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MINOS Centre of Excellence for Nuclear Materials

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The Characteristics and Irradiation Capabilities of MARIA Research Reactor in NCBJ Świerk

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1. MARIA research reactor description

The high flux research reactor MARIA is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels containing concentric six-tube assemblies of fuel elements. It has been designed to provide high degree of flexibility. The fuel channels are situated in a matrix containing beryllium blocks and enclosed by lateral reflector made of graphite blocks in aluminium cans. The MARIA reactor is equipped with vertical channels for irradiation of target materials, a rabbit system for short irradiations and six horizontal neutron beam channels. The MARIA reactor reached its first criticality in December 1974. The reactor was in operation until 1985 when it was shut down for modernization. The modernization encompassed refurbishment and upgrading of technological systems such as:
- enlargement of beryllium matrix,
- inspection of the graphite bocks,
- upgrading of ventilation and temperature systems.

The second step of upgrading the technological system was done from 1996-2002 (during regular maintenance) and it was consisted with: replacement of heat exchangers, replacement of instrumenttation and control system, upgrading of radiation protection system, modernization of fuel element integrity monitoring system. The reactor was fully converted from HEU to LEU fuel in the end of August 2014 [1]. In the end of March MARIA reactor received the new license for reactor operation till 2025 year.

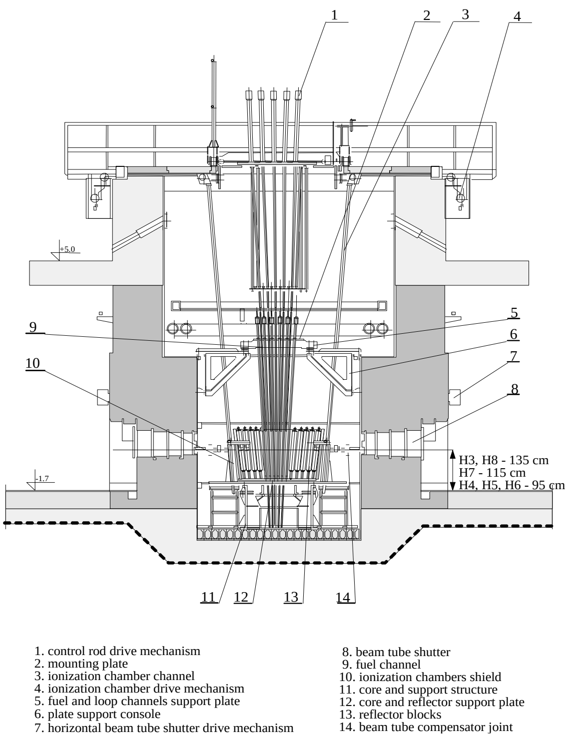
The main characteristics and data of MARIA reactor are as follows [2]:

▪ nominal power	30 MW(th),
▪ moderator	H_2O, beryllium,
▪ cooling system	channel type,
▪ fuel assemblies:	
- material	U_3Si_2
- enrichment	19,75%
- cladding	aluminium
- shape	five concentric tubes
- active length	1000 mm.
▪ output thermal neutron flux at horizontal channels	3 - 5 x 10^9 n/cm^{2}s

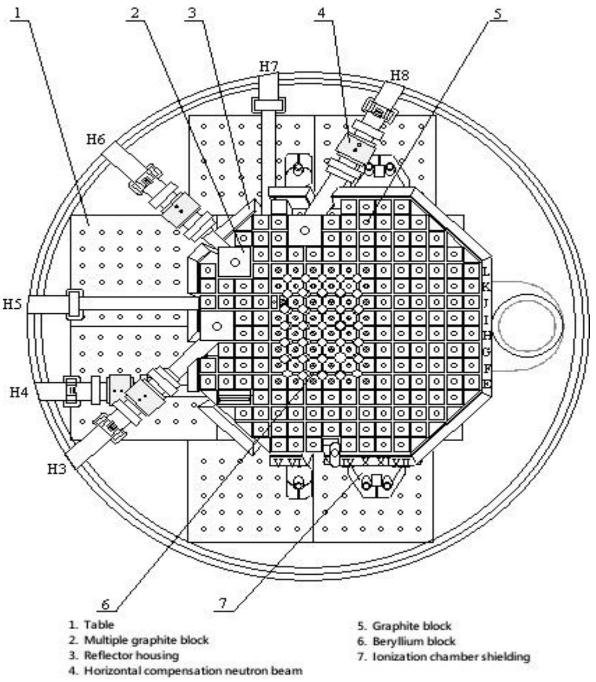
The main areas of reactor application are as follows: production of radioisotopes, testing of fuel and structural materials for nuclear power engineering, neutron radiography, neutron activation analysis, neutron transmutation doping, research in neutron and condensed matter physics. For today the NCBJ has a program for MARIA research reactor operation till 2030.

2. Characteristics of MARIA reactor for installation loops and rigs

MARIA reactor core contains the fuel assemblies which are installed in pressurized channels embedded in matrix sockets. The matrix is composed of beryllium blocks which are fastened to the support slab in reactor pool on the level +2.75 m [3]. Beryllium blocks of the core matrix as well as the graphite blocks creating the radial reflector are positioned in the sockets of separator slab on the level – 1.4 m (6x8) Fig.1 and Fig. 2.



a)



b)

Fig. 1: a) vertical cross-section of the reactor pool, b) top view of the reactor core and reflector.

The possibility of placing of the experimental channel, i.e. channels, rigs and loops depends on the two factors: of the position in the core and arrangement and dimensions of holes in the support slab. The place within in the core can be matched to any experimental device by means of constructing suitable beryllium and graphite blocks.

The neutron-thermal characteristics for the research channels are as follows:

- fast neutron flux $\Phi_f = 1.0 - 1.5 \cdot 10^{14}$ n cm $^{-2}$ s^{-1}
- thermal neutron flux $\Phi_{th} = 1.0 \cdot 10^{14}$ n cm $^{-2}$ s^{-1}
- heat generation $q_{Fe} = 3 - 4$ W $\cdot$ g^{-1}

3. Neutron irradiation services

Neutron irradiation services provided at the MARIA research reactor mainly include radioisotope production. Irradiation services are performed in various facilities in the MARIA reactor, with proper account for the required neutron flux 1, irradiation time, and target mass and geometry. The standard vertical in-core isotope channels as well as special ones equipped with hydraulic transport system are in operation. From 2010 in MARIA reactor started irradiation of uranium plates for Mo-99 production. Irradiations are carried out in two molybdenum channels and irradiated plates are sent to Petten facility in the Netherlands for processing. From September 2014 MARIA offers special irradiation in converter of 14 MeV neutrons.

