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IAEA
International Atomic Energy Agency

IGORR

International Group on Research Reactors (IGORR) Conference
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REACTOR TESTS AND POST- IRRADIATION EXAMINATIONS OF MATERIALS AND FUELS IN JUSTIFICATION OF THE OPERATED AND PROMISING NUCLEAR POWER PLANTS

A.A. TUZOV, A.L. IZHUTOV, E.A. ZVIR, V.A. ZHITELEV, A.V. BURUKIN,
V.A. OVCHINNIKOV, I.YU. ZHEMKOV

RIAR JSC, Dimitrovgrad

Introduction

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RIAR JSC is one of the world's largest nuclear research centers to perform irradiation and post-irradiation examinations of materials and fuels of various types of nuclear reactors.

Experimental base and infrastructure include:

- *5 research reactors (SM-3, MIR, BOR-60, RBT-6, RBT-10/2);*
- *largest in Russia hot lab for post-irradiation examinations of irradiated materials and items, including full-size FAs;*
- *radiochemical laboratories to produce transplutonium elements and radioisotopes, to examine unirradiated and irradiated fuel and to dispose RW;*
- *pilot production of nuclear fuel, fabrication of fuel rods and assemblies for fast reactors;*
- *engineering infrastructure, including SF and RW management.*

Introduction

Currently, RIAR performs a large scope of tests and examinations of materials and fuels in justification of existing nuclear reactors as well as GEN III+ and IV installations for both domestic and foreign Customers. To provide safety of tests, RIAR systematically monitors the state of experimental equipment, extends its lifetime and upgrades the instrumental stock and techniques.

The RIAR's key experimental activities are:

- *irradiation and post-irradiation examinations of materials and core components to justify the operation of existing nuclear reactors and innovative ones;*
- *development of technologies to accumulate transplutonium elements and radioisotopes for industrial and medical purpose;*
- *experimental research in closed fuel cycle, fractioning and transmutation of long-lived fission products and RW disposal*

Current trends and tasks in testing fuels and materials

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	The period of (2021…2025)	New research tasks that require new techniques
1	Justification of VVER-1000/1200 fuel rods performance.	Justification of fuel rods performance under the VVER-1000 power increase to 107% N_{nom}. Determination of fuel limiting temperature before melting. Instrumented tests (RAMP, LOCA, RIA) for improved fuel rods and Gd-doped rods.
2	Irradiation and PIEs ATF experimental fuel rods	Lifetime tests of EFA with ATF fuel rods under VVER and PWR water chemistry in the MIR reactor. Tests of irradiated fuel rods under transient and accident conditions.
3	Justification of VVER REMIX fuel performance	Irradiation of experimental fuel rods up to 60 MW day/kgU, LOCA, RIA.

Current trends and tasks in testing fuels and materials (cont.)

