up determination by mass spectrometry. Oxide layer thickness, measurement by eddy current, TIG welding Fission gas analysis	Design and manufacture of complete irradiation devices Fuel and sample holder instrumentation LL&ML-RW management Licenced shipping cask – INR-RR – testing facility for capsules irradiation – Isotope production	Collaborative research agreement Commercial contract	Suitable for high temperature testing of structural materials

Russian Federation *SM-3* Scheduled/ planned life time- 2017/2030 Operating time at power – 250 days/year Fuel cycle – 10–14 days Outage period – 2–6 days Maintenance period – 40 days	90–100 MW (thermal) High flux, vessel-type reactor Fuel: 90% HEU UO_2 dispersed in Cu-Be matrix Pin type elements in SS cladding Light water as coolant and moderator Beryllium reflector	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 1100ºC W-Re thermocouples up to 2300ºC 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	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%	Suitable for high flux instrumented tests of new materials and fuels of innovative reactors

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Russian Federation *BOR-60* Scheduled/ planned life time – 2015/2020 Operating time at nominal power – 240 days/year, fuel cycle – 45–90 days, number of fuel cycles per year 4–5, outage period 20–40 day	60 MW(th) Experimental fast sodium reactor Fuel: MOX (75% HEU UO_2 + 23 wt% PuO), and 75% HEU UO_2 Coolant: primary and secondary circuits – sodium, third circuit – water Radial reflector – SS Axial reflector – natural UO_2	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 ≤3.6×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ fast (E> 0.1 MeV) ≤3.0×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ 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 ≤1.8×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$, fast (E>0.1 MeV) ≤$1.1 \times 10^{15}$ $n \cdot cm^{-2} \cdot s^{-1}$, dpa/year ≤5–10	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	Temperature: chromel-alumel thermocouples up to 1100ºC Melting monitors, SiC monitors Pressure, stress and strains: bellows rolling diaphragm, spring Neutron fluence activation monitors	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 ≤1.8×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1MeV) ≤8×10^{12} $n \cdot cm^{-2} \cdot s^{-1}$ 2 horizontal beams Neutron flux: total ≤$1 \cdot 10^{9}$ $n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1 MeV ≤3×10^{8} $n \cdot cm^{-2} \cdot s$	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)	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	Bi- and multilateral contracts between laboratories and institutions Degree of utilization: 80–90%	Suitable for high flux instrumented tests of new materials and fuels of innovative reactors

Russian Federation *RBT-6* Scheduled/ planned life time – 2020/2030 Operating time at nominal power – 260 days/year, fuel cycle – 6–40 days, outage period – 2–6 days, maintenance period – 40 days	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	Total irradiation positions (IP) – 16, height of IP 350–400 mm Core positions: 8 IP with Ø ≤69 mm Neutron flux: total $\leq 2.2 \times 10^{14}$ $n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1 MeV) $\leq 5.6 \times 10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$ dpa/year ≤0.6 Reflector positions 8 IP with Ø ≤160 mm Neutron flux: total – $\leq 3.2 \times 10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$ fast (E> 0.1 MeV) $\leq 1.2 \times 10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$ 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.	Temperature: chromel-alumel thermocouples up to 1100ºC, W-Re thermocouples up to 2300ºC 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	Chemistry control and measurement systems of gas environment for ampoule rigs Fission products monitoring and measurement facilities 1 hot cell in the reactor building	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)	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 minor actinides (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: 40–50%	Suitable for in-pile instrumented tests under medium and low fluxes of new materials, testing for pressure vessels possible

