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Current Capabilities of Material Test Reactors (MTRs)

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Research Reactor Section
International Atomic Energy Agency
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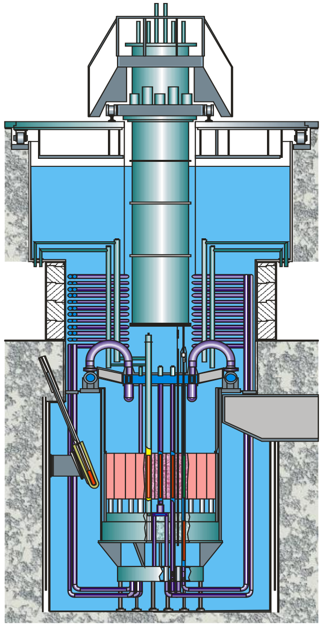
Outline

- Research Reactor Types
- Research Reactor Purpose
- Material Test Reactor Capabilities
- Currently Operating MTRs
- New MTRs and Potential MTR Capability
- MTR Experiment Types
- Some MTR Profiles

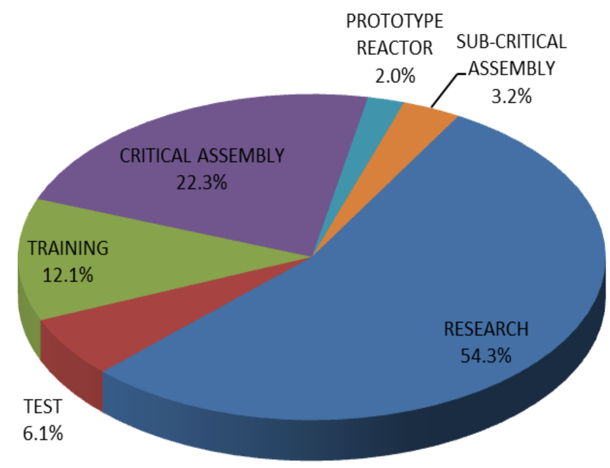
Heavy concrete hot cell operating area, Romania



MIR.M1 reactor layout, Russia

Types of Research Reactors

- Large variety, no easy categorization, 26 different types
- Manufacturer types: Slowpoke, MNSR, Argonaut, TRIGA, IRT, WWR
- Coolant/moderator: heavy water, light water, liquid metal, organic
- Fuel: plate (flat, curved, and concentric), TRIGA, rods, homogeneous
- Purpose: critical assembly, research, test, training, prototype, radioisotope production

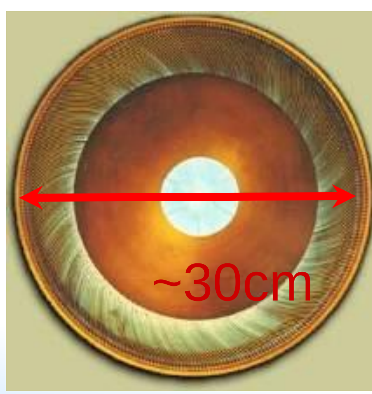


Categories of Research Reactors in Operation

https://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx?rf=1

Features of Research Reactors

- Typically, RR cores have small volume
- Typically, very low powers (many less than 5 MW_{th}) compared to commercial power plant reactor (>3000 MW_{th})
- Higher fuel enrichments (~ 20 %) than power reactors (~5%), some very high enrichments ($\geq$ 20%), but trying to convert fuel to <20%
- Lower temperatures and pressures than power reactors
- Natural and forced cooling
- Pulsing capability



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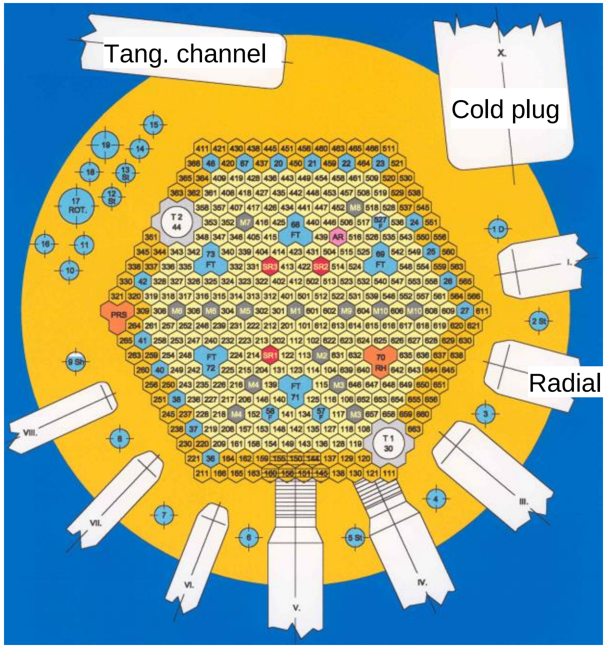
Comparison between ATR and Power PWR

Reactor Parameter	ATR	PWR (Typical)
Power (MW_{th})	250 (Max Design)	~ 3,800
Operating Pressure (psig)	~ 355	~ 2235
Inlet Temp. (F)	~ 125	~550
Outlet Temp. (F)	~ 160	~620
Power Density (kW/ft^3)	~ 28,300	~ 2,800
Neutron Flux	$\sim 10^{15}$	$\sim 10^{11}$
Fuel	Enriched U-235	3 – 4 % U-235
Fuel Temp. (F)	~ 462	> 1000

Research Reactor General Purpose

- Purpose is to produce and provide *access to the neutrons*
- Access to neutrons can be provided:
  - Inside core
  - Along core boundary
  - From external beams
- Typical Power range 100kW to 10MW
- Typical Steady-State Neutron Flux → 10^{12} to 10^{14} n/(cm^2·s)



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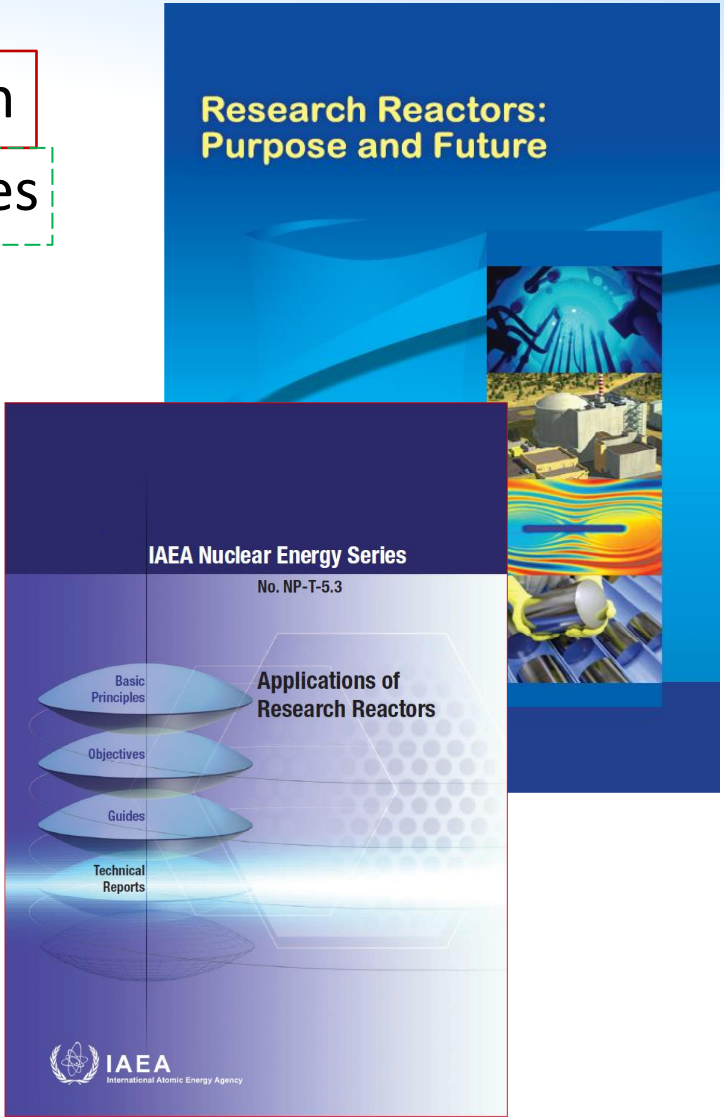
Research Reactor Applications

