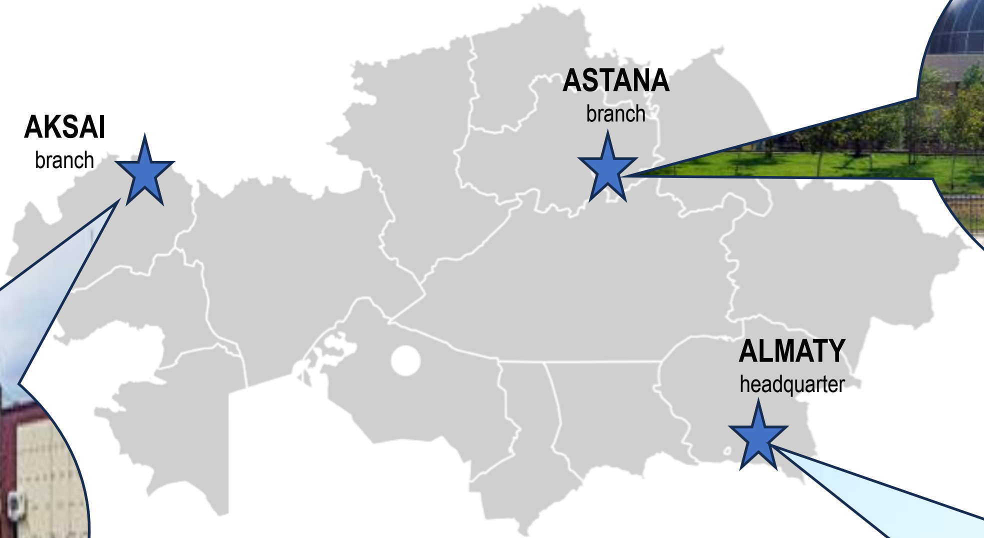
Technical Meeting on the Management of Spent Fuel (Pebbles and Compacts) from High Temperature Reactors, EVT2404558, 7 – 11 July 2025, Vienna, Austria

Experience on the Management of HTGR Spent Fuel at the WWR-K Reactor

A. SHAIMERDENOV, Sh. GIZATULIN, Y. YERMAKOV
The Institute of Nuclear Physics, 1 Ibragimov st., 050032 Almaty, Kazakhstan

The Institute of Nuclear Physics

The headquarter of the Institute is located in Almaty.
There are branches in the cities of Astana and Aksai.



Astana branch

Aksai branch

Headquarter in Almaty

INSTITUTE STAFF IN NUMBERS

216
young specialists
(under 35 years old)

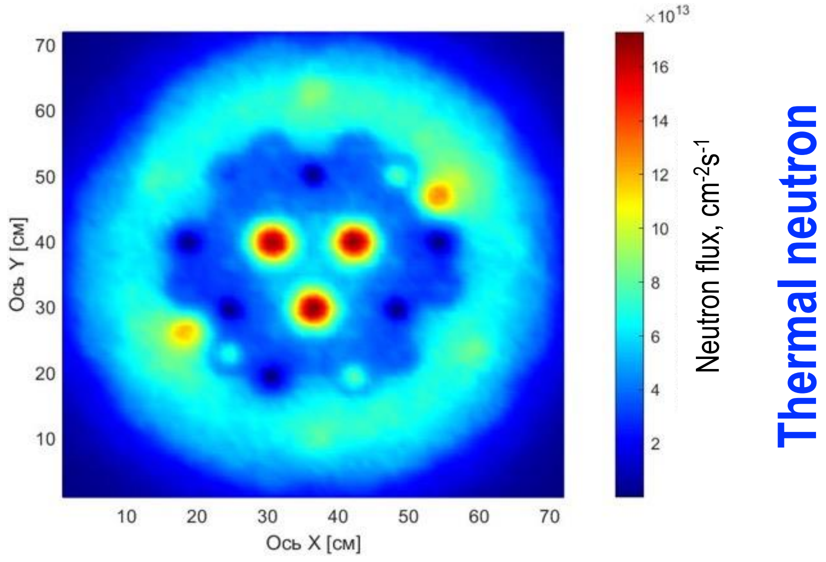
662
employee

68
specialist
with a scientific degree

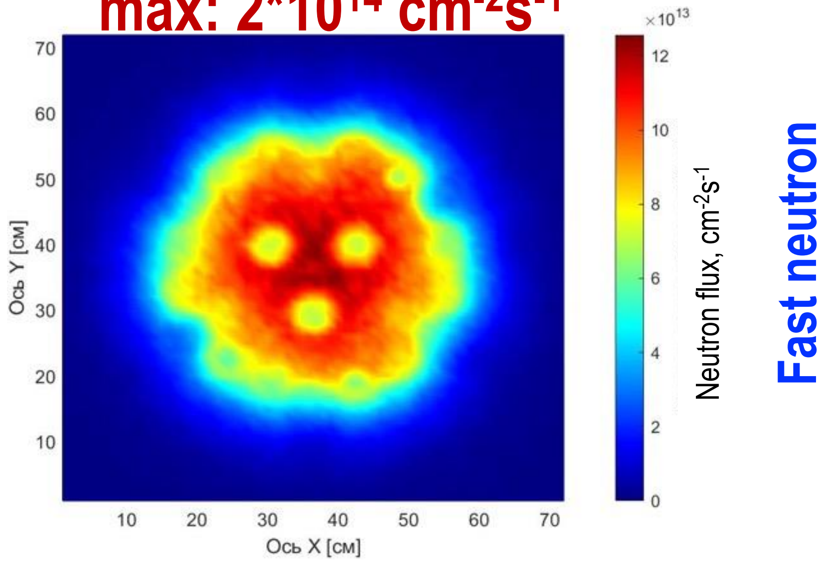
R&D activities to support the development of high temperature gas-cooled reactors

