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MAIN TRENDS AND CONTENT OF WORKS ON FABRICATION OF FUEL RODS WITH MOX FUEL FOR THE WWER-1000 REACTOR

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Abstract

The main trends of production of pellet MOX-fuel for the VVER reactors using the trial-experimental equipment at SSC RF RIAR are set forth. The main realized parameters of fabrication of MOX-fuel pellets are presented. The content of the reactor tests program is considered with allowance for their licensing requirements for the VVER reactors.

1 INTRODUCTION

An important part of the stage of utilization of Russian weapon Pu excess is fabrication of 3 FA with MOX-fuel for the 4-th unit of the Balakov NPP, experimental substantiation of their serviceability during full-scale tests and obtaining the license for operation of MOX-fuel in the VVER- 1000 reactors.

Realization of such a decision supposes implementation of a complex of scientific-technological, test and research works to substantiate the creation of a new type of nuclear fuel as well as organizational and technical works to substantiate its commissioning. SSC RF RIAR possesses a definite technological base, modem research equipment and qualified personnel to fulfil such work. An advantage of RIAR choice to conduct this class of works is the fact that on one site there are technological sections, research reactors and a complex of hot cells for post-reactor material science investigations that allow license tests of fuel in the full volume and at the earliest possible date.

2.MAIN TRENDS OF WORKS ON FUEL TECHNOLOGY AT SSC RF RIAR

SSC RF RIAR has accumulated considerable experience on development and fabrication of ' various fuel rods, their pre-reactor and reactor tests, further material science investigations.

A trial-industrial complex is created at the Institute, at which fuel rods and FA with vibropac oxide uranium and MOX-fuel for fast reactors have been fabricated for more than 20 years. Up to now: in the BOR-60 reactor there are 500 spent FA with oxide uranium fuel and more than 500 FA with MOX-fuel; in the BN-600 - 6 FA **with** MOX and 4 FA with uranium fuel, in the BN-300 - 2 FA with MOX and 7 FA with uranium oxide fuel.

From other types of fuel rods and FA that were developed and fabricated in the Institute the following can be divided:

- fuel rods based on pellet oxide uranium fuel;
- fuel rods of the BOR-60 reactor with pellet MOX-fuel;
- fuel rods with dispersive fuel compositions;

- fuel rods of the BOR-60 reactor with metallic non-alloyed U and U-Pu fuel, with metallic alloyed U-Zr and U-Pu-Zr fuel;
- fuel rods of the BOR-60 reactor with cermet U-Pu fuel.

The technological sections for fuel production and fuel rods fabrication are maintained in the working state. The maintenance personnel-have sufficiently high qualification.

3. CONTENT OF WORKS ON PELLET MOX-FUEL AT SSC RF RIAR

The first stage of mastering the conversion process of Russian weapon Pu plans fabrication and testing of 3 trial FA (1000 fuel rods) with MOX-fuel in the 4-th unit of the Balakov NPP. Taking into account the short time of the test program, up to now the greatest preparedness of Russia is seen to produce fuel at the BTU glove box section of SSC RF RIAR.

The BTU production section has a license for the right of handling fissile materials, according to which 2 kg of Pu-239 or 5 kg of U with 90% enrichment are allowed at the working place.

The fabricated and controlled pellets are sent to the technological section of assembling, control and packing of fuel rods based on the production room with large-sized shielded boxes.

The following scheme of interaction of the project participants must be provided during fabrication of fuel rods with MOX-fuel for 3 FA:

- fabrication and delivery of initial U and Pu dioxides powders to SSC RF RIAR;
- fabrication and delivery of the relevant set of fuel rod claddings to SSC RF RIAR;
- fabrication of MOX-fuel pellets at the SSC RF RIAR technological section;
- fuel rods assembling, their sealing and certification;
- shipment of prepared fuel rods to the FA plant-manufacturer;
- assembling of 3 FA, their transportation to the Balakov NPP and testing in the 4-th unit.

In this case fabrication of the WER-1000 fuel rods is preceded by fabrication of a batch of trial fuel rods to conduct license tests at the MIR reactor.

The design of fuel rods with the pellet MOX-fuel for the WER-1000 reactor in terms of its characteristics must be identical to the regular fuel rod with pellet fuel based on U oxide with the average Pu content in FA - 3.4%.