- Education & Training
- Fuel/material testing and qualification
- Supporting power reactor programmes
- Radioisotope production
- Neutron scattering
- Neutron radiography
- Material science investigations
- Neutron Activation Analysis (NAA)
- Geochronology
- Neutron transmutation doping
- Gemstone colour enhancement
- Positron source
- Neutron capture therapy



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Total Number of Research Reactors*

TOTAL:	768
Operational	216
Temp. shutdown	22
Under construction	8
Planned	11
Shutdown/Decommissioned	502

Application	Number of RR involved (Op.)
Education & Training	146
Neutron Activation Analysis	106
Radioisotope production	79
Neutron radiography	63
Material/fuel testing/irradiations	58
Neutron scattering	40
Nuclear Data Measurements	42
Silicon doping	22
Geochronology	23
Gem coloration	17
Neutron Therapy	16
Other	107

***from the RR Database,**
https://nucleus.iaea.org/RRDB

MTR Capabilities and Considerations

- Neutron Flux – high fast and thermal fluxes
- Number of Experiment Positions
- Size of Experiment Positions
- Flexibility of Experiment Design
- Compatibility with Test Materials
- Steady State, Pulsed, and Transient Operations
- Complementary Capabilities
  - Experiment preparation (cold and hot)
  - Transportation
  - Post irradiation Examination (PIE)

High Power Test Reactors (>20 MW)

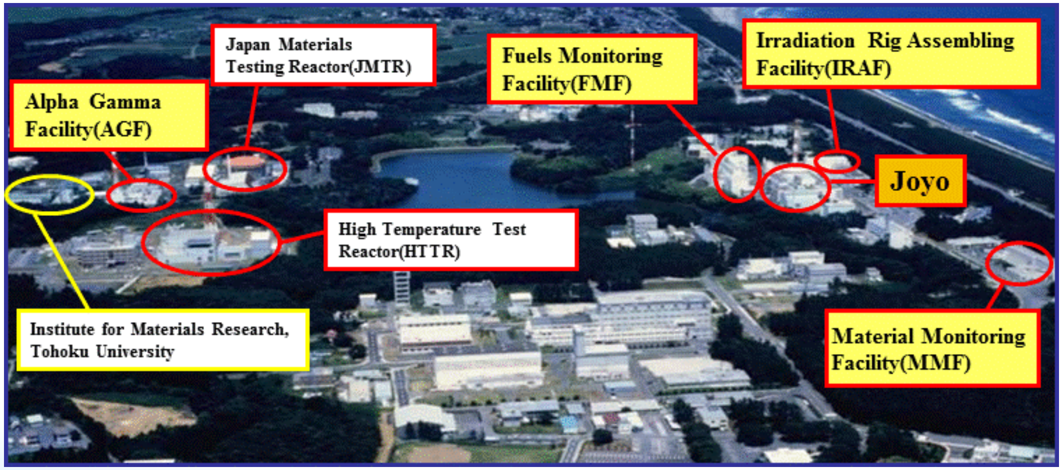
Reactor Name	Country	Type	Power (MWt)	Flux (n/cm^2-s)	Utilization
BR-2	Belgium	Tank	100	1E15 (T), 7E14 (F)	Fuel & material, isotopes
CARR	China	Tank in Pool	60	8E14 (T), 6E14 (F)	Fuel & material
CEFR	China	Pool/ Na	65	3.2E14 (T), 3.5E14 (F)	Fast Rx materials, prototype
ETRR-2	Egypt	Pool	22	2.8E14 (T), 2.2E14 (F)	Neutron sci., fuel
OSIRIS	France	Pool	70	2.7E13 (T), 2.6E14 (F)	Material and fuel
DHRUVA	India	Tank	100	1.8E14 (T)	Material, isotopes, neutron sci.
RSG-GAS	Indonesia	Pool	30	2.51E13 (T), 2.28E14 (F)	Material, neutron sci., corrosion

High Power Test Reactors (cont.)

Reactor Name	Country	Type	Power (MWt)	Flux (n/cm^2-s)	Utilization
JMTR	Japan	Tank	50	4E14 (T), 4E14 (F)	Material, fuel
JOYO	Japan	Fast, Na	140	4E15 (F)	Material, fuel
HANARO	Republic of Korea	Tank in Pool	30	4E14 (T), 2E14 (F)	Material, fuel
HFR	Netherlands	Tank in Pool	45	2.7E14 (T), 5.1E14 (F)	Material
HBWR	Norway	Heavy Water	20	1.5E14 (T), 8E13 (F)	Material, fuel
MARIA	Poland	Pool	30	4E14 (T), 2E13 (F)	Neutron science, materials
SM-3	Russian Federation	Pool	100	5.4E13 (T), 1.5E14 (F)	Material, fuel
BOR-60	Russian Federation	Fast Breeder	60	2E14 (T), 3.5E15 (F)	Material, isotopes

High Power Test Reactors (cont.)

Reactor Name	Country	Type	Power (MWt)	Flux (n/cm^2-s)	Utilization
MIR.M1	Russian Federation	Pool	100	5E14(T), 3E14 (F)	Fuel, material, isotopes
ATR	USA	Tank	250	1E15 (T), 5E14 (F)	Material, fuel, isotopes
HFIR	USA	Tank	85	2.5E15 (T), 1E15 (F)	Isotopes, beam, fuel, material



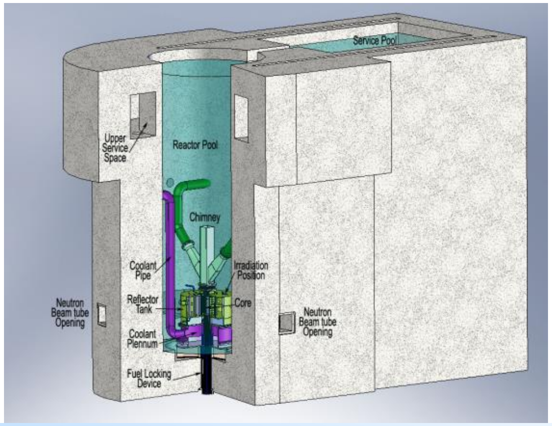
Reactor and related facilities in the Oarai R&D centre (Japan)

Medium Power Test Reactors (5-20 MW)

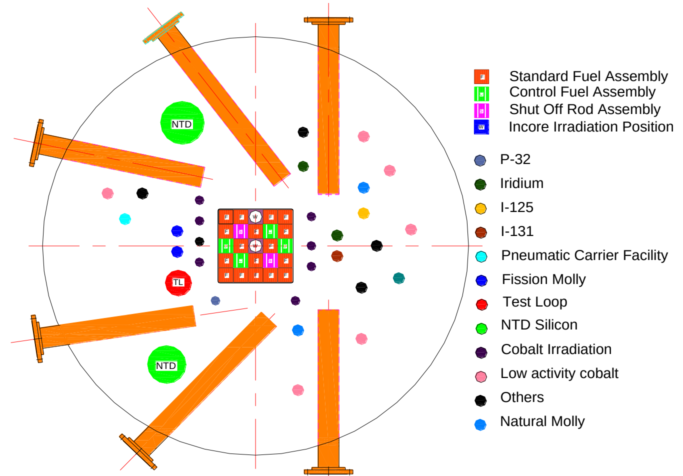
Reactor Name	Country	Type	Power (MWt)	Flux (n/cm^2-s)	Utilization
BRR	Hungary	Tank	10	2.5E14 (T), 1E14 (F)	Material, isotopes, NAA, beams
WWR-K	Kazkhstan	Tank in Pool	6	1E14 (T), 3E13 (F)	Beams, isotopes, radiography
TRIGAII-Pitesti	Romania	Pool	14	4.2E14 (T)	Material, fuel
IVV-2M	Russian Federation	Pool	15	7E14 (T), 2E14 (F)	Material, beams
IR-8	Russian Federation	Pool	8	3.1E14(T), 1.7E13 (F)	Material, beams
RBT-6	Russian Federation	Pool	6	3.2E13 (T), 1.2E14 (F)	Material, fuel
MURR	USA	Tank in Pool	10	6E14 (T), 1E14 (F)	Material, silicon, isotopes, NAA, gemstones
MITR	USA	Tank	5	5E13 (T), 1.7E14 (F)	Material, beams, NAA, silicon