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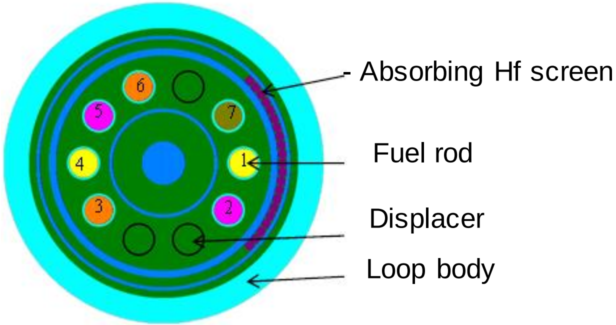
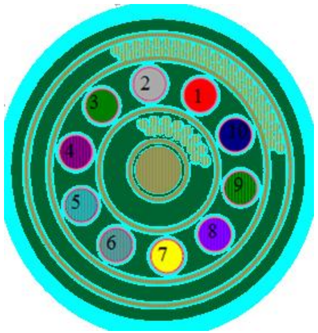
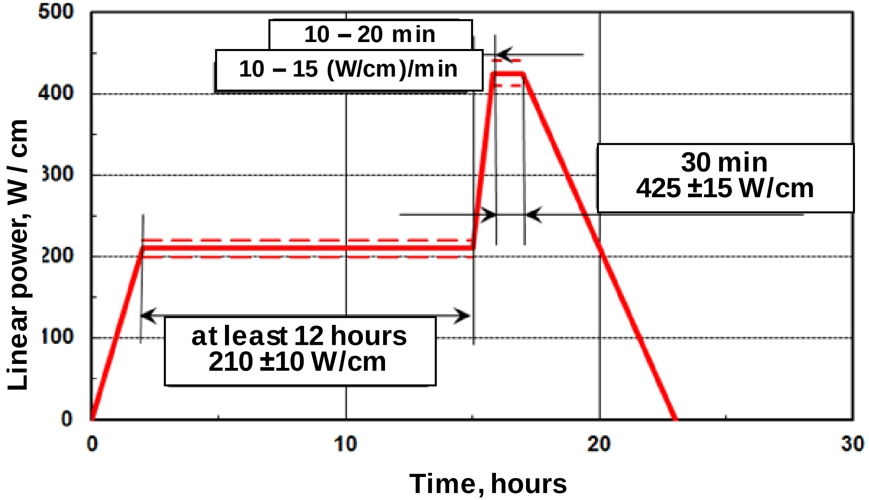
	The period of (2021…2025)	New research tasks that require new techniques
4.	Lifetime tests in BOR-60 of mixed (UN – PuN) fuels for BREST and BN-1200.	Effect of manufacturing characteristics on the fuel performance; justification selected fuel and structural materials.
5.	Tests of mixed (UN – PuN) fuel rods in MIR under simulated transient and accident conditions.	Justification of fuel performance under design-basis initial accidents.
6.	Capsule and loop tests in SM-3, MIR of MSR materials and fuel.	Investigation of radiation and corrosion resistance of selected materials and fuel salt.
7.	Capsule tests in BOR-60 and SM-3 of VVER-1200 internals and SCWR materials.	Justification of selected structural materials.
8.	Tests of fusion reactor materials.	Examination of radiation resistance and justification of performance.
9.	Tests in BOR-60 and SM-3 in justification of HTGR project	Selection of materials and justification of design

Improved Techniques of RAMP Test in the MIR







How to change power

- rotation of absorbing screens around fuel rods in the loop channel

- Ramp time - 0.5…30 min
- Magnification factor ×1.5…5.0
- Quantity fuel rods up to 10

Fuel rod parameters measured on-line:

- Fuel temperature
- Change in fuel cladding length and diameter
- Gas pressure in the fuel rod plenum
- Fuel column elongation (new)

