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Current and prospective fuel test programmes in the MIR reactor

Dimitrovgrad 2007

Introduction

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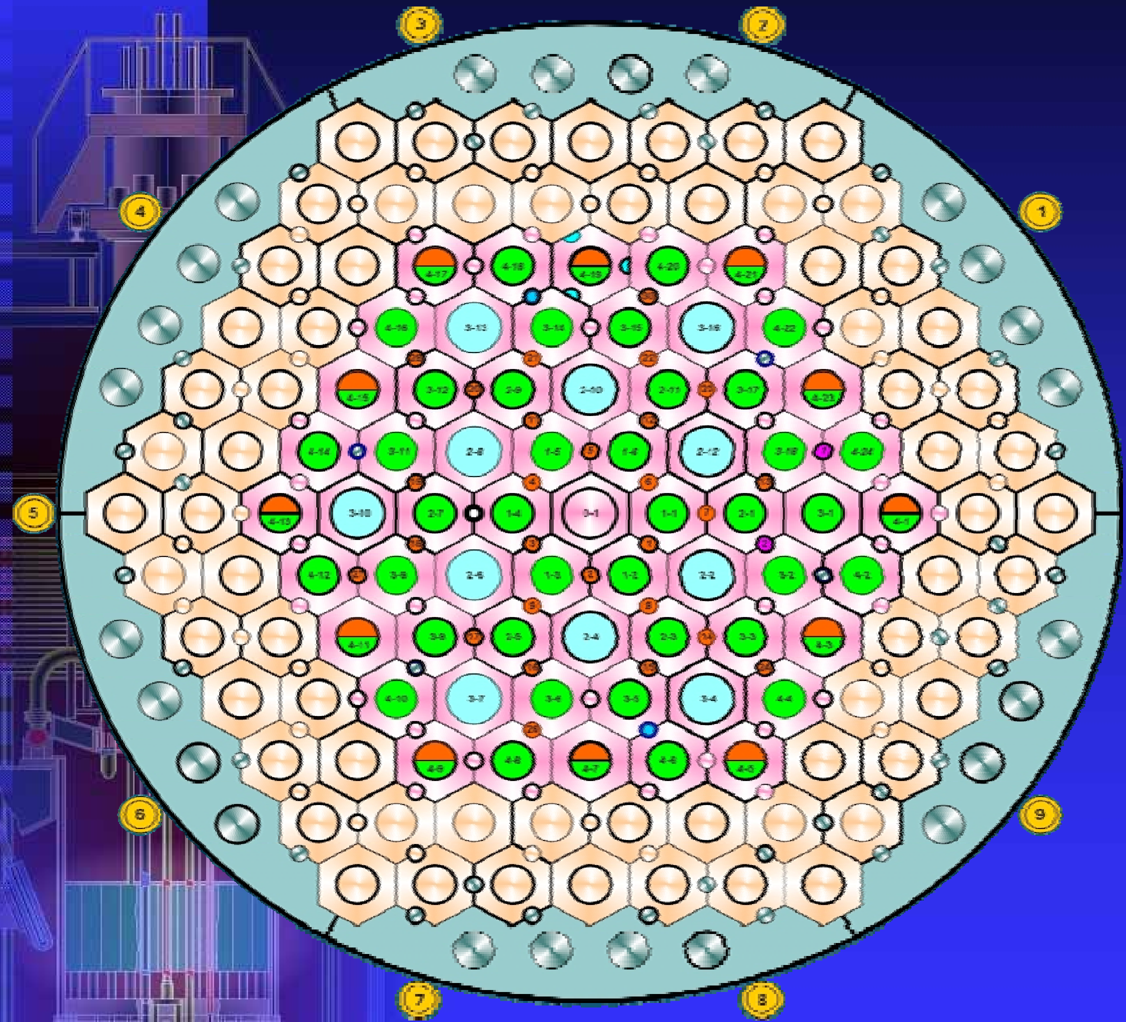


The MIR reactor is mainly designed for testing of different nuclear power reactor fuel under normal (steady-state and transient) operating conditions as well as emergency ones in a certain project.

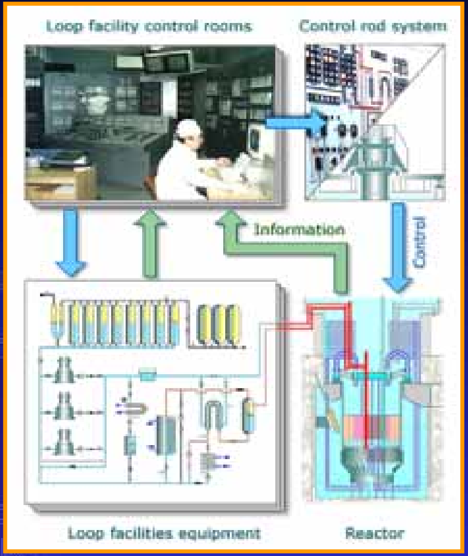
– operating FA channel

– experimental channel

– combined operating FA with absorber

– control rod channel

Introduction



Currently 6 loop facilities are available in the MIR reactor. Each of these facilities is connected with 1-2 loop channels (the maximum diameter - up to 148 mm). The channels are used for setting up experimental devices with experimental fuel.

Loop facilities equipment:

- Circulation circuit (pumps, heat exchangers, pressurizers, etc);
- Cladding integrity control and coolant gamma-activity systems;
- «Detonating mixture» burning circuit;
- Systems providing water condition, feeding and sampling, ion exchange filters;
- Emegency cooling systems;
- Vacuum channel insulation equipment;
- Automatic parameter measuring and registration system.

Introduction

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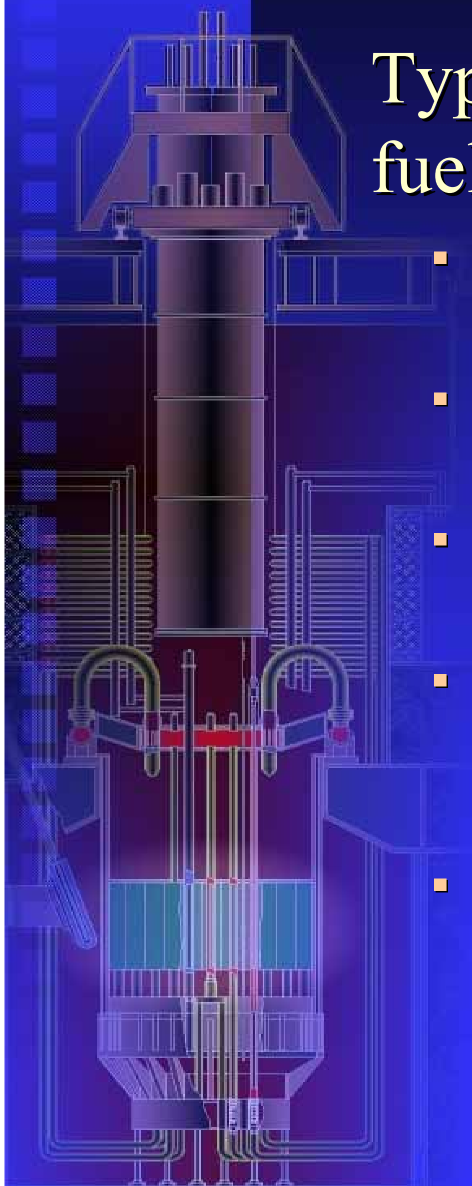
Loop facilities	PV-1	PV-2	PVK-1	PVK-2	PVP-1	PVP-2
Number of channels	2	2	2	2	1	1
Coolant	Water	Water	Water, boiling water	Water, boiling water	Water, Steam	Water, Steam
Maximum parameters						
Pressure, MPa	17	18	17	18	8.5	20
Temperature, oC	340	340	340	350	500	500
Flow rate, t/h	16	16	14	14	0.675	10
Coolant activity, Bq/kg	$3.7 \cdot 10^8$	$3.7 \cdot 10^8$	$3.7 \cdot 10^8$	$3.7 \cdot 10^8$	$3.7 \cdot 10^8$	$3.7 \cdot 10^{11}$