References

[1] G. Krzysztoszek, Full core conversion from HEU to LEU fuel in MARIA reactor, 9th IAEA TM, Samarkand, Uzbekistan 3-5 June 2015.
[2] K. Pytel et all, Operation Safety Report of MARIA reactor, ERBM-2015.
[3] G. Krzysztoszek, Maria research reactor infrastructure for ICERR, IAEA TM, Aix-en-Provence, 10-12 April 2012.

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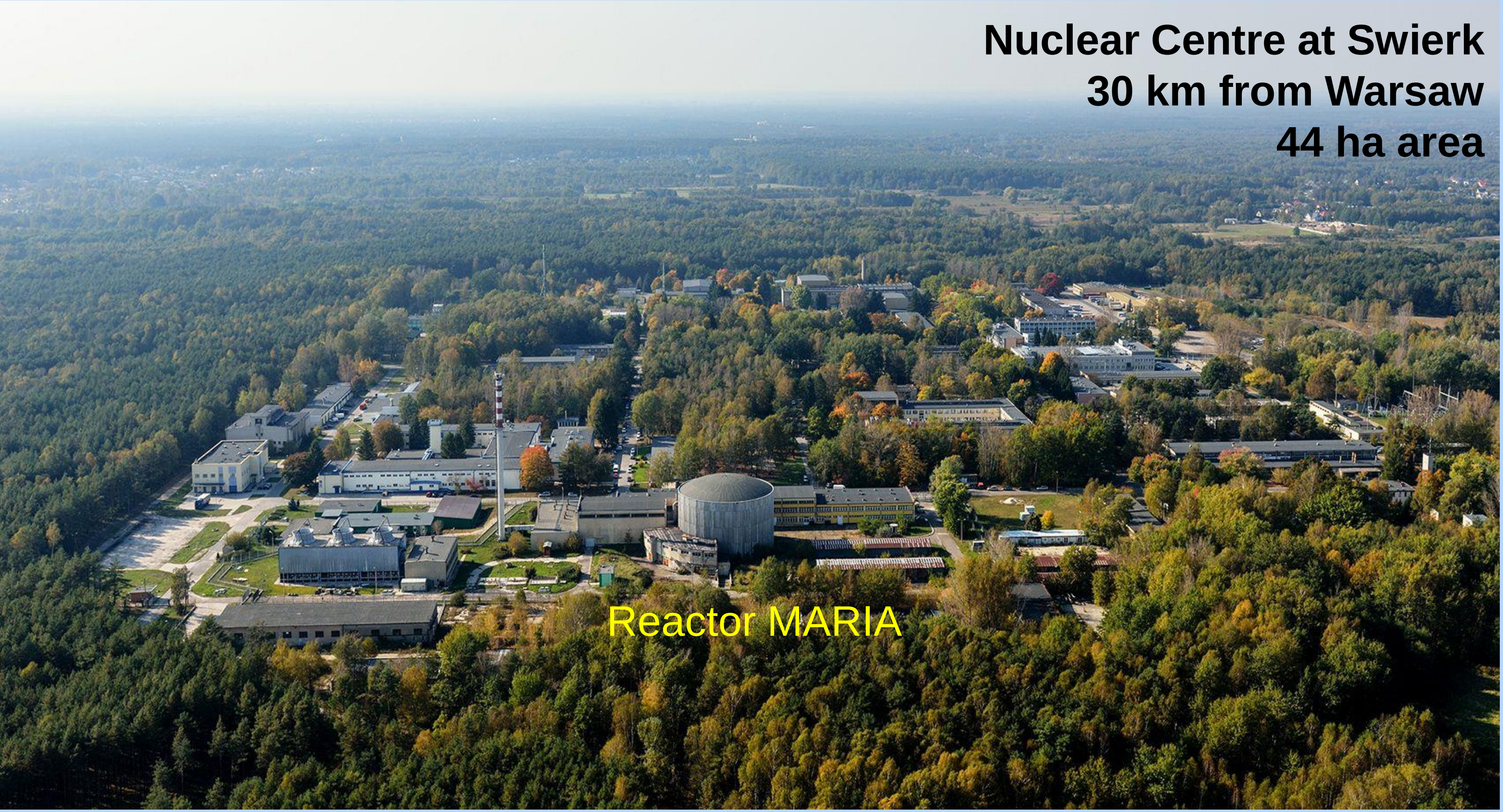

Nuclear Centre at Swierk
30 km from Warsaw
44 ha area
Reactor MARIA

Key dates at MARIA

1974 (December 18): the first criticality was reached

1985 MARIA shut down for major upgrade (including enlargement of beryllium matrix, inspection of the graphite blocks, upgrade of the cooling/ventilation/temperature control systems)

1992 (December): MARIA put again in operation

1993 – till now Regular operations of the MARIA reactor

1996-2002 The second step of upgrading the technological systems in MARIA reactor (during regular maintenance periods)

2009-2014 Conversion of MARIA reactor core from HEU to LEU fuel

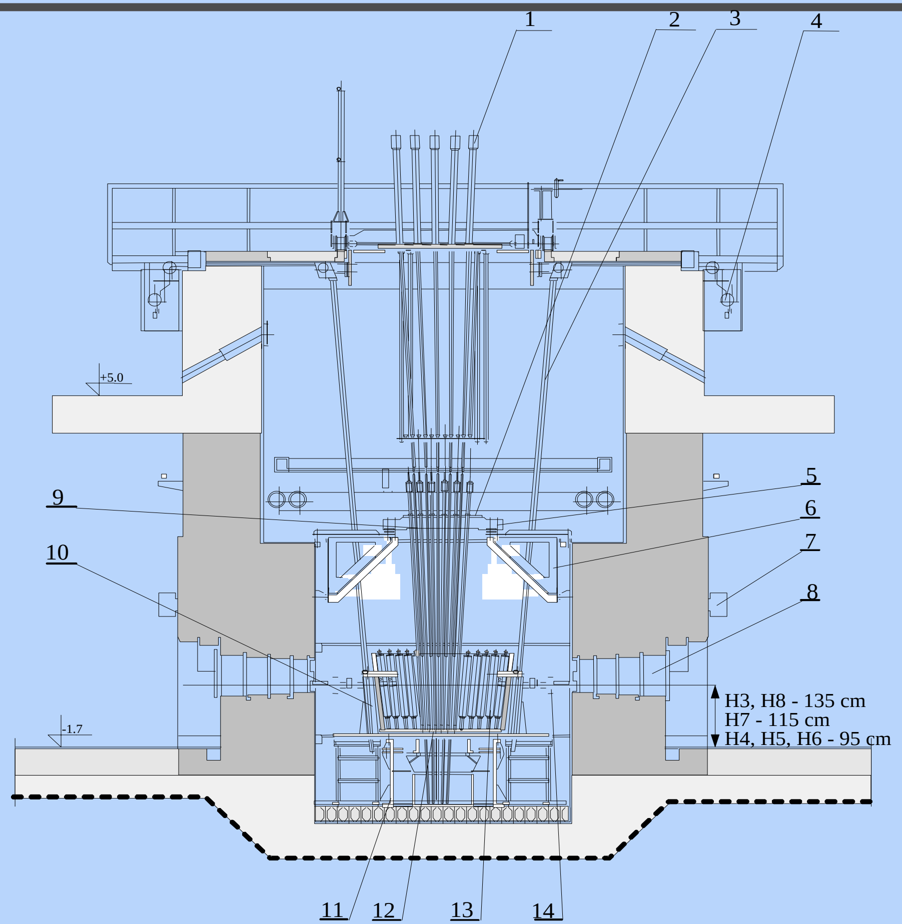
2015 New license for the next 10 years of reactor operation

