National Centre for Nuclear Research

Fast neutron irradiation facilities in MARIA reactor

fission neutrons for fusion materials

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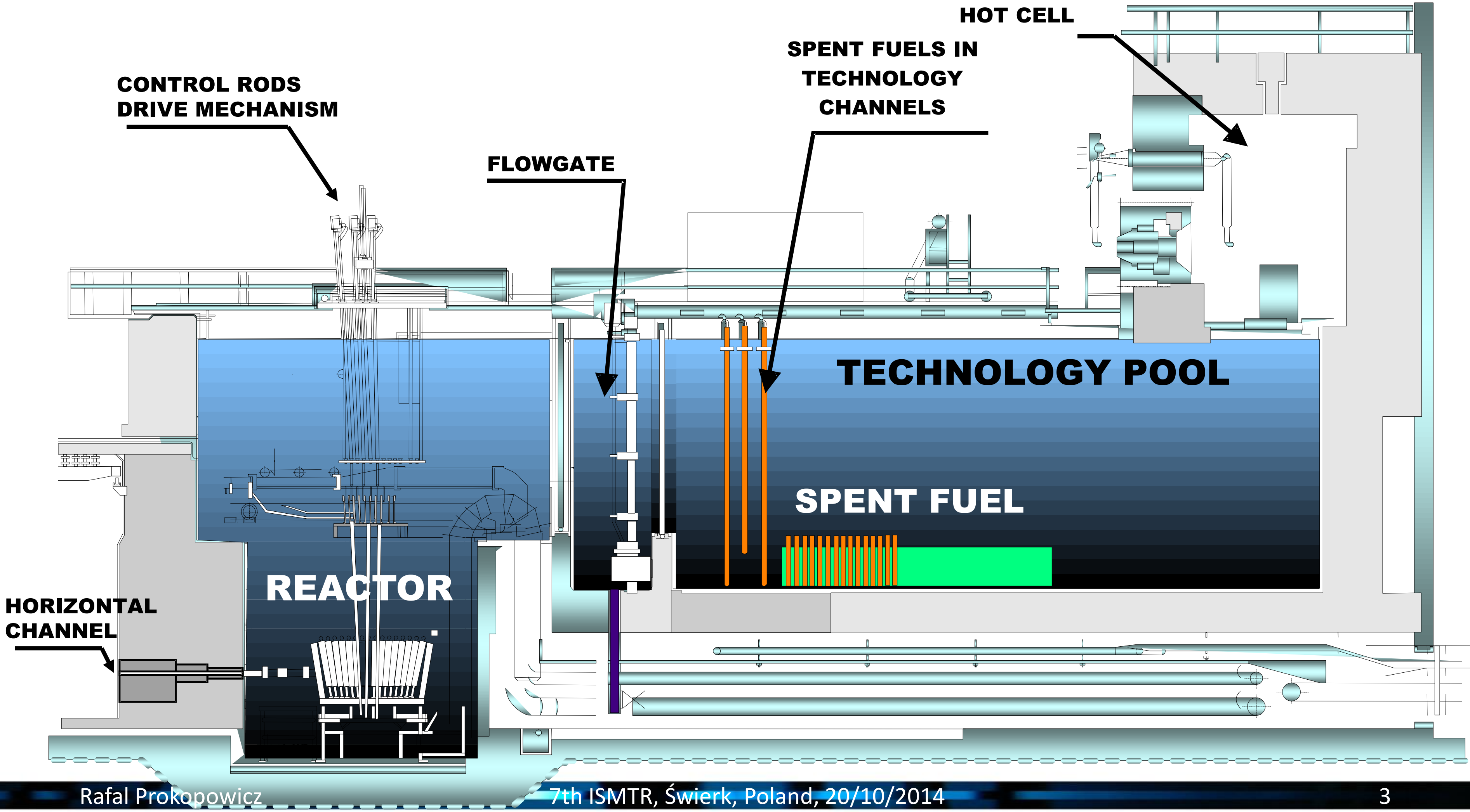
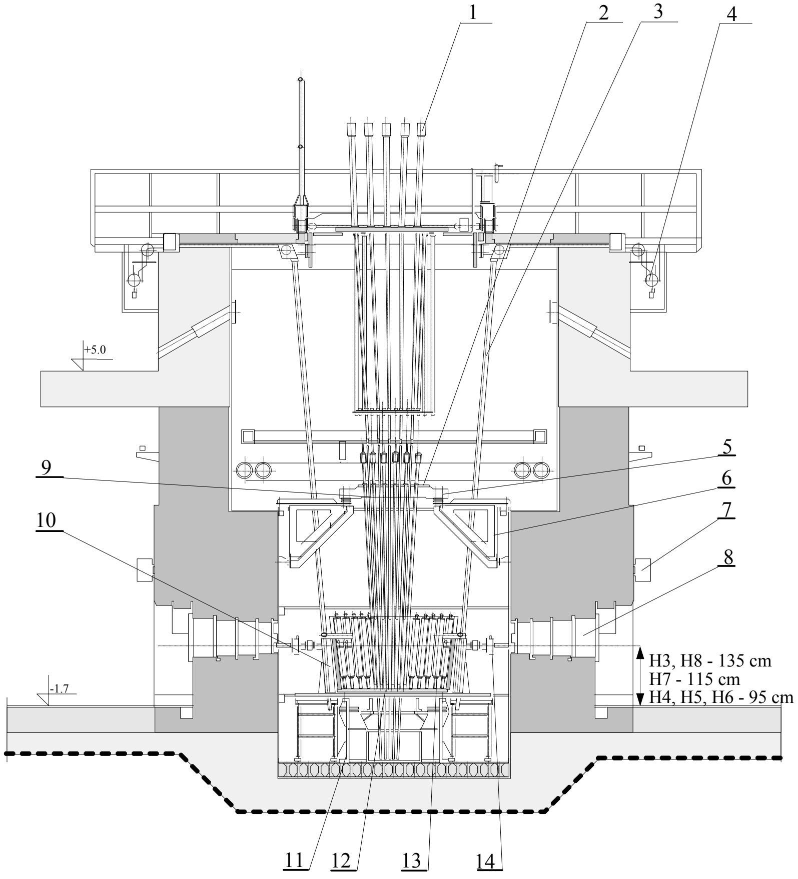
MARIA Research Reactor