LOCA Tests Techniques of VVER and PWR fuel in the MIR

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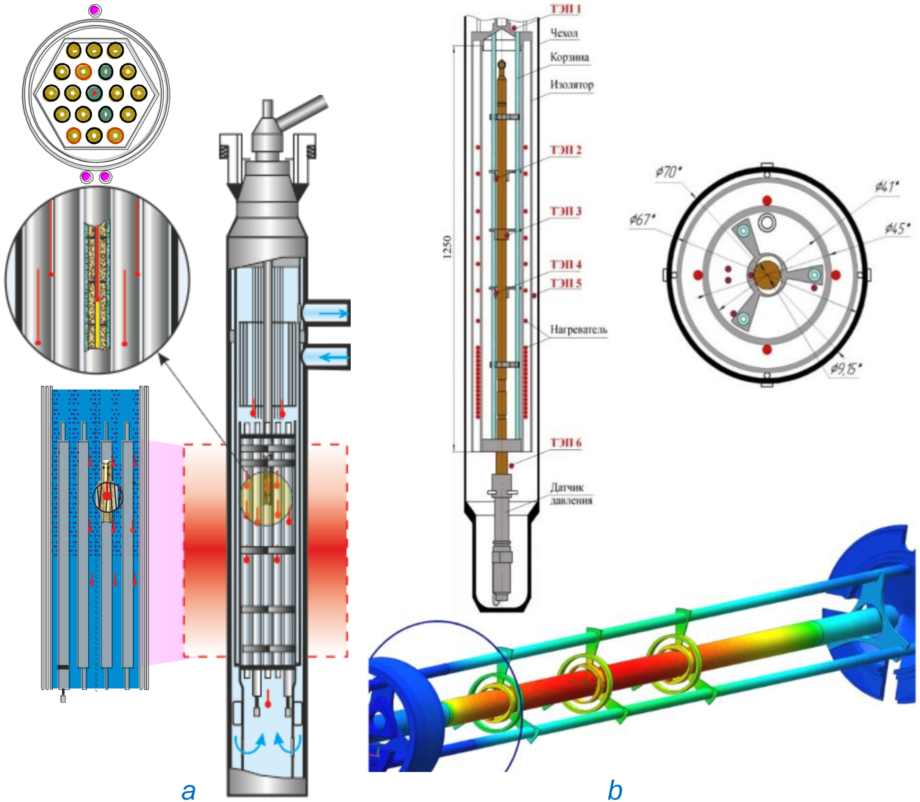
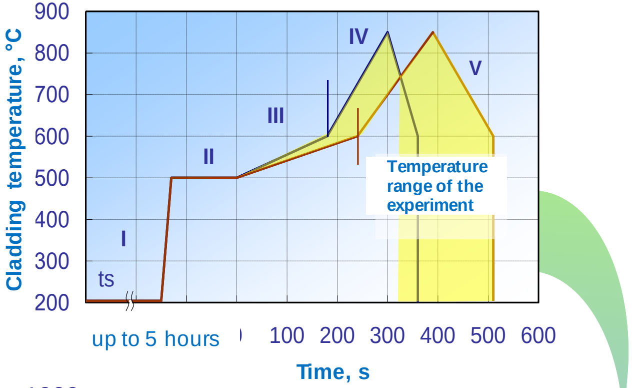
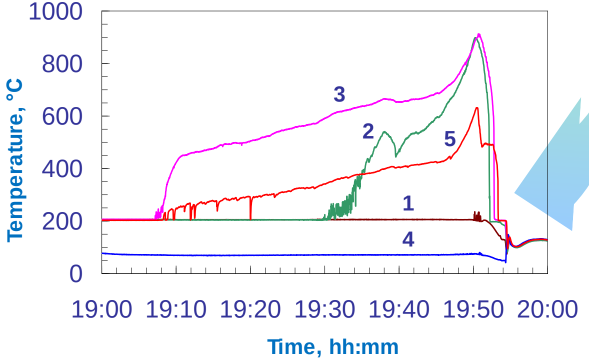


Devices for testing 19 fuel rods (a) and single fuel rod (b)

Temperature scenario





Change in temperature: (cladding- 1, 2, 3) and coolant (4, 5)

Lifetime Tests Techniques of ATF Fuel Rods for PWR and VVER Design in the MIR

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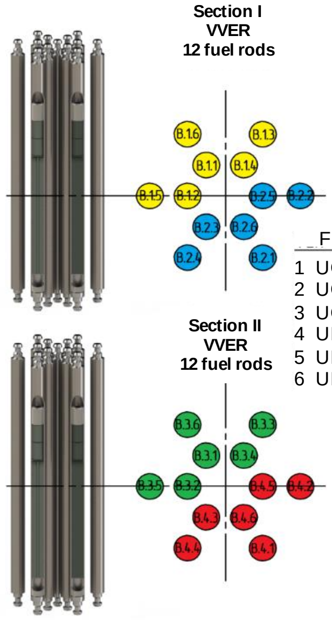
Two-level device for testing different type ATF fuel in VVER and PWR design