MARIA RESEARCH REACTOR DESCRIPTION

- The research reactor MARIA is operated at the National Centre for Nuclear Research;
- It is a water and beryllium moderated reactor of a pool type with graphite reflector and pressurised channels;
- The fuel channels are situated in a matrix containing beryllium blocks;

- Main characteristics and data of MARIA reactor are as follows:

• maximum power	30 MW (th)
• thermal neutron flux density	3.0×10^{14} n/cm^2 s
• moderator	H_2O, beryllium
• reflector	graphite in Al
• cooling system	channel type
• fuel assemblies:	
- material	U_3Si_2
- enrichment	19,75%
- cladding	aluminium alloy
- shape	five concentric tubes
- active length	1000 mm
• output thermal neutron flux at horizontal channels	$3 \div 5 \times 10^9$ n/cm^{2}s



1. control rod drive mechanism
2. mounting plate
3. ionization chamber channel
4. ionization chamber drive mechanism
5. fuel and loop channels support plate
6. plate support console
7. horizontal beam tube shutter drive mechanism
8. beam tube shutter
9. fuel channel
10. ionization chambers shield
11. core and support structure
12. core and reflector support plate
13. reflector blocks
14. beam tube compensator joint

Fig 1. Vertical section of the MARIA reactor.

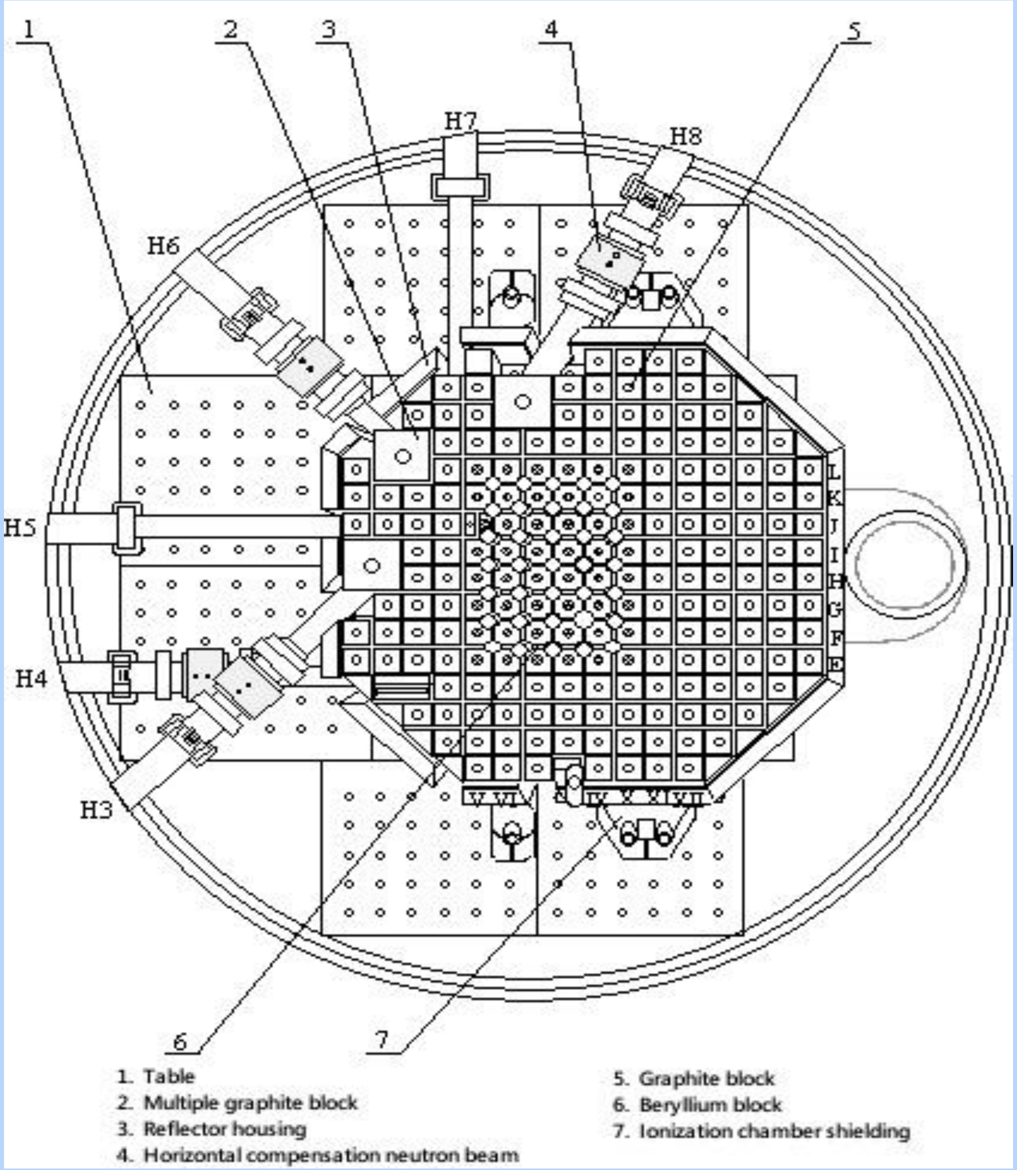


Fig. 2. Top view of the reactor core and reflector.