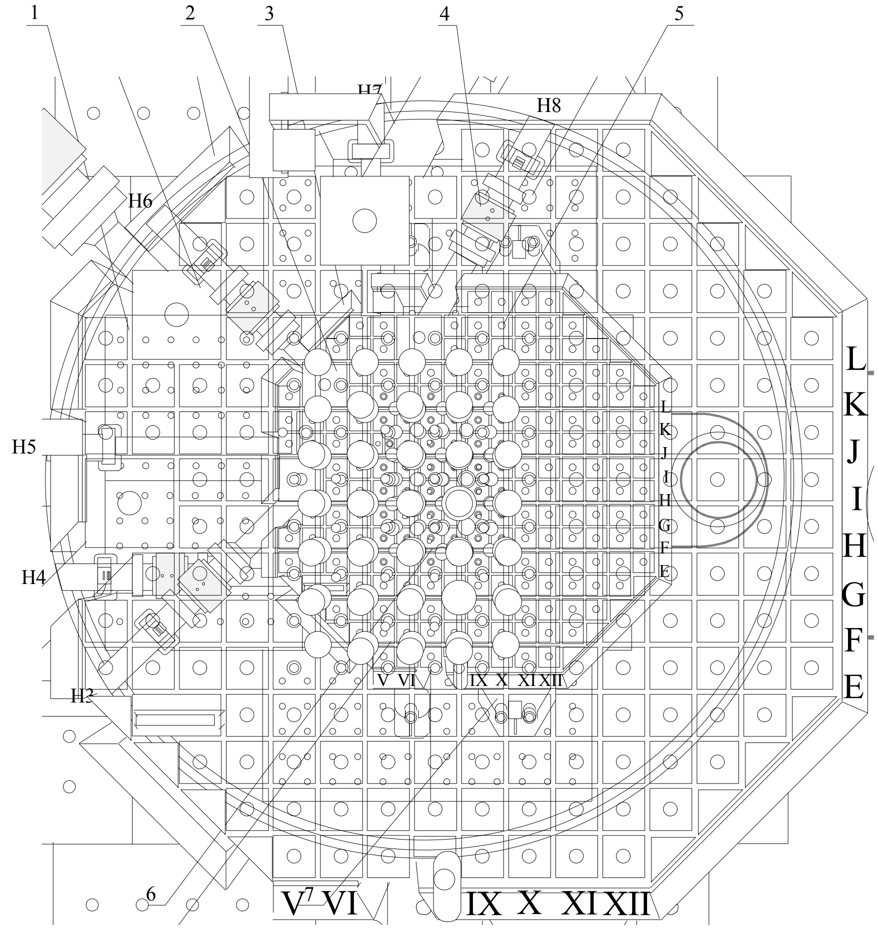
- high neutron flux density research reactor
- water and beryllium moderated
- pool-type reactor with pressurized fuel channels
- concentric tube assemblies of fuel elements
- fuel channels in conical matrix of beryllium blocks surrounded by graphite reflector
- 30 MW of nominal thermal power
- thermal neutron flux density up to $2 \cdot 10^{14}$ cm^{-2} s^{-1}
- fast neutron flux density up to $3 \cdot 10^{13}$ cm^{-2} s^{-1}
- over 4000 hours operation per year
- radioisotope production 600 TBq/year
- Mo-99 production 6000 TBq/year

MARIA reactor



MARIA reactor

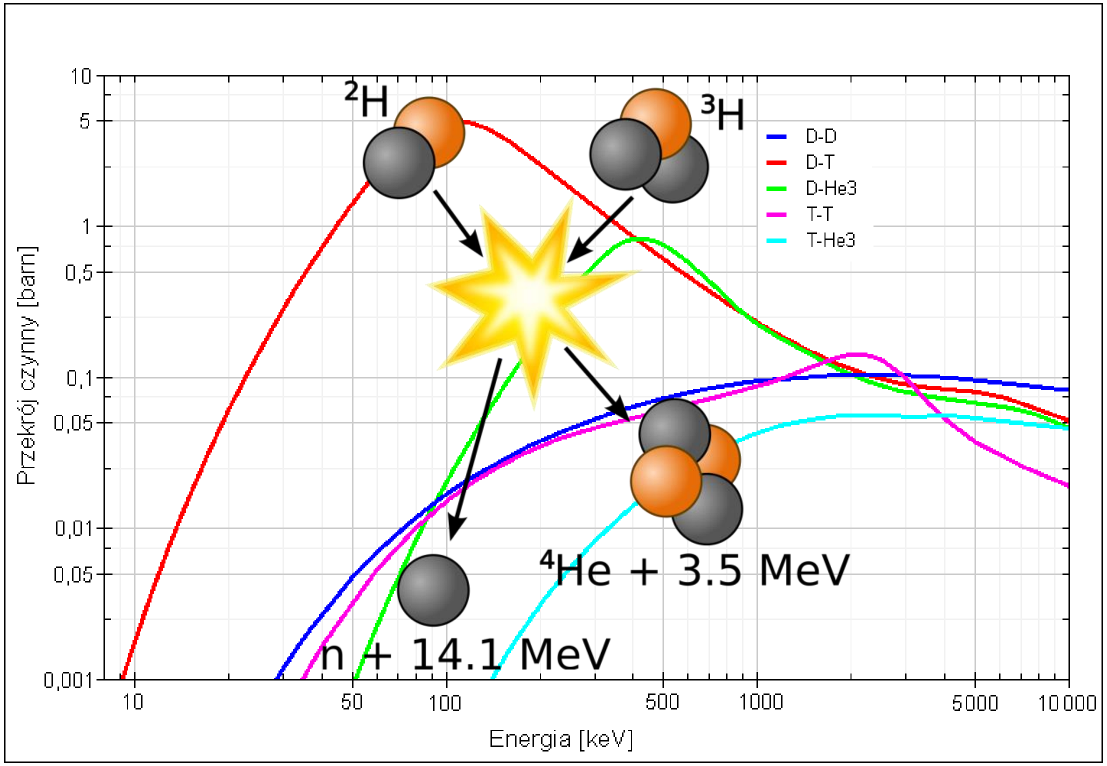




1. control rod drive
2. mounting slab
3. ionisation chamber channel
4. ionisation chamber drive
5. slab supporting structure
6. slab bracket
7. horizontal beam slide damped drive
8. horizontal beam slide damper
9. fuel channel
10. ionization chamber shielding
11. basket basis
12. reflector housing
13. reflector blocks
14. horizontal neutron beam compensator