Introduction

The current fuel tests programs

1. The tests for improving and upgrading the Russian PWR (WWER) fuel:
   - long term tests of short-size rods with different modifications of cladding and fuel pellets;
   - reirradiation of NPP refabricated and full-size fuel rods up to achieving 80 MW·d/kg U;
   - continuation of the RAMP type experiments at high burn-up of fuel;
   - experiments with leaking fuel rods at different burn-up and under transient conditions;
   - in-pile tests with simulation of LOCA and RIA type accidents.
2. Testing of the LEU research reactor fuel within the framework of the RERTR programme:
   - tests of pin-type mini elements with different modifications of U-Mo fuel compositions;
   - tests of full-size fuel assemblies with pin-type and tube-type elements.

1. Experimental techniques for WWER fuel testing in the MIR reactor



Types of irradiation devices for testing of the WWER fuel:

- dismountable devices for testing short-size (≤ 250 mm) fuel rods, up to 4 such rigs can be installed one over another in one loop channel;
- dismountable and instrumented device for testing fuel rods ~1000 mm, containing up to 19 fuel rods;
- device for combined irradiation of refabricated (≤ 1000 mm) and full-size fuel rods (≤ 3500 mm) of spent NPP fuel;
- dismountable devices for power cycling and RAMP experiments of instrumented fuel rods by displacement or rotation of the absorbing screens in the experimental channel;
- instrumented device for testing under LOCA and RIA conditions.

1. Experimental techniques for WWER fuel testing in the MIR reactor

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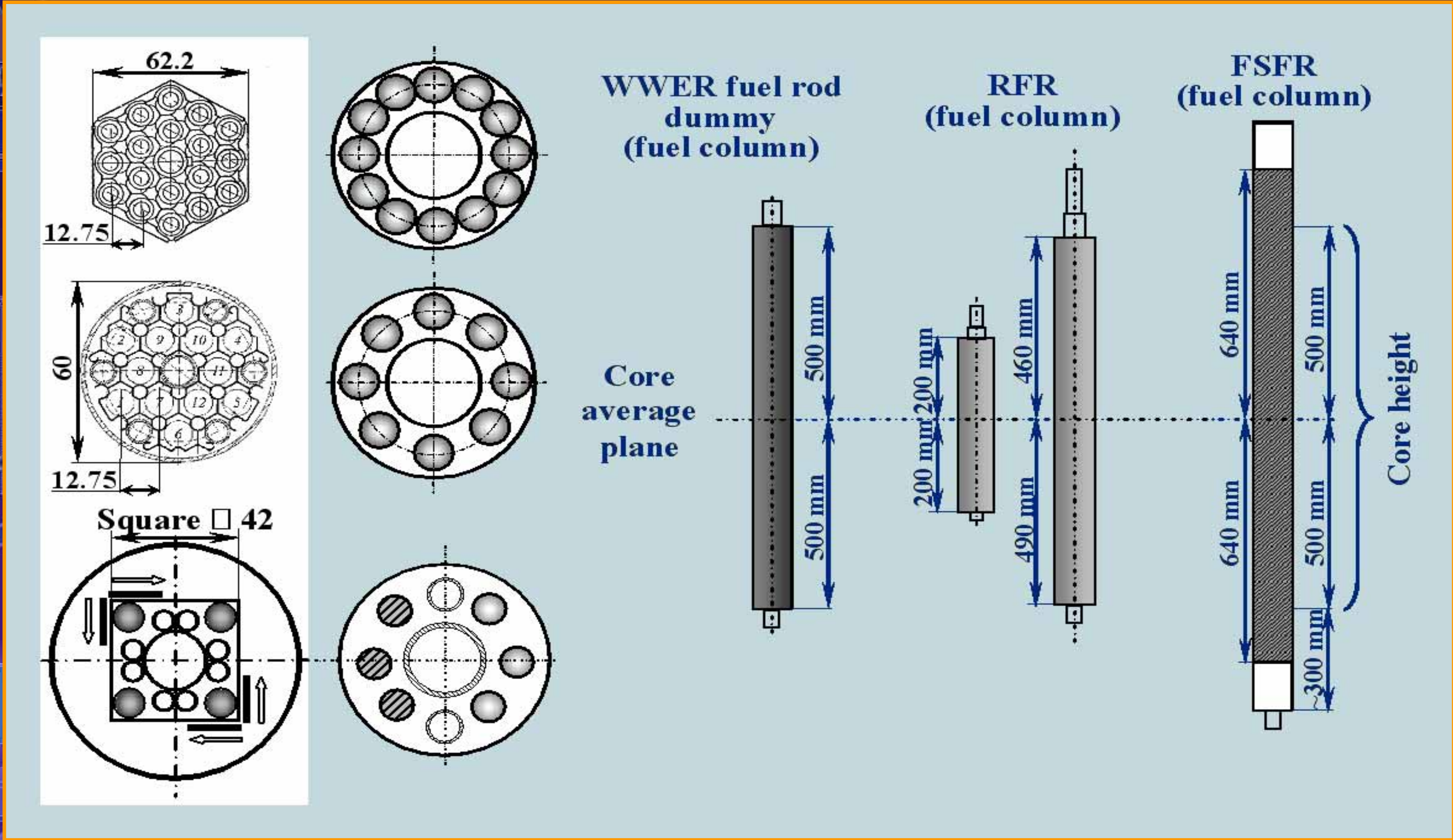
Lay-out of the WWER experimental fuel rods in irradiation rigs



