International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR-2022) in Vienna, Austria at the International Atomic Energy Agency on October 2-5, 2022

Six-Year Experience of the WWR-K Reactor Operation with LEU Fuel

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Historical overview (1)

WWR-K reactor conversion project

2003-2009	2010	2010-2011	2011-2013	2014-2016
Feasibility study	Development of LEU FA design	Manufacturing of LEU FA	Life test of LEU FA	Reactor systems modifications
Neutronic calculations, conceptual design of LEU core and fuel assembly, conversion planning	*Detail technical design*	*Three LEU LTA were manufactured at NCCP*	*In-reactor test of three LEU LTA*	*Upgrade of main reactor safety-related systems*

Historical overview (2)

WWR-K reactor conversion project

03-04.2016

Physical startup

Physical startup with LEU core

05-06.2016

Power startup

Power startup with LEU core

09.2016

Starting operation

Obtained a license from the regulator. Reactor with LEU fuel and water reflector started to operate

11.2016

Beryllium Reflector Formation

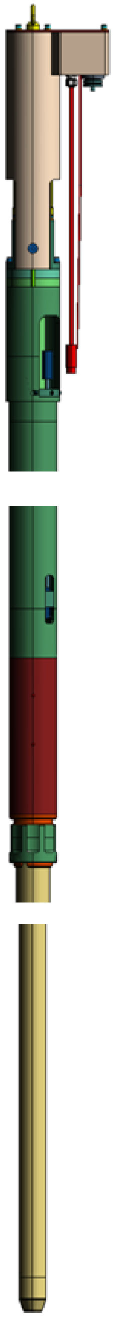
Loaded the first portion of beryllium blocks

11.2017

Beryllium Reflector Formation

Full annular beryllium reflector formed

UPGRADES OF REACTOR SYSTEMS



- ❑ I&C system
  - ➢ Replacement of electronics
  - ➢ Replacement of control rod drive mechanisms
- ❑ Emergency cooling system
  - ➢ Replacement of pumps, some tubes and valves
  - ➢ Installation of uninterrupted power supply
- ❑ Emergency core sprinkling system
  - ➢ Replacement of sprinkler and pumps
- ❑ Primary cooling system
  - ➢ Replacement of gaskets
  - ➢ Inspection of vessel and piping
- ❑ Secondary cooling system
  - ➢ Installation of additional new cooling towers
- ❑ Radiation monitoring system
  - ➢ Complete replacement
- ❑ Gas and aerosol emissions monitoring system
  - ➢ Complete replacement

I&C SYSTEM
ELECTRONICS

Replacement of I&C cabinets

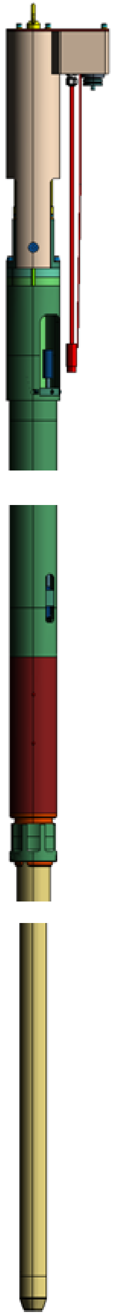
I&C SYSTEM ELECTRONICS

Replacement of control panel

I&C SYSTEM
CONTROL ROD DRIVE MECHANISMS

CRD Mechanism includes drive, control rod and housing channel

- ❑ Designed and manufactured by ŠKODA JS a.s. (Plzeň)
- ❑ Delivered to Almaty in September, 2015



I&C SYSTEM
CONTROL ROD DRIVE MECHANISMS

Dismantling of the reactor plug

Dismantling of old cabling in the reactor hall

EMERGENCY COOLING AND CORE SPRINKLING SYSTEM

- **Replacement of pumps, valves and some piping**
- **Modification of one of two core sprinkling devices**
- **Installation of additional uninterrupted power supply**

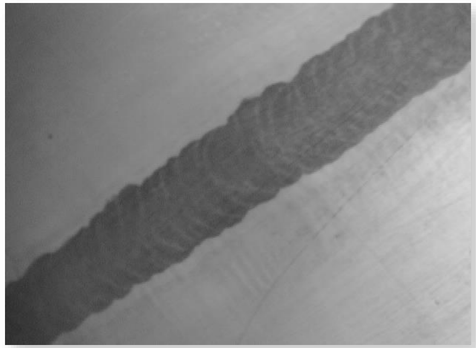
2 pumps, 45 m^3/h each
instead of 10 m^3/h for HEU core

Batteries
30 KW, 6 hours

PRIMARY AND SECONDARY COOLING SYSTEMS

- **Inspection of tubing and reactor tank**
- **Replacement of all gaskets**
- **Replacement of some valves**
- **Installation of new water cooling towers**