Since 2010

WWR-K research reactor

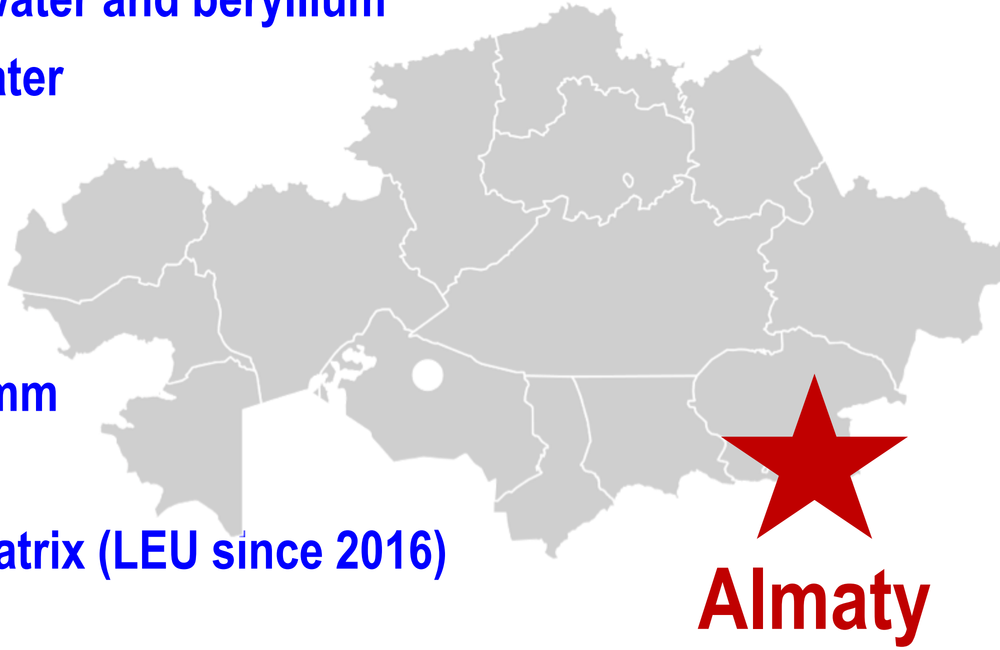


max: $2*10^{14}$ $cm^{-2}s^{-1}$

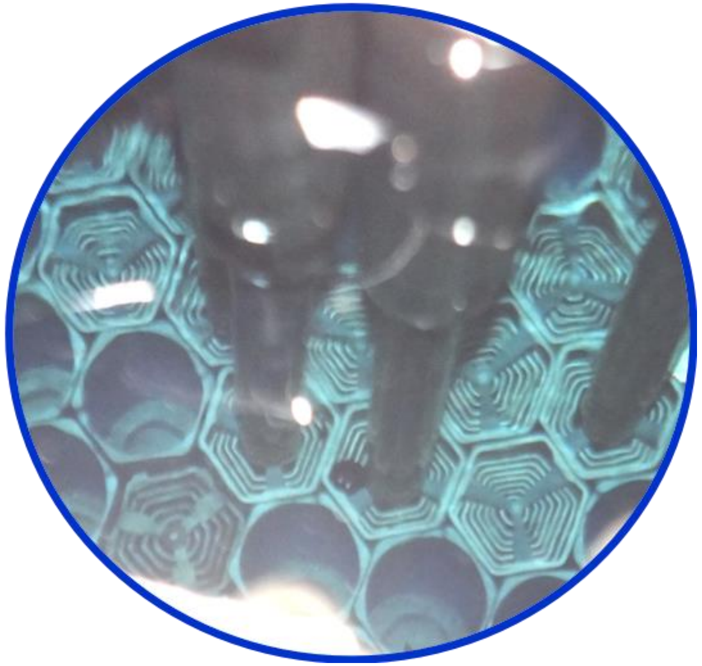


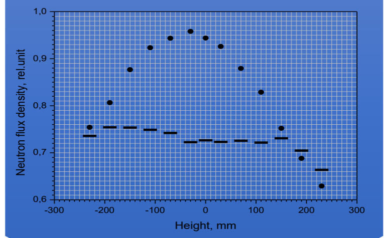
max: $8*10^{13}$ $cm^{-2}s^{-1}$

- Type: tank
- Thermal power: 6 MW
- Moderator: demineralized water
- Reflector: demineralized water and beryllium
- Coolant: demineralized water
- Pressure: atmospheric
- Coolant flow: forced
- Coolant circuits: two
- Core diameter: up to 720 mm
- Core height: 600 mm
- Fuel: dispersed UO_2+Al matrix (LEU since 2016)

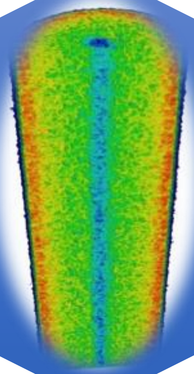


WWR-K research reactor: applications





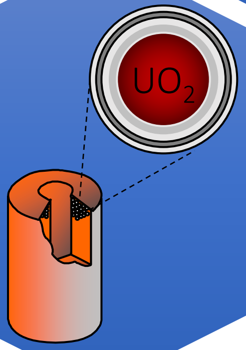
Doping of Silicon (R&D)



Neutron imaging

Neutron coloration of topaz

Neutron activation analysis



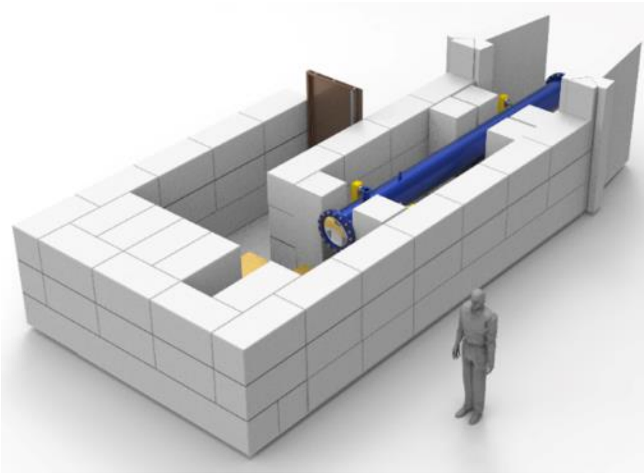
Materials research

Radioisotopes production

Experimental facilities

Additional facilities and instruments:

- ❑ Hot cells (two kind, total 9 cells);
- ❑ Critical assembly (100 W, light water, LEU since 2012);
- ❑ Hydraulic transfer system (loading/unloading capsules);
- ❑ Pneumatic transfer system (loading/unloading capsules for NAA);
- ❑ Gas-vacuum loop facility (high temperature and instrumented irradiation);
- ❑ CIRRA facility (gas release measurements);
- ❑ TITAN facility (neutron imaging and tomography);
- ❑ Neutron reflectometry (optical properties measurements);

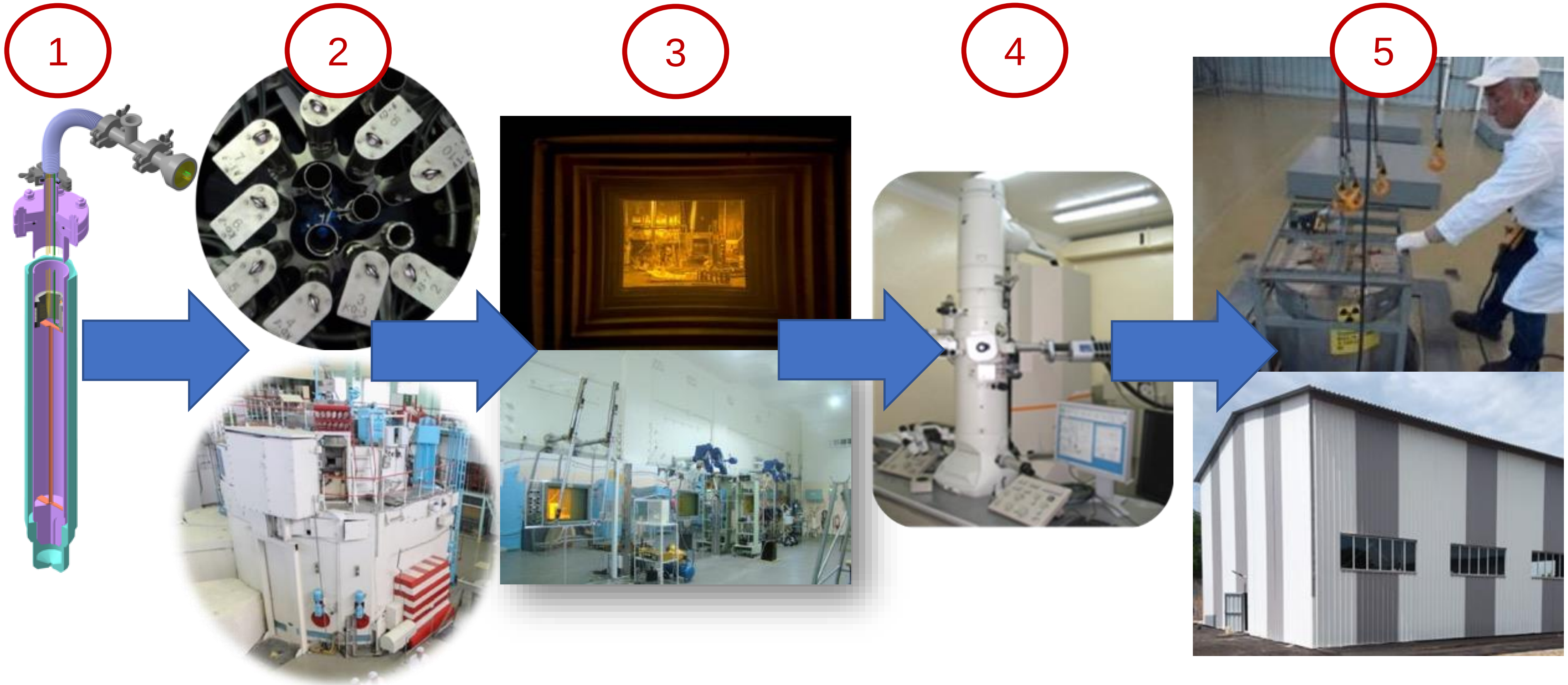


Radioactive waste storage facilities

Low activity radioactive waste storage

Disused sealed radioactive sources storage

PROCEDURE OF FUEL TESTING IN WWR-K REACTOR



Develop and fabrication of irradiation capsule

Irradiation in required condition until reaching required dose/burnup

Capsule dismantling and cutting in hot cell for extraction of samples

Performing PIE

Radioactive waste disposal

PROCEDURE OF FUEL MANAGEMENT IN WWR-K REACTOR

in case of experimental fuel

Incoming inspection

- ✓ Check of input documents
- ✓ Check of some properties
- ✓ Put to accounting and control database
- ✓ Informing of regulatory body and IAEA

Irradiation in required conditions

- ✓ Design of irradiation capsule
- ✓ Irradiation with control and until achieving required parameters

Cooling in controlled conditions

- ✓ Moving to cooling tank
- ✓ Control of cooling conditions
- ✓ Reducing energy release and radioactivity