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Russian Federation *MIR.M1* Scheduled/ planned life time – 2027/2035 Operating time at nominal power – 240 days/year, fuel cycle – 15–25 days, outage period – 2–6 days, maintenance period – 40 days	100 MW(th) channel-type in water pool Fuel: 90% HEU UO2 dispersed in Al-matrix Tube-type elements in Al cladding Light water as coolant Beryllium as moderator and reflector	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} $n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1 MeV) ≤2.0×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Dpa/year ≤1.5; 38 IP with Ø ≤34mm Neutron flux: total ≤6.0×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1 MeV) ≤3.0×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Dpa/year ≤5	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, He-Xe – temperature ≤1100°C, pressure ≤4 MPa (one facility, with one channel)	Temperature: chromel-alummel thermocouples up to 1100ºC, W-Re thermocouples up to 2300ºC Geometry change: liner differential inductosyn transducer (LDIT) Pressure, stress and strains: bellows rolling diaphragm + LDIT Neutron flux: Rh-, 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, RBMK, HTGR conditions Experimental facilities for investigation of steady-state transient, accidental conditions (LOCA, LOFT, RIA) One hot cell in the reactor building	The material testing complex housing 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, bending, impact etc.	Department for design 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: 50–60%	Good for in-pile instrumented loop tests of fuel under steady-state transient, accidental conditions (LOCA, LOFT, RIA

Russian Federation *IR-8* Scheduled/ planned life time – 2016/2025 Operating time at nominal power – 120 days/year	8 MW(th) Pool- type 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* – $\leq 2.1\times10^{14}$ $n\cdot cm^{-2}\cdot s^{-1}$ Flux fast (E>0.1 MeV) $\leq 0.6\times10^{14}$ $n\cdot cm^{-2}\cdot s^{-1}$ dpa/year ≤0.6 Reflector positions – 13 IP with Ø ≤160 mm F *total* – $\leq 3.1\times10^{14}$ $n\cdot cm^{-2}\cdot s^{-1}$ F (E>0.1 MeV) $\leq 1.7\times10^{13}$ $n\cdot cm^{-2}\cdot s^{-1}$ dpa/year ≤0.2	Capsules only Test environment of ampoule rigs in the core and reflector: – water, boiling water – ≤350°C, ≤16 MPa	Temperature: chromel-alummel thermocouples up to 1100ºC 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)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Russian Federation *IVV-2M* Scheduled/ planned life time – 2018/2025 Operating time at nominal power – 290 days/year	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	Total irradiation positions (IP) – 45, height – 500 mm 40 IP with Ø ≤60 mm 2 IP with Ø ≤120mm 1 IP with Ø ≤130mm 1 IP with Ø ≤190mm 1 IP with Ø ≤400mm Neutron flux: total: $\leq 7 \times 10^{14}\ n \cdot cm^{-2} \cdot s^{-1}$ fast (E>0.1 MeV) $\leq 2 \times 10^{14}\ n \cdot cm^{-2} \cdot s^{-1}$ Dpa/year ≤2.0	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.	Temperature: chromel-alumel thermocouples up to 1100ºC Neutron flux: Rh-, V-, Hf – direct charge detectors Neutron fluence: activation monitors	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	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)	Department for design of experimental facilities Facilities to dispose radwaste and spent nuclear fuel and materials	Bi – and multilateral contracts between laboratories and institutions Degree of utilization: 70–80%	Suitable for in-pile instrumented tests of new materials. under medium and low fluxes Beam studies of irradiated materials

USA *ATR* Operating cycles 1–59 days average – 49 days Refuelling 14 days long 6 weeks outage per year No end of life planned	Licenced to 250 MW Operates at power levels (≈ 110 MWth) Aluminium plate fuel Light water cooled Light water moderated Beryllium reflected	Total of 77 test positions, up to 1.22 m long (at all testing locations) and 1.27 cm up to 12.7 cm diameter Thermal neutron fluxes range from 1.7×10^{13}–4.4×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ Fast flux (E>1MeV) 1.3×10^{12} –2.2×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ dpa/year estimated to be ≈ 7, depending on axial location of specimen in test position	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	Four 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	No beams No NAA facilities No gamma tubes	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 The high temperature test laboratory (HTTL) contains specialized equipment to conduct high-temperature testing and develop in-pile test instrumentation	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	Can be accessed via a bilateral agreement at full cost recovery Can be accessed at reduced or no cost through the ATR national scientific user facility peer reviewed proposal system Much of the reactor is full of experiments, however, there are some positions available, and other plans change to enable new experiments	Operational 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 No end of life planned due to constant refurbishment and beryllium reflector replacement every ~ 10 years

TABLE A-1 (cont). OPERATIONAL RESEARCH REACTORS; OVERVIEW OF CURRENT CAPABILITIES FOR MATERIAL TESTING RESEARCH (MTR)