New RRs or Developing MTR Capability

Reactor Name	Country	Type	Power (MWt)	Flux (n/cm^2-s)	Utilization
RA-10	Argentina	Pool	30	6E14 (T), 5E14 (F)	Material, fuel, radiography
MYRRHA	Belgium	ADS/ Critical	100	4.2E14 (T)	Material, fuel
JHR	France	Tank	100	5.5E14 (T), 5.5E14 (F)	Material, fuel
HFRR	India	Pool	30	6.7E14(T), 1.8E14 (F)	Material, beams, NAA, silicon

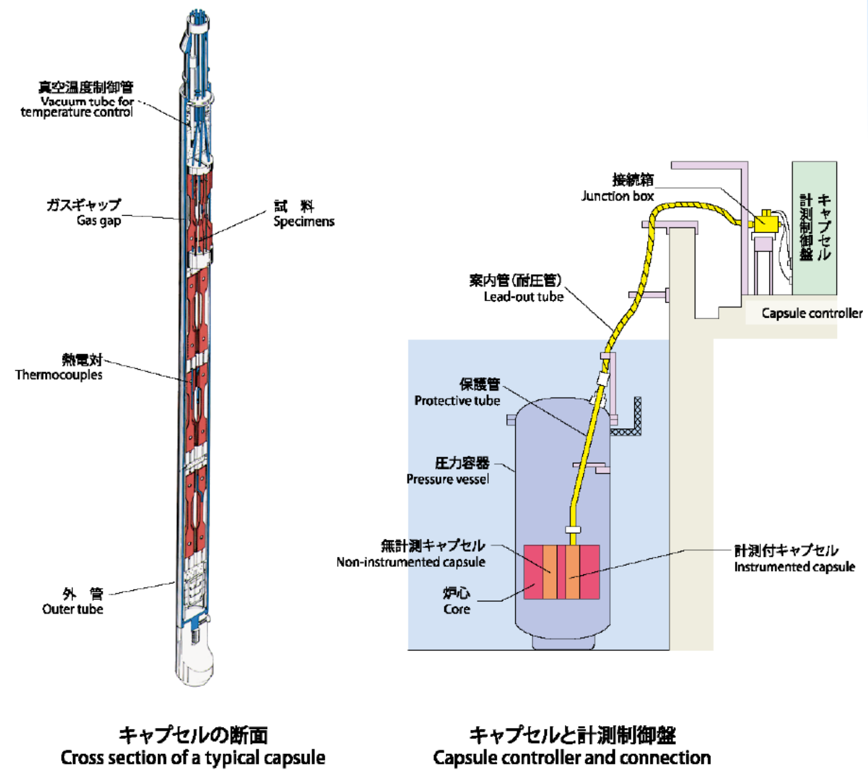


HFRR facility and experiment positions, India



MTR Experiment Types

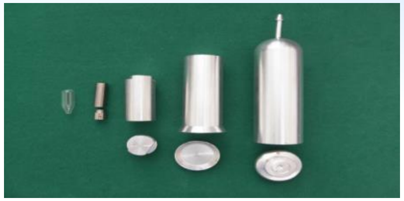
- Static Capsule
- Hydraulic or Pneumatic Tube
- Instrumented Lead
- Loops
  - Water
  - Gas
  - Other coolants
- Radial Beams
- Tangential Beams



Capsule and capsule controller in JMTR, Japan

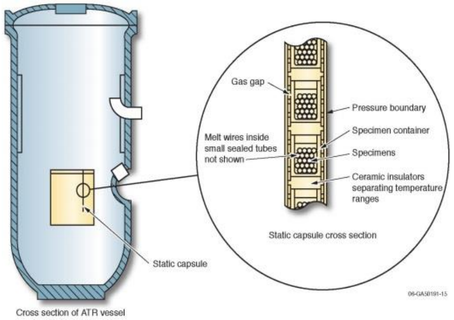
Static Capsule Experiments

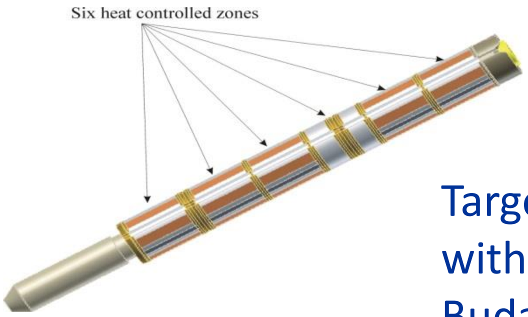
- Passive instrumentation (flux wires, melt wires)
- Enclosed in sealed tube, or fuel plates
- Temperature target controlled by varying gas mixture in conduction gap and with material selection
- Used for isotope production, fuel and material testing
- Single internal capsule, or multiples in stacks