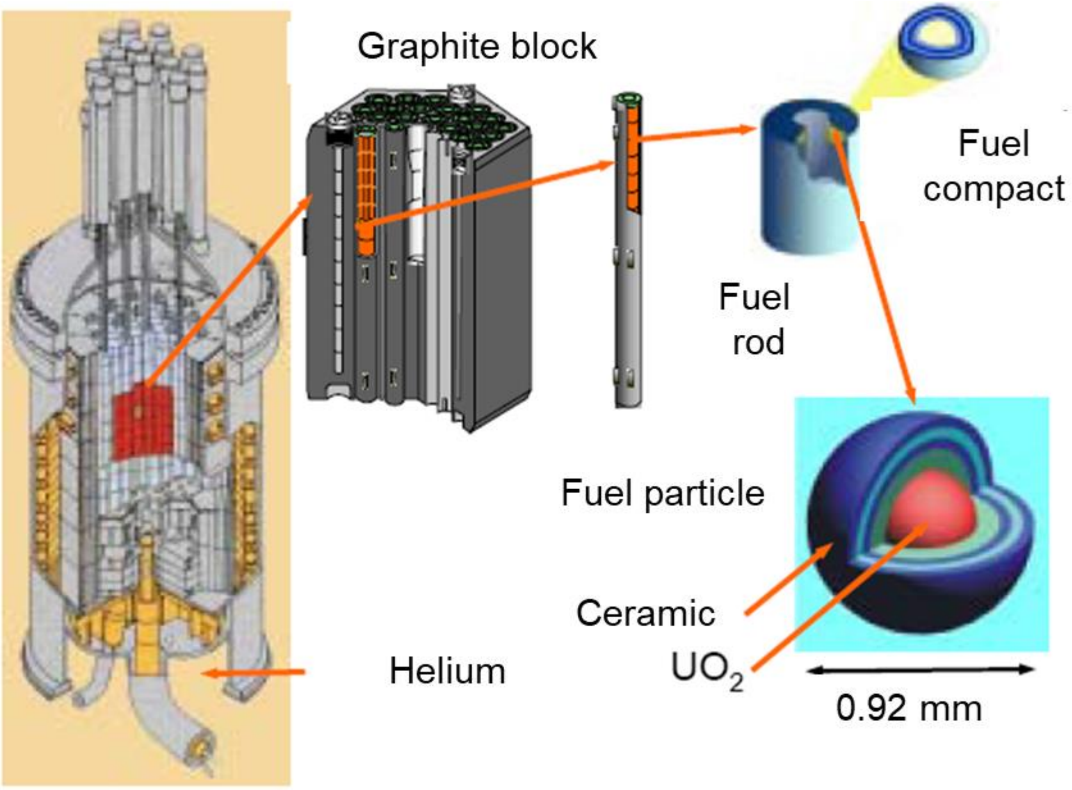
Post-irradiation examination

- ✓ Dismantling and cut-off irradiation capsule in hot cell
- ✓ Extract samples (fuel) in hot cell
- ✓ Preparation of samples to PIE
- ✓ Performing PIE

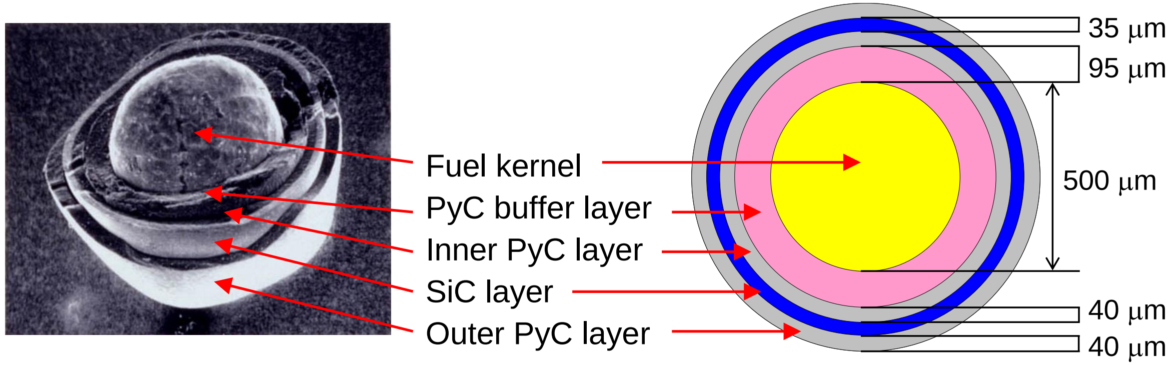
Storage in dry/wet condition

- ✓ Moving spent fuel to storage
- ✓ Control storage conditions
- ✓ Put to accounting and control database
- ✓ Informing of regulatory body and IAEA

Nuclear fuel of HTGR

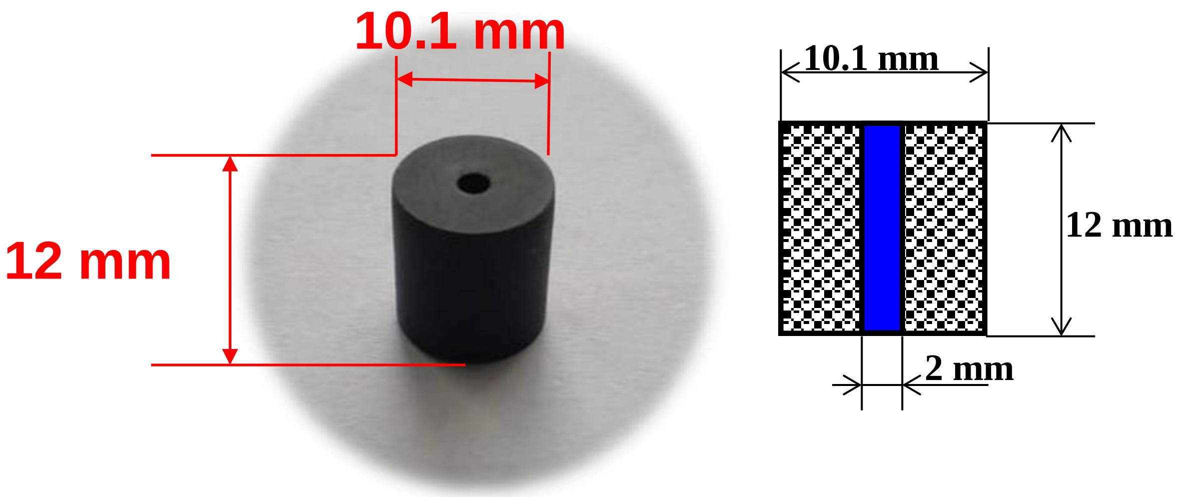


Prismatic type



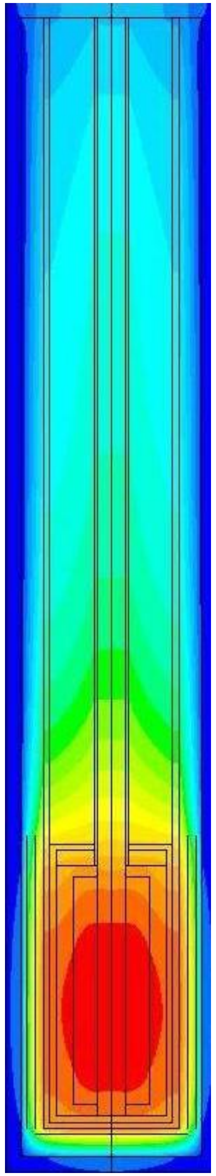
Enrichment of uranium-235 is 9.9%.