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n{\cdot}cm^{-2}{\cdot}s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
USA *HFIR* 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	85 MW High flux, pressure vessel-type Light water as coolant and moderator Beryllium reflector Primary inlet coolant temperature: 120°F (48.89°C)	Irradiation positions (IP) – 83 IP height– 760 mm 37 IP in flux trap: Ø13 mm (can also provide Ø 22 mm positions), Ftotal – $4.5{\times}10^{15}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$, F (E >0.1 MeV) $1.2{\times}10^{15}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$ Max 14 dpa/year in flux trap 24 IP in Be-reflector: 8 RB Ø 38–70 mm, Flux total – $2.3{\times}10^{15}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$, F (E >0.1 MeV) $2.50{\times}10^{14}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$ 16 SVXF, Flux total – $1.5{\times}10^{15}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$, Flux fast $1.1{\times}10^{14}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$ 6 LVXF, Flux total – $3.7{\times}10^{14}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$, F (E >0.1 MeV) $0.8{\times}10^{13}$ $n{\cdot}cm^{-2}{\cdot}s^{-1}$	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	Direct contract with ORNL via Work for others (WFO) contracts, or irradiation services (IR) contracts Also, access via the national scientific user facility (ATR-NSUF)	Multi purpose, high flux material testing research capabilities

USA *MITR* 9 weeks operation per cycle, 24 h/day, 7 days/week Two weeks refuelling and maintenance outage	6 MW Tank Light water cooled Heavy water moderated	Fast flux 1.2×10^{14} n·cm^{-2}·s^{-1} Thermal flux 5×10^{13} n·cm^{-2}·s^{-1} 3 in-core facilities, up to 1.8" ID × 24" length (4.572 cm × 60.96 cm)	Pressurized water loops: – Can simulate typical PWR and BWR flow and chemistry conditions 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	Thermocouples Experiment residual gas monitoring Fission gas monitoring Electrochemical corrosion potential DC potential drop strain Crack growth measurement	NAA (both prompt and delayed) One pneumatic tube can be set up to transfer the irradiated sample directly into the counting lab for short-lived sample analysis 3 beam ports, up to 12" (30.48 cm) ID Inductively coupled plasma – optical emission spectrometer	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	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	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

TABLE A-2. PLANNED RESEARCH REACTORS. OVERVIEW OF FUTURE CAPACITIES FOR MATERIAL TESTING RESEARCH

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Argentina *RA-10 (planned 2018)* Argentinean multipurpose reactor	30 MW Open-pool Square array with 19 MTR LEU fuel assemblies Light water as coolant and moderator Heavy water reflector	6 in-core irradiation channels 12–65 cm long Ø 5–8 cm Total flux: ≤ 6×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ fast flux (max): ≤5×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ 8 dpa/year	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) Temperature 320ºC (max.) Pressure 15bar (max.)	In pile temp, pressure, stress, strain	Pneumatic system for NAA and long irradiation capsules, cold source and beams guides (cold and thermal), Isotope production, neutron transmutation doping (NTD)	Hot cell for fresh and irradiated experimental material in-pool neutron radiography facility for irradiated devices inspection			

Belgium *MYRRHA* Planned to be operational by 2024	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)	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^{15} n·cm^{-2}·s-^{1} Fast flux (>0.75 MeV) 4.2×10^{14} n·cm^{-2}·s-^{1} dpa/year: 23 in IPS, up to 30dpa/year below target zone in ADS mode	Test configuration is IPS design dependent Sample surface temperature range 100–650°C Temperature gradient ΔT over sample <30°C IPS coolant possibilities: inert gas (He, Ar, CO_2…), water, liquid metal (LBE, Pb, Na) Possibilities for material testing, fuel tests, instrumentation tests, etc.	Instrumentation & control is IPS dependent		On-site hot cells available On site PIE facilities	IPS design group and IPS manufacturing/ assembly in-house Waste handling & shipping possible	Via MYRRHA consortium Commercial access Scientific merit (via PAC)	Primary mission: demonstration No paper

