Fabrication possibilities and experience of fuel elements based on high-activity fuel types at the SSC RF RIAR hot laboratories

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Introduction

In the modern stage of nuclear power engineering development the problems of disposing accumulated plutonium (various grades) and minor-actinides (Np, Am, Cm) are of prime importance.
The SSC RF RIAR has developed and is constantly improving scientific principles, engineering approaches and technical means for solving these problems.
At the same time, firstly, the SSC RF RIAR puts a particular emphasis on fast reactors with sodium coolant (BOR-60, BN-600 etc.), which is related to the fact, that it is the fast reactors having hard neutron spectrum that are the most effective both for plutonium disposal accompanied by power generation and MA burning.
Secondly, it is planned, that the procedures and equipment, which were used for vibropac oxide fuel pins fabrication, will be applied to solve these problems. It is explained by the fact, that, as a rule, the fuel to be disposed originally represents oxides (mixture of oxides) in the form of granulated particles. Therefore compositions of fuel portions to be loaded in the cladding tubes can be varied in a wide range. So can shapes, dimensions and irradiation conditions of the fuel pins containing disposed fuel.
The level of radiation hazard of the original product (Pu, Np, Am) to be disposed or the items with this product (specimen, fuel pin or fuel assembly) determines scientific, engineering and technical problems to be solved during this work.
At present, the SSC RF RIAR has designed the equipment and gained the experience in production of granulated oxide fuel, fabrication of fuel pins containing this fuel and also fuel assemblies incorporating such fuel pins.
This equipment and experience are used for:

1. production of fuel containing:
    - weapon grade plutonium dioxide;
    - power-generating plutonium dioxide;
    - recycled plutonium dioxide;
    - neptunium dioxide additives;
    - americium oxides additives;
2. fabrication of:
    - standard BOR-60 fuel pins and FAs;
    - non-standard fuel pins incorporated in the dismantled BOR-60 FA;
    - standard BN-350 fuel pins and FAs;
    - standard BN-600 fuel pins and FAs;
    - refabrication of oxide fuel pins, which were irradiated in power generating rectors of VVER-type, for subsequent irradiation of their fragments in the water loops of testing reactor MIR.

The equipment designed, both fast and thermal reactors (BOR-60, MIR, SM-2, RBT-10) in which specimens, fuel pins and fuel assemblies can be irradiated and a gained experience in carrying out postirradiation material science and radiochemical examinations in hot cells forms the unique process and investigative complex. Its application enables the SSC RF RIAR to solve difficult problems related to the development of new advanced types of fuel, fuel pins, fuel assemblies, reactors and closed fuel cycles.

1 Fuel pins containing vibropac MOX fuel

For 25 years the SSC RF RIAR has been carrying out R&D to validate the closed fuel cycle of the BN-600 reactor, which involves the pyroelectrochemical reprocessing of high-level nuclear fuel in molten salts with subsequent production of granulated MOX fuel suitable for fuel pins fabrication by vibropacking technology. The experience has been gained in designing, manufacturing and operating the equipment for granulated UO_2 and $UPuO_2$ fuels production and fuel pins fabrication. Feasibility of the fuel pin fabrication by vibropacking has been demonstrated in two variants: manual – in the glove boxes and remote – in the hot cells. Application of either variant depends on the fuel activity. Table 1 provides information on fabrication of vibropac fuel pins containing fuels of various activities (various grades)[1].

These fuel pins are characterized by addition of getter in the form of metal uranium particles to vibropac oxide fuel to improve their efficiency. The mass getter content varied within the range of 3-10%.

Table 1.
MOX fuel produced at RIAR

Fuel type	The reactor using this fuel	Number of fuel pins fabricated	Number of FAs fabricated
$UPuO_2$*	BOR-60	15762	426
$UPuO_2$**	-/-	1184	32
UO_2***+PuO_2****	-/-	15	1
$UPuO_2$**	BN-350	254	2
$UPuO_2$**	BN-600	1143	9
$UPuO_2$*	-/-	1016	8

* - weapon grade Pu;
** - power generating plutonium;
*** - plutonium produced by reprocessing of spent fuel at RT-1 facility;
**** - plutonium produced by reprocessing of the BOR-60 (B=24 % h.a.) and BN-350 (B=4,9 % h.a.) spent fuels in RIAR hot cells