1. table
2. multiple graphite block
3. housing
4. compensator
5. graphite block
6. beryllium block
7. shielding of ionisation chambers

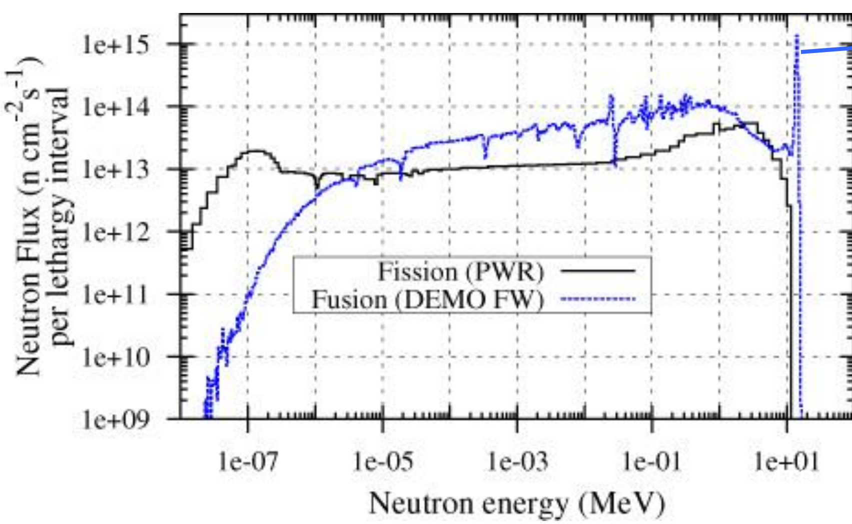
Neutrons from fusion

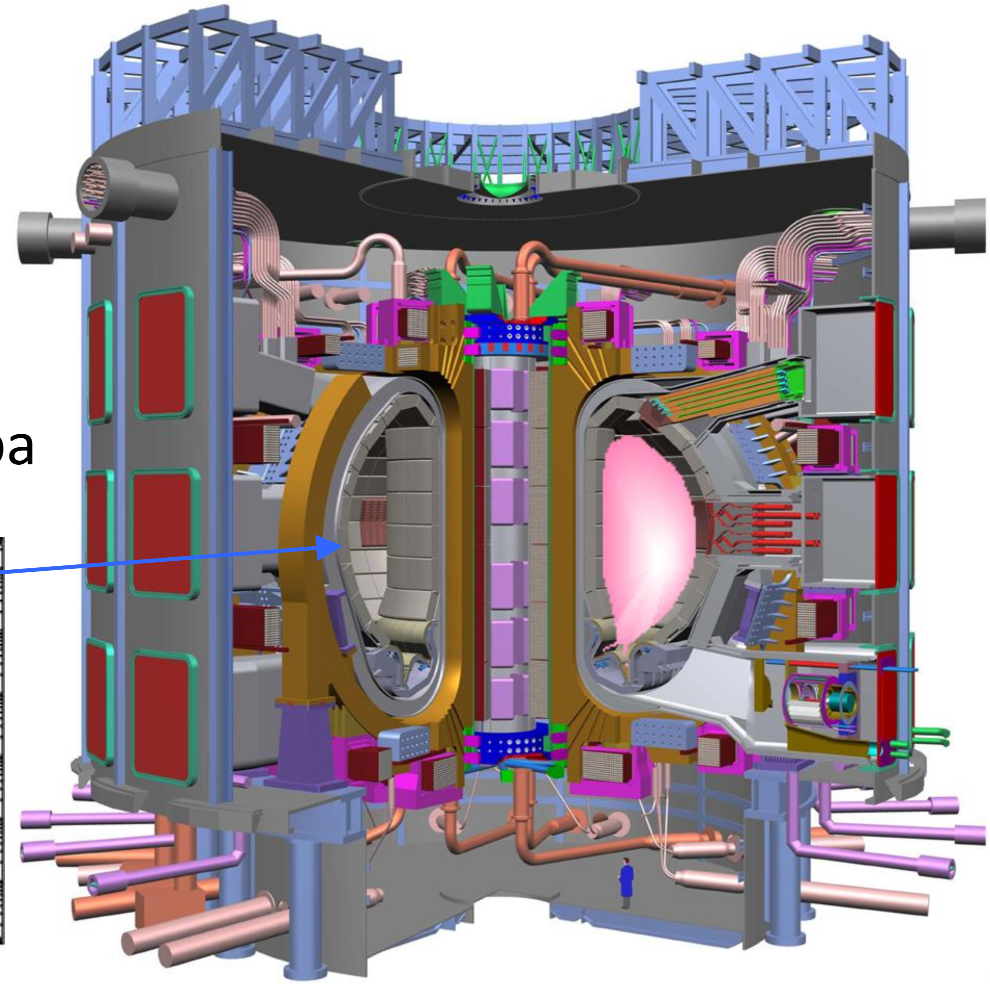


Fusion reactor

- heat load 10 MW/m^2
- temperature 4K÷800K
- fast neutron flux density

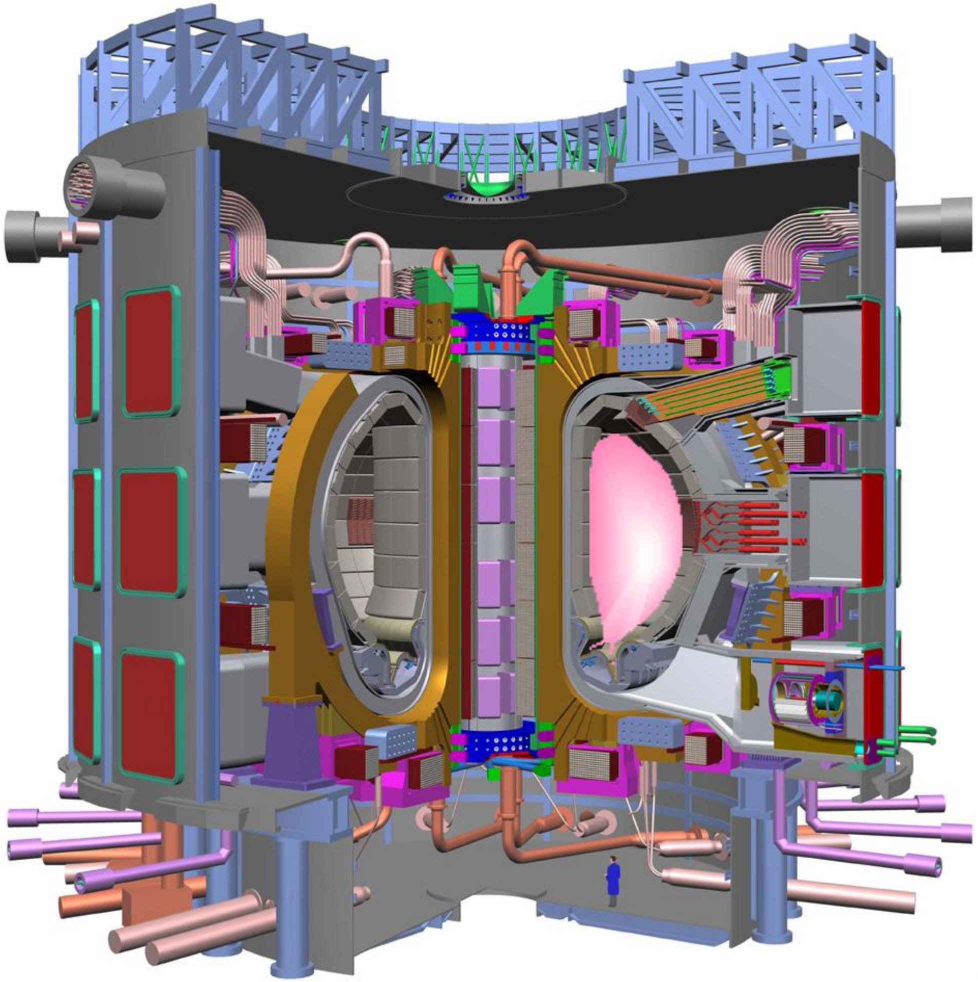