The indispensable condition of fuel rods fabrication for 3 FA is the maximum compliance with their fabrication technology under plant conditions.

The basis of the requirements for the delivered U and Pu dioxides powders can be the characteristics of powders used in industrial fabrication of fuel rods for the WER reactors.

4. SCHEME AND POSSIBILITIES OF PELLETS AND FUEL RODS FABRICATION SECTIONS

The MIMAS technology spent under industrial conditions and that underwent comprehensive checking was taken as the basis for MOX-fuel pellets fabrication.

The BTU glove box section consists of 13 heavy glove boxes (BTU 1-130 and 2 boxes (BTU-A and BTU-B) with enhanced protection served using tight manipulators. The boxes

Milling, granulation, sieving
(*) Mill, 2 kg/h ; Granulation facility, Grinding of pellets
(*) Grinding machine

Storage of special products
Storage (U5% enrichment up to 35 kg; Pu up to 2 kg)

Preparation of powders, control of pellets
VLKT-500 scales
Mixing of powders, pressing of pellets
Mixer, press 10 t
(*) Pellet pressing facility, 20 kg/shift
pressing of briquettes and pellets, drying,
sintering
Calcination apparatus, 1000°C
Press 63 t; furnace 1700°C, loading of 2 kg

Drying of briquettes and pellets
Induction furnace 1500°C, VLKT-2000 scales

Pressing of pellets
Press 63 t,
Pellet pressing facility, 5 kg/shift

Drying and sintering of pellets
Furnace 1700°C, loading of 2 kg

Control of pellets (geometrical characteristics)
Pellet diameter measurement facility

Assembling of columns, fuel rods

Welding of fuel rods (up to 1100 mm)

Control of fuel rods tightness

Loading of sets of pellets to transport canisters

Decontamination and loading of canisters to transport
container. Control of Pu distribution.