- The main areas of reactor application are as follows:
  - production of radioisotopes,
  - research in neutron and condensed matter physics,
  - neutron radiography,
  - neutron activation analysis,
  - neutron transmutation doping,
  - testing of fuel and structural materials for nuclear power engineering.

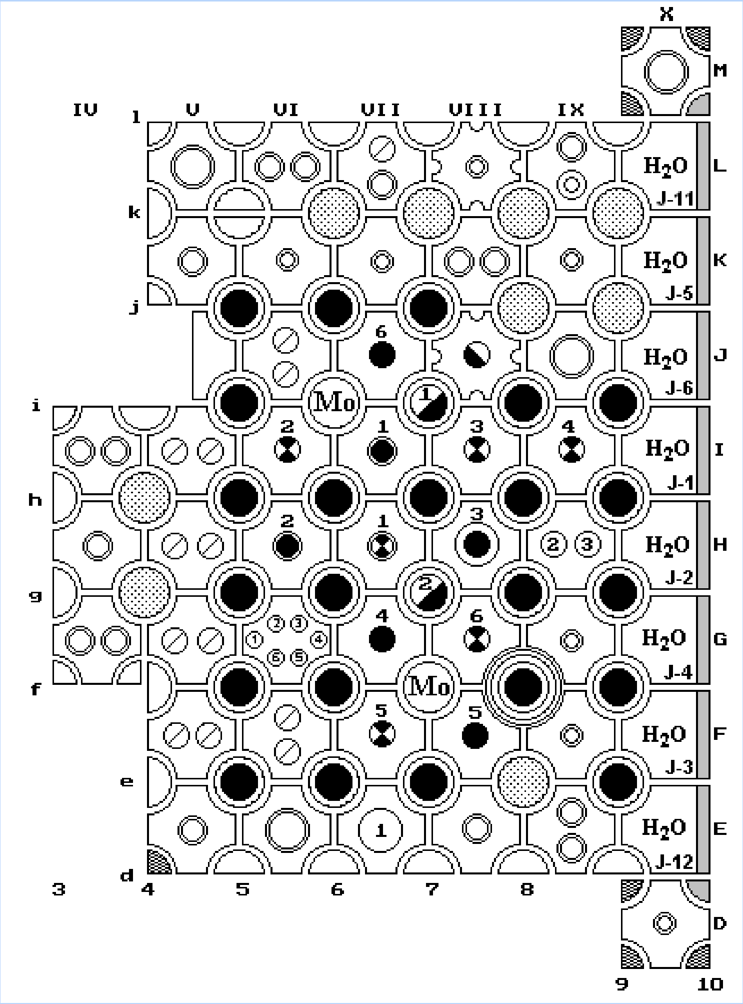


Fig 3. A typical configuration of the MARIA reactor core with molybdenum channels.

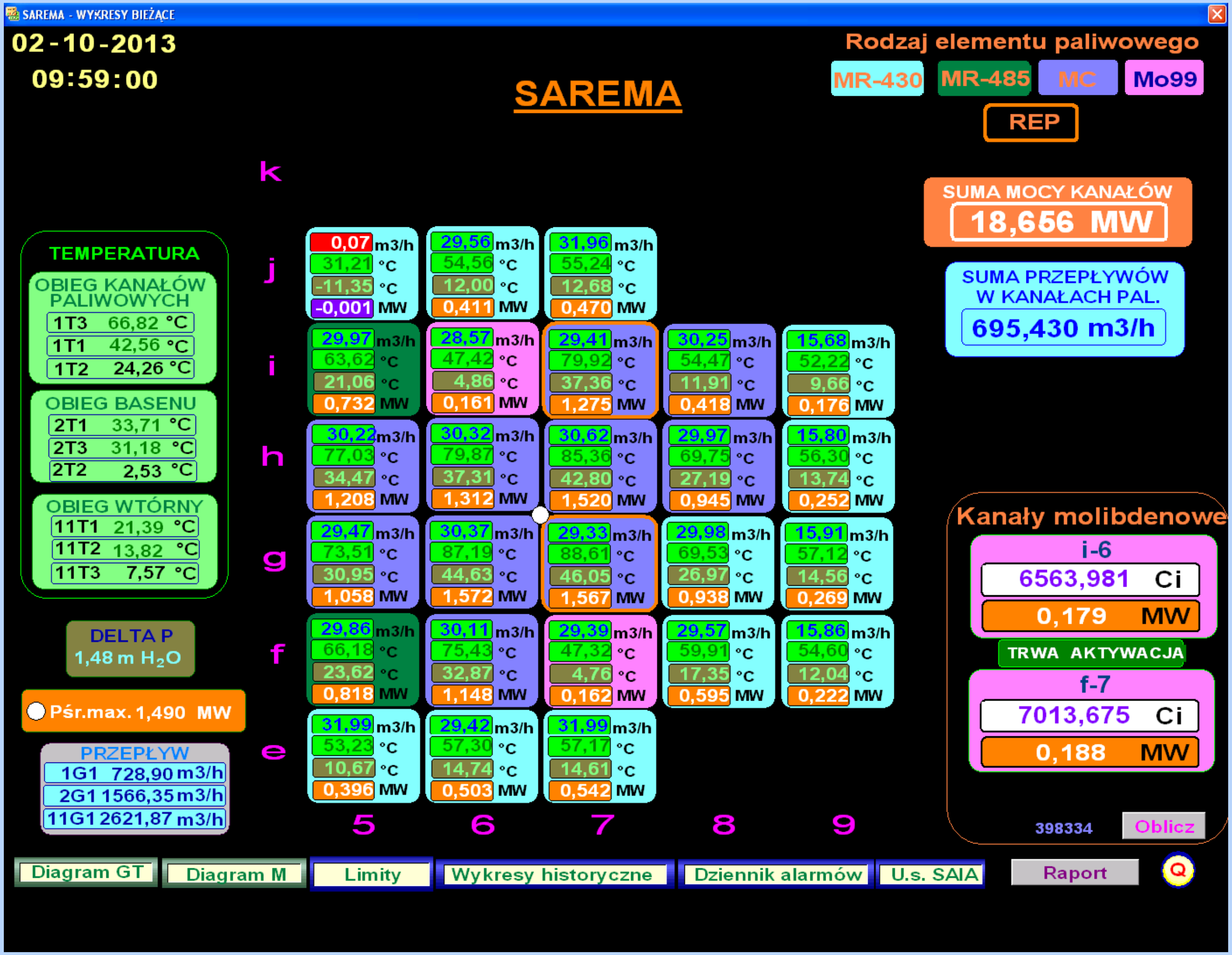


Fig 4. Diagram of MARIA RR core.