  $3{\cdot}10^{14}\ cm^{-2}\,s^{-1}$
- structure degrad. 3÷150 dpa





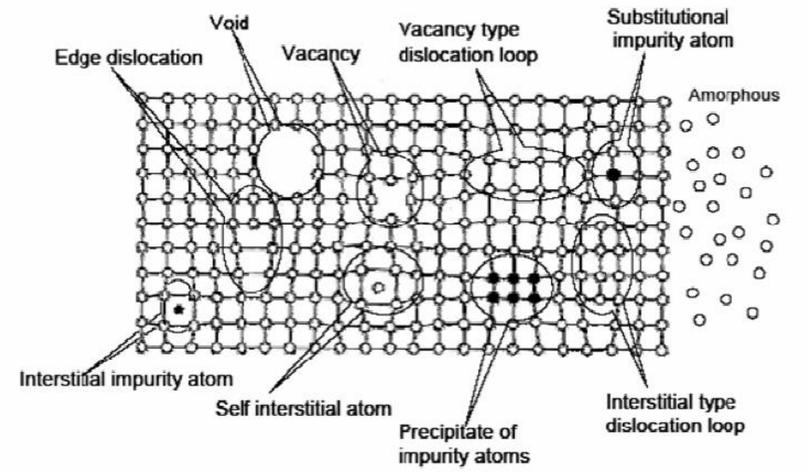
Fusion materials

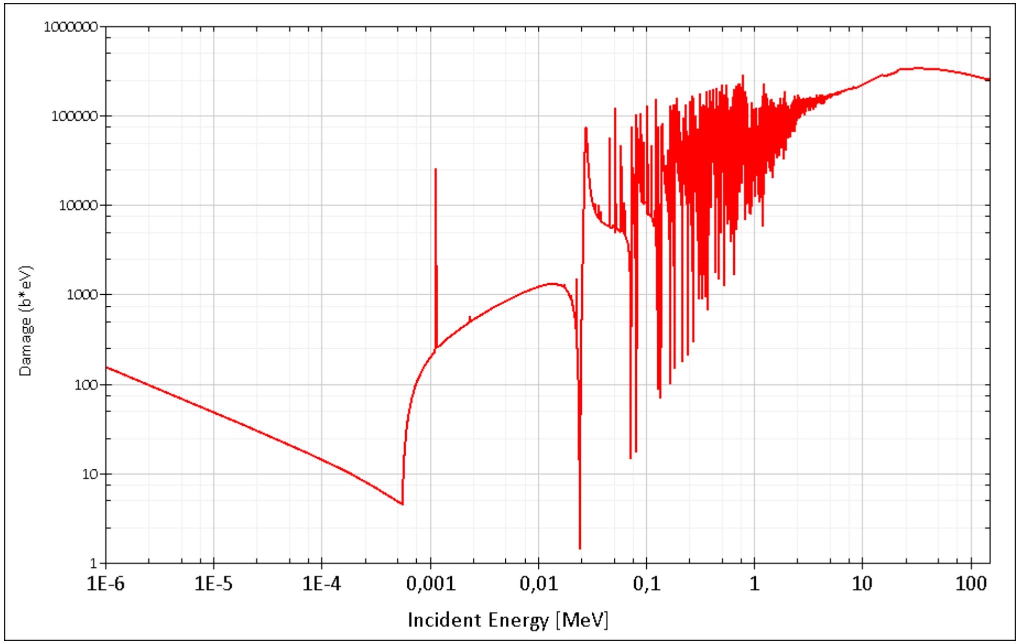
- berylium (1st wall, blanket)
- lithium compounds
- tungsten (divertor)
- carbon fibre composite (divertor)
- austentic steel
- nickel alloys
- titanium alloys
- ferritic steel
- ceramics (insulators)