1. Experimental techniques for WWER fuel testing in the MIR reactor

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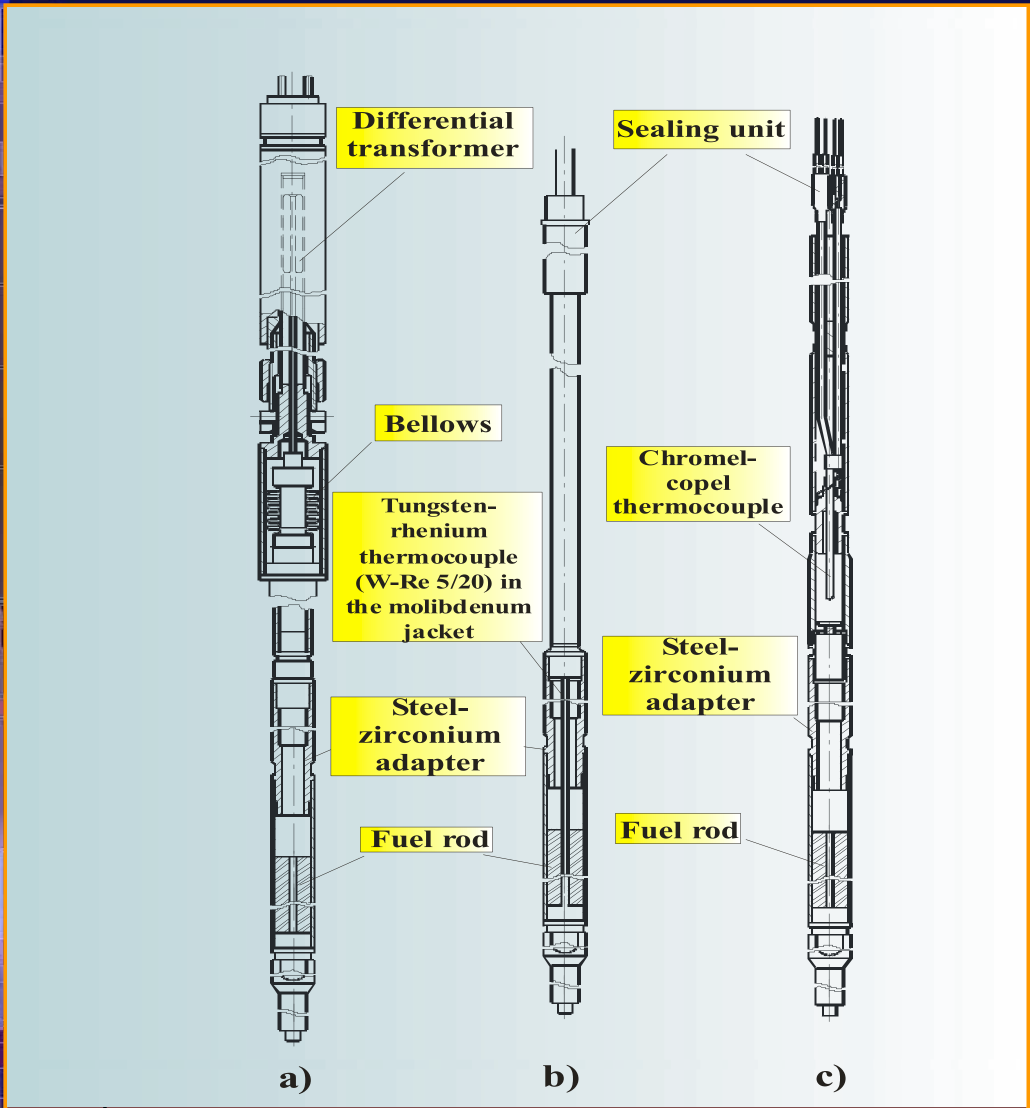
Types and characteristics of instrumentation for in-pile measurements

Parameter	Transducer	Measurement range	Measuring error	Sensor dimensions, mm	
				Diameter	Length
Coolant (T_c) and cladding temperature (T_{cl})	Chromel-alumel thermocouple	up to 1100 °C	0.75%	0.5	
Fuel pellet temperature (T_f)	Chromel-alumel thermoprobe	up to 1100 °C	0.75%	1…1.5	
	W-Re thermoprobe	up to 2300 °C	~ 1.5%	1.2…2	
Cladding elongation (δL)	Liner differential inductosyn transducer (LDIT)	(0…5) mm	± 30µm	16	80
Diameter change (δD)	LDIT	(0…200)·µm	± 2µm	16	80
Gas pressure inside of fuel rod (P_f)	Bellows rolling diaphragm + LDDT	(0…20) MPa	~ 1.5 %	16	80
Neutron flux (F)	Rh-, V-, Hf -direct-charge detector	$10^{15}…10^{19}$ $m^{-2}s^{-1}$	~ 1%	2…4	50…100
Volume steam content in coolant (β)	Cable-type resistivity sensor	20…100%	10%	1.5	

1. Experimental techniques for WWER fuel testing in the MIR reactor



Instrumented fuel rods: (a) - with cladding elongation transducer;

(b) – with thermoprobe;

(c) - with fission gas release gauge .

2. The program and main results of WWER fuel testing in the MIR reactor

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2.1. Irradiation of refabricated and full-size WWER fuel rods

The test objective is to investigate the behavior of fuel under higher burn-up and to achieve higher burn-up for preparation of RAMP, LOCA and RIA tests.

General data on irradiation of the WWER refabricated and full-size fuel rods:

Type of fuel rod	Number of fuel rods	Length of fuel rods, m	Initial burnup, MWd/kgU	Final burnup, MWd/kgU	Liner power, kW/m
WWER-1000	2	3.53	49…50	62…63	18…30
WWER-1000	1	0.95	49	63	19…31
WWER-440	2	2.42	61	72	17…28
WWER-440	1	0.94	60	72	19…31
WWER-1000	5	3.53	53…55	74…75	18…24
WWER-1000	3	0.4	53…58	74…78	18…24

2. The program and main results of WWER fuel testing in the MIR reactor

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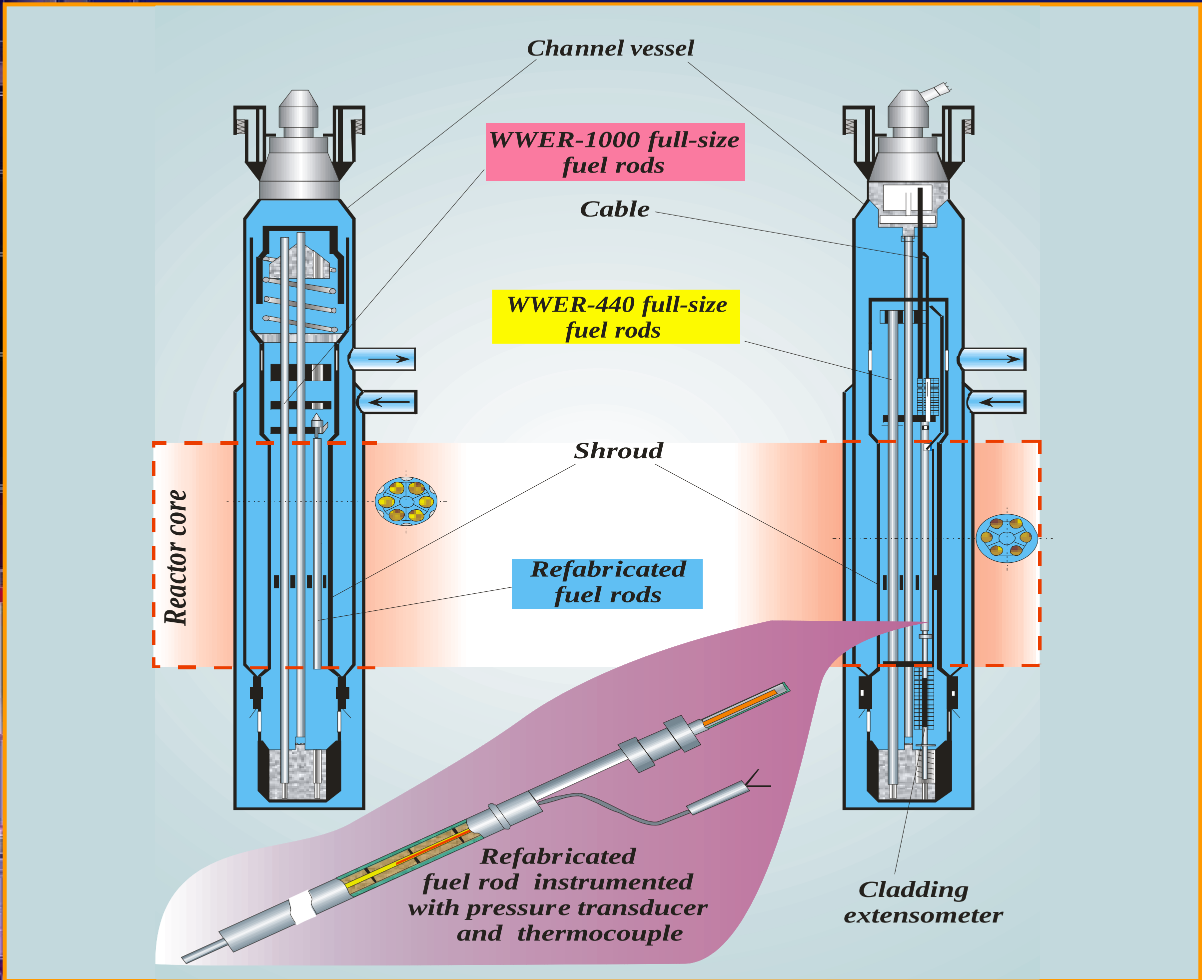
2.1. Irradiation of refabricated and full-size WWER fuel rods