Reactor tank wall and weld

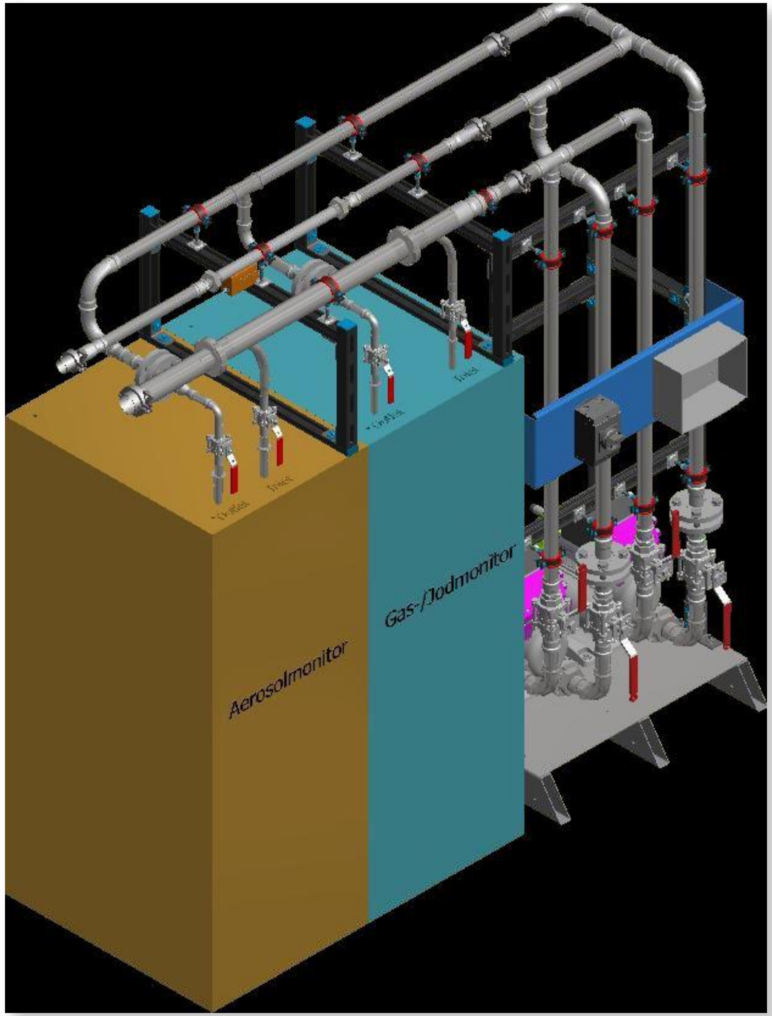


4 new water towers
replace 8 old ones

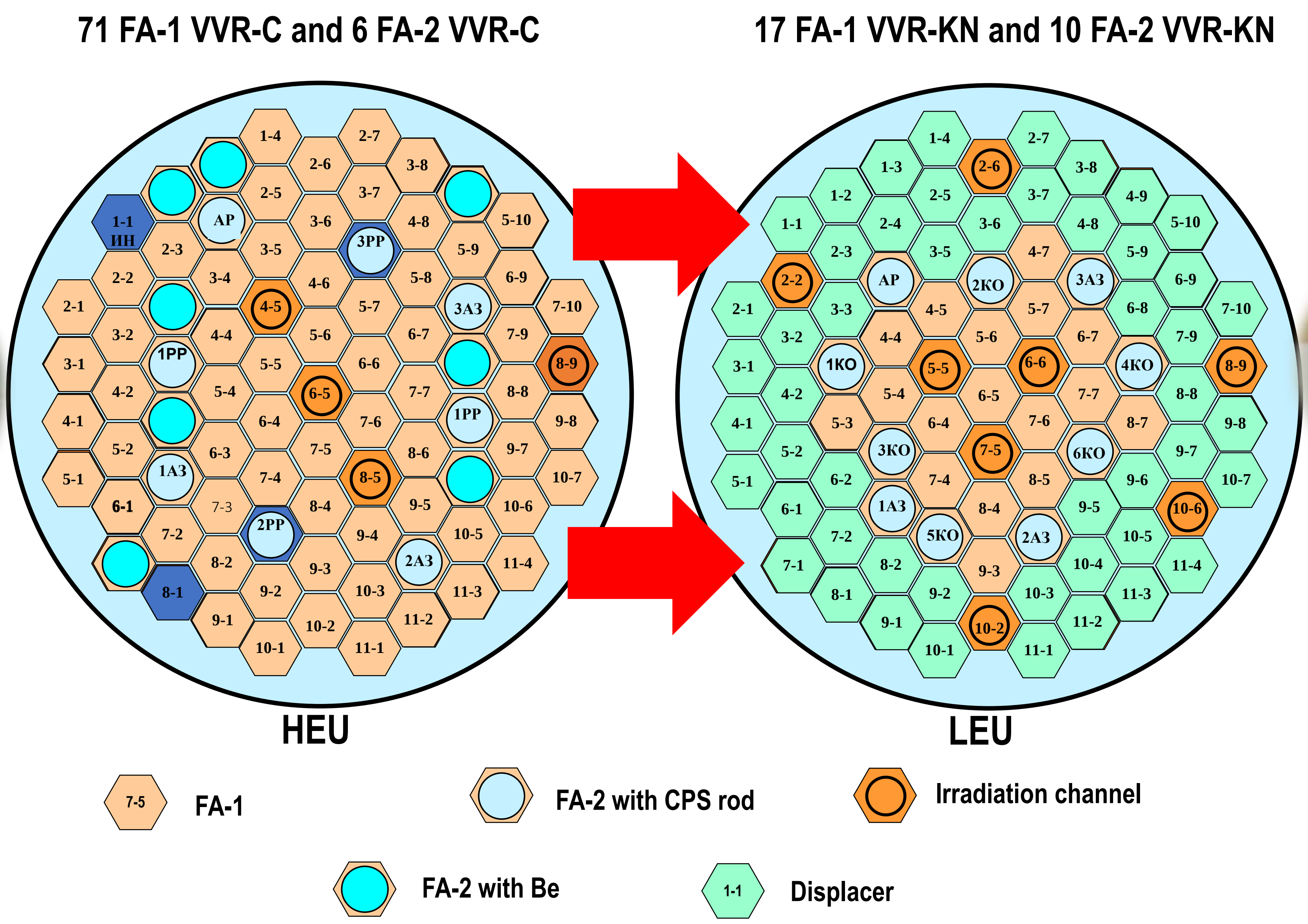
RADIATION, GAS AND AEROSOL EMISSIONS MONITORING SYSTEMS

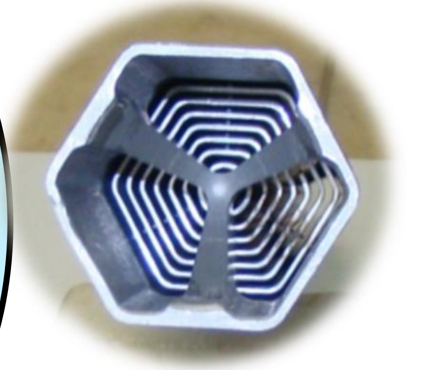
The new systems providing:

- Continuous monitoring of gamma dose rate in the reactor building
- Continuous monitoring of alpha, beta and gamma activity of aerosols, inert gases and iodine-131 in ventilation systems and reactor chimney
- Continuous monitoring of gamma dose rate in cooling water (both primary and secondary circuits)
  - totally >50 detection devices
- Periodical measurement of alpha, beta and gamma activity in water
- Alarm signals
- Data collection and archiving