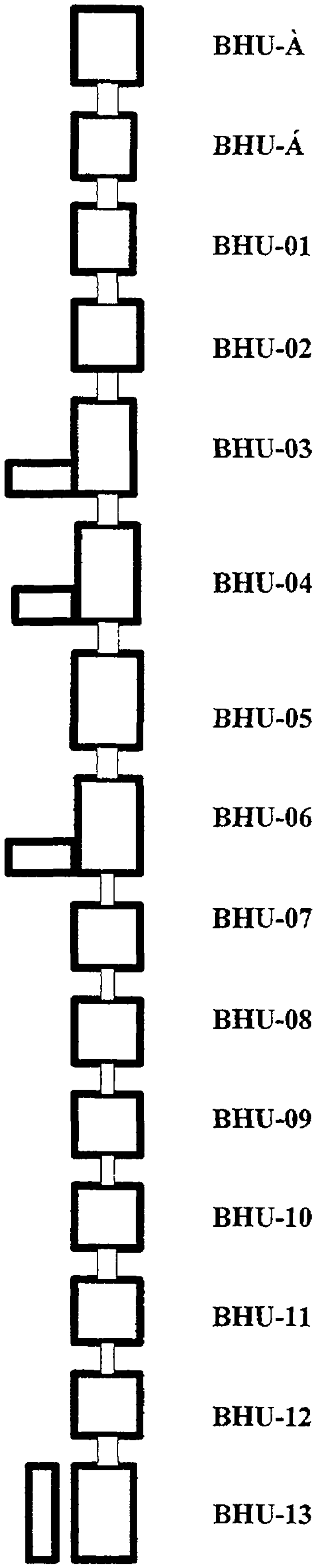


FIG.1. *Placement of the equipment for pellets fabrication for 1000 fuel rods*

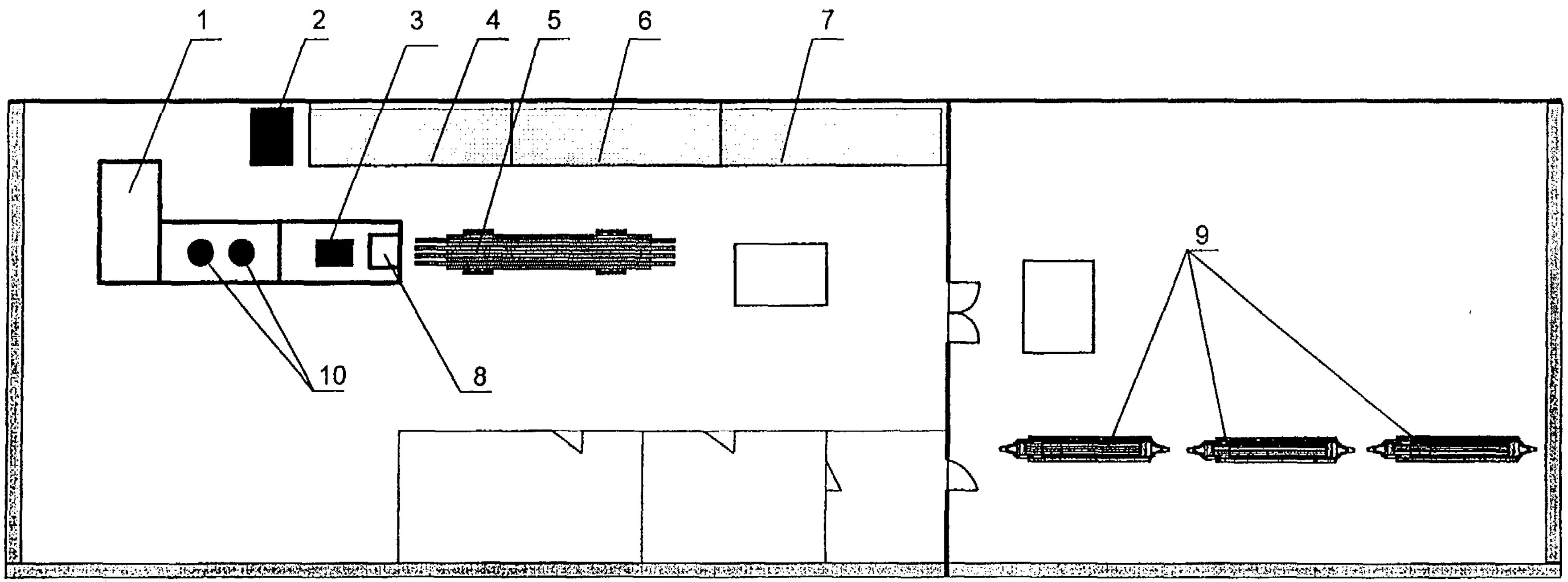


Fig.2. Scheme of layout

1 - box (1800б700) for recieving, weighing and drying MOX-fuel; 2 - the stand of ultrasound check; 3 - the stand of butt-resistance welding (BRW); 4 - the stand of X-ray check; 5 - freight truck; 6 - the stand for checking integrity of fuel pin cladding; 7 - ACORT installation; 8 - technologic prechamber; 9 – TK-C2 container; 10 - furnace for pellet drying

are equipped with all engineer-technological systems necessary for normal work. All boxes are connected by the common transporter line. Each box is a box design of thin-sheet stainless steel. The box vessel is lined with steel sheet of biological protection with the front wall, up to 50 mm thick. Under each box there is a room for equipment and auxiliary systems (vacuum, electrical, testing instruments). The chain equipment can be quite easily re-adjusted to fulfil operations with fuel rods of various designs and sizes.
The purpose of the boxes and equipment placed in them is shown in Fig. 1. To fabricate the MOX-fuel pellets to assemble 1000 fuel rods of the VVER-1000 type, the section is supplied with the following:

- ball mill/mixture loading of 1.5-2 kg/;
- automatic press /up to 15-20 kg/shift/;
- mixer-homogenizer /loading of 2 kg powder/;
- sintering furnace /10 kg pellets per cycle/.

Meeting the requirements of high quality of the products assumes organization and control at all stages of the process, including:

- input control of the initial powder and documents;
- operational control of the technological process;
- control of the prepared pellets.

Besides, the progress of the technological process is under selective periodical control by the available techniques: porosity and structure of pellets, Pu distribution, oxygen/metal ratio, chemical composition, residual gases, etc.