Small irradiation receptacles, HANARO, Republic of Korea

Static capsule configuration in ATR, USA

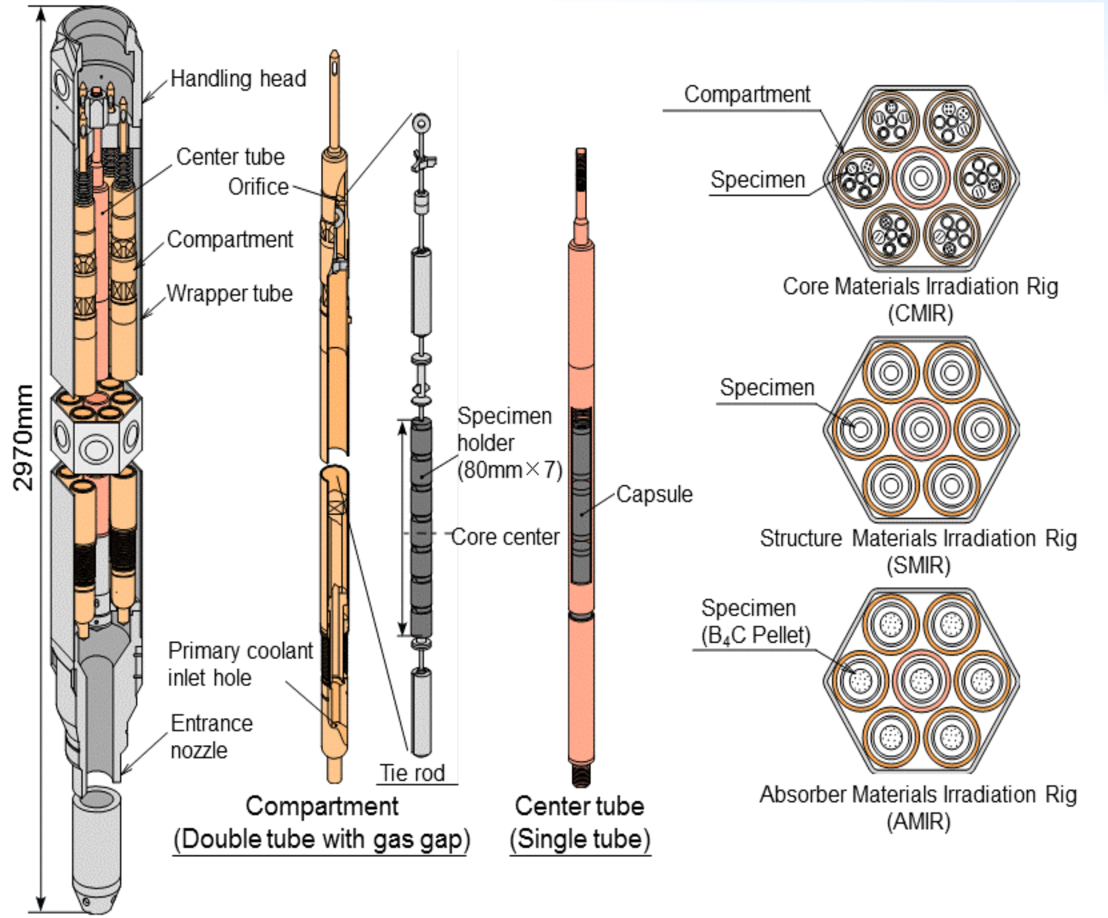




Target holder, filled with specimens, in the Budapest Research Reactor, Hungary

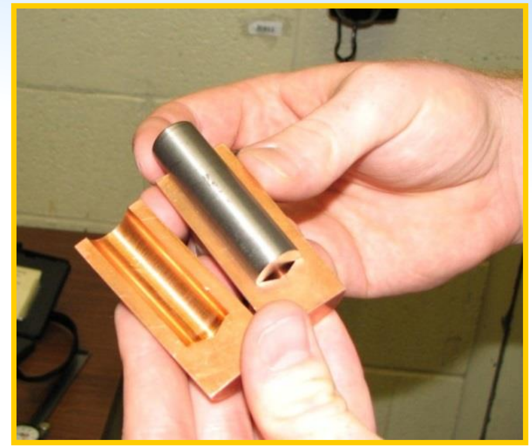
Material Tests in JOYO, Japan

- Capsules can be sealed or unsealed
- Can be filled with Na or inert gas (HE, Ar)



Hydraulic or Pneumatic Shuttle Tests (aka "rabbit")

- Used for small quantity of sample material
- Insertion and removal of experiment during reactor operations
- Short irradiation times; can be scoping test for longer irradiation tests
- Can have single capsule or a "train" of multiple capsules
- Capsule/specimen combination needs to account for heating during the irradiation time (avoid over-pressure)
- NAA laboratories can have direct shuttle delivery to counting station
- Materials, NAA, isotope production