Dismountable experimental devices meant for WWER full-size and refabricated fuel rods testing

2. The program and main results of WWER fuel testing in the MIR reactor

2.2. Testing under power ramping conditions

By now 14 RAMP tests with the WWER fuel rods have been performed in the MIR reactor. Experimental fuel rods of different modifications, as well as full-size and refabricated fuel rods were tested at burn-up values from ~10 MWd/kgU up to ~70 MWd/kgU.

In 2008 it is planned to finish RAMP experimental program for WWER-1000 fuel with high burn-up ~80 MWd/kgU.

2. The program and main results of WWER fuel testing in the MIR reactor

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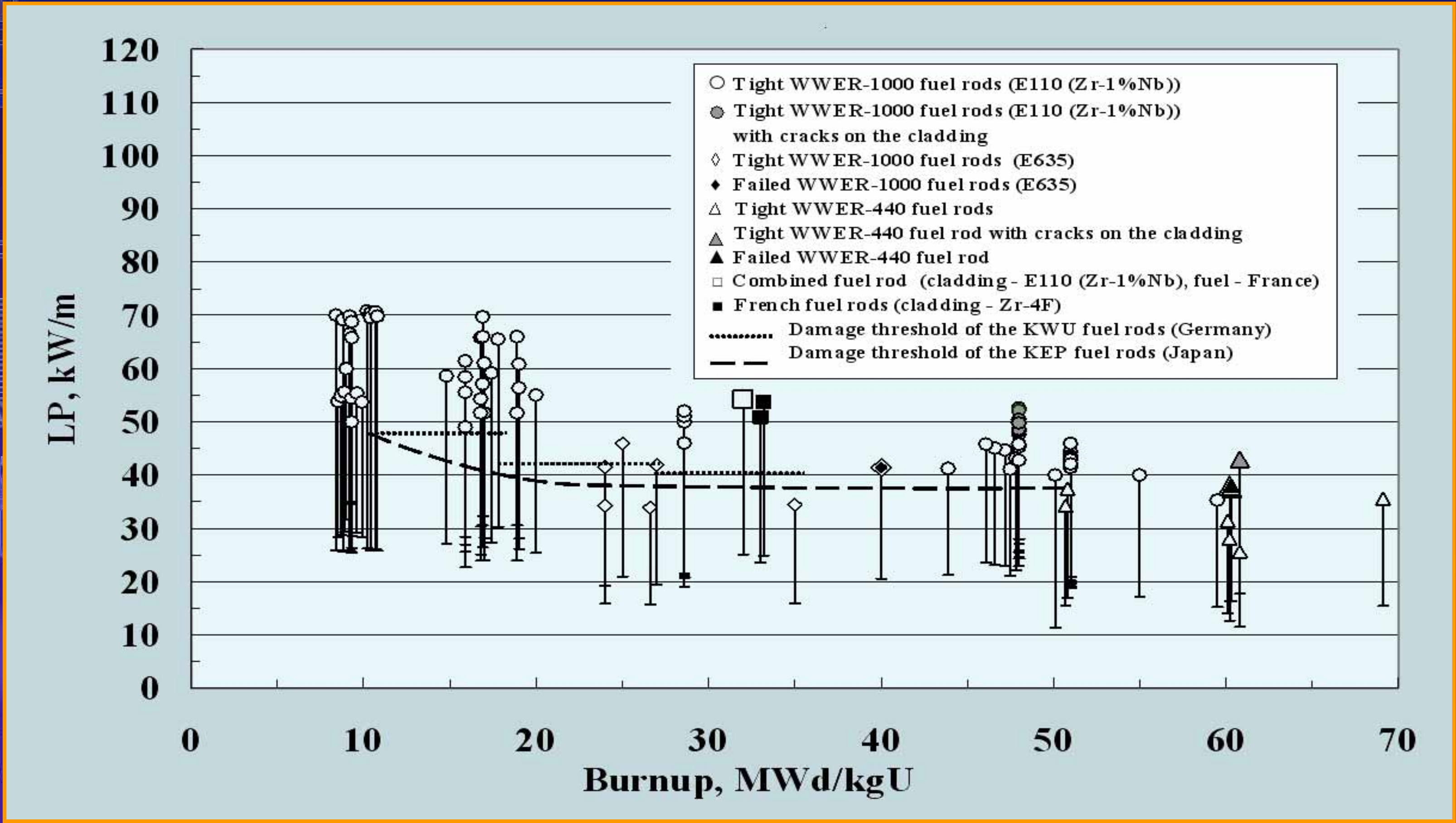
2.2. Testing under power ramping conditions