NATIONAL CENTRE FOR NUCLEAR RESEARCH

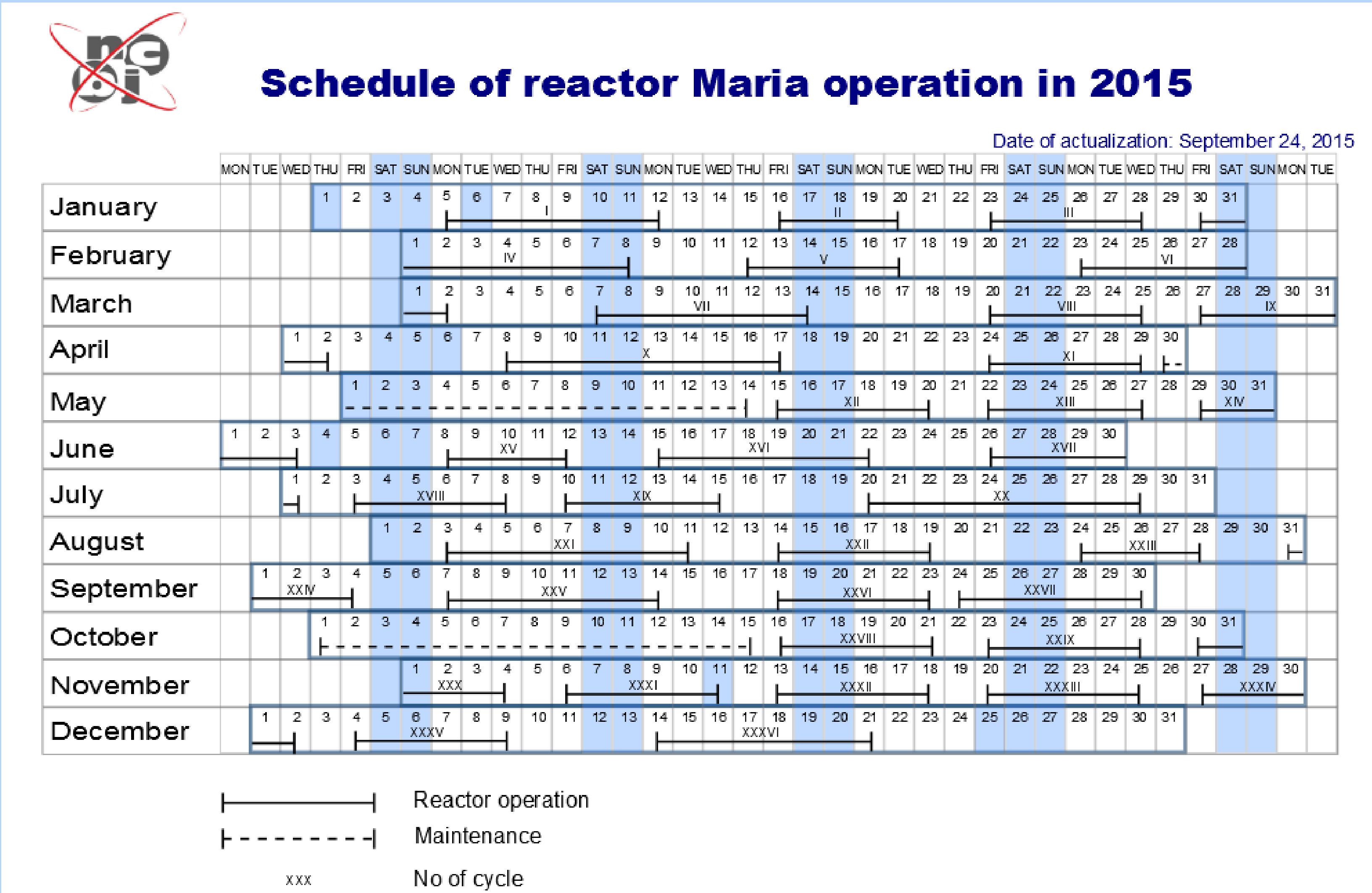


Fig. 5. Schedule of reactor MARIA operation in 2015.

Characteristics of MARIA reactor for installation loops and rigs

- MARIA reactor core contains the fuel assemblies which are installed in pressurized channels embedded in matrix sockets.
- The matrix is composed of beryllium blocks which are fastened to the support slab in reactor pool on the level +2.75m.
- Beryllium blocks of the core matrix as well as the graphite blocks creating the radial reflector are positioned in the sockets of separator slab on the level – 1.4m (6x8) Fig. 1, 5.
- At the support slab for the fuel and loop channels (Fig. 6) there have been made altogether 33 connectors to be used for the fuel channels.