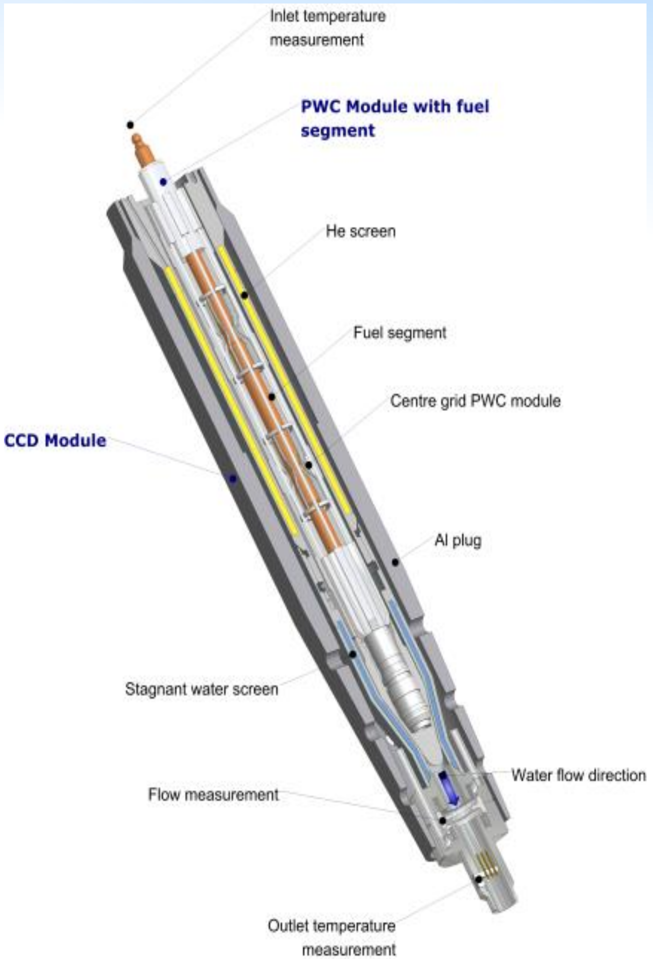


Hydraulic shuttle capsule for ATR, USA

Capsule send and receive stations for ETRR-2, Egypt

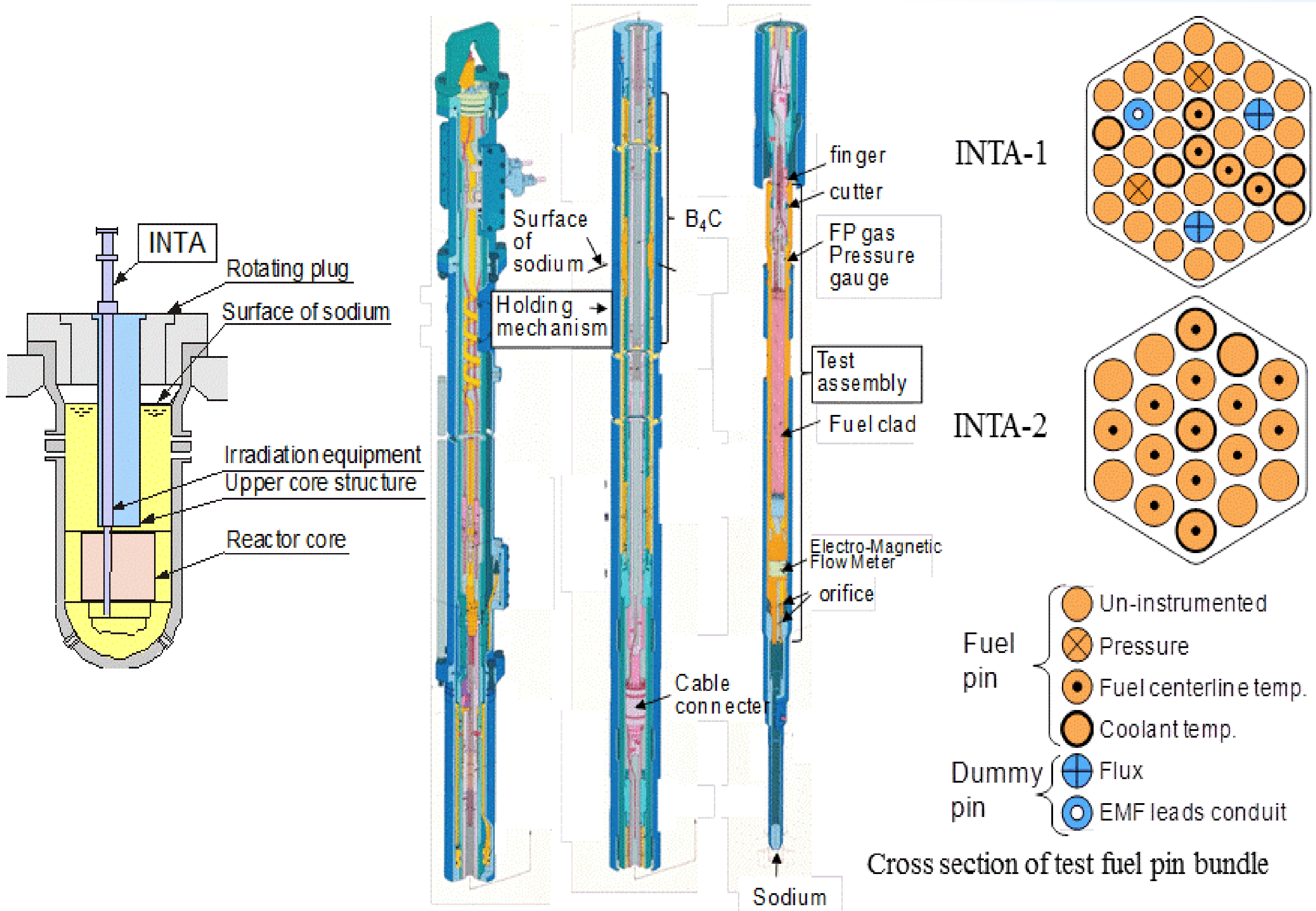
Instrumented Lead Experiments

- On-line experiment measurements and control
- Temperature, pressure, gas and water chemistry
- Monitoring of temperature control exhaust gases for experiment performance (e.g., fission products, leaking materials, etc.)
- Monitoring can be built into experiment or in reusable experiment facility
- Specialized gas environments (oxidized, inert, etc.)

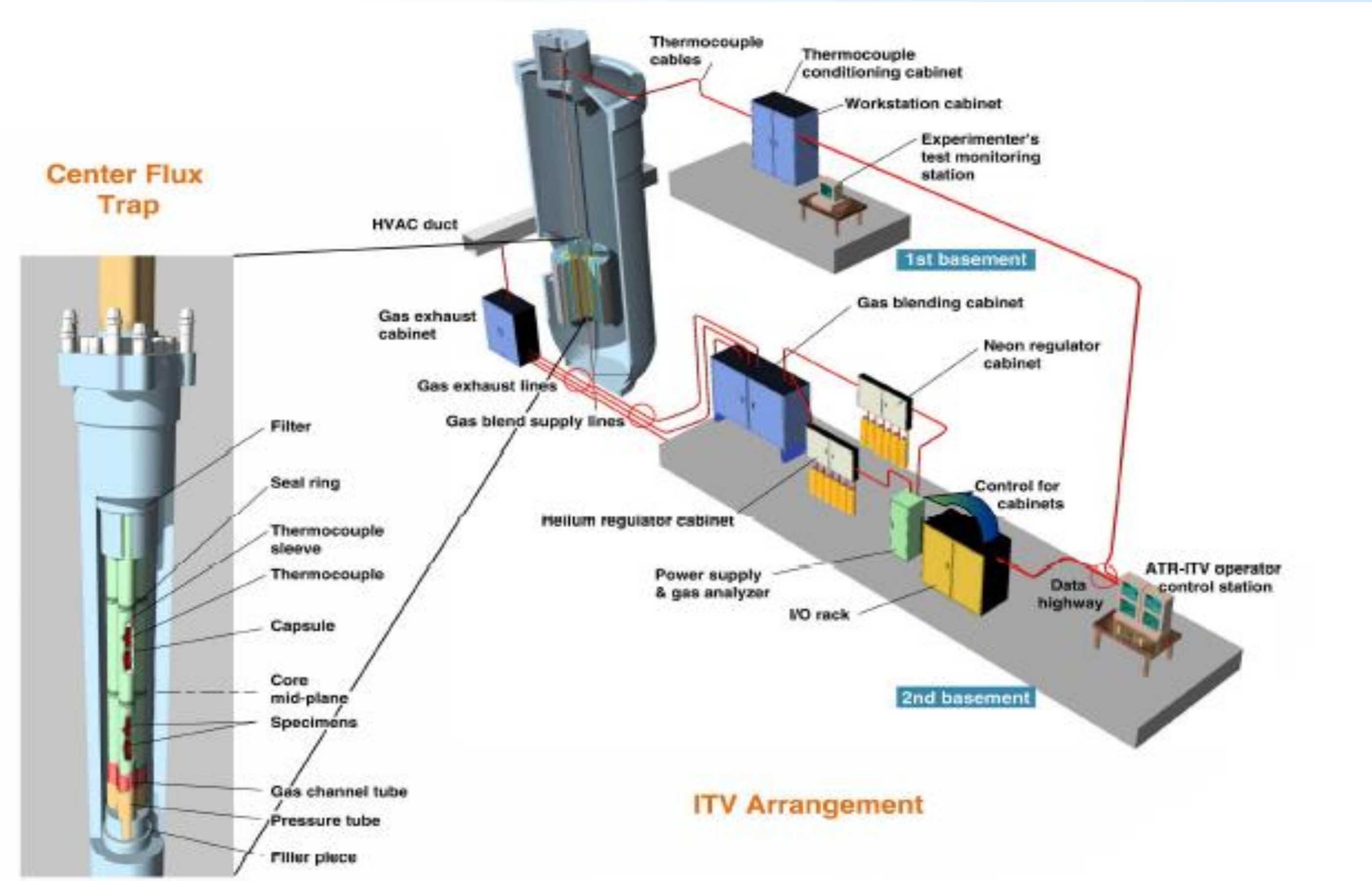


Pressurized water capsule/Cycling and calibration device (PWC/CCD), BR2, Belgium

Material Test Rig with Temperature Control, JOYO, Japan



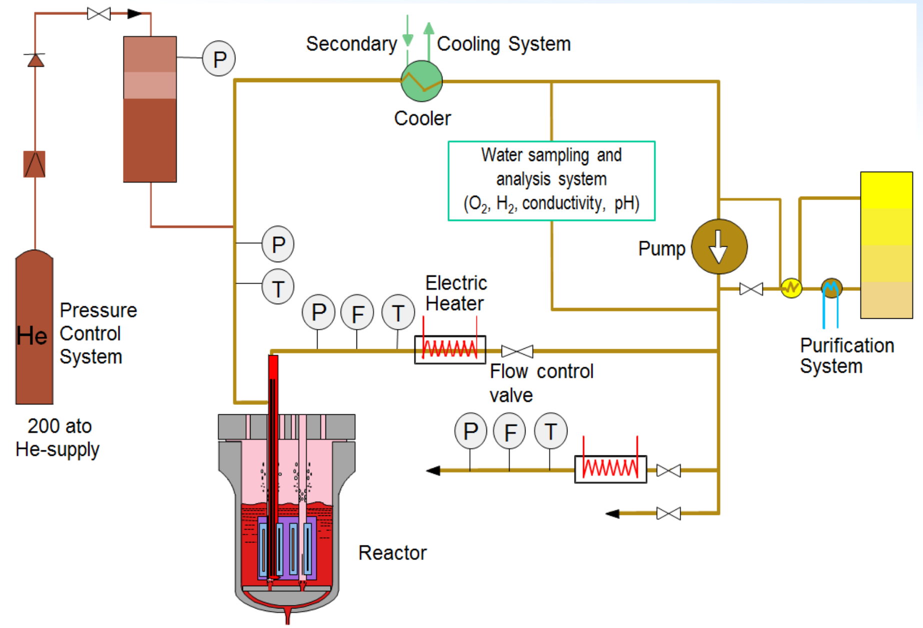
Irradiation Test Vehicle



- Reusable irradiation test rig, for fuel or materials, ATR, USA
- Three independent irradiation rigs in one reactor position