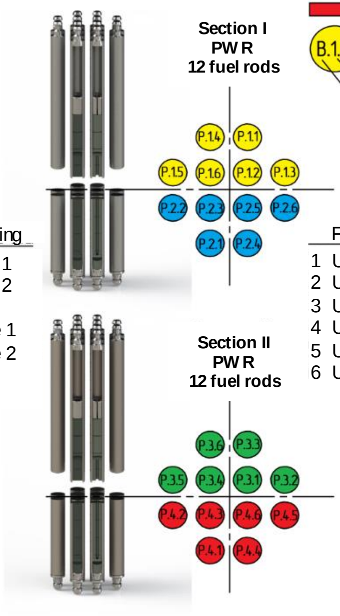
VVER

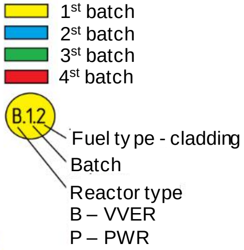


Fuel type - cladding

1 UO_2 - E110 type 1
2 UO_2 - E110 type 2
3 UO_2 - 42XHM
4 UMo - E110 type 1
5 UMo - E110 type 2
6 UMo - 42XHM

PWR





Fuel type - cladding

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5 UMo - E110 type 2
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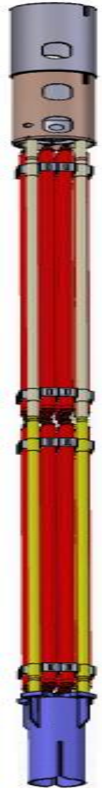

Scenario to Determine Power to Fuel Melting in the MIR

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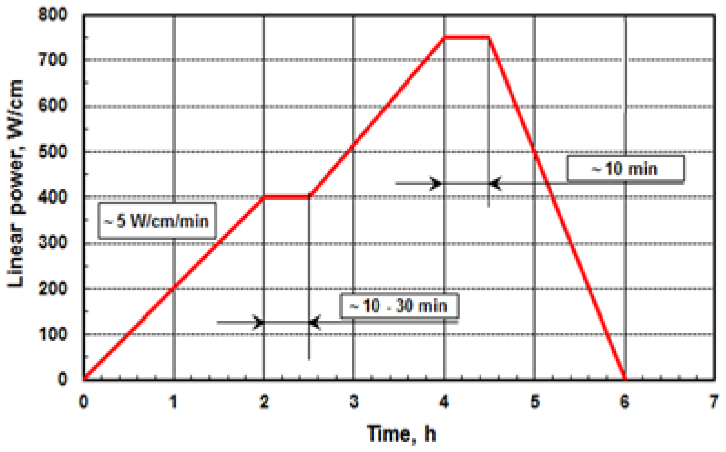

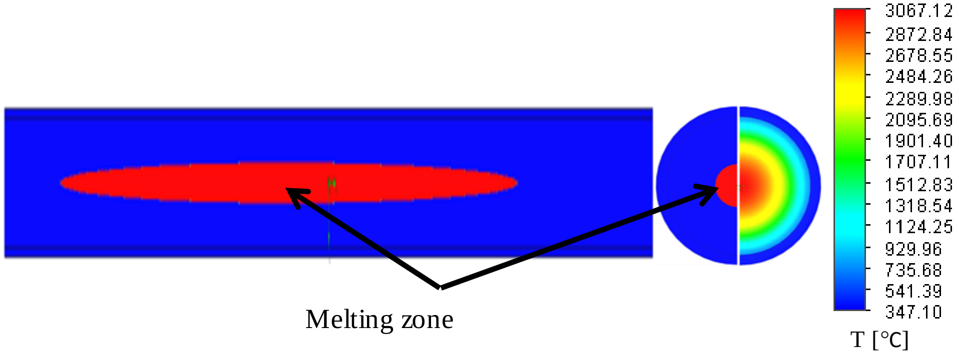

Purpose: to determine power when fuel starts melting to justify the design-basis thermo-physical criterion TC1 (limited fuel temperature).

Test objects – high burn-up fuel (40…70) MW day/kg U

FRs are equipped with gas pressure and fuel temperature gages

After tests melting zones are defined.