TABLE A-2 (cont). PLANNED RESEARCH REACTORS. OVERVIEW OF FUTURE CAPACITIES FOR MATERIAL TESTING RESEARCH

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, (n·cm^{-2}·s^{-1}): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
India *HFRR* Planned – 2022 start-up 12 cycles in a year, each 25 days	30 MW (Th) Open pool type Plate type U3Si2, 19.75% enrichment (LEU) dispersed in Al matrix with a clad of Al-alloy Coolant and moderator demineralised water Heavy water reflector tank	Irradiation position, thermal neutron (<0.621 eV), Epithermal (0.625 eV–821 keV), Fast neutron (>821keV) In-core water hole, 6.7 × 10^{14} n·cm^{-2}·s^{-1} 3.4 × 10^{14} n·cm^{-2}·s^{-1} 1.8 × 10^{14} n·cm^{-2}·s^{-1} In-core peripheral water holes, 4.4 × 10^{14}, n·cm^{-2}·s^{-1} 2.4 × 10^{14}, n·cm^{-2}·s^{-1} 1.3 × 10^{14} n·cm^{-2}·s^{-1} Irradiation holes in D2O, 7 cm away from core edge, 3.7 × 10^{14} n·cm^{-2}·s^{-1} 6.0 × 10^{13} n·cm^{-2}·s^{-1} 1.2 × 10^{13} n·cm^{-2}·s^{-1} Irradiation holes in D_2O, 20 cm away from core edge, 2.9 × 10^{14} n·cm^{-2}·s^{-1} 5.0 × 10^{13} n·cm^{-2}·s^{-1} 1.7 × 10^{12} n·cm^{-2}·s^{-1}	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	Temperature, pressure, fluence	Six beam tubes NAA facility NTD silicon facility	Hot cells	Necessary in-house expertise exists		Material irradiation facility planned

France *JULES HOROWITZ* *REACTOR* *(JHR)* High performances material testing reactor	100 MW Light-water reactor, slightly pressurized core U3Si2 Al fuel (19.75% or 27%) 10 cycle per year 25 days cycle	20 irradiation positions (about 10 for fuel experiments; 10 for material experiments) Fast flux (E >0.1 MeV): 5.5 E14 $n \cdot cm^{-2} \cdot s^{-1}$ Thermal flux 5.5×10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ Material ageing: up to 16 dpa/year – max value in specific location Diameter available in the core: 30 mm (3 possibility to 80 mm) Outside the core in displacement system (6 available) flexibility	Experimental loops under developments allowing to represent thermo hydraulic conditions of PWR, BWR and WWER (nominal, incidental-ramps and accidental scenario – LOCA – are considered) For material corrosion loop to address irradiated assisted stress corrosion cracking (IASCC) 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… 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 No neutron beam available	Non-destructive analysis: X and Gamma measurement (tomography) – elongation via LCDT… 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: design of new experimental device, transport, waste management	JHR is an material testing research steer and fund by an International Consortium (12 members at the end of 2013) According to the Consortium agreement, possibility for non-member to have access to JHR experimental capacity	Advanced Under construction Plan to be in full operation by the end of this decade Multi purpose with primary mission – material testing

TABLE A-3. RESEARCH REACTORS WITH POTENTIAL FOR MATERIAL TESTING RESEARCH. OVERVIEW OF CAPABILITIES AND CAPACITIES

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n\cdot cm^{-2}\cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Egypt *ETRR-2* 1997–2020 30 years of operation 10 cycles per year Each cycle of 15 days	Thermal power: 22 MW Reactor type: pool Moderator: light water Coolant: light water Reflector: light water and beryllium	One cobalt irradiation device (CID) in the core centre position with neutron flux of 2.7×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ Two positions in the core with neutron flux of 2×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ 23 irradiation boxes at the irradiation grids with neutron flux 10^{13}–10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ and two rigs in thermal column with flux 10^{13} $n\cdot cm^{-2}\cdot s^{-1}$ Max thermal flux: 2.8×10^{14} $n\cdot cm^{-2}\cdot s^{-1}$ Max fast flux: 7.6×10^{13} $n\cdot cm^{-2}\cdot s^{-1}$		2 pneumatic tubes for fast irradiation for use in neutron activation analysis applications	Neutron transmutation doping (NTD) irradiation rigs NAA labs Large sample neutron activation analysis (LSNAA)	Radio isotope production cells Material testing cell	Very good engineering and workshop capabilities Training capabilities Code validation and benchmarking against experiments	Access of experimenters during full power operation	Limited capability for in-core material testing research