Structure degradation

displacement per atom (dpa)



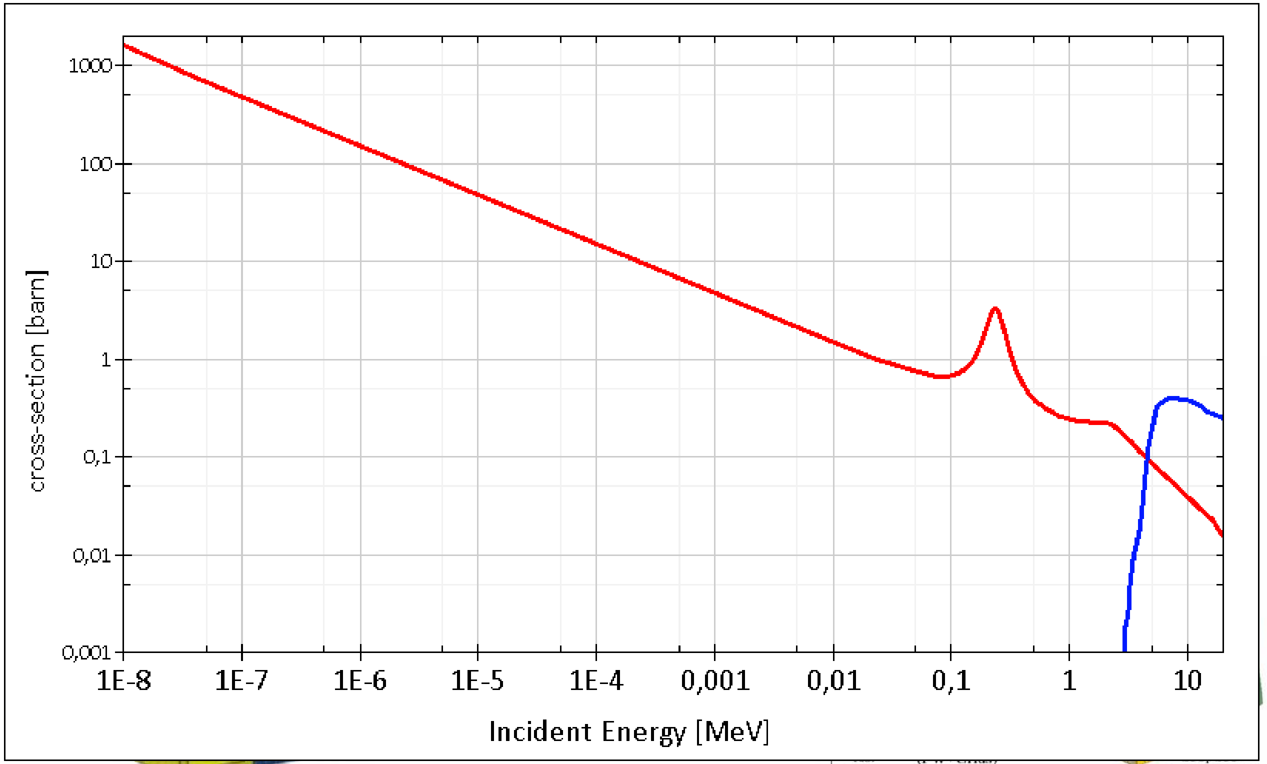


Tritium breeding

Breeding blankets

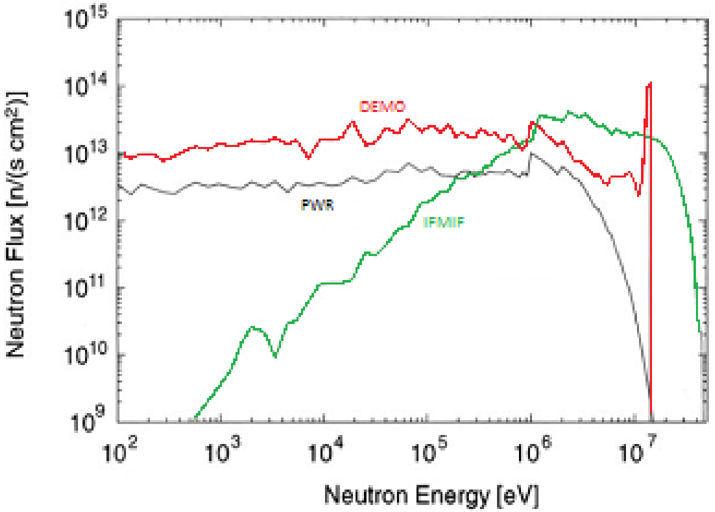
$^{6}Li + n \rightarrow T + {}^{4}He$ $^{7}Li + n \rightarrow T + {}^{4}He + n$

- heliu
- heliu
- wate



The 14 MeV neutreon sources

- accelerator sources
  - solid target (ASP AWE ~$2 \cdot 10^{10}$ cm^{-2} s^{-1}, FNG ~$1 \cdot 10^{9}$ cm^{-2} s^{-1}, IFJ ~$1 \cdot 10^{7}$ cm^{-2} s^{-1})
  - plasma target (GDT, Nowosybirsk)
- plasma sources
  - mcf – tokakak, stellarator (JET (dt) < $1 \cdot 10^{12}$ cm^{-2} s^{-1}, t<10 s)
  - icf (NIF $1 \cdot 10^{9}$ cm^{-2} imp^{-1})
  - z-pinch (NST DPF 1MJ (dt) ~$1 \cdot 10^{11}$ cm^{-2} imp^{-1})
- spallation source (ISIS $3 \cdot 10^{7}$ cm^{-2} s^{-1})
- **MARIA LiD <$1 \cdot 10^{10}$ cm^{-2} s^{-1}, 4000 h/y, 60cm^{3}**
- designed sources
  - ITER ($4 \cdot 10^{14}$ cm^{-2} s^{-1}, t≈500 s)
  - DEMO ($1 \cdot 10^{15}$ cm^{-2} s^{-1})
  - ESS ($1 \cdot 10^{13}$ cm^{-2} s^{-1})
  - IFMIF (~$8 \cdot 10^{14}$ cm^{-2} s^{-1}, 20 dpa/y, 500cm^{3})