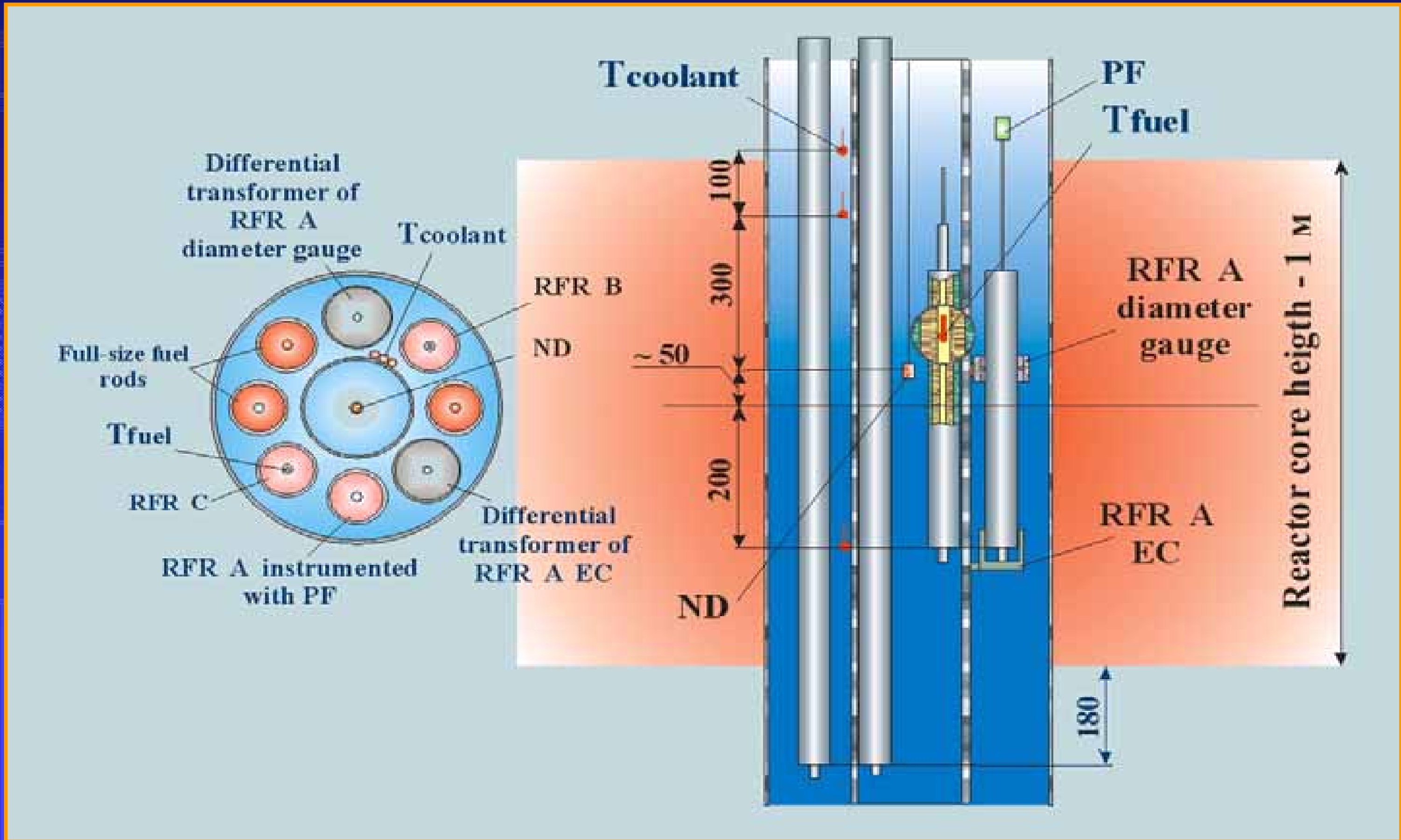
RAMP tests liner power amplitudes versus WWER fuel rods burn-up



2. The program and main results of WWER fuel testing in the MIR reactor

2.2. Testing under power ramping conditions

Disposition of fuel rods and sensors in the irradiation device



2. The program and main results of WWER fuel testing in the MIR reactor

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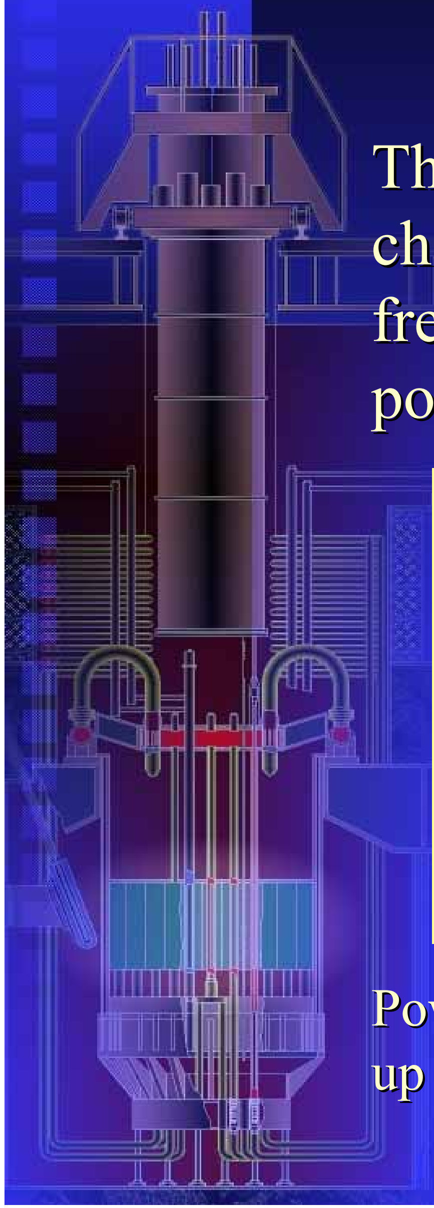

2.3. Testing under power cycling conditions

The objective of testing is to obtain experimental data that characterize a change in the cladding strain, gas pressure in the free volume of a fuel rod, fuel temperature in course of daily power cycling.

Type of fuel rod	Number of fuel rods	Instrumentation	Burnup, MWd/kgU	Initial LP, kW/m	LP increase step, kW/m	LP increase rate, kW/m/min
WWER-440	1	P_f, δL, δD	51	19	10	0.3
WWER-440	5	T_f	51…60	15…19	8…10	~ 0.3
WWER-440	4	T_f	52...61	18	11	~ 0.9
WWER-1000	2	T_f, L	49…50	21; 21*	9; 21*	0.6; 0.9*
WWER-1000	2	P_f, δL	49...50	21	9	0.6

Power cycling tests will be continued for WWER-1000 fuel rods with burn-up ~ 60 MWd/kgU and higher in 2007–2008.