NATIONAL CENTRE FOR NUCLEAR RESEARCH

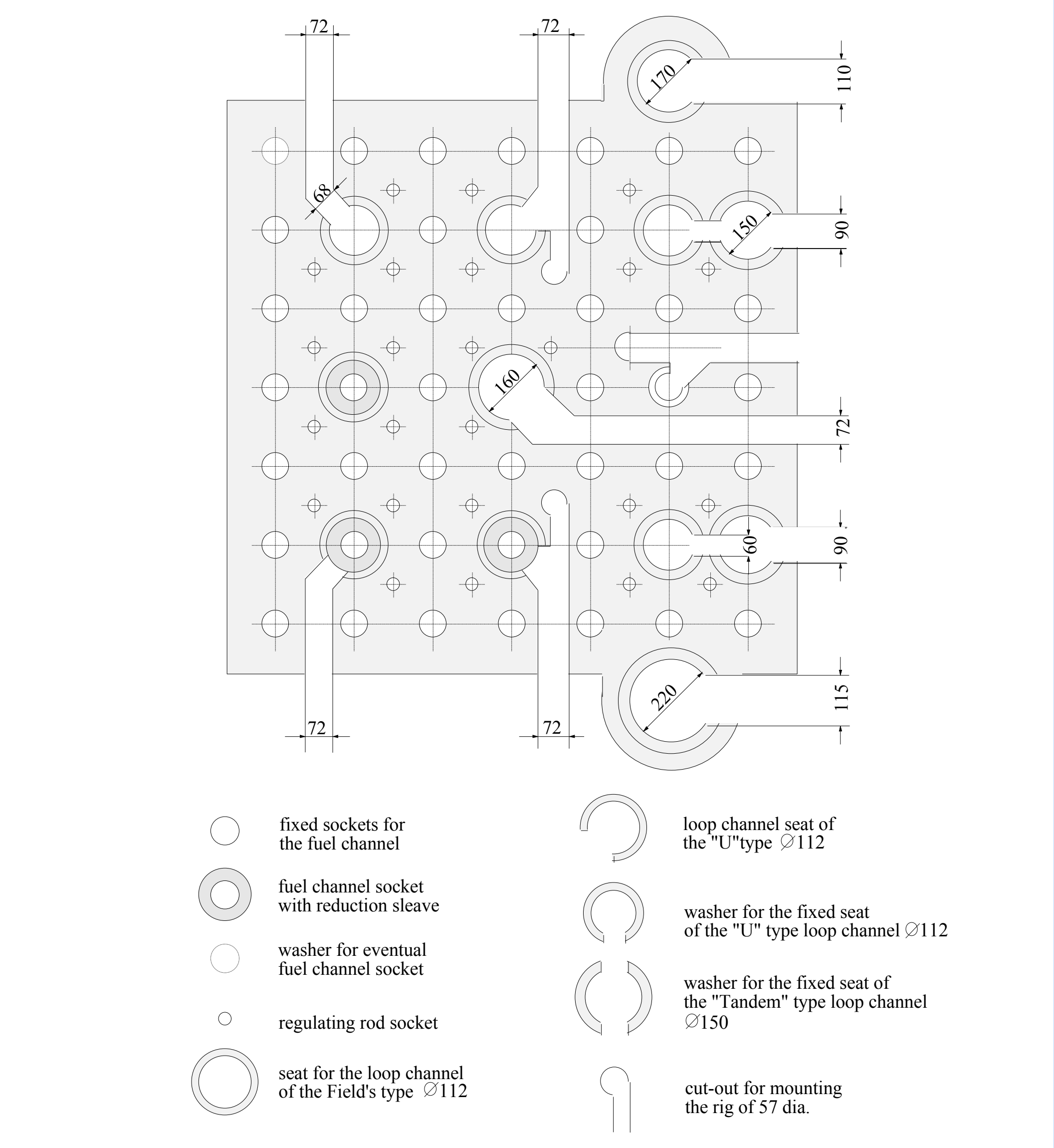


Fig. 6. Layout of the socket in mounting plate over the reactor core.

- The possibility of placing of the experimental channel, depends on the two factors:
  - the position in the core,
  - arrangement and dimensions of holes in the support slab.
- Distribution of openings, i.e. the sockets in the mounting plate is totally determined by its construction.

- On the mounting plate the were located the following sockets:

  - 1 pc. of diameter 112 mm for the tube of Field type ,
  - 4 pcs. of diameter 112 mm for the channels of U type,
  - 1 pc. of diameter 160 mm for the channels of U type,
  - 1 pc. of diameter 900 mm for the channels of U type,
  - 2 pcs. of diameter 112 mm to be compatible with sockets of diameter 150 mm,
  - 1 pc. of diameter 220 mm,
  - 1 pc. of diameter 170 mm.

- The neutron-thermal characteristics for the research channels are as follows:
  - fast neutron flux $\Phi_f = 1.0 \div 1.5 \cdot 10^{14}$ n cm $^{-2}$ s^{-1},
  - thermal neutron flux $\Phi_{th} = 1.0 \div 2 \cdot 10^{14}$ n cm $^{-2}$ s^{-1},
  - heat generation $q_{Fe} = 3 \div 4$ W $\cdot$ g^{-1} .
- Distributions of gamma generation in steel are shown in Fig. 7 and 8.

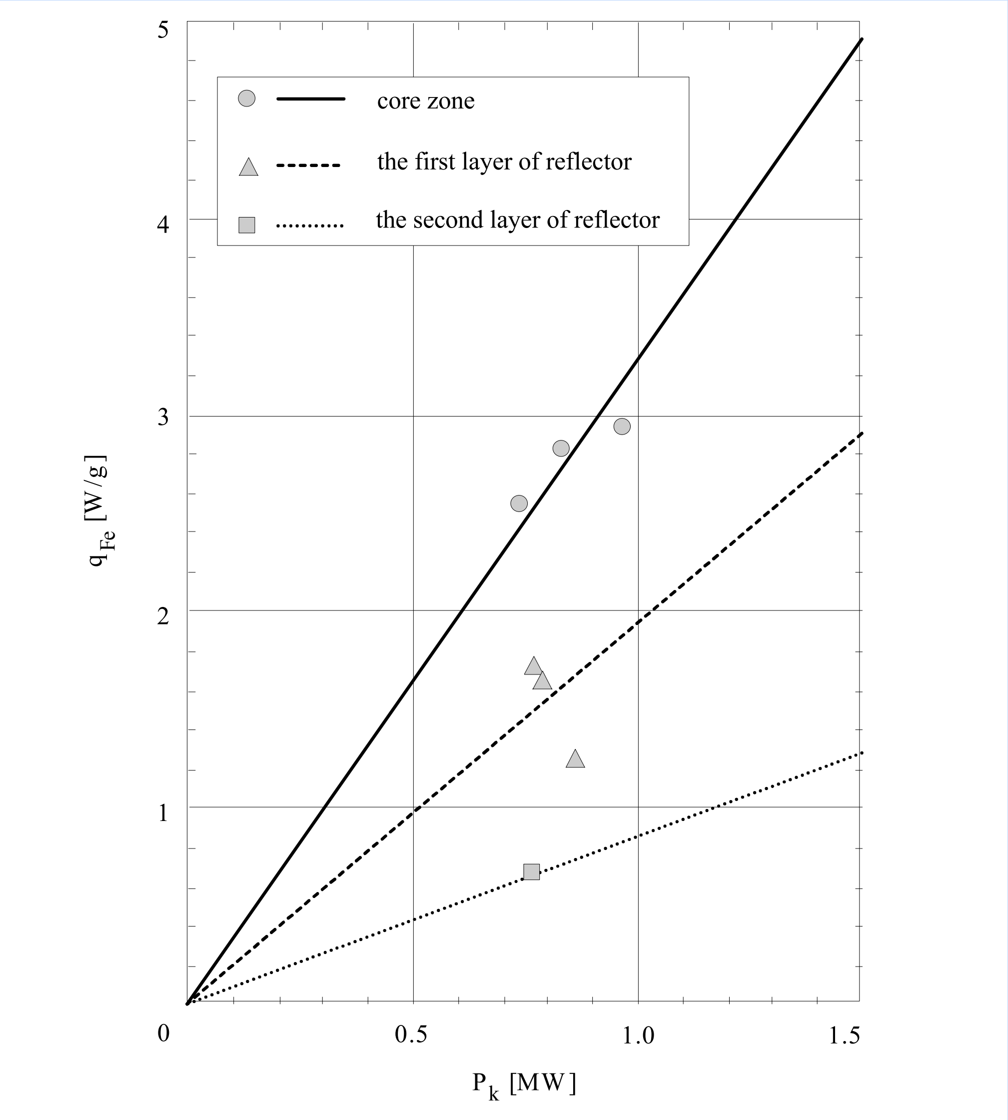


Fig. 7. Correlation between the heat generation in steel and the average power to be generated in the adjoined channels.