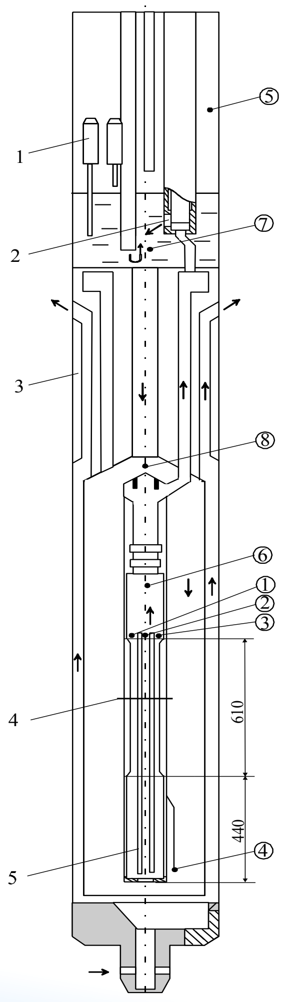
Loop Experiments

- Used to perform experiments in prototypic operating conditions for variety of power reactor designs
  - PWR
  - BWR
  - VVER
  - CANDU
  - Liquid metal
- Isolated from reactor primary coolant system
- Most complex type of MTR experiment
- Enables fuel failure tests without spread of fission products into reactor primary coolant sytem or other experiments
- Some MTRs can operate several loop experiments simultaneously



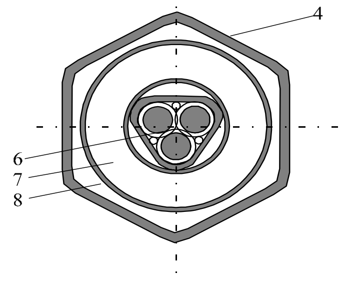
HBWR water loop schematic, Norway

Loop Experiments in BOR-60, Russia

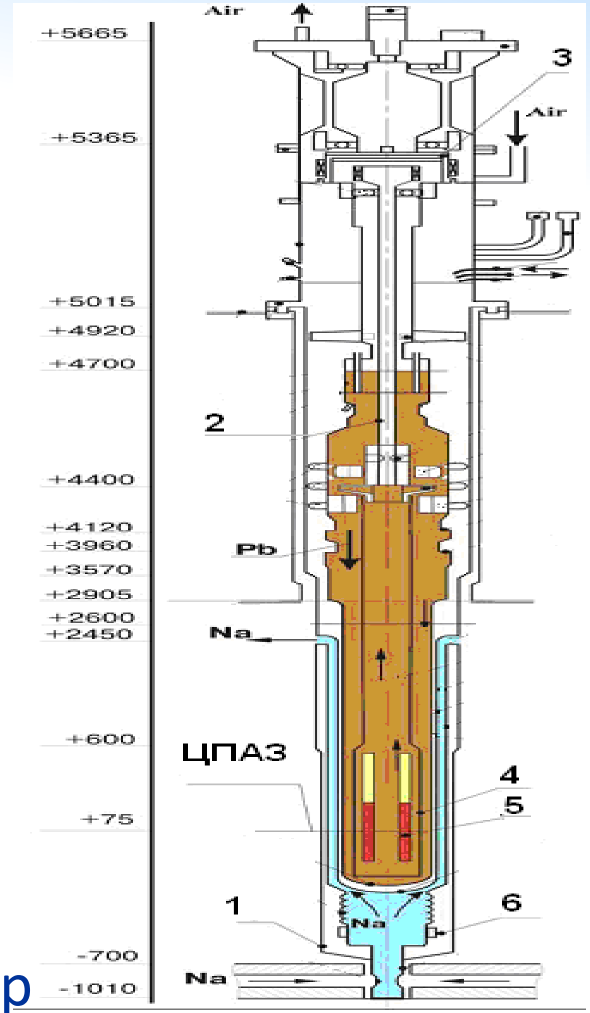


1 - уровнемеры внутри канала;
2 - регулятор расхода натрия;
3 - МГД насос;
4 - центр активной зоны;
5 - тепловыделяющие элементы;
6 - восходящий поток петлевого натрия;
7 - нисходящий поток петлевого натрия;
8 - поток реакторного натрия
①-⑧- термопары

Сечение по центру активной зоны петлевого канала



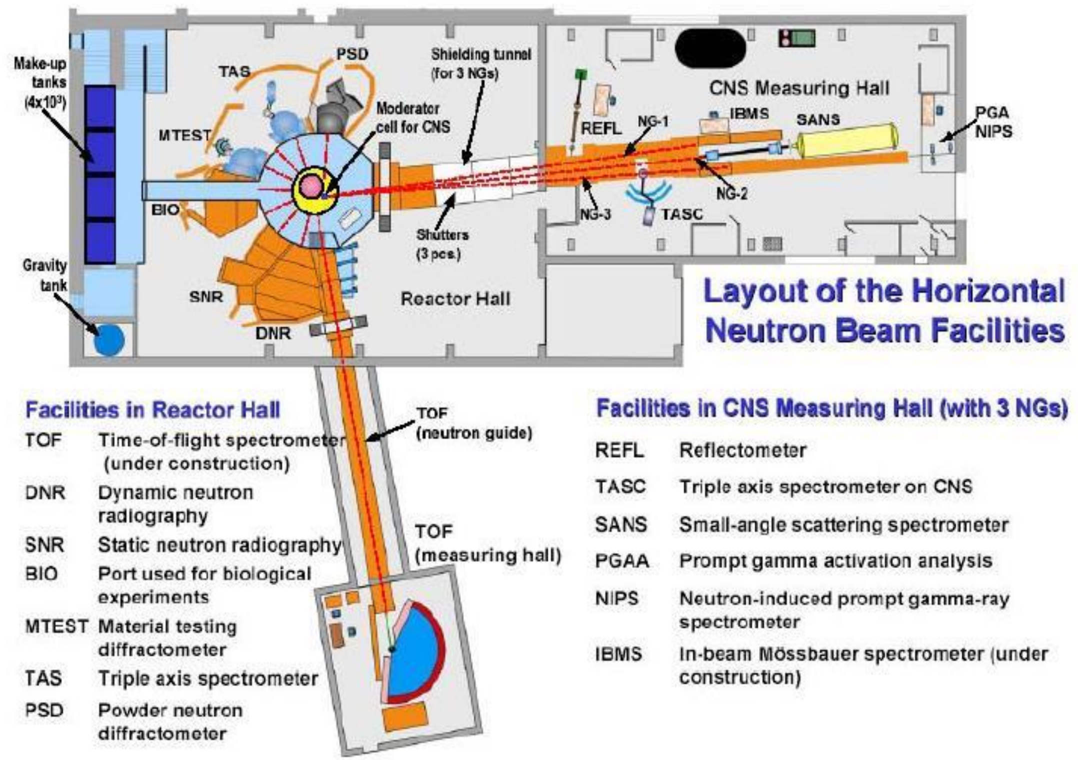
Na Loop



Pb Loop

Neutron Beam Experiments

- Support to material irradiation with investigative instruments
- Neutron scattering science

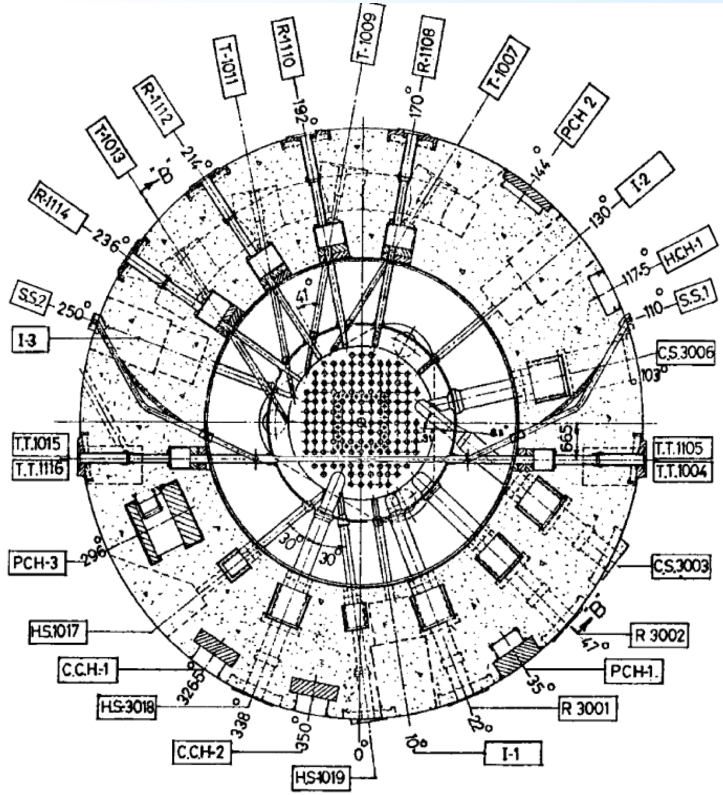


Layout of the horizontal neutron beam facilities at the BRR, Hungary

Neutron Beam Experiments (cont.)