2. The program and main results of WWER fuel testing in the MIR reactor

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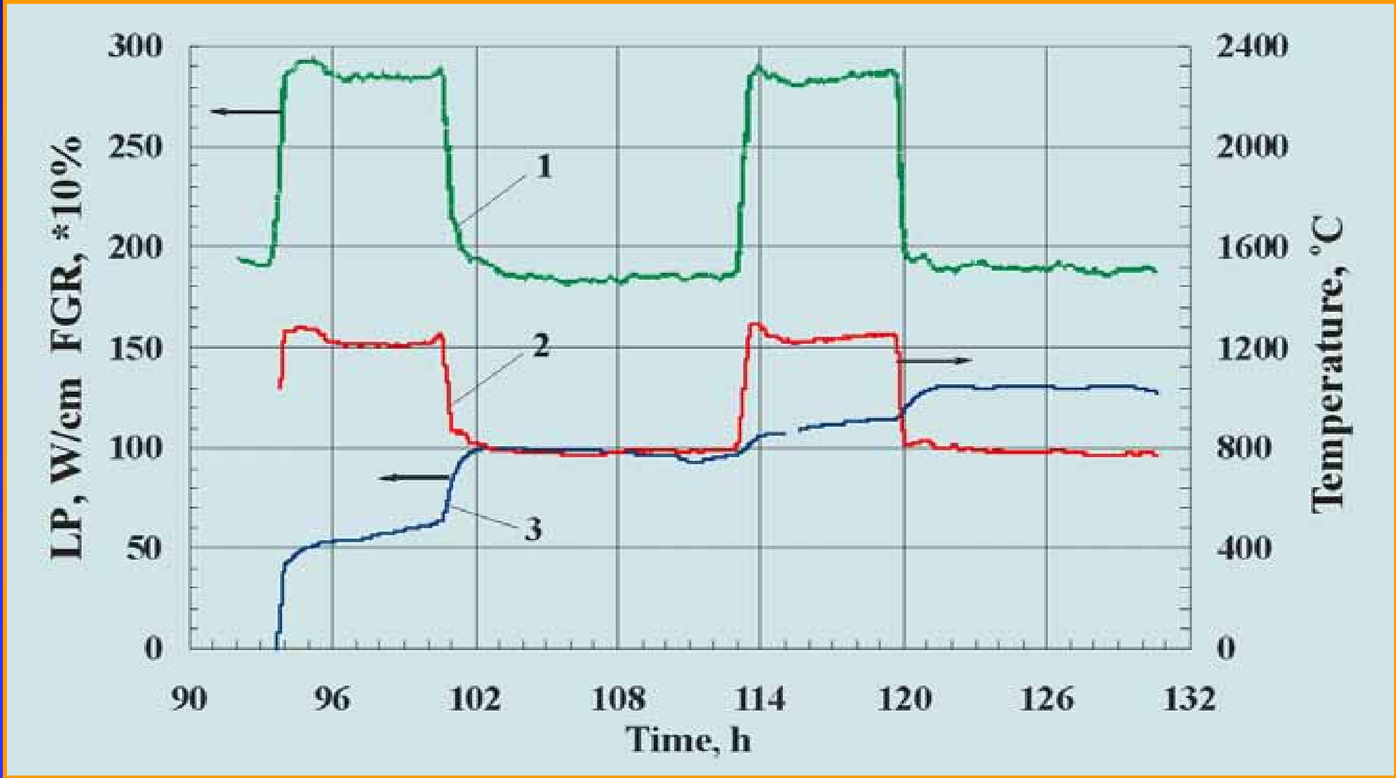
2.3. Testing under power cycling conditions

Change of the maximum linear power of fuel rod A (1), fuel temperature of fuel Cand (2), fuel rod A fission gas release (FGR) (3) during testing



2. The program and main results of WWER fuel testing in the MIR reactor

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2.4. Testing under fuel rod drying, overheating and reflooding conditions (LOCA)

A series of tests was performed with the WWER-440 and WWER-1000 fuel assembly fragments under different phases of design-basis LOCA conditions. The objective of the tests is to verify or refine serviceability criteria of fuel rods.

Experiment	Number of fresh fuel rods	Number/burn-up, of irradiated fuel rods, MWd/kgU	Pressure in loop, MPa	Implemented temperature range, °C	Instrumentation	Fuel rod status	
						Non-failed	Failed
SL-1	18	-	12	530…950	Tc, T_{cl}, T_f, F, β	+	
SL-2	19	-	12	Up to 1200	-”-		+
SL-5	6	1/52	4.9	750…1250	-”-		+
SL-5P	6	1/49	6	700…930	-”-	+	
SL-3	19	-	4	650…730	Tc, T_{cl}, T_f, F, P_f	+	
LL-1	19	3/50	4	550...850	-”-	+	

LOCA experiments will be continued for WWER-1000 fuel rods with burn-up ~60 MWd/kgU and higher in 2007–2008.

2. The program and main results of WWER fuel testing in the MIR reactor

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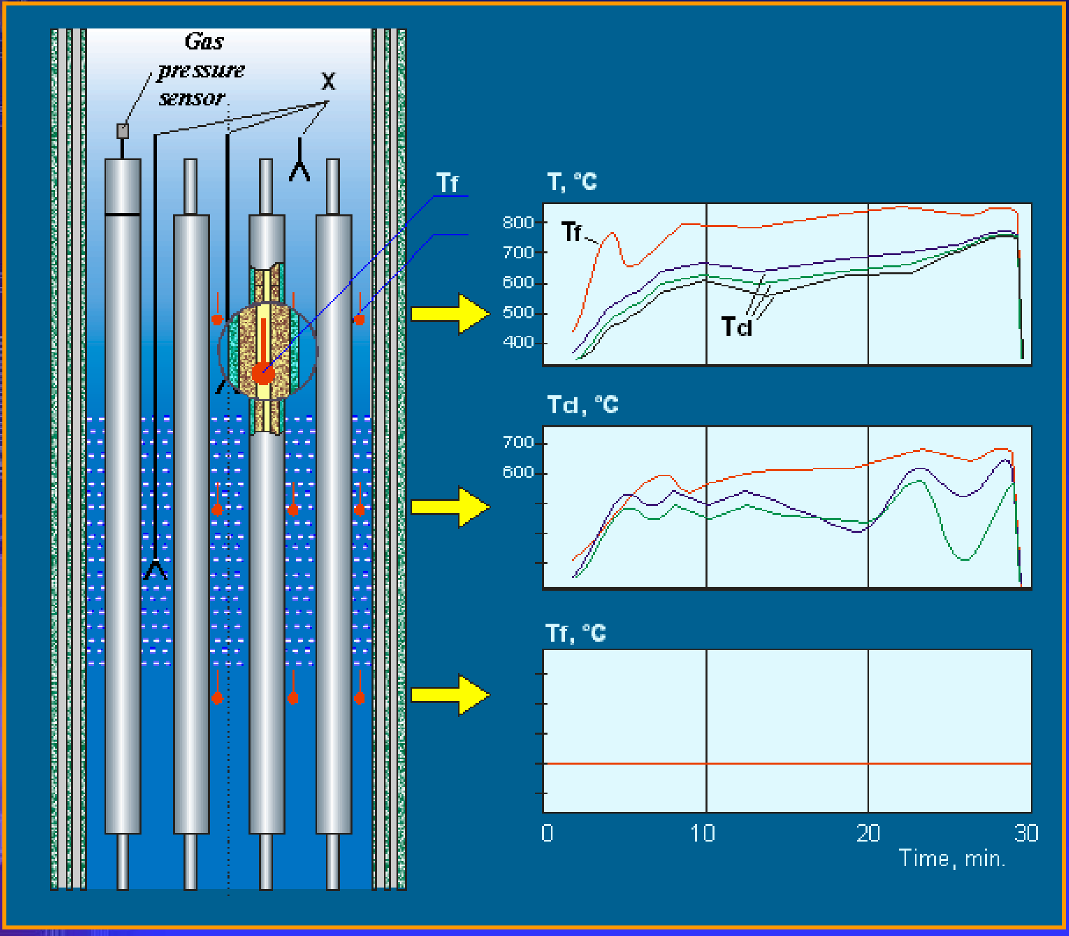
2.4. Testing under fuel rod drying, overheating and reflooding conditions (LOCA)



Simulation of loss of coolant and partial core dryout accident (LOCA)