Capsule Tests of Structural Materials in the SM-3

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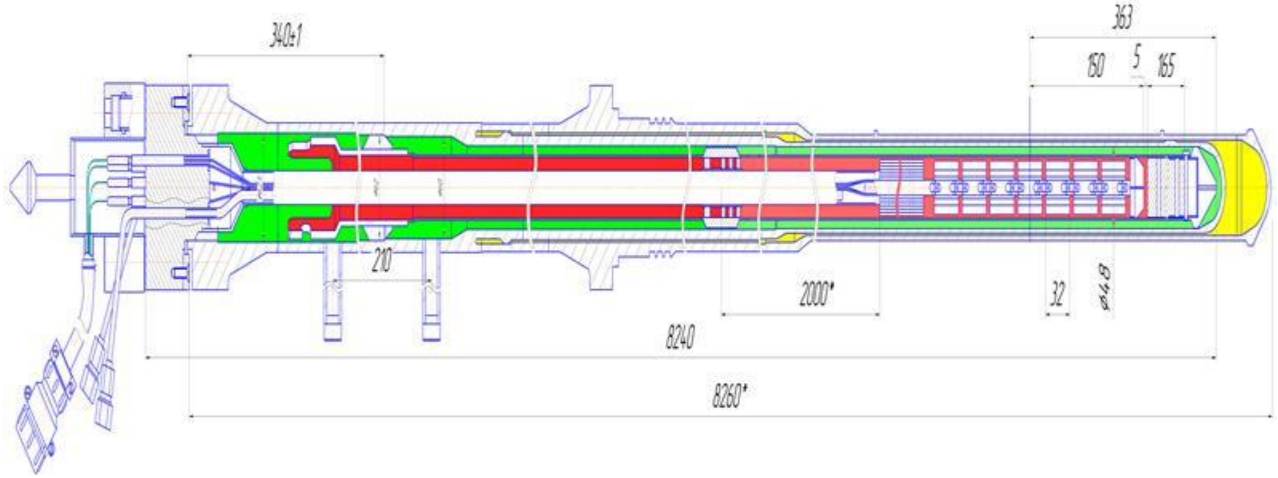
Loop capsule with natural coolant circulation with VVER and PWR water chemistry to investigate SCC, stress relaxation, etc.



Measurement of pressure, coolant temperature, specimens temperature; control and maintenance of water chemistry parameters of coolant.

In-pile Examination of Fuel Pellets Creep in RBT-6

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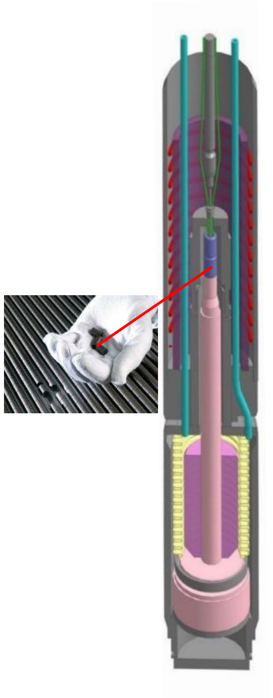
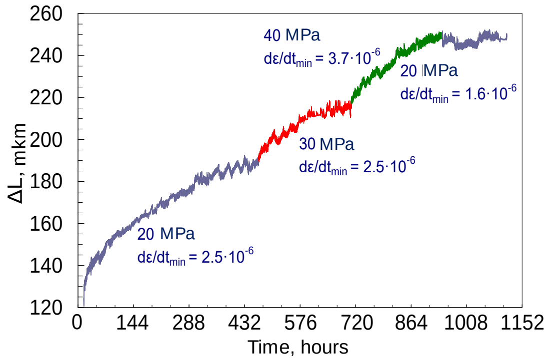
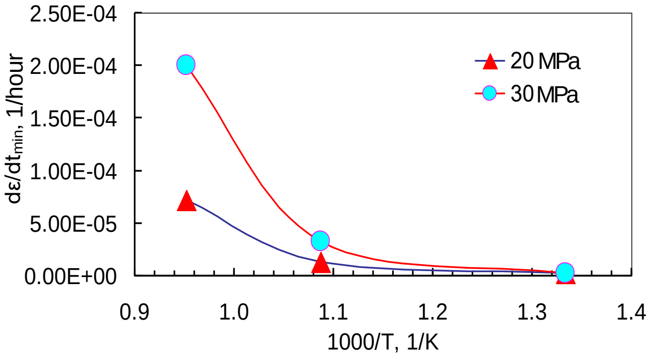


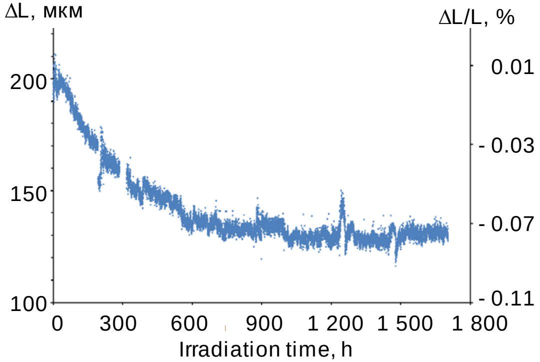
IR to test fuel creep



Fuel deformation at 750 °C



Temperature dependences of UO_2 radiation creep rate at 20 and 30 MP stress loading and fission density 10^{13} $cm^{-3}s^{-1}$



Absolute and relative movement of fuel samples vs. irradiation time at 650-700 °C

Tests of fuels and materials in BOR-60

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Experimental sodium-cooled reactor BOR-60 was put into operation in 1969 to experimentally justify all fast reactor technologies, including turbine to produce electricity. The reactor was licensed to operate till 31 December 2025.