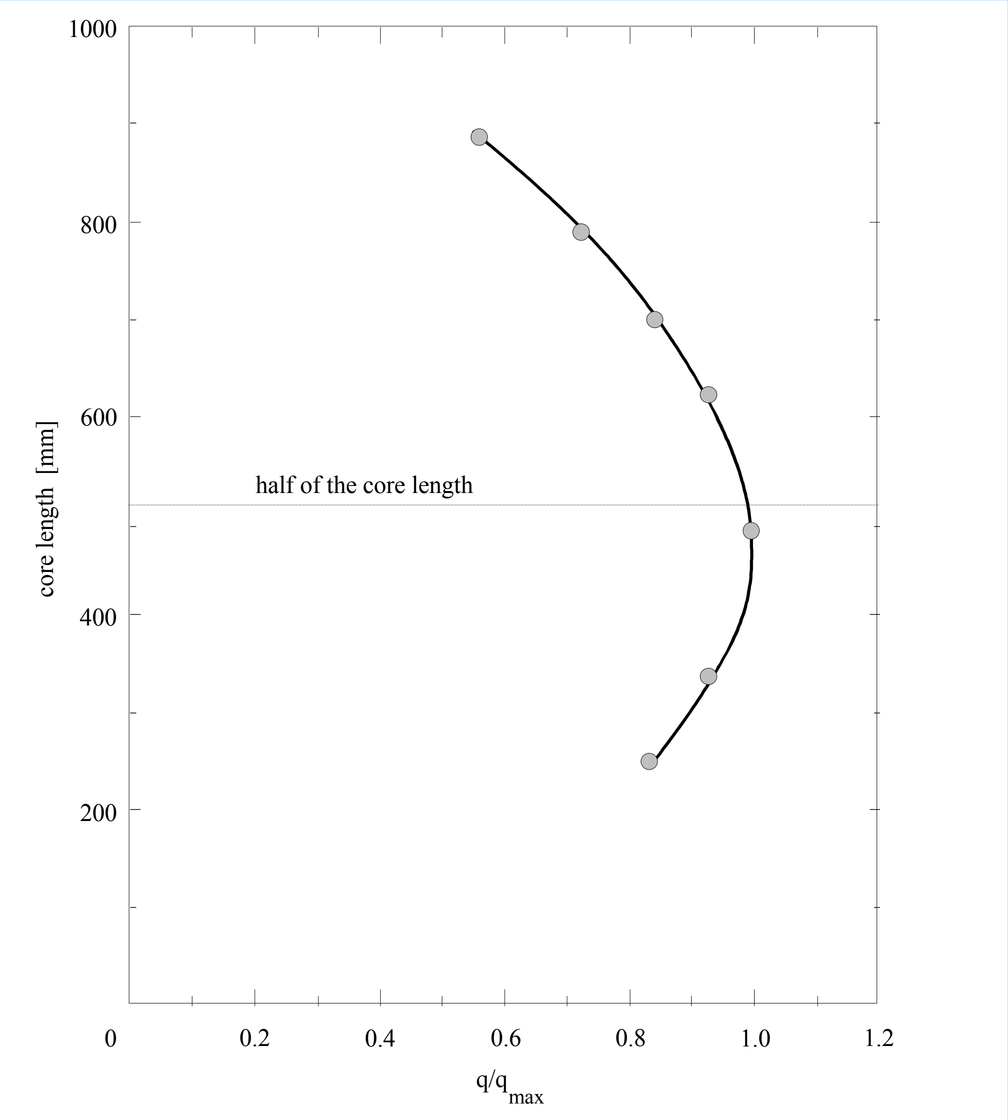


Fig. 8. Relative distribution of gamma heat generation in steel along the vertical axis of the channel for irradiation.

- Between the experimental hall and reactor hall there are two hatchways in the region of loop installations of overall dimensions: 388 x 968 cm and 388 x 628 cm.
- These hatchways are to be used at construction of the loop installations and their shielding by using the main overhead crane of lifting capacity 16t.
- For the expansion of the loop installations it have been provided the culverts in the building wall enabling to pulling out the ancillary devices to the pavilion adjoining to the reactor building.

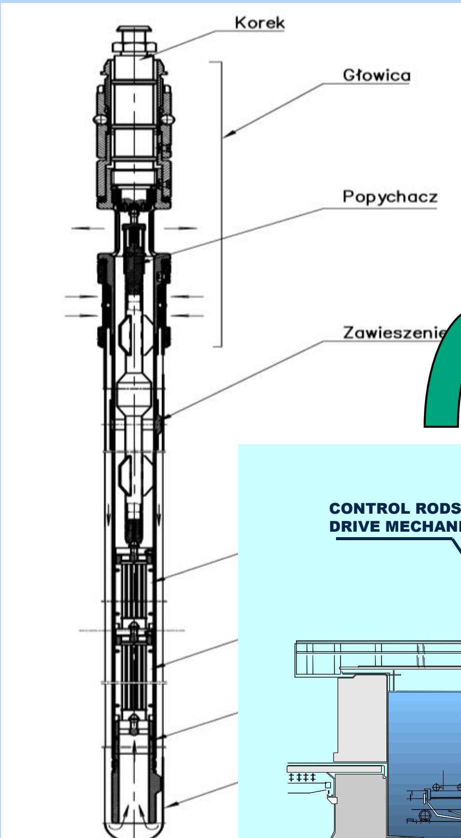
- The pipelines and instrument leads of experimental installation, by means of following routes:

  - Installation channels running in side the shielding walls of the storage pool and sloping down on the level – 1.7m;
  - Culverts in the shielding hall of the reactor pool on the level +5m (for the instrument leads).

- The heavy and requiring effective shielding the equipment and installation of the loop circuits are set up in the experimental hall.