2. The program and main results of WWER fuel testing in the MIR reactor

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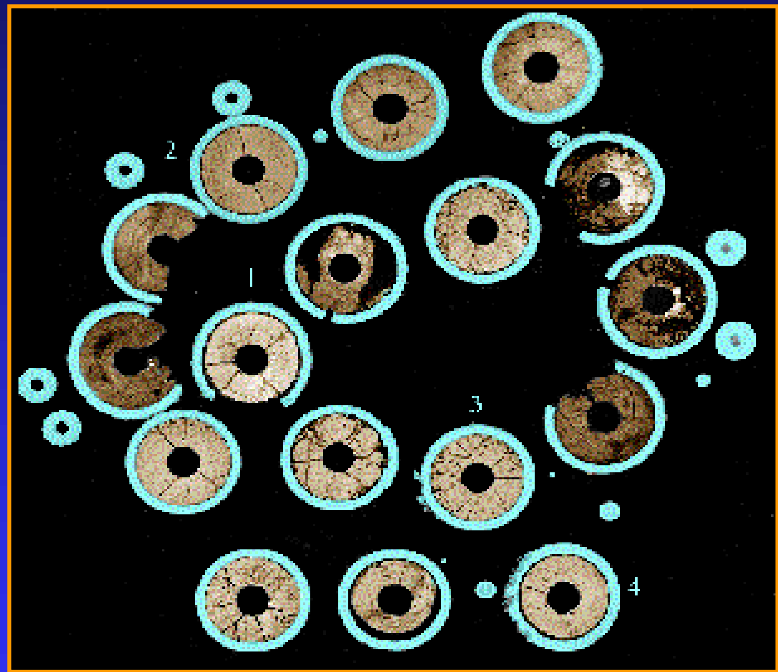
2.4. Testing under fuel rod drying, overheating and reflooding conditions (LOCA)



Simulation of loss of coolant and partial core dryout accident (LOCA)

2. The program and main results of WWER fuel testing in the MIR reactor

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2.5. Testing of the WWER-1000 high burn-up fuel rods under design-basis RIA conditions

A program and technique for testing of WWER-1000 fuel were developed to obtain experimental data on behaviour of high-burnup fuel rods under design-basis RIA conditions.

WWER-1000 reactor parameters of the design-basis RIA conditions are as follows: power ratio in impulse ~2, half-width of impulse – (2…2.5) s, power rise duration ~1s.

In the MIR loop channel it is possible for high burn-up fuel to provide a rising of liner power in impulse up to ~4.0 times and to control power rise duration from ~0.5s and more.

In 2006 was started experimental program and were provided 2 experiments for WWER-1000 fuel rods with burn-up ~50 MWd/kgU, in 2007–2008 the program will be continued.

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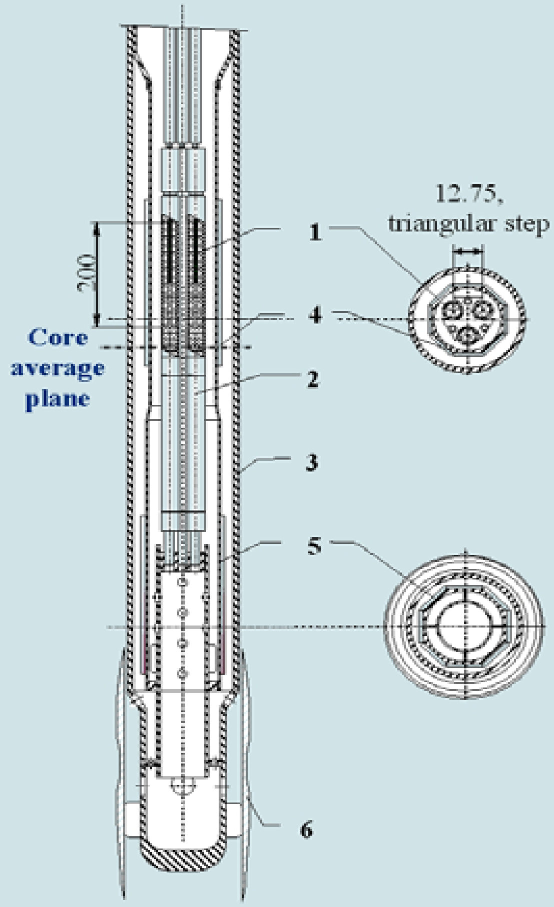
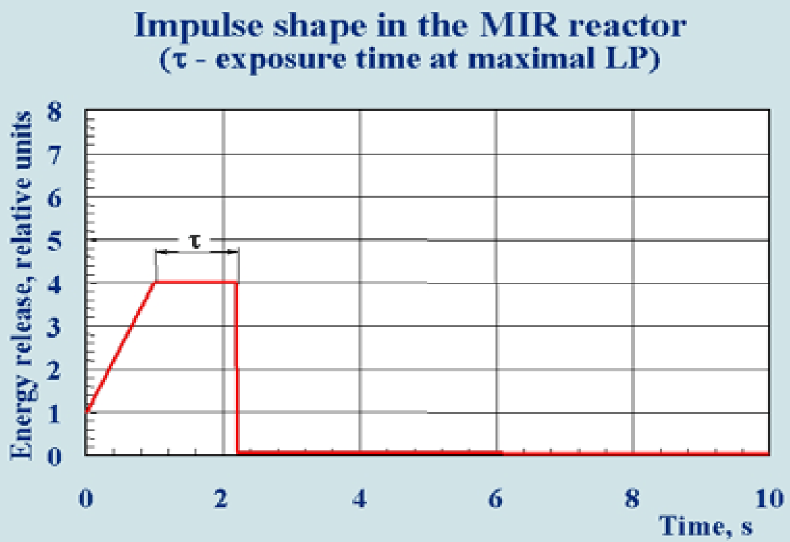
2.5. Testing of the WWER-1000 high burn-up fuel rods under design-basis RIA conditions





Schematic diagram of the irradiation rig designed for RIA test in the MIR reactor
1 – fuel rods, 2 - conductor pipes, 3 – shroud, 4 –upper shield, 5 –lower shield, 6 – loop channel vessel

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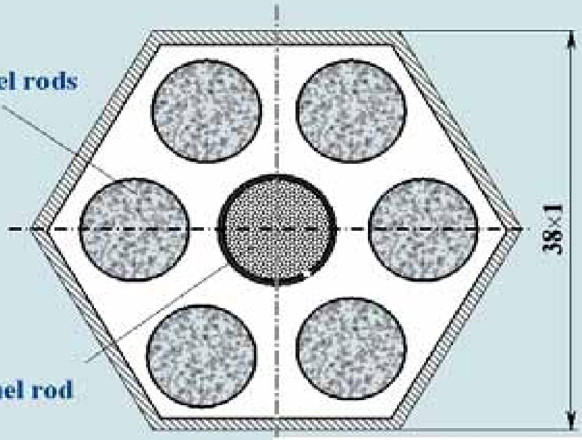
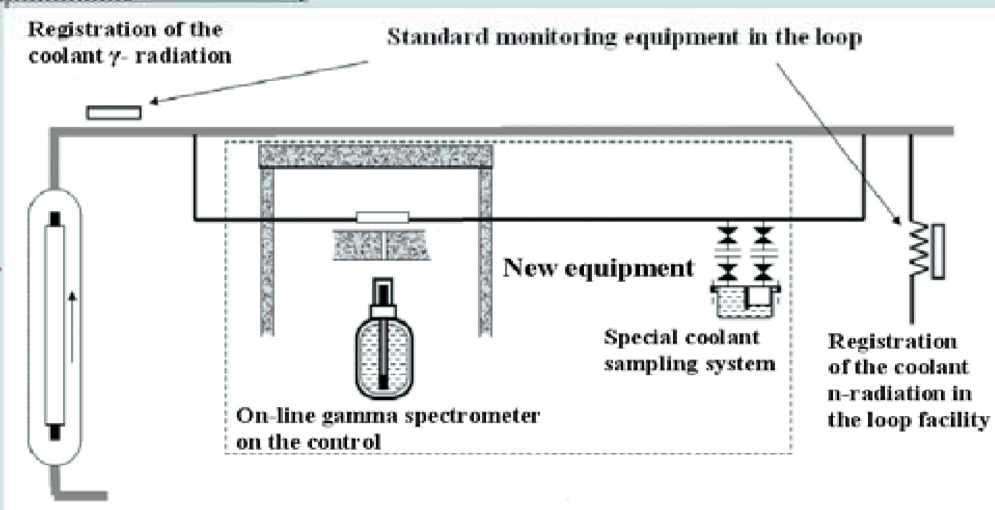
2.6. Leaking high burn-up fuel rods testing