In the BOR-60 reactor, promising types of fuel are tested at high thermal loads (up to 50 W/m), temperatures (to 3000°C) and burn-up (35 % h.a.), as well as structural and absorbing materials are tested in a wide temperature range (320...1000°C) to high fast (E> 0.1MeV) neutron fluence (1.8 × 10^{23}cm^{-2}) and damage doses (200dpa).

To test materials and fuel are used dismountable devises that allow to provide periodic intermediate examinations and replacement of irradiated samples in the reactor hot cell, instrumented autonomous loop channels with various coolants, and instrumented dismountable fuel assemblies, etc.

Irradiation Devices for Testing Fuel and Materials in BOR-60

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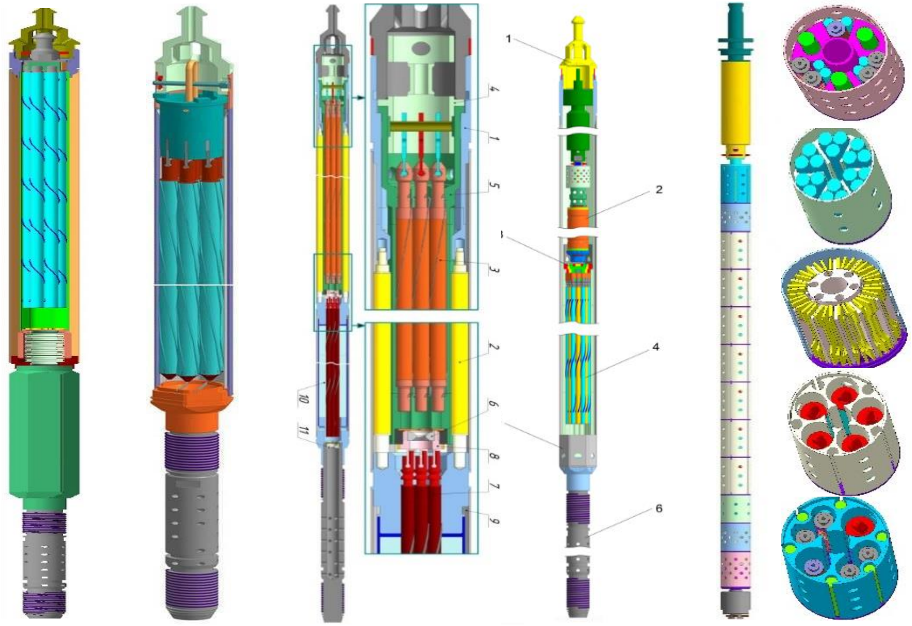

a) b) c) d) e)

The examples of dismountable devices that allow periodic intermediate examinations and replacement of irradiated samples and fuel rods in the reactor hot cell.

Devices to test fuel rods in BOR-60 (a, b, c) and structural materials (d, e).

Key directions in PIEs of fuels, materials and core components

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The Reactor Materials Testing Complex is oriented on handling highly active items. The uniqueness of Complex in comparison with other hot laboratories in Russia and abroad is in the ability of investigation full-scale fuel assemblies of all types of reactors existing in Russia and abroad, and the availability of various types of research reactors on one site allows for a full cycle of reactor tests and post-irradiation examinations of any materials.

The PIE equipment is located in two buildings and has 51 hot cells and 9 heavy-shielded boxes. The first building for non-destructive examinations (NDE) has equipment to handle and examine full-size FAs and fuel rods from reactors VVER-1000, VVER-440, RBMK-1000, BN-600, BN-800 as well as experimental FAs and fuel rods irradiated in test reactors. The second building is intended for destructive examinations (DE) to study the physical and mechanical properties of irradiated materials as well as their structure and composition.