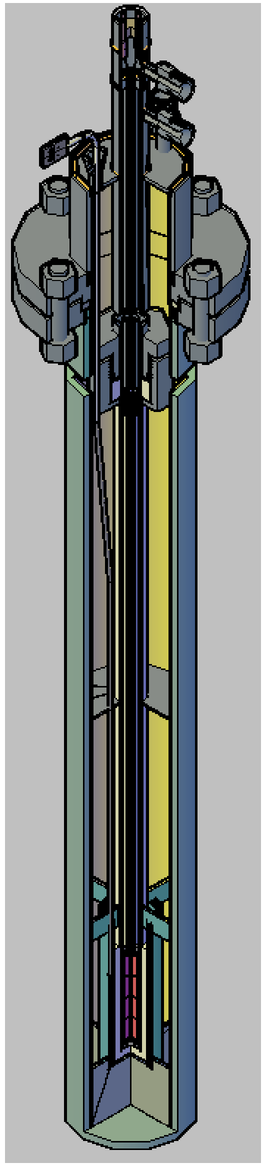
The fuel compact specimens are the cylinders fabricated by a technique of pressing the coated fuel particles with graphite powder and carbonized binder.



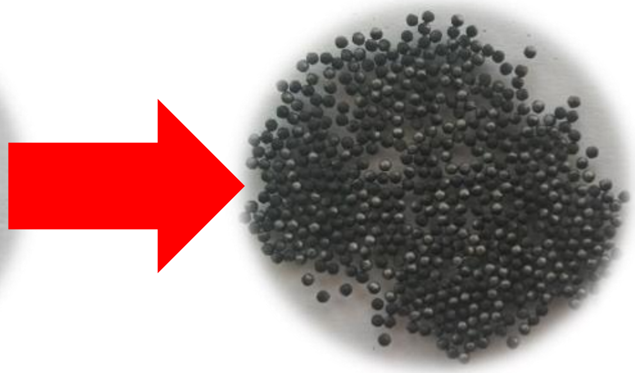
Reactor test of TRISO fuel

High temperature irradiation tests





Diameter: 10 mm
Length: 12 mm

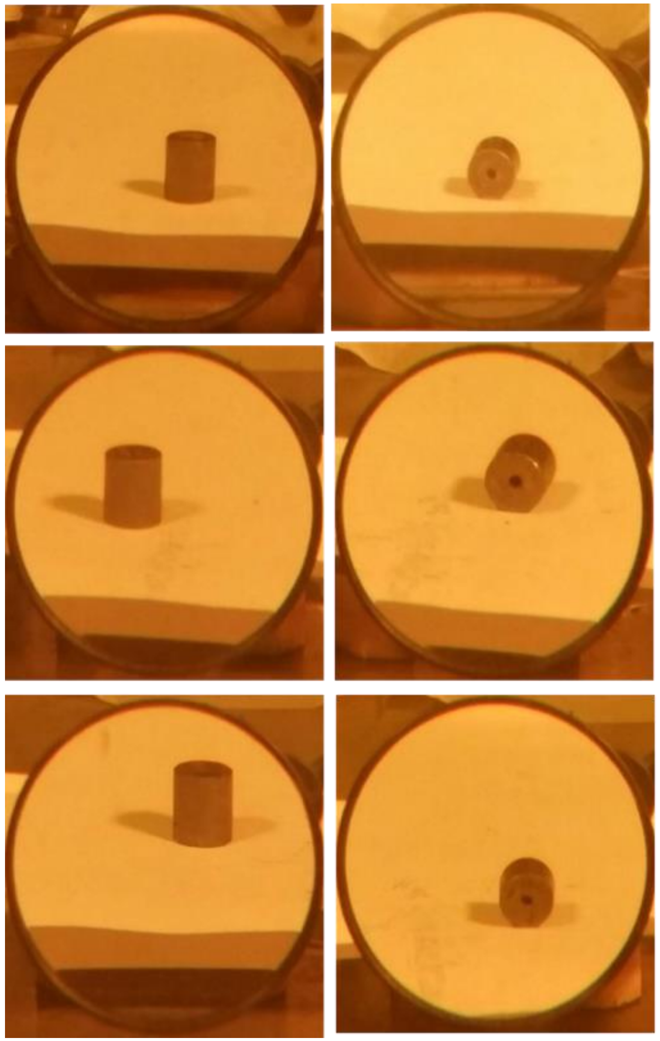


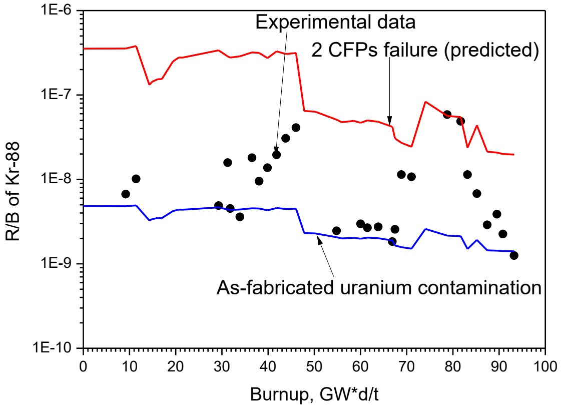
TRISO CFP

Spent fuel management strategy is dry onsite storage

PIE method	Instrumentation	Information obtained
Appearance observation	Lens	Visual inspection
Dimensional change	Mechanical micrometer MATRIX with the measurement uncertainty 0.01 mm	Swelling or shrinkage effect
Gamma spectrometry	Canberra GX-2518 germanium semiconductor gamma spectrometer	Determination of fuel failure fraction, fuel burnup
X-ray radiography	RPD-250 X-ray unit	Determination of fuel failure fraction

TRISO FUEL WITH GRAPHITE MATRIX TESTING





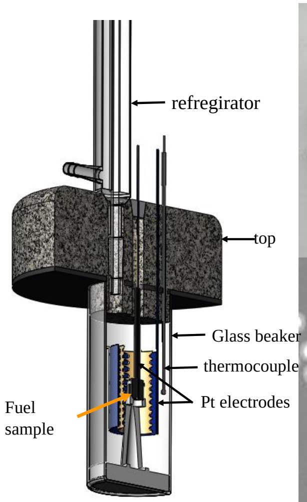
Achieved in-pile results:

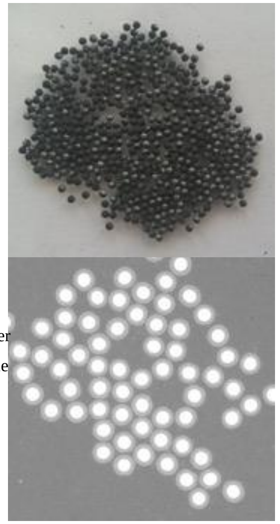
- ❑ Net irradiation: **400 EFPD**
- ❑ The time-average temperature: **991 ºC**
- ❑ Volume-average burnup: **93.3 GW×d/t**
- ❑ Maximal fast neutron fluence: **8.3×10^{24} m^{-2}** (E>0.8 MeV)

Integrity of TRISO fuel was confirmed by two techniques:

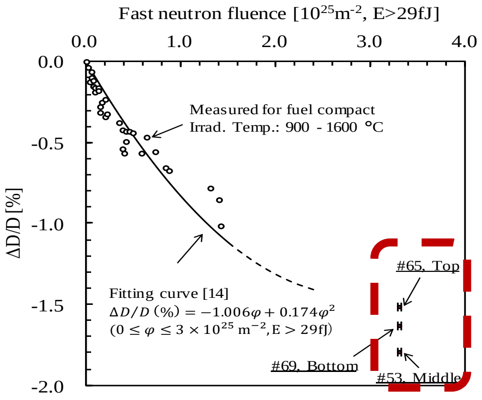
(1) in-situ by measurement of gas release from fuel (gamma spectrometry): *~2 CFPs*

(2) PIE by non-destructive method (X-ray imaging): *not more than 5%*



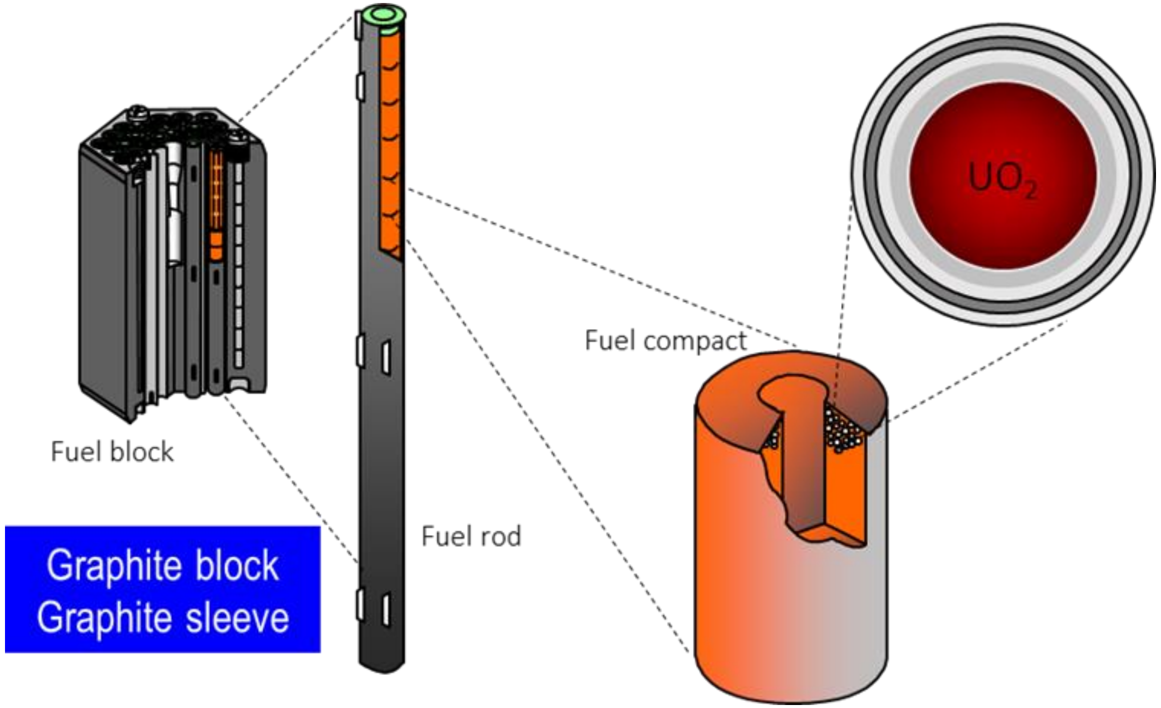


Shrinkage rate in diameter of the irradiated fuel compacts as a function of fast neutron fluence



Obtained data trends to agree with a fitting curve made with Japanese HTTR data so far

In-reactor test of HTGR fuel compacts with SiC matrix



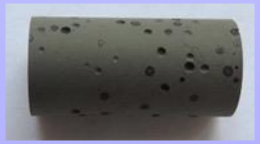
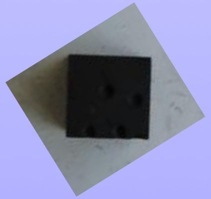
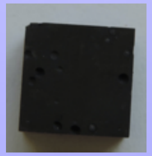
Graphite & carbon used for conventional fuel compact matrix

Keeping geometry of fuel compact
Improving of oxidation-resistance

SiC-matrix fuel compact

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

Samples of study

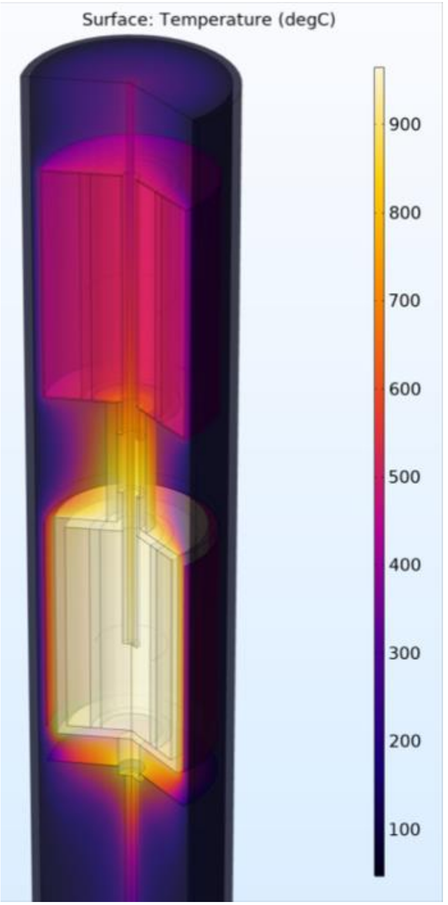
Sample type	Sample size, mm				
	Ø 10×20	Ø 5×10	Ø 10×5	5×5×5	10×10×5
SiC					
SiC + mockups					