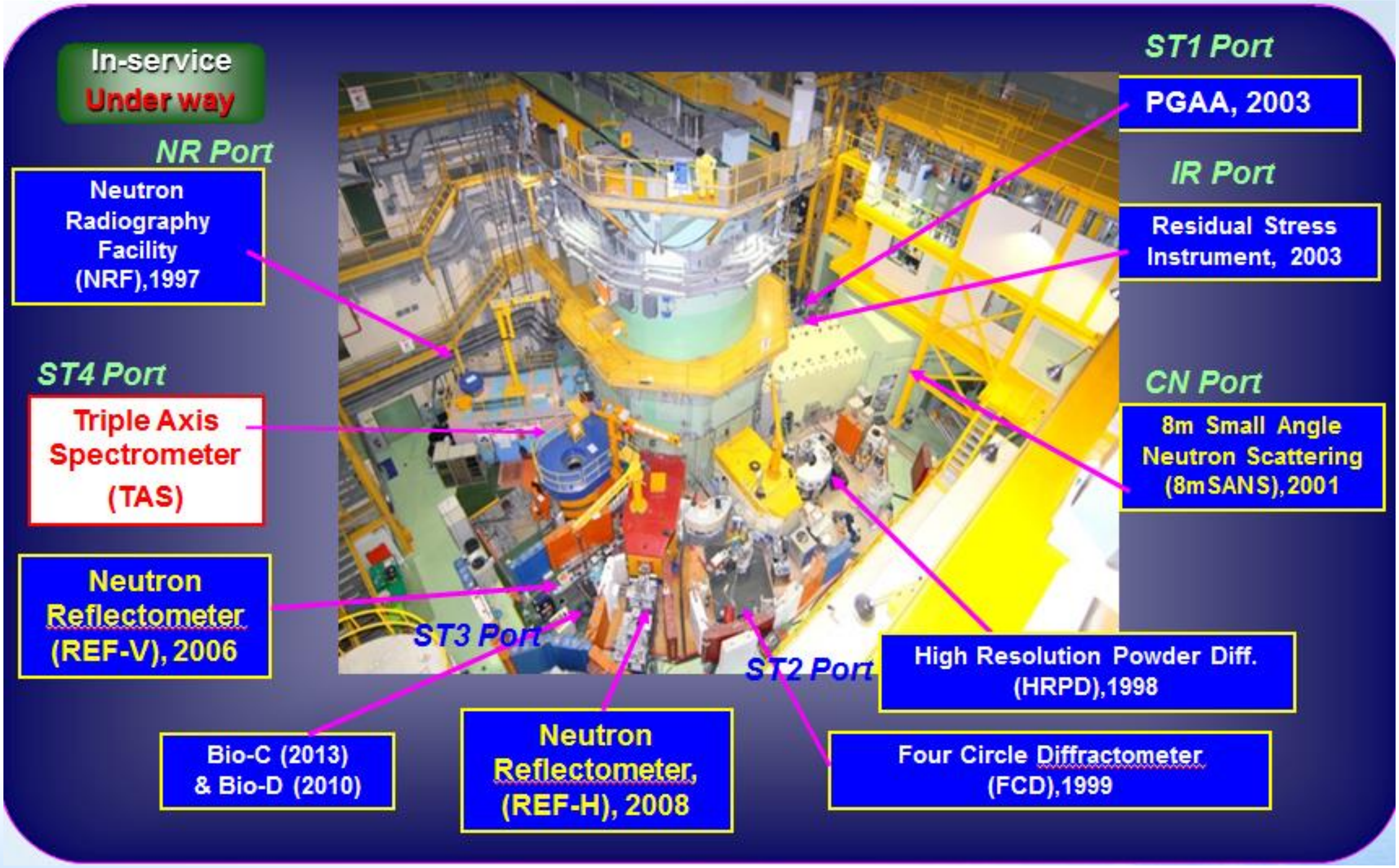
In DHRUVA

- 4 tangential beams
- 6 radial beams
- Two though- beam tubes
- Cold neutron source beam
- Hot neutron source with side ports for beam extraction
- Used for
  - development and testing of ion chambers
  - Other instrumentation for NPPs
  - Material property investigations



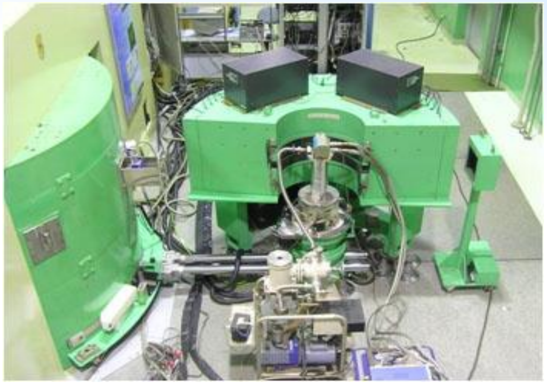
Cross section of DHRUVA, showing the beam ports, India

Neutron Scattering Instruments in HANARO Reactor Hall, Korea



Complementary Facilities

High temperature sodium static test facility for corrosion studies, CEFR, China



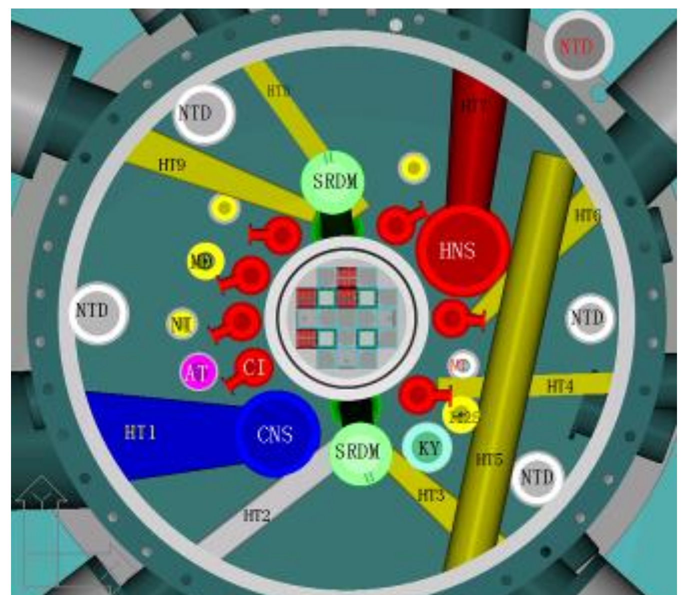
DN3 — high resolution powder diffractometer. For investigations on crystal structure, RSG-GAS, Indonesia

NRG's actinides laboratory; inset shows examples of experimental fuels for incineration of plutonium for the OTTO and FP6 experiment LWR Deputy, respectively; Netherlands