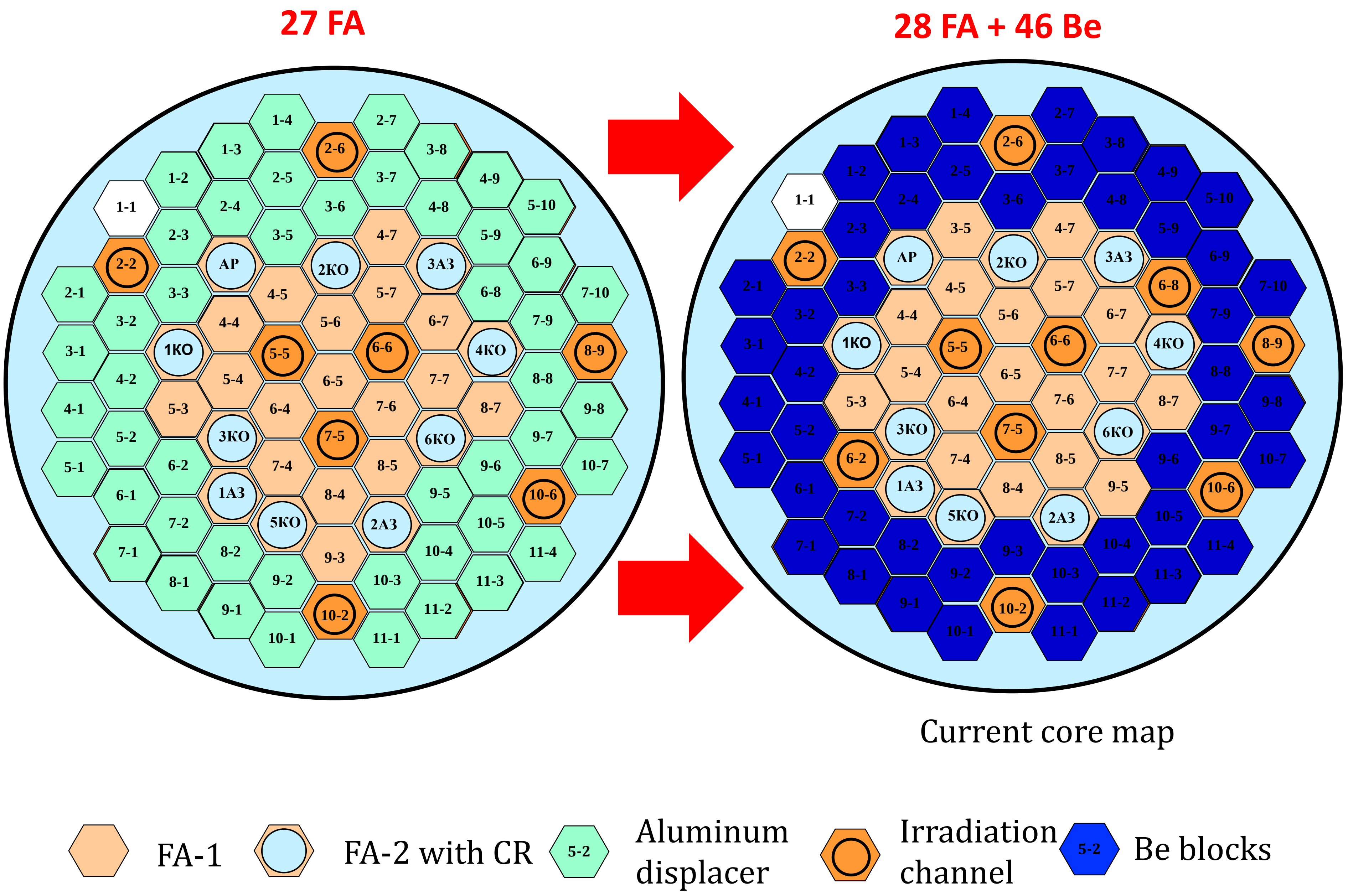


LEU CORE

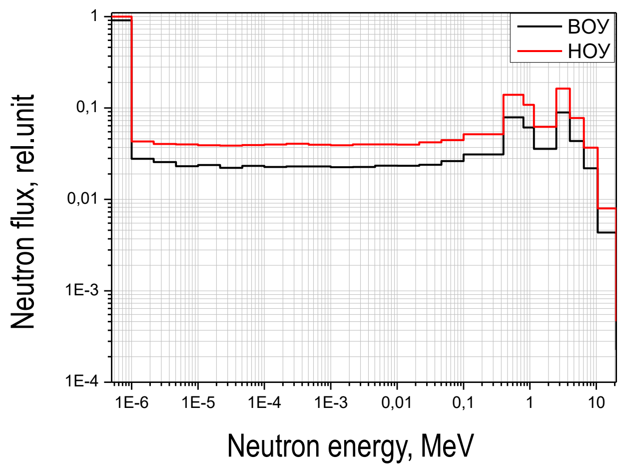

71 FA-1 VVR-C and 6 FA-2 VVR-C
17 FA-1 VVR-KN and 10 FA-2 VVR-KN
HEU
LEU
FA-1
FA-2 with CPS rod
Irradiation channel
FA-2 with Be
Displacer