Irradiation conditions:

- ❑ High temperature, 500 and 950°C
- ❑ Helium coolant
- ❑ Power release, 5 W or 8 W/cm^3
- ❑ Neutron flux, 10^{14} n/(cm^{2}s)
- ❑ Irradiation in specially designed instrumented capsule: equipped by thermocouples, neutron sensors, pressure sensors

Spent fuel management strategy is dry onsite storage

Design and Fabrication of the irradiation device



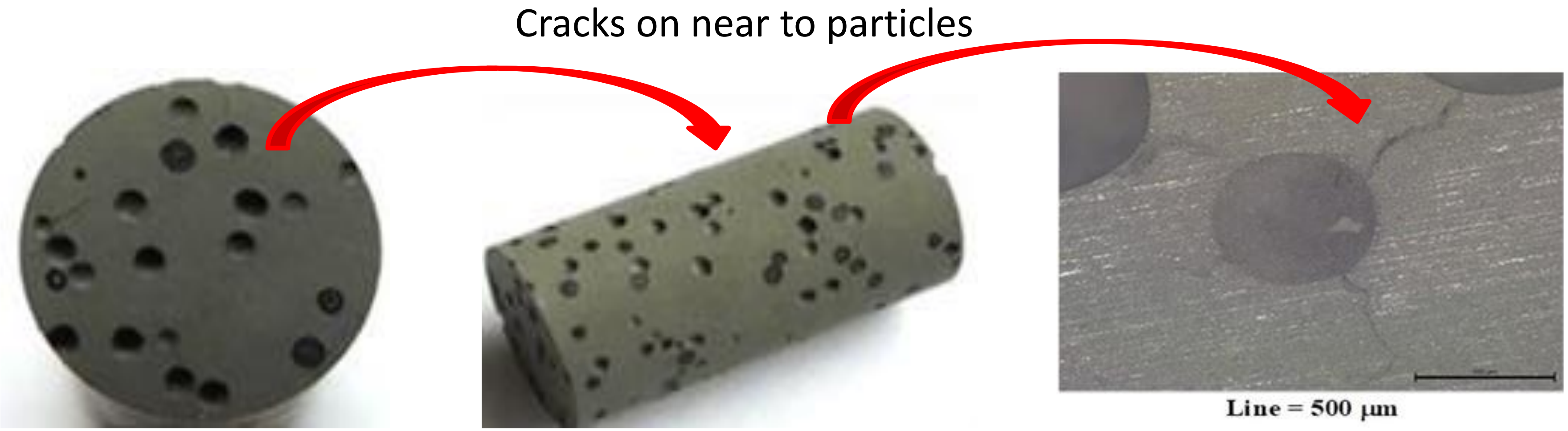
Scope of reactor test

List of PIE

Properties	Method	Sample sizes, mm
Geometric dimensions	Profilometer (0,01mm)	5 x 5 x 5 mm; 10 x 10 x 5 mm
Density	Method of hydrostatic weighing in distilled water	5 x 5 x 5 mm; 10 x 10 x 5 mm
Compressive strength	Uniaxial compression Universal Testing Machine «LR50Kplus»	Ø10 x 20 mm
Coefficient of linear thermal expansion	Dilatometer DIL-402C	Ø5 x 10 mm
Microhardness	Indenting a Vickers diamond pyramid PMT-3M	10 × 10× 5 mm
Young's modulus and nanohardness	Nano-indentation Nano-Hardness Testers «NanoScan Compact»	5 x 5 x 5 mm
Thermal conductivity	Thermal conductivity meter KIT-1000	10 x 10 x 5 mm

- Neutron fluence for thermal neutrons (E <0.683 eV) – 1.0×10^{21} cm^{-2};
- Neutron fluence for fast neutrons (E >0.1 MeV) – 1.1×10^{21} cm^{-2}.
- Irradiation duration: 220 EFPDs

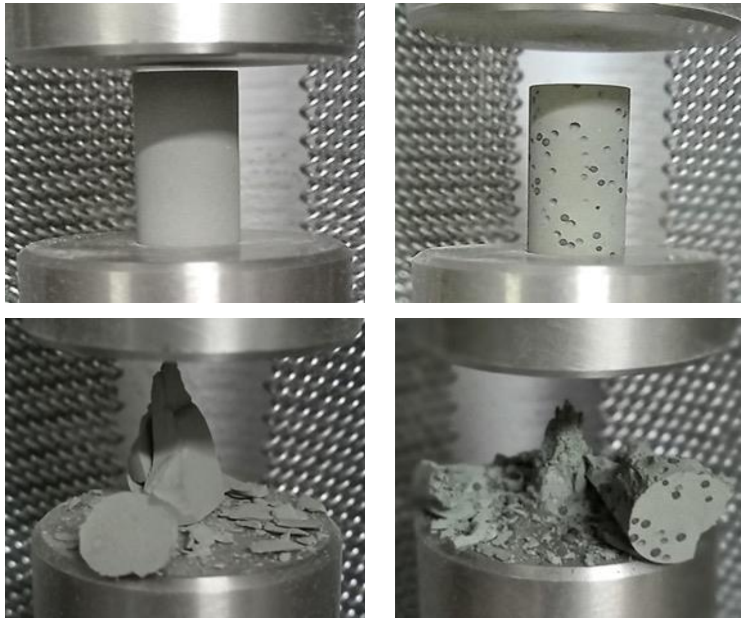
Post-irradiation examination



- **No changes** in geometric dimensions, density.
- Irradiation led to an **increase** in the microhardness of SiC matrix samples by ~2 times.
- The value of Young's modulus after irradiation **decreased** from **39 to 19 GPa**.
- The nanohardness of the sample also **decreased** from **59 to 39 MPa**.