Impact Testing Machine, BOR-60, Russian Federation

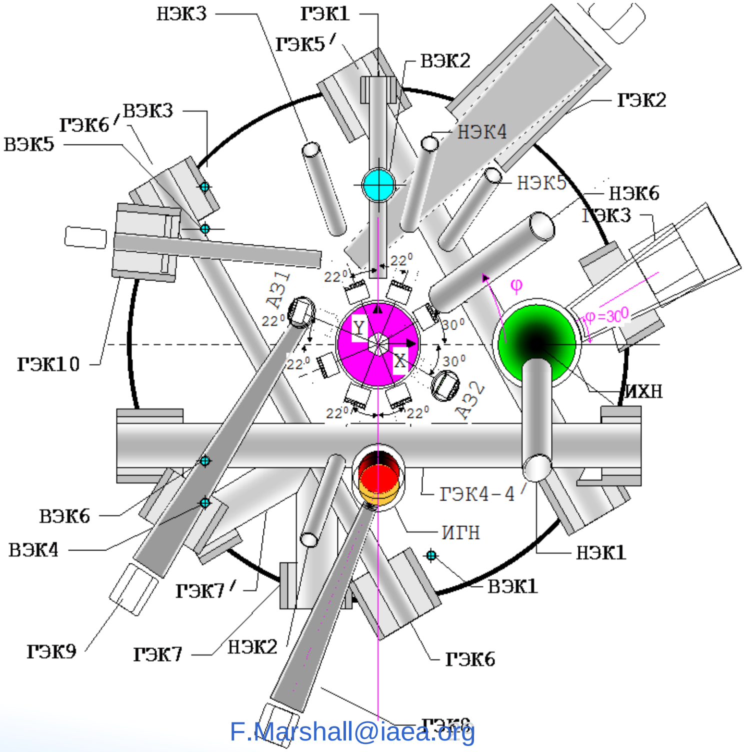
New RR: CARR, China

- 1st criticality in May 2010
- 60 MW, in core flux ~1×10^{15} n/($cm^2\cdot s$)
- Fuel: 19% U-235, Moderator: H_2O, Reflector: D_2O
- Replacement for 10MW HWRR (2007)
- Multipurpose RR with the main objectives in basic research
- Open to users from universities, governmental laboratories, industry



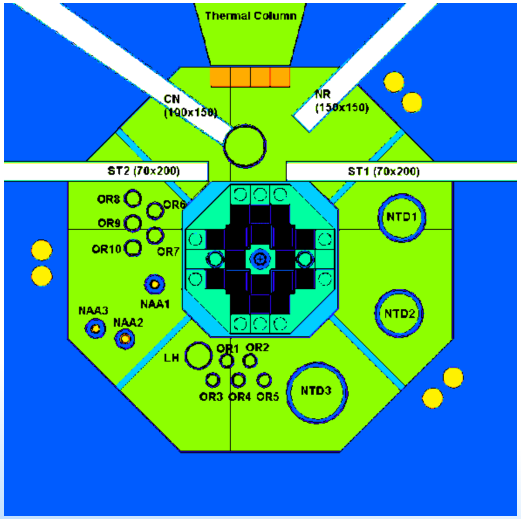
New RR: PIK, Russian Federation

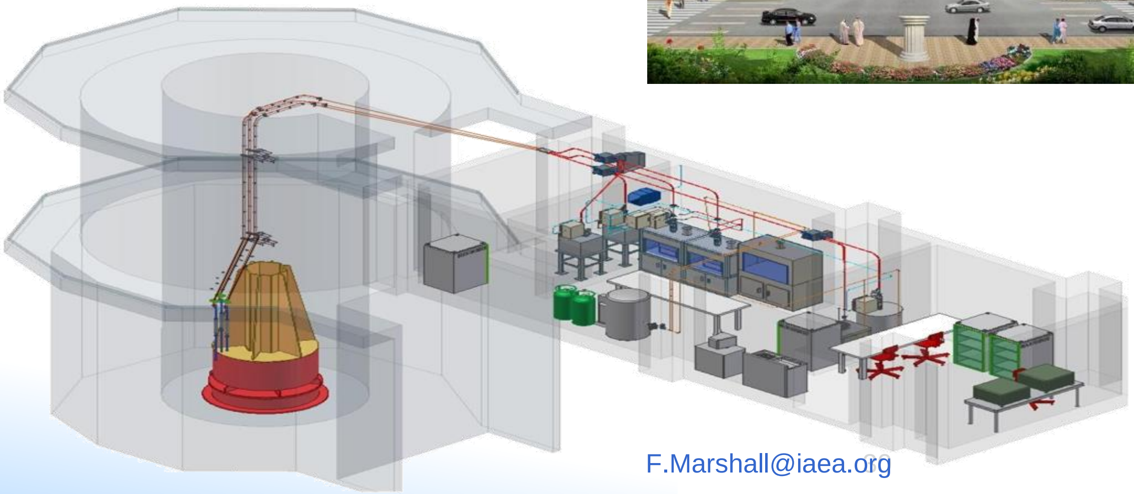
- 1st criticality in March 2011, still considered under construction
- 100 MW, in neutron trap flux ~4.5×10^{15} n/(cm^2·s)
- Fuel: ~90% U-235, Moderator & Reflector: D_2O
- Replacement for WWR-M (18MW)
- Multipurpose RR with the main objectives in basic research
- Open to users from universities, governmental laboratories, industry



New RR: Jordan Research & Training Reactor (JRTR)

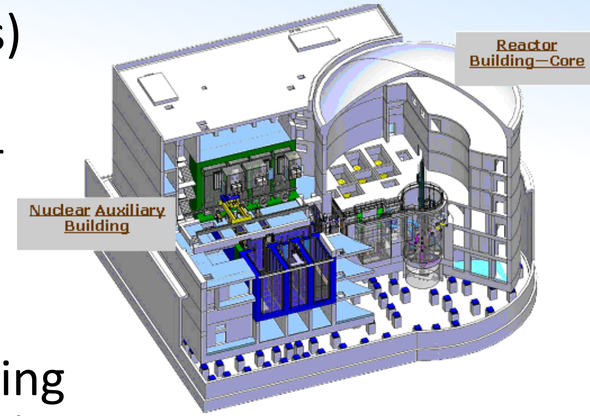
- Fully constructed, in commissioning operations
- 5 MW (upgradable to 10MW), neutron flux ~1.5×10^{14} n/(cm$^2\cdot$s)
- Fuel: ~19.75 % U-235, U_3Si_2-Al, Coolant & Moderator: H_2O, Reflector: Be
- Multipurpose RR: radioisotope production, Si doping, neutron beams, NAA, E&T, etc.
- 1st step to the national NPP programme

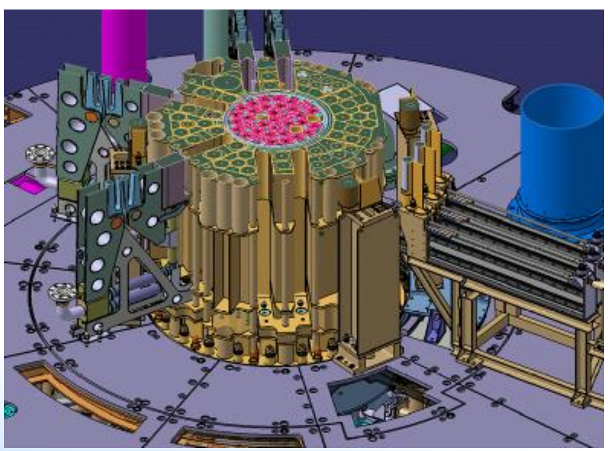




New RR: Jules Horowitz Reactor

- MTR pool, 100 MW
  - In core maximum fast flux ~1×10^{15} n/(cm^2·s)
  - Maximum thermal flux ~5×10^{14} n/(cm^2·s)
- Startup fuel U_3Si_2 20-27 % U-235; use of LEU U-Mo possible
- In support of future nuclear power, Gen3+ & Gen4
- Dedicated for material/fuel irradiation and testing
- Other applications planned (isotope production)
- Funded and steered by an International Consortium





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