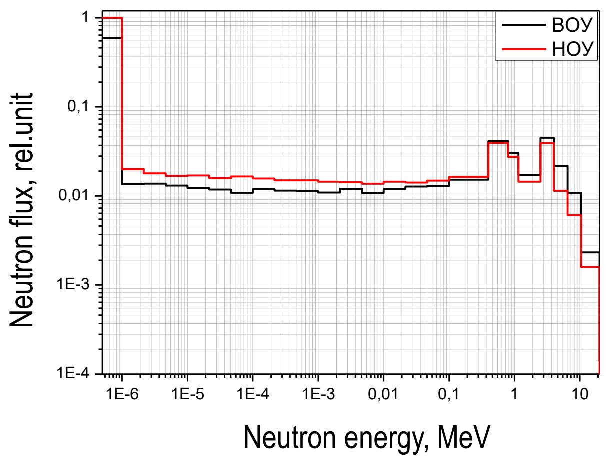
Formation of the beryllium reflector



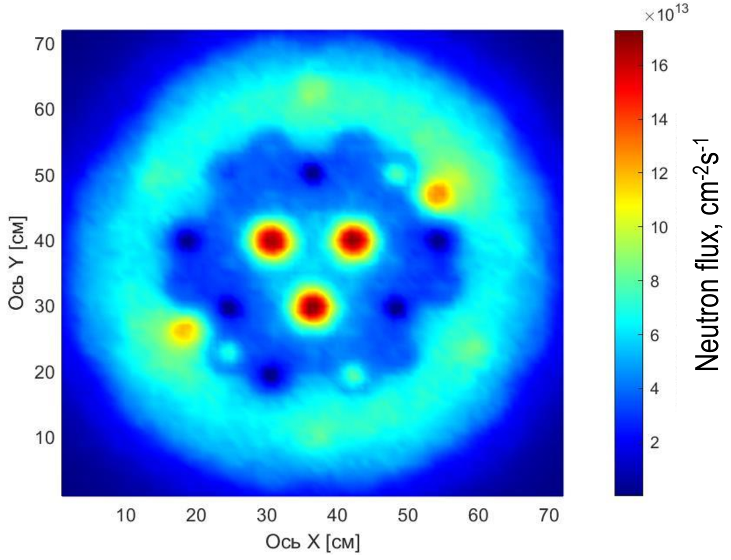
Neutron energy spectrum
HEU versus LEU



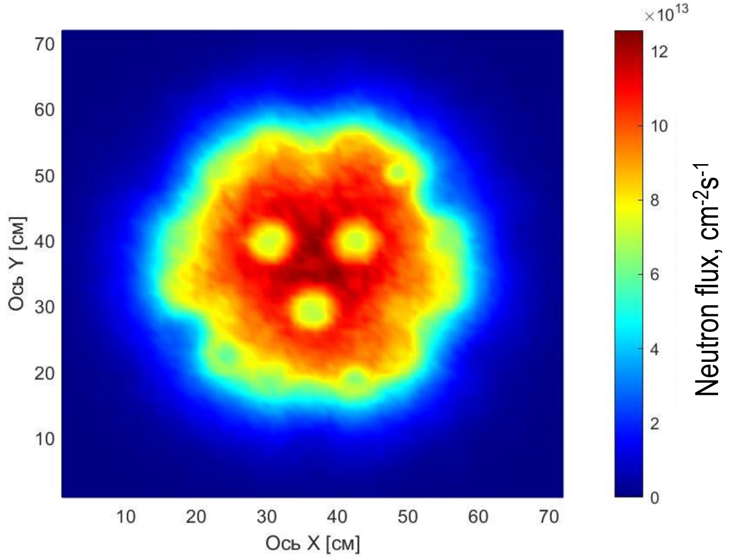
Core center



Core periphery



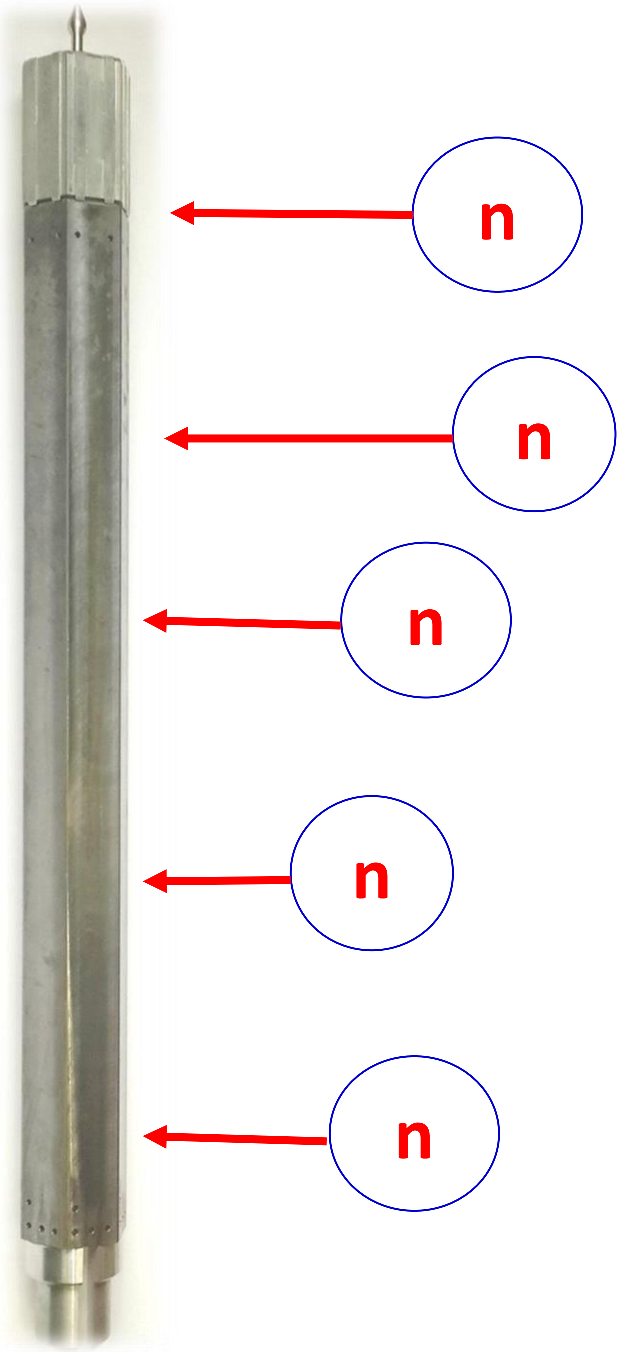
Thermal neutron



Fast neutron

Core position	HEU	LEU	LEU/HEU
Center (E_n<0.625 eV / E_n>0.1 MeV)	$1.4\ 10^{14}$ / $5.9\ 10^{13}$	$1.9\ 10^{14}$ / $8.0\ 10^{13}$	0.56/0.44
Periphery (E_n<0.625 eV / E_n>0.1 MeV)	$5.6\ 10^{13}$ / $1.8\ 10^{13}$	$8.9\ 10^{13}$ / $1.5\ 10^{13}$	0.62/0.72

Poisoning of beryllium reflector (1)



$${}^{9}_{4}Be\ (n,\alpha)\ {}^{6}_{2}He$$

$${}^{6}_{2}He \xrightarrow{\beta-} {}^{6}_{3}Li, \qquad T_{1/2}=0{,}8\ \text{sec}$$

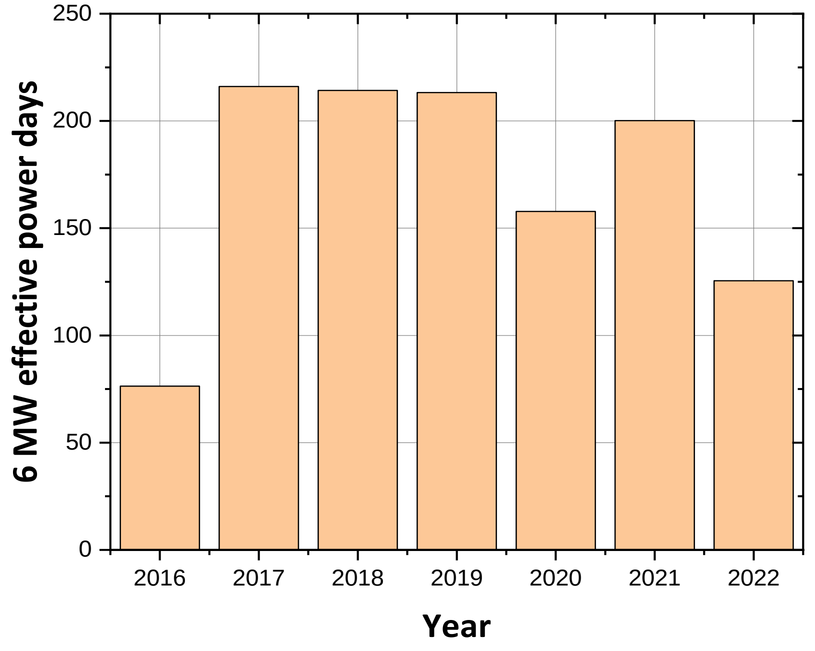
$${}^{6}_{3}Li\ (n,\alpha)\ {}^{3}_{1}H$$

$${}^{3}_{1}He \xrightarrow{\beta-} {}^{3}_{2}He, \qquad T_{1/2}=12{,}33\ \text{y}$$