The neutron „conversion”

$$^{6}Li + n_{th} \rightarrow T + {}^{4}He \quad (Q \cong 4.79\ MeV)$$

$$T + D \rightarrow {}^{4}He + n_{14MeV} \quad (Q \cong 17.58\ MeV)$$

$$T + {}^{6}Li \rightarrow {}^{8}Be + n_{14MeV} \quad (Q \cong 16.02\ MeV)$$

The converters „history”

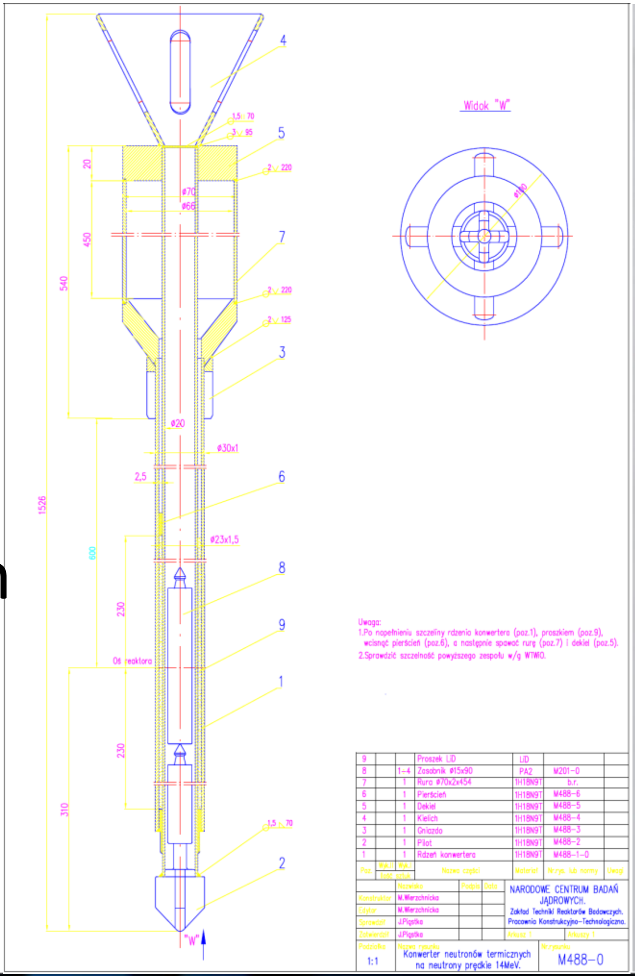
- TRIGA Mark II, Kansas – $^{6}LiOD\cdot D_2O$, $3\cdot 10^4$ cm^{-2} s^{-1}, 1976
- MURR, Missouri – $^{6}LiOD\cdot D_2O$, 32 cm^3, $6\cdot 10^4$ cm^{-2} s^{-1}, 1982
- KUR, Kyoto – ^{6}LiD, 100 cm^3, $3\cdot 10^5$ cm^{-2} s^{-1}, 1988
- TRIGA Mark II, Wien – ^{6}LiD, $4\cdot 10^8$ cm^{-2} s^{-1}, 1997
- IVV-2M, Zariechnyj – 0.85g ^{6}LiD, 1.3 cm^3, $3\cdot 10^{10}$ cm^{-2} s^{-1}, 2002
- MARIA, Świerk – ^{6}LiD+$^{6}LiOD\cdot D_2O$, 60 cm^3, $<1\cdot 10^{10}$ cm^{-2} s^{-1}, 2014
  10 g 55 g

The converter in MARIA reactor

- converting materials
- conversion efficiency
- geometry optimization
- neutronic calculations
- thermo-hydraulic calculations
- reactivity calculations
- safety analysis
- converter design
- converter construction
- operation procedures
- regulator permission

Converter construction

- cylindrical shape
- concentric vertical tubes
- cylindrical converting layer (2.5 mm thick, 35 cm high) surrounds container Ø18mm
- flowing down water cooling inner and outer clad
- gas expansion chamber 1.4 l

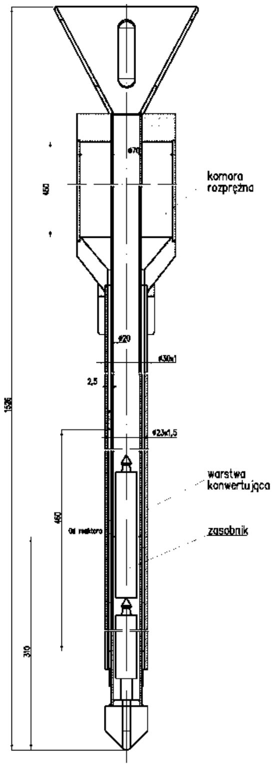


Converting materials

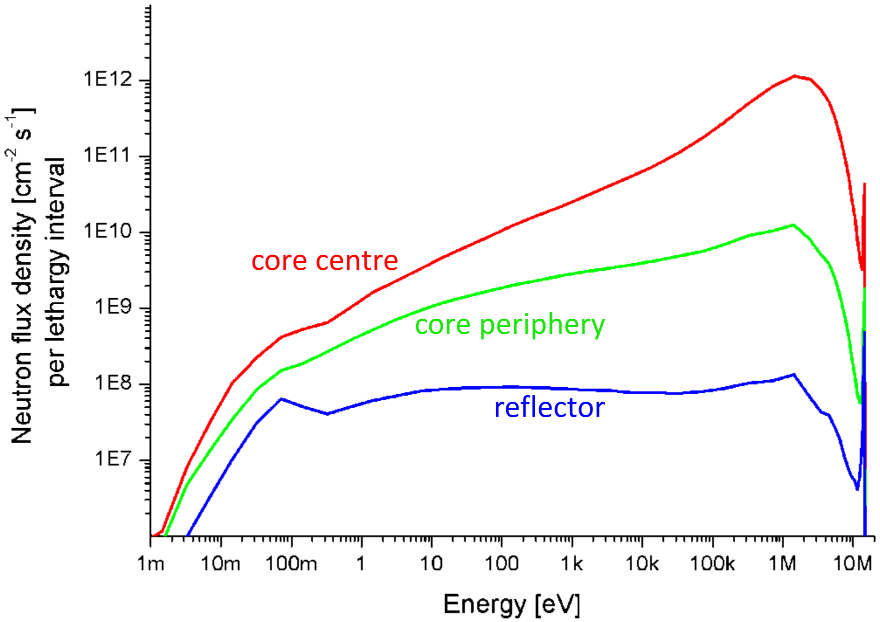
- ^{6}LiD (10 g), ^{6}LiOD·D$_2$O (55 g)
- conversion efficiency