All operations of assembling, fabrication and control of fuel rods with MOX-fuel are typical for the technological fabrication process of fuel rods with pellet uranium fuel and are conducted in the following order:

- input control of assembling parts and fuel;
- drying of pellets;
- making up of fuel columns;
- assembling of fuel rods and filling with helium;
- sealing with welding;
- decontamination;
- control operations;
  packing and transportation to the FA plant-manufacturer.

Trial fuel rods with MOX-fuel for irradiation in the MIR reactor are fabricated at the existing technological section.

Realization of the program of fabricating 1000 experimental fuel rods of the VVER reactor - 1000 fuel rods with pellet MOX-fuel requires the creation of a new section of fuel rods fabrication on the existing production areas using the large-sized shielded boxes and providing them with the pipelines of engineer systems.

The layout of the equipment at the fuel rods fabrication section is presented in Fig.2.

The obligatory types of equipment include the contact-butt welding and ultrasound control stand for fuel rods.

5. FUEL LICENSING

Licensing of a new fuel type assumes the availability of the experimental and calculated information on its behavior in all design states of the reactor facility.

5.1. **The initial position to form the program of works to substantiate licensing is, thus, determined by the following information:**

license requirements for fuel characteristics (including the requirements for FA and fuel rods) identified as fuel with serviceability. The main normalized parameters:

- pressure of helium and GFP under the cladding by the end of campaign;
- maximum fuel temperature;
- plastic deformation of the cladding due to its interaction with fuel;
- content of hydrogen in the cladding material;
- crack-formation in the fuel rod cladding (pressurized corrosion cracking);
- mechanical strength of the cladding in the axial direction;
- temperature of the fuel rod cladding at maximum design accident;
- oxidation depth of the 'fuel rod cladding (as part of the wall thickness);
- fuel enthalpy during the RIA type accident;
- power margin before fuel melting;
- ultimate number of untight fuel rods (for gas and fuel in the core);
- probability of fuel rod failure during operation.

main types of operating conditions of the WER-1000 reactor typical for normal operation (due to technical characteristics of the reactor) and emergency design situations determined by the Chief designer, namely:

- long operation at nominal power modes;
- bringing the reactor to power and its shutdown;
- change of the reactor power (FA while changing its placement in the core);
- after-loading modes (power ramp);
- emergency situation (event) related to fast unauthorized introduction of positive reactivity;
- break of the heat removal from the fuel rods surface (partial drying of the surface, heat removal crisis, type 1);
- operation of untight fuel rods.

license requirements for fuel must be met at all the design operation modes of the reactor.

5.2. **Test and investigation types:**

A set of tests and investigations is aimed at determining the values of fuel license parameters during realization of all design situations typical for the power reactor. The basic criterion of the fuel initial state is its burnup achieved at the regular irradiation parameters (except the tests of untight fuel rods). Therefore, the experimental information to substantiate the fuel licensing is obtained in 2 stages - implementation of reactor experiments modeling the loading modes typical for the reactor design states and post-reactor (nondestructive and destructive) investigations indicating the relevant fuel state (with determination of the license characteristics).

A set of tests includes:

- service-life tests;
- tests in transient modes (including: RAMP tests, manoeuvering experiments, tests of instrumented fuel rods);
- heat removal damage tests (including: tests simulating loss of coolant (LOCA tests), heat removal crisis tests);
- power pulse tests;
- tests of untight fuel rods (including: power pulse tests and RAMP type tests, heat removal damage tests);
- capsule experiments.

A set of post-reactor investigations includes:

- y-scanning;
- profilometry;
- cladding puncture with analysis of amount and composition of intra-fuel rod gas;
- fuel rods dismantling to samples, their preparation and photography;
- a-autoradiography of samples;
- mathematical processing of the results and building of models.

5.3. **Tests of FA mock-up in the MIR reactor:**

Start of the trial operation of new fuel in the power reactor can be provided prior to obtaining the full set of license information by parallel (with license experiments, which cannot be finished before 2006) testing of FA mock-up in the research reactor. In this case the mock-ups in the research reactor are irradiated ahead of schedule as compared to tests of first FA in the VVER- 1000 reactor. Such irradiation is an additional confirmation of fuel serviceability. The test schedule is built on the basis of parameters of standard 3-year utility, the advance of the burnup gained in fuel of the mock-up assembly (the MIR reactor) makes up 1.5 years. Test modes of the mock-up will be deliberately more rigid as compared to the trial operation modes of FA in the VVER- 1000 reactor, which is stipulated by more intense power manoeuvering typical for the research reactor. Rigidity of the irradiation modes of the mock-up in its turn will provide some reliability margin of trial FA.