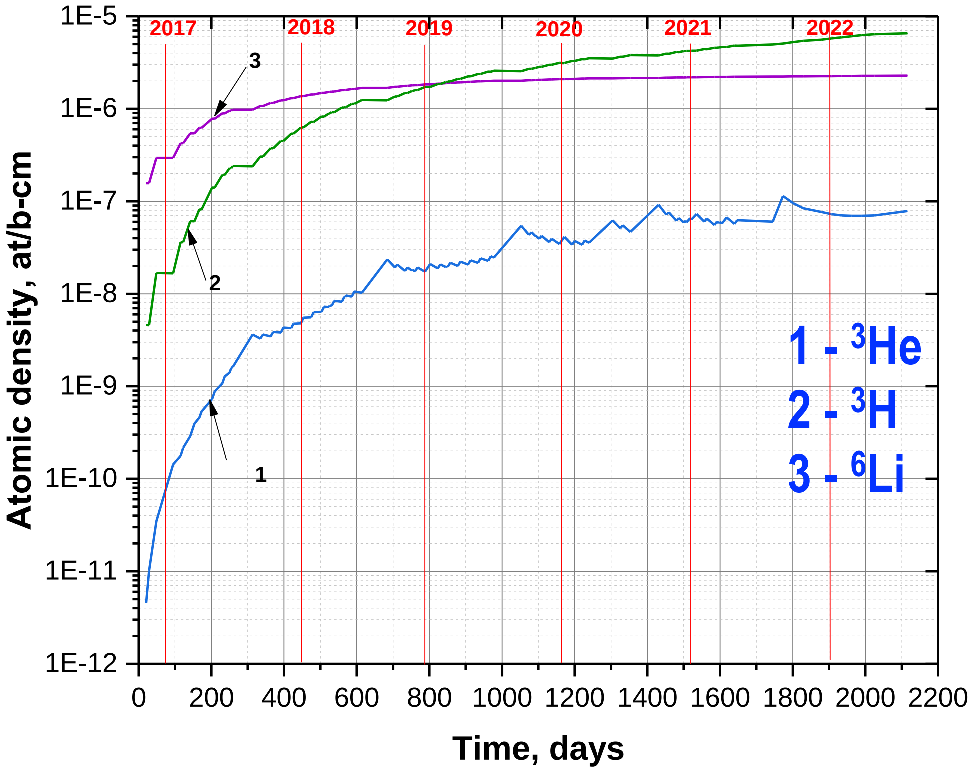
$${}^{3}_{2}He\ (n,p)\ {}^{3}_{1}H.$$

Poisoning of beryllium reflector (2)

$$\frac{dN_{Be}}{dt} = -N_{Be}\{RR\}_{Be}$$
$$\frac{dN_{Li}}{dt} = N_{Be}\{RR\}_{Be} - N_{Li}\{RR\}_{Li}$$
$$\frac{dN_T}{dt} = N_{Li}\{RR\}_{Li} - \lambda_T N_T + N_{He}\{RR\}_{He}$$
$$\frac{dN_T}{dt} = N_{Li}\{RR\}_{Li} - \lambda_T N_T + N_{He}\{RR\}_{He}$$
$$\frac{dN_{He}}{dt} = \lambda_T N_T - N_{He}\{RR\}_{He}$$

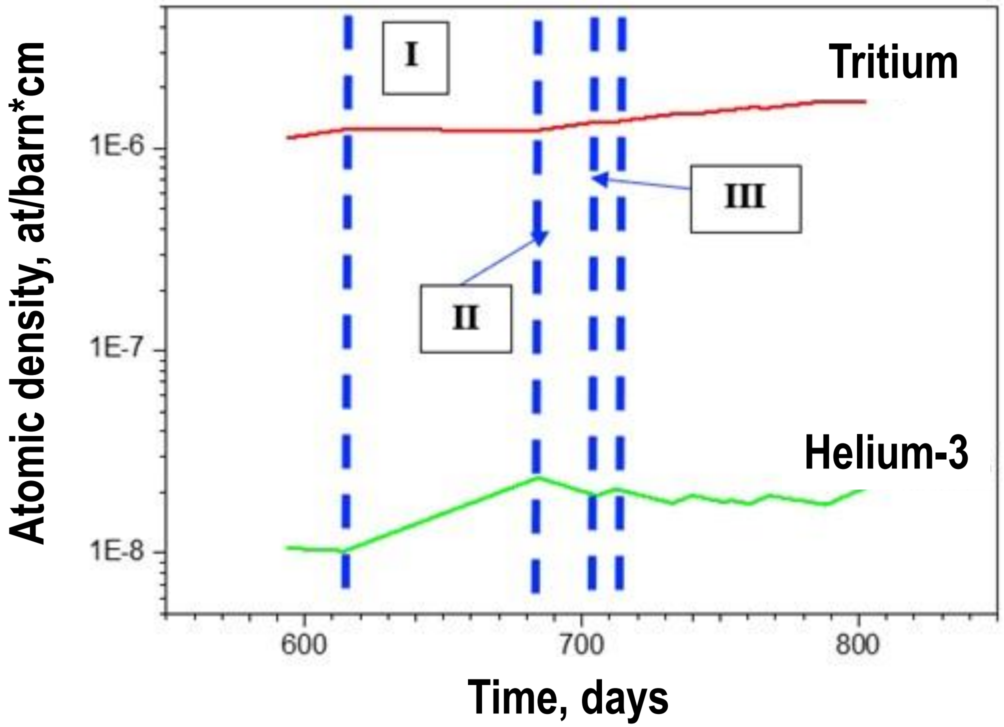


$\Delta\rho = \rho_{clean} - \rho_{poisoned} = -0.5\ \%\ \Delta k/k$



Li-6: $2.3 \cdot 10^{-6}$ at/barn*cm
H-3: $6.6 \cdot 10^{-6}$ at/barn*cm
He-3: $7.8 \cdot 10^{-8}$ at/barn*cm

Poisoning of beryllium reflector (3)



Dynamics of accumulation of H-3 and He-3 isotopes

Area I – the period of scheduled preventive maintenance of the reactor equipment

Area II – one of the regular operation cycles of the reactor at 6 MW

Area III – the reactor cooling time after the operation cycle.