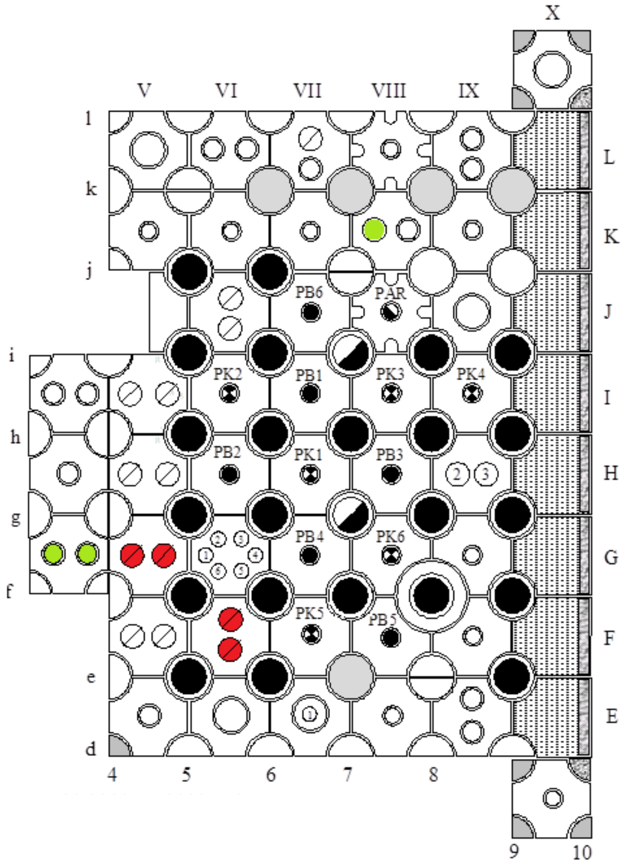
Converting material	Reaction probability	
	T - D	T – ^{6}Li
^{6}LiD	$1.71 \cdot 10^{-4}$	$0.84 \cdot 10^{-4}$
^{6}LiOD·D$_2$O	$1.28 \cdot 10^{-4}$	$0.19 \cdot 10^{-4}$

- thermal neutron flux density $0.5 \cdot 10^{14}$ cm^{-2} s^{-1}
- 14 MeV neutron flux density $0.5 \cdot 10^{10}$ cm^{-2} s^{-1}



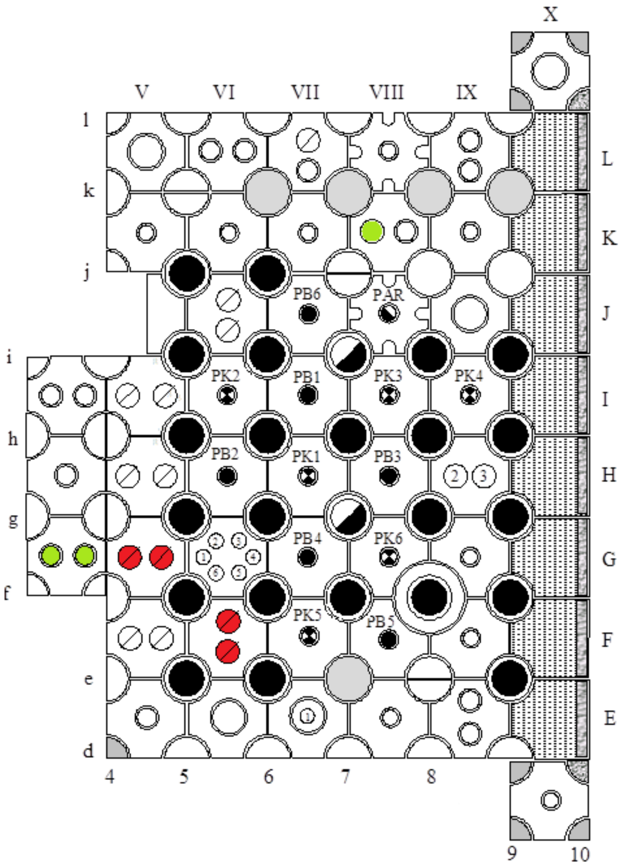
Neutronic calculations





Reactivity perturbation

Location	Reactivity [$]
J-IX/A	- 0.15
J-IX/B	- 0.20
G-IV/A	- 0.10
G-IV/B	- 0.19
G-V/A	- 0.49
G-V/B	- 0.77
K-VIII/A	- 0.06