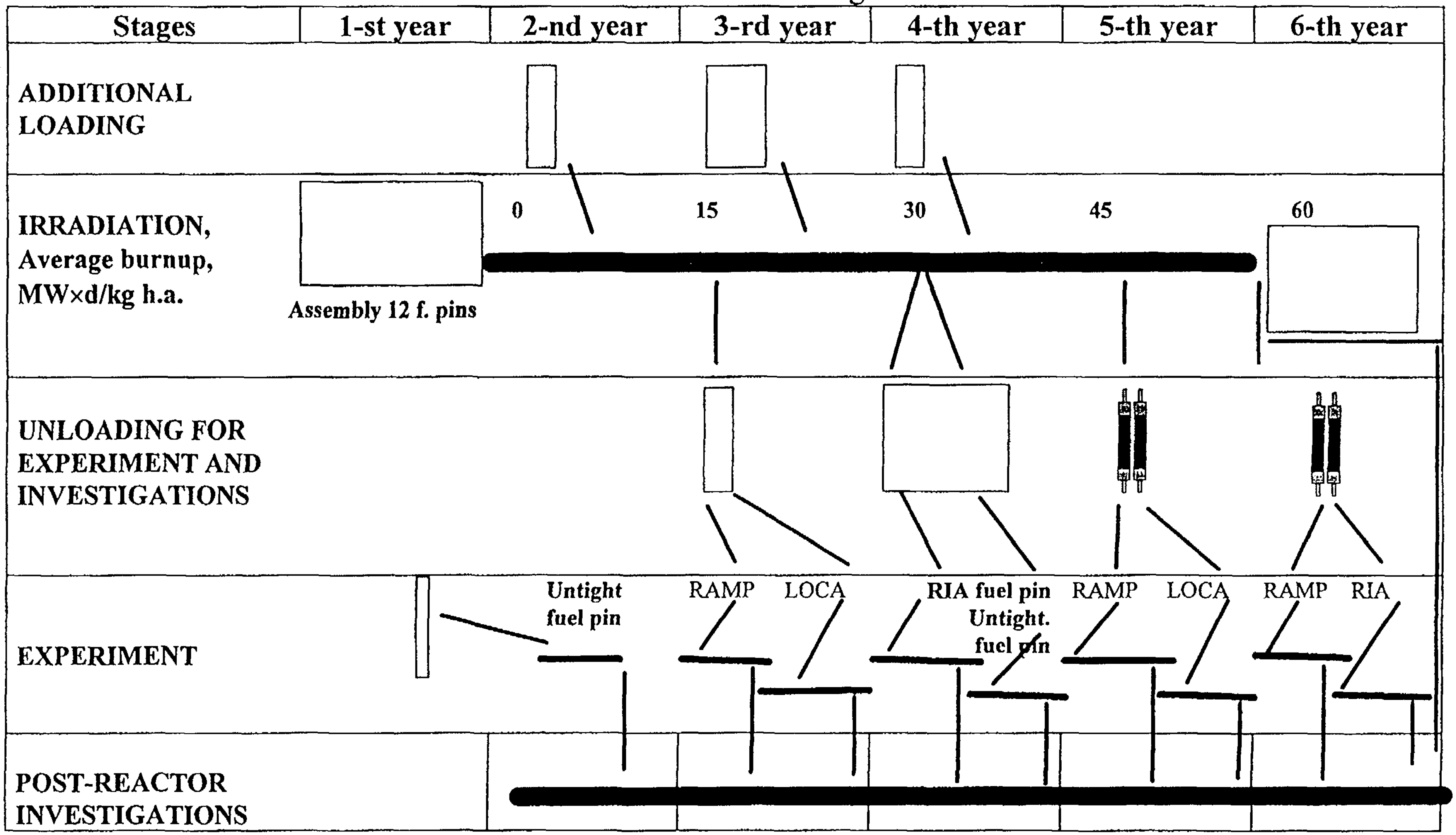
6. CONCLUSION

SSC RF RIAR possesses the necessary technological and test equipment to fulfil the following main works on substantiation of MOX-fuel usage in the VVER reactor:

- fabrication of pellet MOX-fuel for fuel rods in the MIR and VVER reactors;
- fabrication of the VVER-1000 type fuel rods (up to 1000) for tests in the WER reactor;
- fabrication and tests of experimental fuel rods in the MIR reactor within the frames of the licensing program of MOX-FA delivery for irradiation to the WER- 1000 reactor.