New facilities at WWR-K reactor

Neutron activation analysis

Upgraded

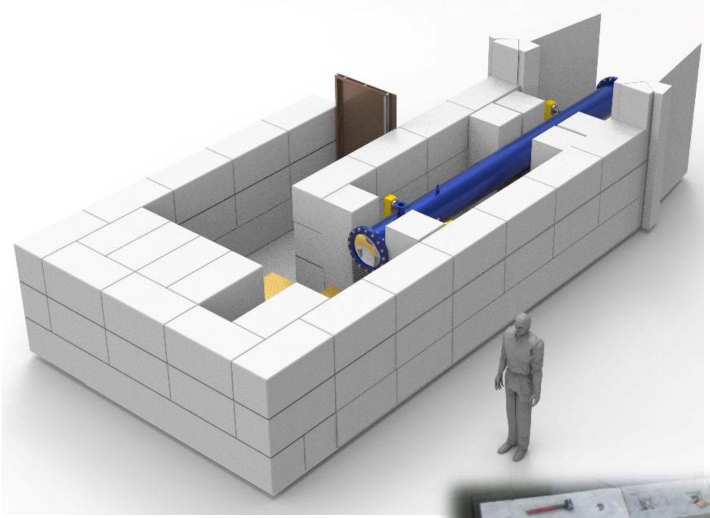
Neutron activation analysis (NAA) section at the WWR-K reactor using modern automation systems and software:

- ❑ Short-lived isotope study
- ❑ Study on medium- and long-lived isotopes

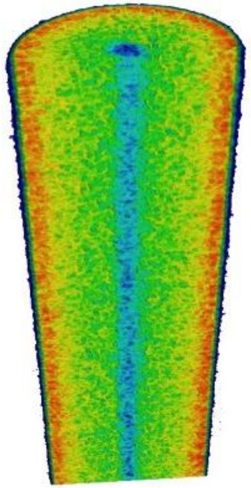
At the WWR-K reactor, in a dry neutron beam with flux of 10^{11} n cm^{-2} s^{-1}, an automated pneumatic transport system is installed and operates. The system allows transporting samples (in special transport capsules) to the irradiation area and back, as well as from the irradiation area directly to the measuring equipment - a horizontal semiconductor gamma spectrometer made of high-purity germanium.

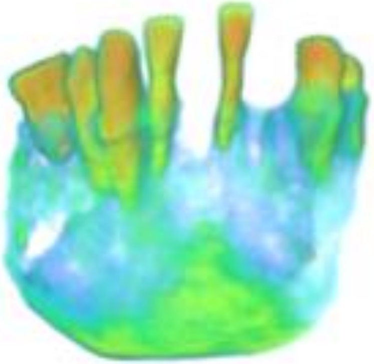
Neutron imaging facility

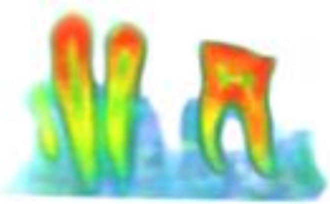
The facility is designed to study the internal structure of objects by non-destructive methods.

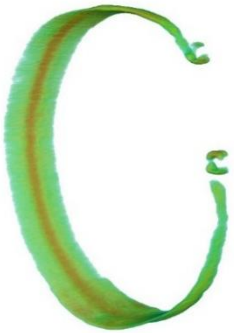


Neutron spectrum	Thermal
Distance from moderator to diaphragm	3.5
Distance from diaphragm to sample	7 m
Beam diameter	20-100 mm
L / D	350
Field of view	20*20 cm^2
Scintillator	$^6LiF/ZnS$: Ag
CCD camera	HAMAMATSU-S12101 2048*2048 pixels
Neutron flux at sample	$1*10^7$ n/cm^2/s
Neutron filter	Sapphire (thickness - 106 mm)
Exposition time	20 s