Hungary *BRR* (Budapest research reactor) 9–10 operation cycles in a year 1993–2023	10 MW Tank type reactor VVR-U type LEU fuel (20% U-235) Light water as coolant and moderator Beryllium reflector	Flux (th) 2.5×10^{14} n·cm^{-2}·s^{-1} Fast $1{\times}10^{14}$ n·cm^{-2}·s^{-1} in flux trap 60 irradiation channels Fast flux 1.5×10^{13} n·cm^{-2}·s^{-1} 0.5 dpa per year in steel	2 gas cooled irradiation rigs Temperature range 150–650°C Future plans – supercritical water rig		Beams with material structure and elemental analysis, NAA facility, neutron-, gamma- and X ray radiography and tomography	Hot cell for investigating irradiated structural materials, (tensile test machine, metallography)			Fundamental studies Isotope production Not for high dpa
Indonesia *RSG-GAS*	30 MW LEU (U3Si2, 19.75%) fuel Light water as coolant and moderator Beryllium reflector	Flux(th) 2.5×10^{14} n·cm^{-2}·s^{-1} Flux fast 2.3×10^{14} n·cm^{-2}·s^{-1} Power ramp test facility (PRTF) 40 cm length	Main irradiation facilities: – Irradiation holes for general irradiation power ramp test facility (PRTF) – Capsule type ramping test of LWR fuel (PWR, BWR environment), 130 to 160 bar, 3.6 L/h cooling, 0.1 to 1 W/cm^2, 900 W/cm max power velocity, 100 W/cm min, max power ramp 500 W/cm – Beam tubes – Maximum heat flux 2.20 MW/m^2		NAA, isotope production, etc.	Hot cell for investigating irradiated fuel characteristic including fission product distribution within the fuel			Suitable for material testing research, but system upgrade required

TABLE A-3 (cont.). RESEARCH REACTORS WITH POTENTIAL FOR MATERIAL TESTING RESEARCH. OVERVIEW OF CAPABILITIES AND CAPACITIES

Country Research reactor Scheduled and planned life-time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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)
Japan *JOYO* 5 cycle/year 60 days/cycle	140 MW power Sodium cooled loop-type fast reactor MOX (18% U-235, 30 wt% Pu) fuel Liquid Na coolant in primary and secondary circuit	Number: 21 irradiation rigs (max) Height of core: 600 mm Flux total: 5.7×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ Flux fast: 4.0×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ 15–49 dpa/year	Temperature: – Sodium bonded irradiation: 350–750°C – Gas bonded irradiation: high temperature material test (with tungsten holder) >1000°C	Material testing rig with temperature control (MARICO) Instrumented test assembly (INTA) with thermocouple and gas pressure gauge		Run-to cladding-breach (RTCB) PIE facilities: – Fuel monitoring facility (FMF) – Material monitoring facility (MMF) – Alpha Gamma facility (AGF) Stainless steel-lined, nitrogen-gas-tight hot cells X ray computed tomography Helium accumulation fluence monitors for dosimetry Field-emission transmission electron microscopy TEM			High potential, advanced Time of restart uncertain