Technics of NDE

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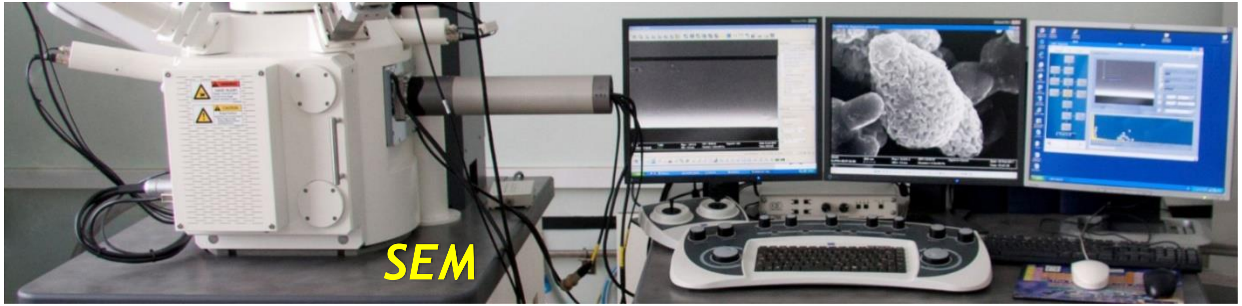
Stands and equipment for non-destructive examinations of core components:

- *visual inspection;*
- *geometry and eddy-current;*
- *gamma-scanning;*
- *oxide film thickness on the cladding surface;*
- *X-raying;*
- *control of integrity of claddings;*
- *mesurement pressure, volume and composition of plenum gas.*
- *Installations for refabrication and instrumentation of irradiated fuel rods;*
- *Stand for thermal tests of full-size irradiated fuel rods*
- *Equipment to measure thermo-physical characteristics of irradiated materials*

Technics of DE

Technics and equipment for destructive examinations of physical and mechanical properties, structure and composition of irradiated materials:

- *composition of irradiated materials;*
- *metallography;*
- *SEM, EPMA; TEM;*
- *tensile tests; LCF; creep; long-term strength; fracture toughness in air, inert medium and in vacuum at a wide temperature range;*
- *X-Raying;*
- *thermo-physical characteristics of irradiated materials;*
- *autoclaves tests;*
- *mass-spectrometry of irradiated materials, incl. nuclear fuel*



Improvement of PIE Techniques

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The experimental base is to be upgraded and new techniques are developing:

- *upgrading of equipment to perform PIEs of VVER-1200 SFAs;*
- *in-cell stand to study the kinetics of FGR from irradiated fuel under a high-temperature annealing;*
- *development of techniques for mechanical tests of irradiated materials;*
- *development of a technique and equipment for long-term relaxation and creep tests of longitudinal segmental samples from spent claddings;*
- *techniques for creep and stress relaxation tests, including applied axial load under tension/compression;*
- *improvement of testing techniques for brittle claddings under simulated stress-strain state conditions close to the operational ones;*
- *techniques in delayed hydride cracking of irradiated claddings;*
- *development of techniques to assess thermo-physical characteristics of fuel, structural and absorbing material irradiated at temperatures up to 2800°C.*

Conclusion

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RIAR has the largest fleet of research nuclear installations, which play an important role in the development of nuclear power. Key scientific, technical and technological competencies of the Institute, a unique research base for conducting a full range of reactor and post-reactor research.

The Institute conducts complex experimental studies of the fuel and materials of various nuclear power plants, reactor tests and post-reactor studies are provided with representative methods based on modern equipment and are carried out by highly qualified specialists.

The implementation of projects to improve and modernize research reactors and experimental facilities is aimed at developing promising water-cooled power reactors, fast reactors with sodium and heavy liquid metal coolants, as well as innovative Generation - IV nuclear power plants.

RIAR is ready to carry out experimental research for the development of nuclear power by both Russian and foreign organizations.

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Thank you for your attention

Research Institute of Nuclear Reactors, State Scientific Centre, Joint-Stock Company (RIAR JSC)

Tel.: +7 (84235) 7 93 40
E-mail: adm@niiar.ru
www.niiar.ru/eng