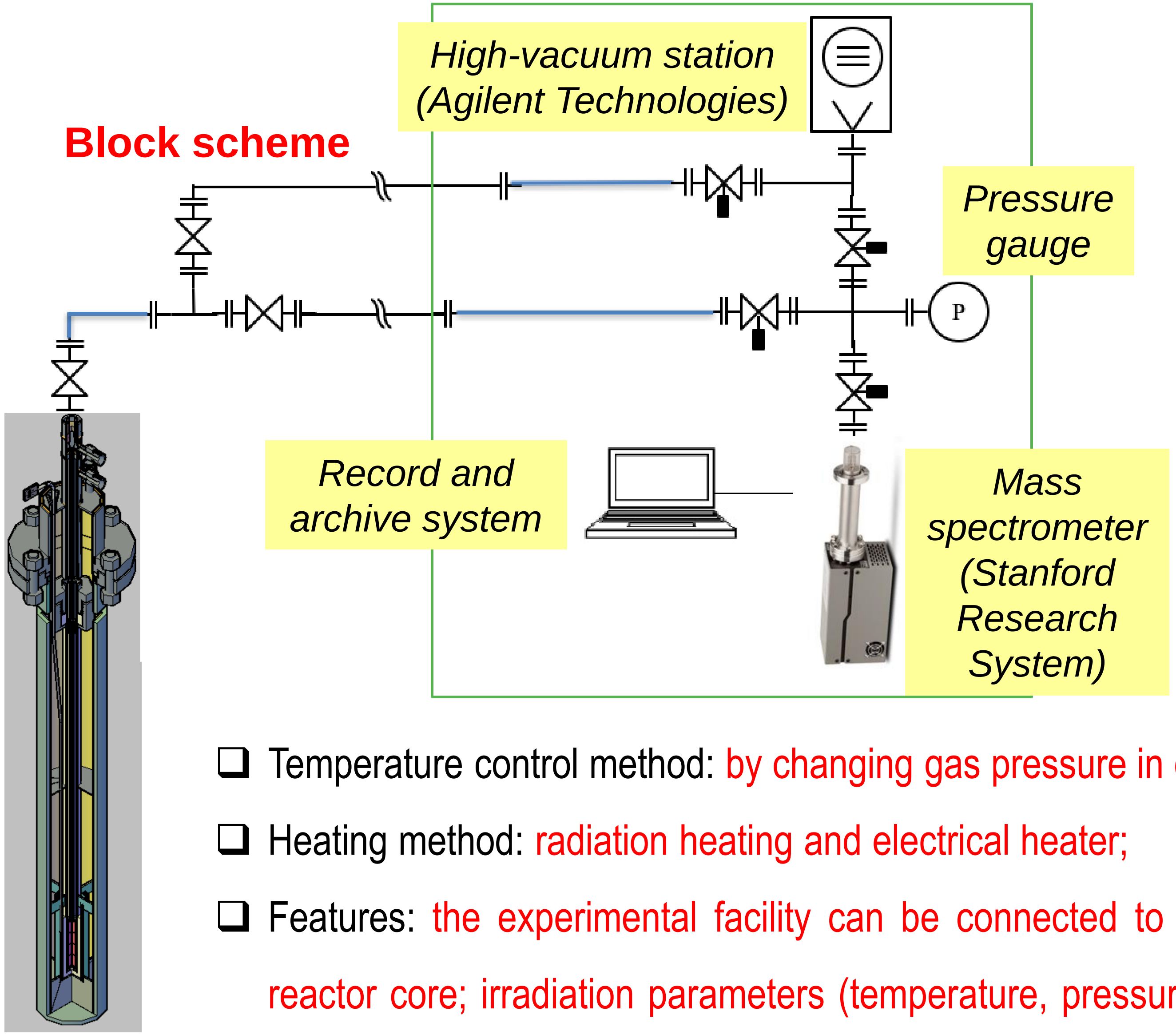








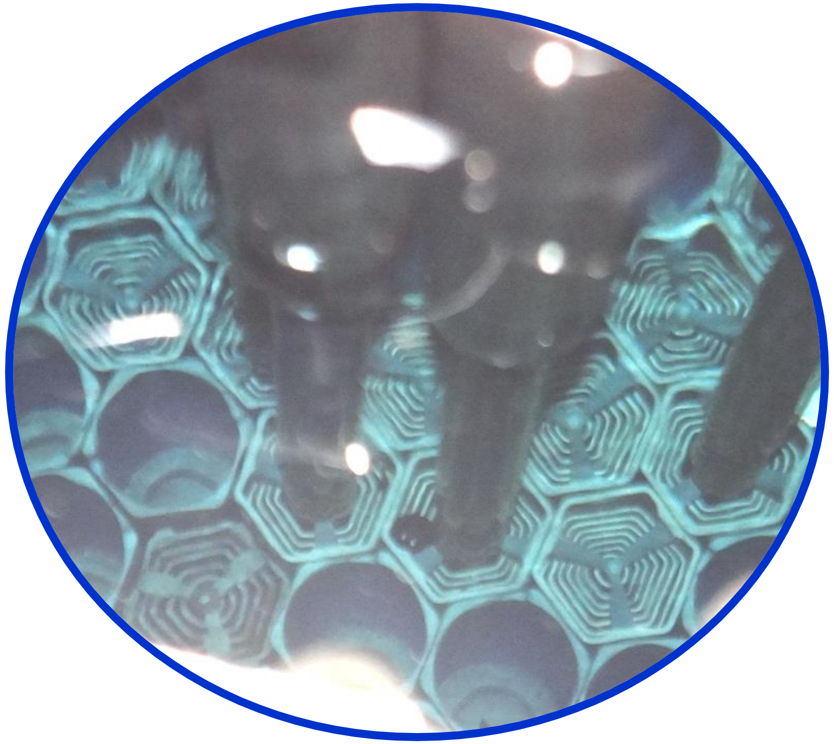
Complex for in-reactor gas release analysis (CIRRA)



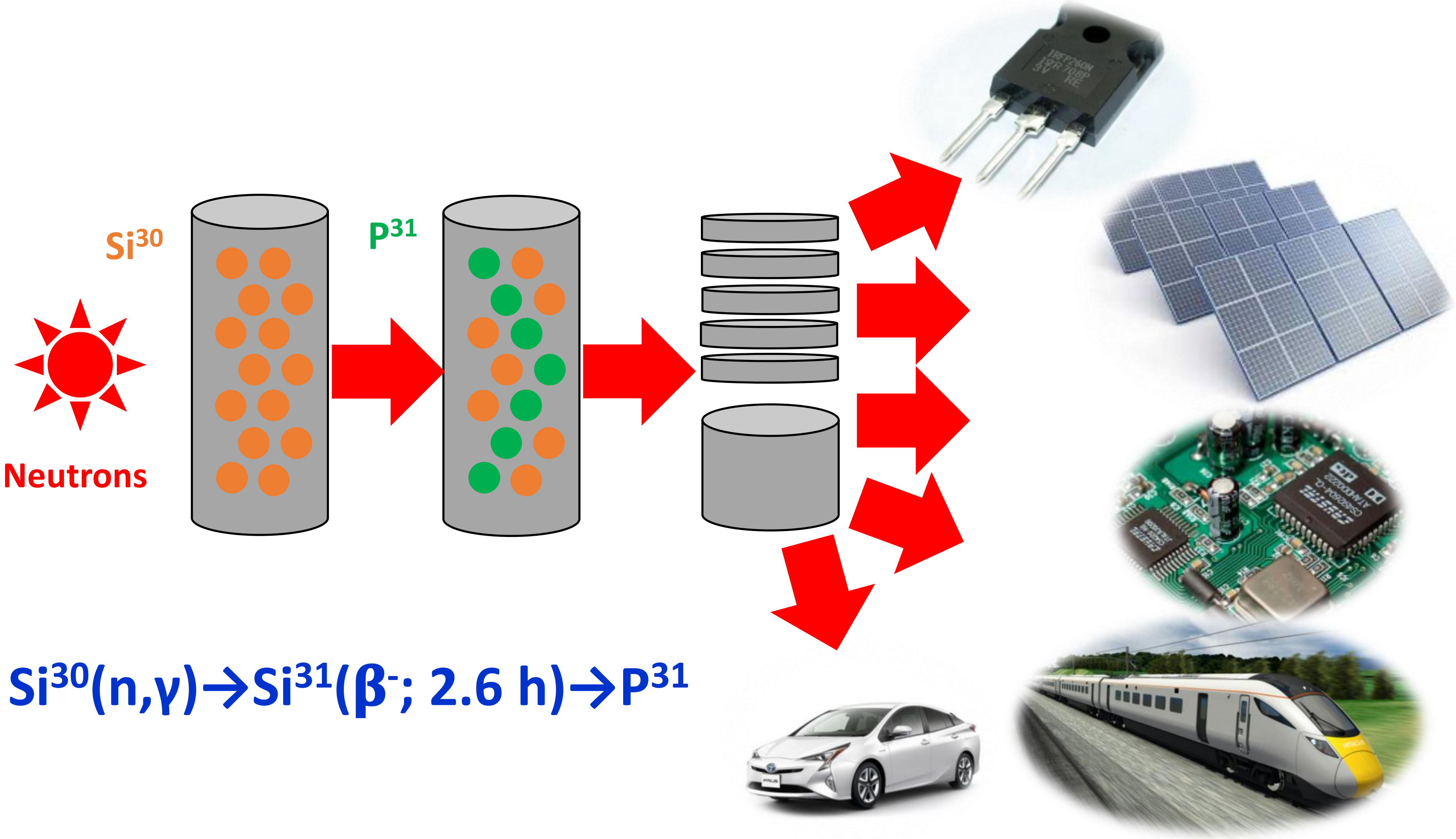
- Irradiation temperature: 50-1500 ºC;
- Measurement of elements mass: up to 100 a.e.m.;
- Measurement method: determination of a separating fluid at the condition of vacuum extraction under uninterrupted exhaustion;

- Temperature control method: by changing gas pressure in capsule gap and using electrical heater;
- Heating method: radiation heating and electrical heater;
- Features: the experimental facility can be connected to the experimental devices installed in any cell of the reactor core; irradiation parameters (temperature, pressure, the neutron flux relative density, etc.) are recorded and archived.

Present irradiation activities at WWR-K reactor



R&D for Doping of Silicon



$Si^{30}(n,\gamma) \rightarrow Si^{31}(\beta^-; 2.6\ h) \rightarrow P^{31}$

Neutron coloration of topaz

Neutrons

RI production

INP has a GMP certificate to produce radiopharmaceuticals.