Kazakhstan *WWR-K* 10 cycles/year 20 days/cycle	Power 6 MW Tank in pool type reactor VVR-Ts HEU (36%) fuel Light water as coolant and moderator Light water and beryllium reflector	3 vertical channels with Ø 62 mm and 600 mm in height Flux (thermal) 1×10^{14} n·cm^{-2}·s^{-1} Flux (fast) 3×10^{13} n·cm^{-2}·s^{-1} 2 vertical channels with Ø 62 mm and 600 mm in height Flux (thermal): 3×10^{13} n·cm^{-2}·s^{-1} Flux (fast): 10^{13} n·cm^{-2}·s^{-1}	Gas-vacuum loop (helium) Temperature: 50–1200°C Pressure: 10^{-4}–10^{-1}MPa Sealed and unsealed capsules in water coolant temperature: 50–200°C, pressure: 10^{-1} MPa	In-pile temperature (thermocouples), neutron flux (SPND), fission gas monitoring	5 radial and 1 tangential horizontal beam tubes; NAA lab with pneumatic rabbit, neutron radiography; critical assembly	Concrete and steel-shielded hot cells (dismantling, cutting, grinding) mechanical testing and microstructure research equipment outside hot cells	Waste handling and disposal, Radiochemistry	Contract or collaborative research agreement	Limited capability for in-core material testing research
Poland *MARIA*	20 to 30 MW (thermal) Channel in pool type reactor 36% enriched HEU and 19.75% enriched LEU fuels Light water as coolant, beryllium moderator and graphite reflector	Thermal flux 4×10^{14} n·cm^{-2}·s^{-1} Fast flux 2×10^{14} n·cm^{-2}·s^{-1} 6 horizontal channels for controlled use of neutron beams channels of Ø 23 mm in Be blocks, channels of Ø 28 mm in graphite reflector, channels of Ø 38 mm in graphite reflector, channels of Ø 18 mm inside modified fuel element, channel located under safety rod, channels equipped with hydraulic transport system. >5 inch (12.7 cm silicon doping channel Irradiation of U target for Mo-99 production	NA	NA	Out-of-core irradiation facility to irradiate the large-size (up to 90 mm in Ø) target materials/ devices with fast neutron flux density up to 1.7×10^{12} n·cm^{-2}·s^{-1} and well reduced thermal neutron flux limited down to $3.4 \cdot\times 10^{10}$ n·cm^{-2}·s^{-1} 6 horizontal channels equipped with scattering and diffraction instruments for condensed matter studies	Hot cells for radioisotope production	NA	NA	Limited capability for in-core material testing research

TABLE A-4. PULSED RESEARCH REACTORS. OVERVIEW OF CAPABILITIES AND CAPACITIES

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$):*) – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
France *CABRI* Lifetime: 1964 to NA Pulsed research reactor	25 MW at steady state 30 GW during power transient (10 ms half width pulse) Light-water reactor, open-core pool type UO2 fuel enriched at 6%	Irradiation positions: – Central cell – Max Ø 140 mm – Total active height 800 mm Steady power at 25 MW: – Thermal flux (max): 9×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ – Epithermal flux (max): 7×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ – Fast flux (max): 2×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ Transient at 30 GW: total flux (max): 2×10^{17} $n \cdot cm^{-2} \cdot s^{-1}$	In pile pressurized water loop reproducing thermohydraulic, neutronic and chemical conditions of PWR power reactors (300°C, 155 bars) Device for test on single irradiated UO2 or MOX fuel pin, designed for: RIA transients (up to 30 GW at peak power) LOCA tests	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 m^3/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

Kazakhstan *IGR* Life-time is not specified Operation cycle is not specified Two main reactor operation modes: aperiodic pulse (neutron flash) and programmed pulse (pulse with different pre-determined shape)	Aperiodic pulse max 10000 MW, programmed pulse max 1000 MW Thermal impulse graphite reactor Fuel – U_xO_x dispersion in graphite, 90% U-235 Heat capacity type (without coolant) Moderator & reflector – graphite	Two vertical experimental channels: – Central one with Ø 228 mm and 3825 mm total height and active height 1400 mm – Lateral one with Ø 82 mm and 3440 mm total height and active height 1400 mm Thermal flux up to 7×10^{16} $n \cdot cm^{-2} \cdot s^{-1}$ (neutron flash with minimal half width 0.12 s), up to 7×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ (programmed pulse) Fast flux up to 10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ and 10^{14} $n \cdot cm^{-2} \cdot s^{-1}$ respectively Max fluence (at programmed pulse) up to 3.7×10^{16} J/cm^2 programmed pulse duration is limited by core temperature limit – 1400K (coincide core energy release – 5.2 GJ)	Environment in the experimental rigs: hydrogen, nitrogen, carbon dioxide, helium, water, sodium and others during different diagrams of flow, pressure and temperature	Temperature (thermocouples, infra-red method) Acoustic signals Pressure of the gaseous and liquid medium Pressure impulse (e.g. in the liquid sodium) Level of liquids (level-meters) Voids in boiling liquid (void meters) Local neutron flux (small scale neutron detectors) Gas fission product release Energy release in the fuel using spectrometry and by thermal method Speed of the tested fuel movement inside IGR	The pneumo-hydraulic test bench is an extensive system with open loops for test object coolant Number of gas paths – 11 Number of liquid paths – 7 Gas discharge system – 950 m^3 Liquid discharge system – 25 m^3	Hot cell for non-destructive examination: X ray installation Gamma-scanning facility Sample production room X ray phase analysis diffractometer DRON-3 Metallographic examinations Two horizontal grinding and polishing machine NERIS and LaboPol-25			Long experience with transient testing (RIA)