Mechanical compression tests

	T_{test}, C	σ_c, MPa	δ, %
Before irradiation			
Without particles	RT	209.7	4.65
With particles	RT	98.7	2.55
Irradiated at 500 ºC			
Without particles	RT	194.2	4.33
With particles	RT	90.9	2.42
Irradiated at 900 ºC			
Without particles	RT	253.6	5.79
With particles	RT	112.8	2.93



Without particles

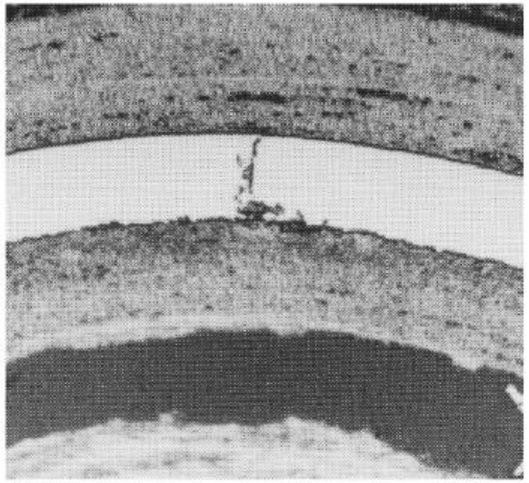
With particles

Destruction is brittle and accompanied by loud sound

Next R&D

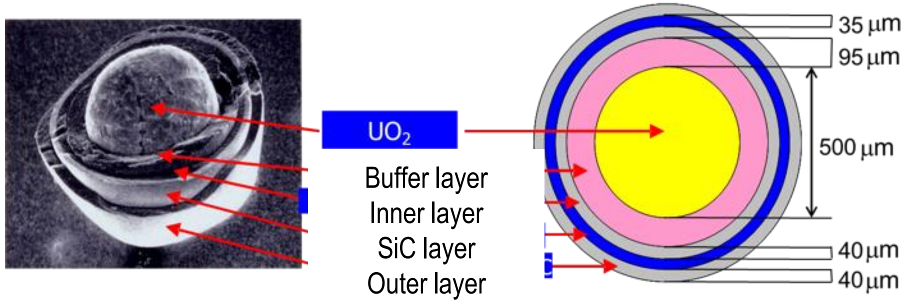
Since 2025, study on chemical interaction of SiC coating layer with fission product palladium in highly-burned TRISO-coated fuel particle is started.

It is 3 years project.

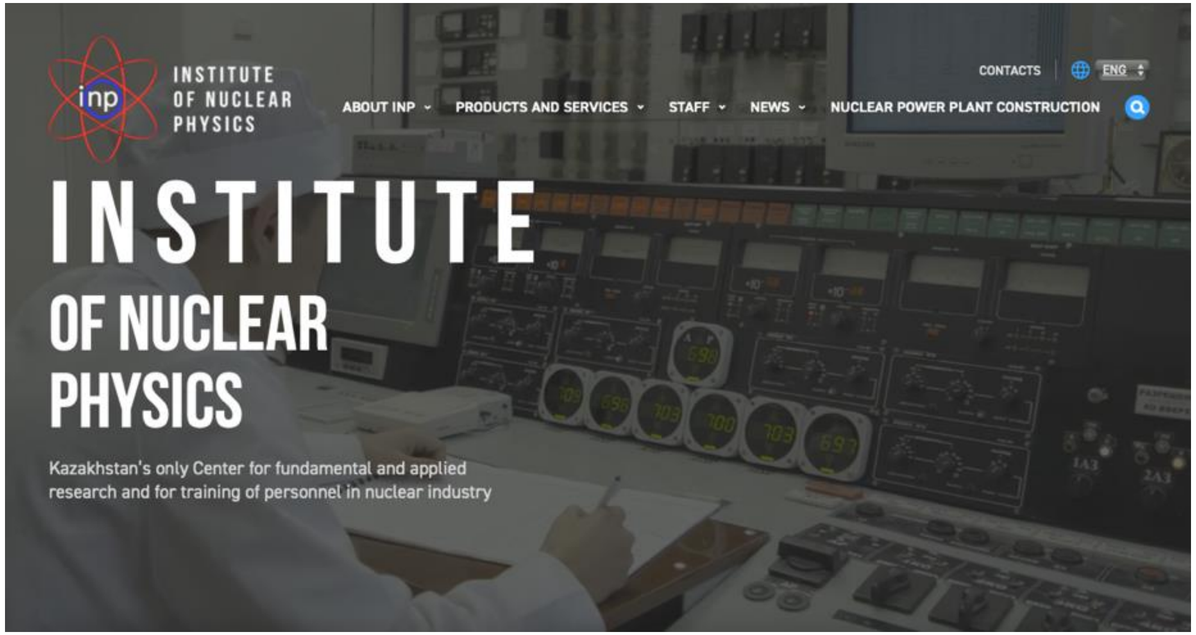


The main hypothesis of the project is that palladium (Pd), as a transition metal product of uranium fission, interacts with the SiC coating, which leads to degradation of the SiC coating, and, ultimately, to the destruction of the through coating of the TRISO-coated fuel particle itself.

Obtained experimental data will allow to better understand mechanism of Pd corrosion in TRISO CFPs



- ✓ Since 2010, extensive R&D of HTGR fuel and other materials has been performed at the WWR-K research reactor. The main focus of R&D was on in-reactor testing of materials under their operating conditions with further investigation of the properties of the materials.
- ✓ As a result of this activity, measures and protocols for the safe management of fresh and spent HTGR fuel were developed and a strategy for the handling of spent fuel was developed.
- ✓ The generated spent fuel of HTGR has been safe/secure stored at the INP for more than 12 years.
- ✓ Disposal path for spent HTGR fuel still to be determined.



Thank you for your attention!

@inp_kz

@inp1957

@inp_kz

www.inp.kz