Test and investigation schedule to substantiate the vibropac

MOX-fuel licensing

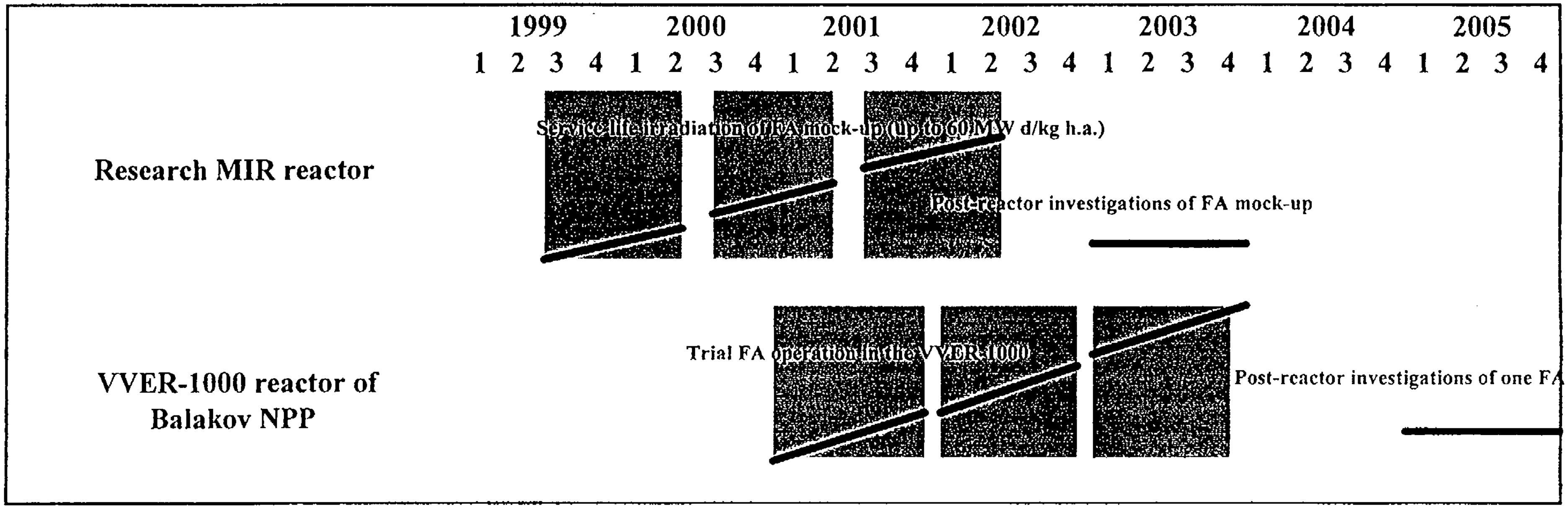


Reactor tests to substantiate MOX-fuel

I	Name	Purpose and content	Initial fuel state	Test results, investigated processes, mechanisms and parameters
1	**Service-life tests**	**Determining the state of fuel rods (fuel and cladding) in the range of design burnup of the VVER fuel, preliminary irradiation for further experiments (RAMP, LOCA, RIA).**	**Fresh fuel**	**Depend on burnup - medium pressure in the fuel rod cavity, deformation parameters, hydrogen saturation and oxidation depth of cladding, fuel structure and its characteristics**
2	**Tests in transient modes**	**Determining the state and kinetics of change of state parameters for fuel rods under *conditions modeling regular transient modes* corresponding to the reactor manoeuvering operations**	**Fresh fuel, irradiated fuel**	**Depend on parameters of power change and initial state of fuel rod - gas release, mechanical characteristics of fuel and cladding, critical linear *thermal* loading**
2.1.	RAMP tests	Determining the state (change of state) of fuel rods under power ramp conditions	Fresh fuel, irradiated fuel	Depend on the rate, power ramp, initial and final power level, burnup - gas release, relaxation thermo-physical characteristics, threshold thermal loadings
2.2.	Manoeuvering experiments	Investigation of state change of fuel rods under conditions modeling the reactor manoeuvering modes, including cyclic ones.	Irradiated fuel	Depend on frequency and parameters of power manoeuvers (regular scenarios), burnup - gas release and relaxation thermo-physical parameters
2.3.	Tests of instrumented fuel rods	Direct (during operation) and constant change of parameters in the fuel rod cavity during modeling of transient modes (step-by-step change of power)	Irradiated fuel	Depend on parameters of power and burnup change - gas pressure in fuel rod cavity, fuel temperature, change of fuel column geometry; revealing the change extremums of the registered parameters
3.	**Heat removal damage tests**	**Determining the characteristics of state change of fuel rods under reduced (as compared to nominal modes) heat removal intensity conditions**	**Fresh fuel, irradiated fuel**	**Depend on parameters of heat removal - changes of state**
3.1.	Tests simulating loss of coolant (LOCA)	Integral experiment on study of behavior of fuel rods included in the bundle (FA) under cladding surface drying conditions and fuel overheating	Fresh fuel, irradiated fuel	Depend on temperature, flow rate and modular state of coolant, burnup and linear power - time of preserving serviceability of fuel rod, character of cladding damage, change of fuel structure, reta of oxidation and corrosion processes (including steam-zirconium reaction), FP yield