Operation conditions

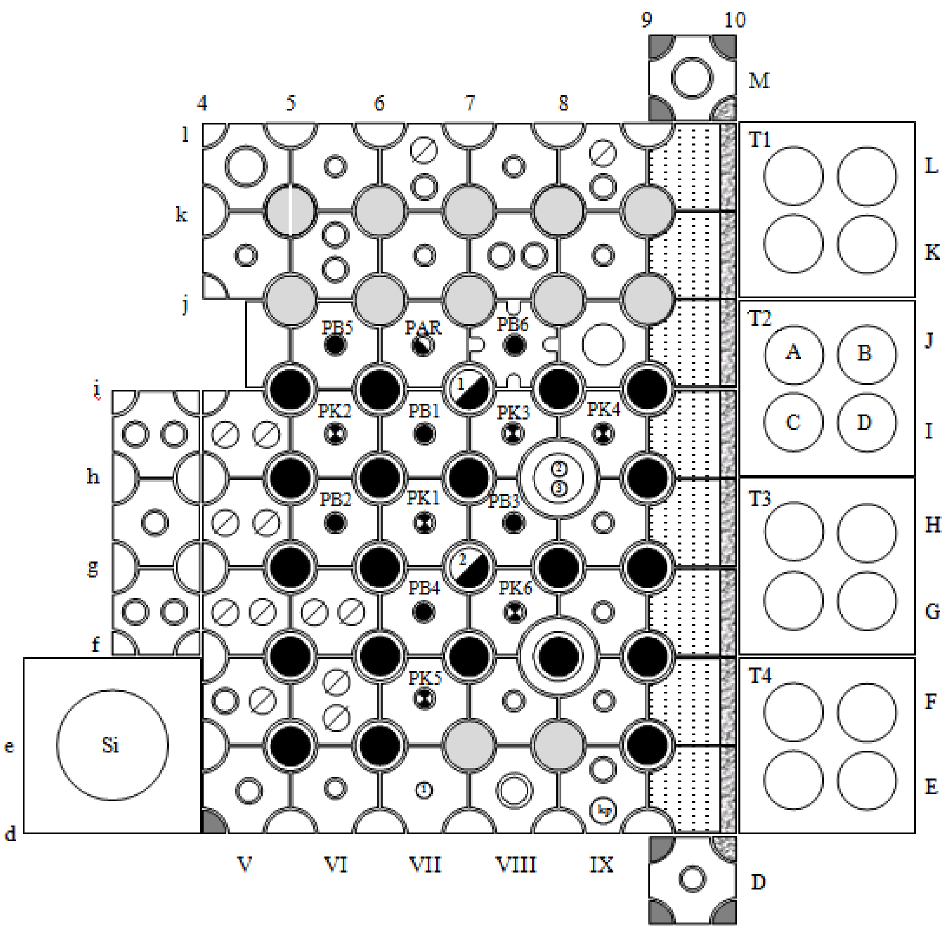
- heat generation
  - cooling water heating 40°C
  - max clad temperature 100°C
  - max temp. of converting layer 320°C
- after 2800 h operation (neutron fluence $5 \cdot 10^{20} cm^{-2}$)
  - tritium activity 280 TBq
  - gas pressure inside converter – 1.0 MPa

Testing operation

- 18/09/2014 ÷ 24/09/2014, 134.5 h
- channel K-VIII/A (reactivity -0.06$)
- max clad temperature 80°C
- irradiated targets: steel samples, activation detectors
- thermal neutron flux density $0.5 \cdot 10^{14}$ cm^{-2} s^{-1}
- 14 MeV neutron flux density *~*$0.5 \cdot 10^{10}$ cm^{-2} s^{-1}

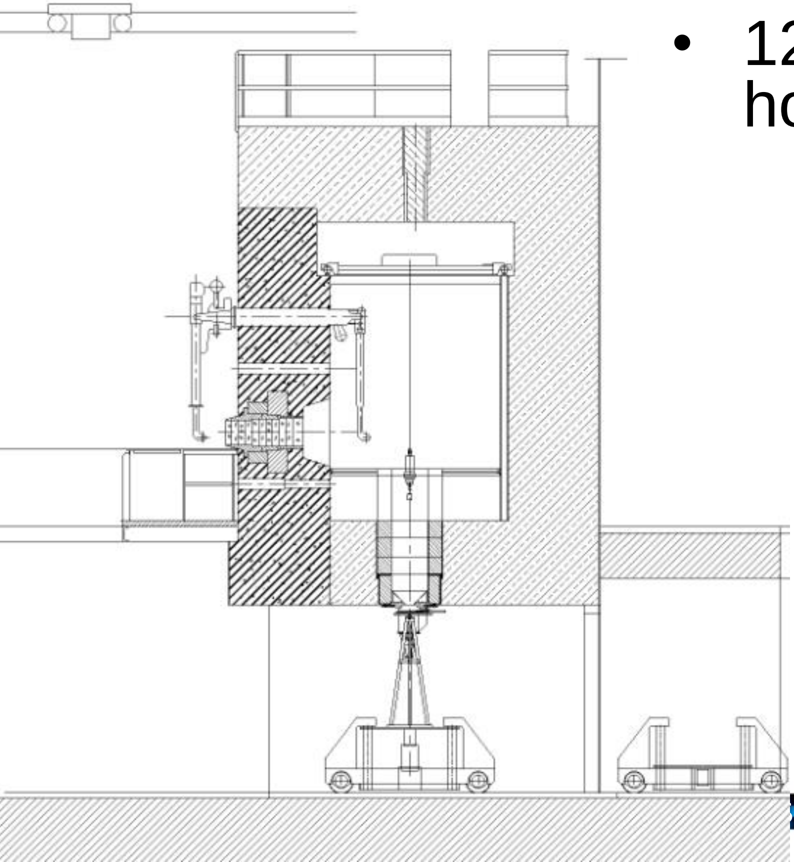
Fast neutron irradiation channels

- fast neutron (Watt spc.) flux density up to $3 \cdot 10^{12}$ cm^{-2} s^{-1}
- thermal neutron flux reduced down to $3 \cdot 10^{10}$ cm^{-2} s^{-1}
- 16 irradiation channels (Ø90 mm × 900 mm)
- possible irradiation of samples, apparatus, etc.



Post-irradiation examination

- 3 reactor hot cells (10^{12}÷10^{15} Bq) with instrumentation
- 12 NCBJ Material Research Laboratory hot cells (10^{12} Bq) with instrumentation
- transport system of radioactive materials form reactor



Future prospects

- fast neutron irradiation inside purpose-build fuel element
  - fast neutron (Watt spc.) flux density over $2 \cdot 10^{14}$ cm^{-2} s^{-1}
  - thermal neutron flux density up to $3 \cdot 10^{14}$ cm^{-2} s^{-1}
  - channel ~Ø15÷45 mm
- out-of-reactor (on horizontal channel) thermal to 14 MeV neutron converter
  - 14 MeV neutron flux density ~$1 \cdot 10^{6}$ cm^{-2} s^{-1}, no gamma ray
  - irradiation of large size apparatus, devices, etc.,
  - operation 4000 h/year