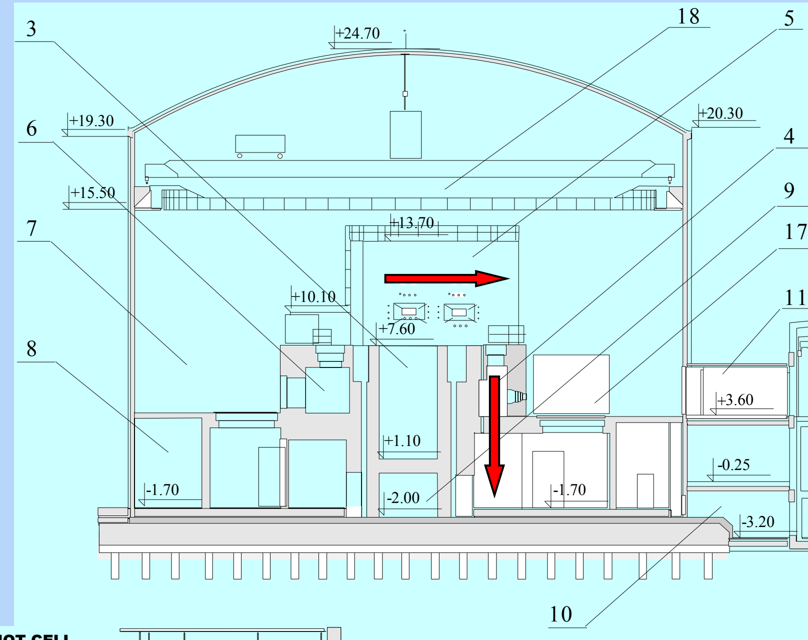
- Admissible load of floors in that place is 6 t/m^2.

Handling of irradiated materials in Maria reactor

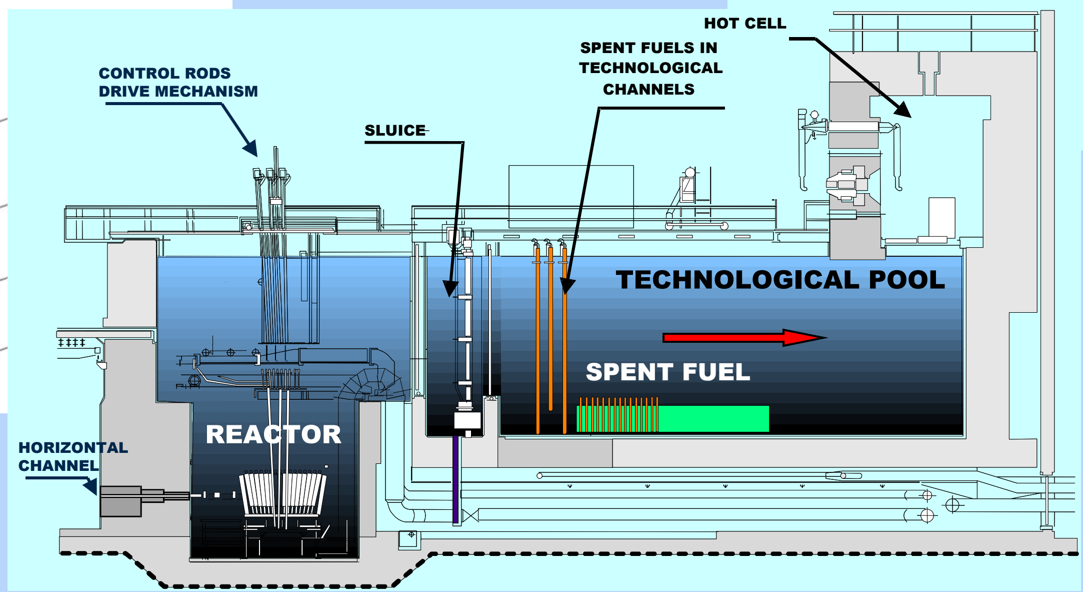


Irradiation Rig

Irradiation rigs & transport irradiated targets to Hot Cell



Reloading operation in Hot Cell

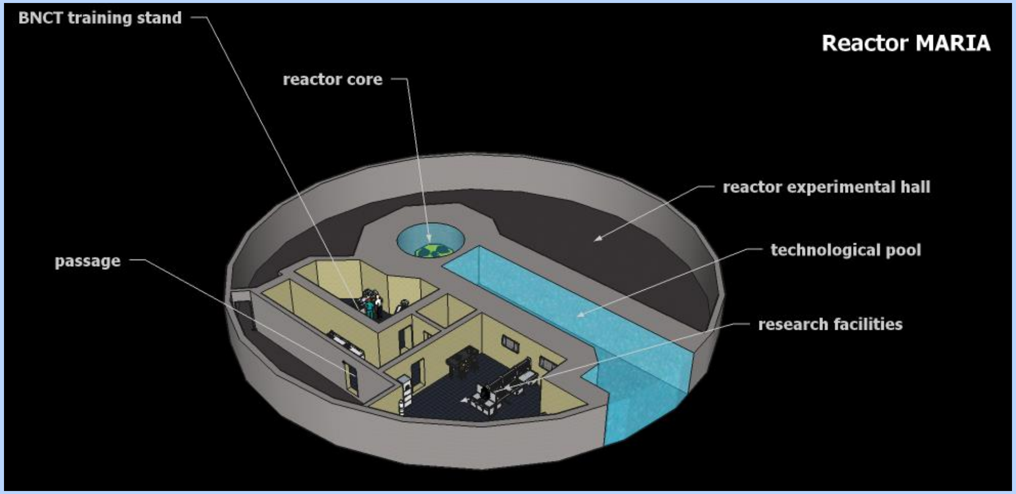


Transport Container

- Special irradiation in 14 MeV neutrons converter
  - conversion from thermal to 14 MeV
  - 14 MeV neutron flux density up to $5 \cdot 10^{10}$ cm^{-2} s^{-1}, 60 cm^3 (containers Ø 15x90 mm)
  - energy spectrum depending on location in reactor

Future of MARIA

- BNCT research/ training station (neutrons H2)
  - radiobiology,
  - boron carriers,
  - dosimetry,
  - Pg-SPECT,
  - biological material irradiation,



  - oncologists, radiologists, medical physicists and medical staff training,
  - treatment planning systems,
  - preclinical studies,
  - phantom for BNCT development and tests,
  - technical equipment for BNCT.

CONCLUSIONS

- MARIA reactor will be operated at least to 2030:
  - basic technological system of the reactor upgraded (pumps, heat exchangers, dosimetry I&C system);
  - movable components of reactor's core and reflector will allow to prolong operating lifetime of reactor;
  - lining of the reactor pools made from stainless steel;
  - export of spent nuclear fuel to Russian Federation (enough place in storage pool for the next 20 years of reactor operation).