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-4. (cont.). PULSED RESEARCH REACTORS. OVERVIEW OF CAPABILITIES AND CAPACITIES

Country Research reactor Scheduled and planned life- time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, n·cm^{-2}·s^{-1}): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
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

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	Fast pulse graphite reactor with ceramic UO_2 0.5 MW power at steady-state operation Energy release 280 MJ Minimum pulse half-width 2 ms 0.5 s quasi pulse half-width 1 pulse per day Peak power in quasi-pulse peak up to 75 GW Power in a quasi-pulse peak 1.5 GW	Cylindrical core with Ø 76 cm and 67 cm height Dimensions available for samples 55 cm height and Ø 10 cm Total fluence 1×10^{16} $n \cdot cm^{-2} \cdot s^{-1}$ and in central channel 8.5×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$ The facility is equipped with additional equipment which makes it possible to vary n-γ-radiations in a greater range, namely: different n-γ-converter modifications, large-sized reflectors made of steel, graphite, polyethylene and beryllium	1 pulse per day and then the facility is left to cool down (i.e. no steady state conditions) Tests can be performed in water varied pressure up to 17 MPa or in air at atmospheric pressure	Measuring of temperatures of fuel element and ampoule elements, medium pressure in the ampoule		Facilities are mentioned to be equipped for PIE but not listed Gas filling and laser welding available	The neutronic code CMK, 1D and 3D thermo mechanical codes for numerical analyses of experiments	Collaborative research agreement Commercial contract	Very fast and high intensity pulse Modernization of irradiation complex will allow testing fuel elements with high burn-up, and several elements with fuel part up to 1000 mm The modernization foresees development of loops for tests of fuel in different coolants at their parameters, corresponding to real parameters in power reactors

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

Country Research reactor Scheduled and planned life-time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n{\cdot}cm^{-2}{\cdot}s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
Slovenia TRIGA Mark II Operating cycle: 800 working days per year Lifetime: 1966, reconstructed in 1991	250kW 1MW in pulse operation (possible) Pool type 20% U mixed by ZrH (standard TRIGA fuel) Water coolant Graphite reflector	Max thermal flux in central channels: 7.6×10^{12} $n{\cdot}cm^{-2}{\cdot}s^{-1}$	– Central vertical aluminium irradiation channels Ø int.=2.5cm – Triangular channel Ø int.=5cm – 2 radial beam ports Ø int.=15cm – 2tangential ports Ø int.=15cm – 2 graphite blocks leading to irradiation facilities 10 cm x 10cm (Thermal column and thermalizing column) – Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm		– Irradiation channels in outer ring Ampoules Ø int.=5cm Height 10cm – Rotary groove: 40irradiation positions for ampoules Ø int.=5cm Height 10cm – DT converter: irradiation by 14 MeV neutrons	Hot cell facility 2 cells: connected with reactor by pneumatic transfer system, equipped by master-slave manipulators			