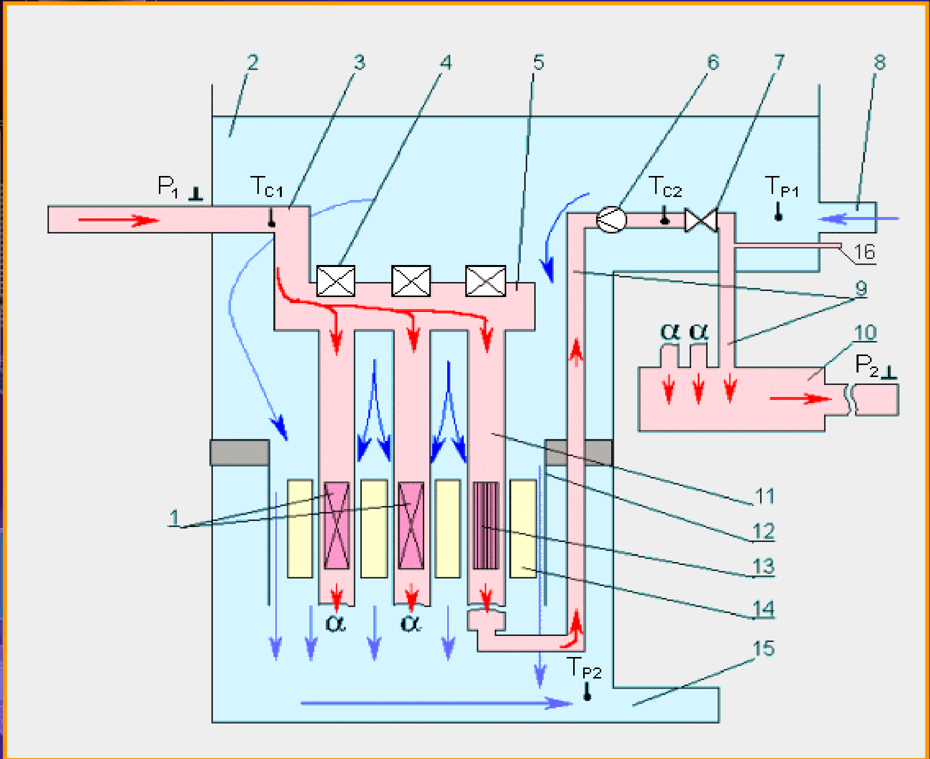
Cross-section of irradiation rig for testing defective fuel rod

Lay-out of the special equipment for determination of fission product release into the coolant of the loop facility primary circuit in the MIR reactor



3. Testing of the LEU research reactor fuel

In the MIR reactor will be continued testing of the LEU research reactor fuel within the framework of the RERTR program, and in March 2007 will be started testing of 4 full-scale IRT-4 type fuel assemblies.



T_{C1}, T_{C2}; T_{P1}, T_{P2} – thermometers;
P_1; P_2 – pressure transducer.

1 – operating FA; 2 – reactor pool;
3 – primary coolant inlet; 4 – channel plug;
5 – inlet collector; 6 – flowmeter;
7 – adjustable valve; 8 – coolant inlet to the pool; 9 – RC outlet pipe; 10 – outlet collector; 11 – reactor channel;
12 – reactor casing; 13 – irradiation rig;
14 – beryllium block; 15 – coolant outlet from the pool; 16 – coolant sampling to cladding leakage detector.

3. Conclusion

Several types of irradiation devices have been designed for testing WWER-type fuel rods under steady state parameters; daily power cycling with a fast power change (power ramping); design-basis accidents have been developed. The current fuel tests program aimed at improving the Russian operating WWER-440 and WWER-1000 fuel should be finished in the MIR reactor in 2008.

At present prospective program of fuel testing for evolutionary design of WWER with improved economics and safety (project AES-2006) is being created. The testing program of upgrading fuel AES-2006 reactors will start in 2008.

3. Conclusion

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In the MIR reactor will be continued testing of the LEU research reactor fuel within the framework of the RERTR program.

Upgrading of gas cooled PG-1 loop with increasing coolant outlet temperature up to 1100°C for in-pile investigations HTGR fuel and steam cooled PVP-2 loop with increasing the pressure up to 22.5 MPa for testing fuel and constructive materials sub-critical water-cooled reactor are scheduled.

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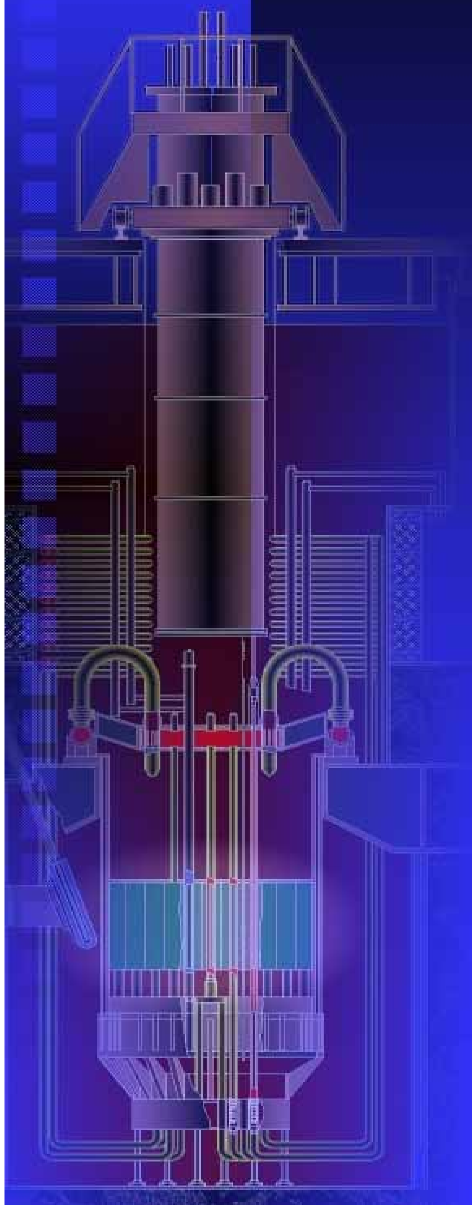

Thank you for your attention!