3.2	Heat removal	Experiment to study the fuel properties after	Fresh fuel,	The same with more rigid conditions up to maximum design

ı	Name	Purpose and content	Initial fuel state	Test results, investigated processes, mechanisms and parameters
.	crisis tests	realization of fuel rod overheating modes (heat removal crisis, type 1)	irradiated fuel	accident conditions
4.	**Power pulse tests**	**Determining the state of fuel rod after power pulse (a series of pulses)**	**Fresh fuel, burnt-out fuel**	**Depend on shape, duration, amplitude, quantity and periodicity of power pulses - fuel enthalpy, destruction threshold, character of cladding destruction and change of fuel structure, FP yield.**
5.	**Tests of untight fuel rods**	**Investigation of peculiar behavior of untight fuel rods in regular and emergency modes**	**Fresh fuel, burnt-out fuel**	**Depend on type, shape, placement and size of cladding defect, burnup, irradiation mode - fuel rod parameters and degree of serviceability**
5.1.	Long tests of fuel rods	Investigation of fuel rod serviceability and estimation of qualitative indices of its operation	Fresh fuel, burnt-out fuel	Depend on irradiation parameters and initial characteristics of defects, burnup - defect development kinetics, time of formation of secondary damages, FP and fuel yield to the coolant, permissible operation time, parameters of cladding degradation and changes of fuel structure.
5.2.	Power pulse tests and RAMP type tests	Investigation of state change of fuel rods in transient (power) modes and at impact thermal loadings	Fresh fuel, burnt-out fuel	Depend on initial defect state, burnup and parameters of power change - enthalpy destruction threshold and linear power, character of cladding destruction, change of fuel structure, FP and fuel yield to the coolant.
5.3.	Heat removal damage tests	Investigation of state change of defect fuel rod with its overheating	Fresh fuel, burnt-out fuel	Depend on temperature, flow rate and coolant modular state, burnup, linear power, initial characteristics of defect - time of preserving serviceability of fuel rod, character of cladding damage, change of fuel structure, rate of oxidation and corrosion processes (including steam-zirconium reaction), FP and fuel yield to the coolant.
6.	**Capsule experiments**	**Investigation of separate ageing and destruction mechanisms of fuel rods accompanying their operation to verify the calculated programs and codes.**	**Fresh fuel, burnt-out fuel**	**A set and parameters of experiments are determined by algorithm and data base of the verified program.**

Schedule of test works with FA mock-ups in the MIR reactor and trial operation of FA in the VVER-1000 reactor.



Note: average annual rate of burnup gain in the FA mock-up fuel in the MIR reactor is specified by the relevant characteristics of the VVER-1000 reactor.