Country Research reactor Scheduled and planned life-time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, ($n \cdot cm^{-2} \cdot s^{-1}$): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
Italy *TRIGA* *RC-1* Operating cycle: NA Lifetime: NA	1MW Natural demineralized water convection cooling Uranium – ZrH alloy (8.5% Wt U) 20% U-235 H_2O, ZrH moderator	Experimental facility, thermal flux ($n \cdot cm^{-2} \cdot s^{-1}$), R_{Cd}*, shape, dimensions (mm) A radial channel, 4.8×10^{12}, ≈ 2.2, cylinder, Ø int.=152 B radial channel, 4.3×10^{10}, ≈ 3, cylinder, Ø int.= 152 C radial channel, 4.3×10^{10}, ≈ 3, cylinder, Ø int.= 152 D radial channel, 5.4×10^{10}, 10.4, cylinder, Ø int.= 152 tangential channel, 1.1×10^{6}, 2.22, cylinder, Ø int.= 152 piercing tangential channel, 1.1×10^{6}, 1.24, cylinder, Ø int. = 180 Thermal column horizontal channel, 2.2×10^{6}, 3.2, cylinder, Ø int.= 40	Liquid sample irradiation facility (LOOP) Rotary specimen rack		Neutron radiography/ tomography		Design and manufacture of experimental devices and measurement systems Including neutron collimators, shutters, irradiation devices, hydraulic loops, etc.)		

* R_{Cd} = Cadmium ratio.

		Thermal column vertical channel (with plug of graphite), 1.9 $\times 10^{10}$, 4.3, square, side = 100 Thermal column vertical channel (without cap of graphite), 4.2 $\times 10^{9}$, ≈ 4, square, side = 100 Central thimble, 2.68 $\times 10^{13}$ $n \cdot cm^{-2} \cdot s^{-1}$, 1.73, cylinder ‘S’ shaped, Ø int.=34.04 Thermalizing column, 1.3 $\times 10^{8}$, >100, Parallelepiped, 608 × 608 × 155 Rotary specimen rack, 2.0 $\times 10^{12}$, 2.7, cylinder ’S’ shaped, Ø int. = 32 Removable grid cavity, 1.25 $\times 10^{13}$, 2.21, triangular prism, l ≈75 h = 650 Rabbit (Pneumatic transfer tube), 5.1 $\times 10^{12}$, 2.00, cylinder, Ø int.= 14 Ø int. tube = 27 Loop for irradiation of liquids, ≈5.0 $\times 10^{12}$, cylinder, V ≈ 150 ml							

TABLE A-5 (cont.). LOW POWER RESEARCH REACTORS (LPRR). SOME EXAMPLES OF COMPLEMENTARY ROLE TO MATERIAL TESTING RESEARCH

Country Research reactor Scheduled and planned life-time Operation cycle	Power Type Fuel Coolant Moderator Reflector	Irradiation positions: – number – height – diameter Flux, (n·cm^{-2}·s^{-1}): – total flux – fast flux (≥0.1 MeV) Estimated dpa/year in steel	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
Italy *TAPIRO* *TA*ratura *PI*la *R*apida Potenza Zer*O* (Fast pile calibration at 0 power)	5 kW U-Mo alloy (weight 98.5% U – 1.5% Mo) Density: 18.5 g/cm^3 Enrichment: 93.5% U-235 Forced He: 100 g/s at 7.35 bar	3 channels at the reactor midplane 1 tangential (to the top edge of the core) Source of fast neutrons with a wide variety of neutron spectra Max flux: 4×10^{12} n·cm^{-2}·s^{-1}		ISOCS (In Situ Object Counting System)	Neutron activation analysis		Validation of codes; benchmark for nuclear data testing		
Russian Federation *BFS-1* *BFS-2*	Power 200 W Full-scale fast reactor critical assemblies Fuel – highly enriched uranium, plutonium, MOX, UN, PuN etc. Coolant – air, 80ºC	Holes of the 15-cm diameter for the counters are about 20 cm from the core vessel 3 large cylindrical regions (60 cm diameter) that are used to store fresh fuel tubes	Various medium is possible for modelling different types of coolant	Fission chambers and other neutron and Y ray detectors for investigations of axial, radial traverses, spectrum indexes, Doppler effect, Beff	Electron accelerator – M1-30 Neutron activation analysis		Design and manufacturing departments of experimental rigs and instrumentations Reactor neutronic measurements: validation of codes, benchmarking and mock-up	Via collabo-ration agreement Commercial	Unique experimental experience in studies of fast reactor physics, safety, core design optimization