Medical radioisotopes:

- ❑ ^{99}Mo/ ^{99m}Tc
- ❑ ^{131}I
- ❑ ^{192}Ir
- ❑ ^{198}Au

New radioisotopes produced after reactor conversion

Sodium iodide ^{131}I:

$^{130}Te(n,\gamma)^{131}Te \rightarrow {}^{131}I$

Target: powder

Gold ^{198}Au:

$^{197}Au(n,\gamma)^{198}Au$

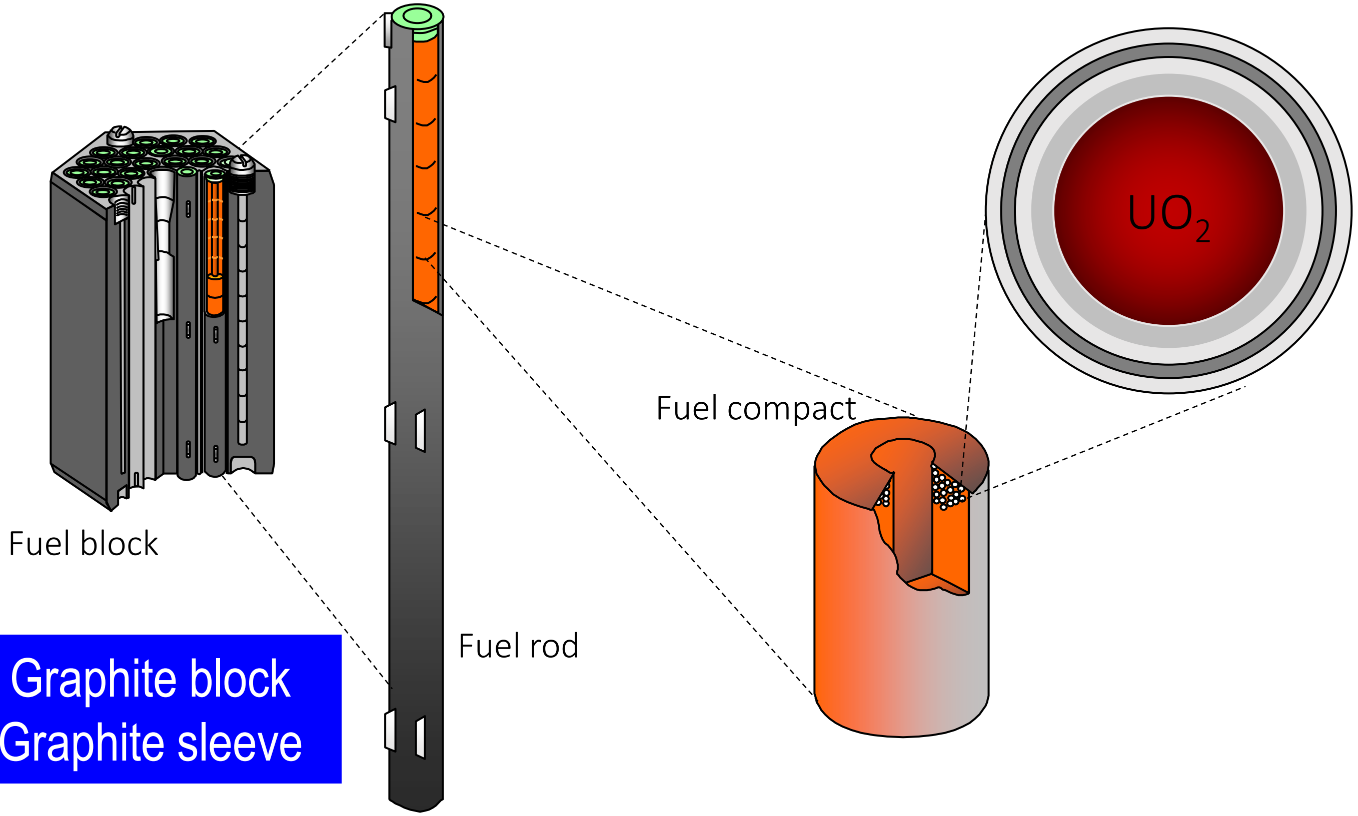
Target: grains

Industrial radioisotopes:

- ❑ ^{192}Ir
- ❑ ^{60}Co

In-reactor test of HTGR fuel compacts with SiC matrix

The study of properties of the irradiated SiC-matrix of the HTGR fuel element



Graphite block
Graphite sleeve

Graphite & carbon used for conventional fuel compact matrix

↓

Keeping geometry of fuel compact
Improving of oxidation-resistance

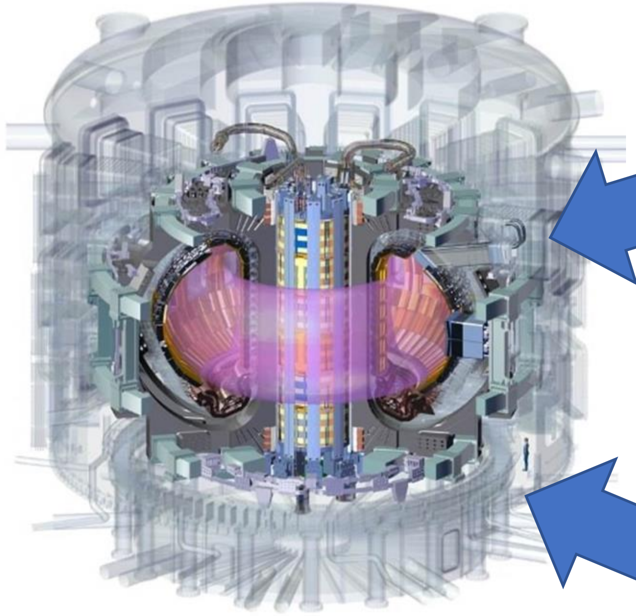
↓

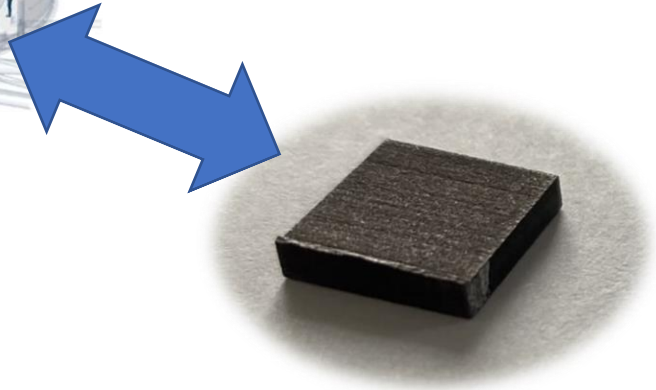
SiC-matrix fuel compact

↓

Investigation of the neutron irradiation effect on SiC-matrix is undergoing

Studies of functional materials of the fusion reactor





- ❑ Study of Solid Breeder Blanket Materials (lithium ceramics)
- ❑ Study of Neutron Breeder Materials (titanium beryllide)

In-situ gas release analysis is performing using CIRRA complex

Thank you for your attention!