Figures 1 and 2 show schemes of MOX fuel pin and FA fabricated at RIAR under the Program on weapon grade plutonium conversion in BN-600.
Three fuel assemblies incorporating such fuel pins were fabricated at RIAR and loaded into the BN-600 reactor for irradiation in 2000. Their irradiation was successfully completed in 2002 after achieving the design burnup of $B^{max} \approx 11$ % h.a. The program on fabrication of fuel pins containing weapon grade plutonium and their irradiation in BN-600 is still under way.
Simultaneously, the SSC RF RIAR continues investigations, developments, in-BOR-60 irradiation and postirradiation examinations of MOX fuel pins having various PuO_2 content (within 2-45%) to study their reliability at superhigh burnups (the burnup has been achieved B^{max} = 32 % h.a.), [2].

2 Vibropac fuel pins containing Np and Am oxides

2.1 ^{237}Np has the highest fraction of the minor actinides in the spent fuel of thermal power generating reactors. That is why a principle emphasis was made on development of the technology for the given element burning. The pyroelectrochemical reprocessing was applied to produce granulated uranium-neptunium oxide fuel: 0,95 UO_2 + 0,05 NpO_2. This fuel together with the additives of metal uranium particles (5 %) was mixed, poured and compacted in the experimental fuel pins, intended for irradiation in BOR-60.
Irradiation conditions of the fuel pins with $UNpO_2$ granulated fuel were typical of the MOX fuel pins and changed during irradiation because of burnup, FA relocations and changes in the reactor power:$T_{clad.}^{max}$=600…680°C; q_l^{max}=450…530 W/cm.

2.2 The fuel pins, that were irradiated up to the burnup B^{max} = 13,7 and 20% h.a., were found to be leak-tight, and no anomalies of the main postirradiation properties (dimensions and corrosion damage of cladding, fuel structure and density, etc.) were observed (fig.3).

2.3 The procedure of the pyroelectrochemical reprocessing of spent fuel, which had been developed at RIAR, was successfully applied to produce granulated UPuAm oxide fuels of different compositions (table 2).

Table 2.

AMOX fuel produced at RIAR

Fuel composition (mass fraction), %	Isotopics of fuel components
95 U + 2 Pu + 3 Am	$^{234}U/^{235}U/^{236}U/^{238}U \approx 1/75/9/15$ $^{239}Pu/^{240}Pu/^{241}Pu/^{242}Pu \approx 65/21/10/4$ $^{241}Am \approx 100$
79 U + 18 Pu + 3 Am	- " -
47 U + 51 Pu + 2 Am	- " -

The fuel pins with AMOX fuel are being prepared for irradiation in the BOR-60 reactor.

3 Fuel production, fuel pins and FAs fabrication in hot cells

All the operations of the pyroelectrochemical reprocessing of high-level nuclear fuel in molten salts resulting in granulated MOX fuel production suitable for fuel pin fabrication by vibropacking technology are performed in the hot cells, which are equipped with viewing systems (lead glass) and mechanical manipulators.
Fuel pins containing high-active fuel are fabricated in hot cell KL-03 equipped with viewing systems (lead glass) and mechanical manipulators. Figures 4 and 5 provide the flowsheet of their fabrication and the equipment layout in KL-03 [3].
The BN-600 fuel assemblies are fabricated in hot cell RF-2 equipped with viewing systems (lead glass) and mechanical manipulators. The equipment layout in this hot cell is presented in fig.6.
Experimental capabilities of RIAR have greatly increased due to irradiation of the fuel pins incorporated into the experimental dismountable FA in the BOR-60 core. This FA design makes it possible to dismantle it in the hot cell at the interim stage, withdraw several fuel pins for inspections, reassemble the fuel pins inspected, reload the fuel assembly in the core and continue its irradiation, The dismountable FA is similar to the standard FA by design (fig.7,8), so it can be irradiated in any cell of the BOR-60 core.
A long experience has been gained in fabrication and application of dismountable FAs (Table 3). Hot cells located in 160 (BOR-60) and 118 (Material Science Division) buildings are used for assembling and dismantling these fuel assemblies and also for withdrawing and reassembling fuel pins.

Table 3.

Dismountable BOR-60 FAs

FA No	Fuel type in fuel pin	Number of FA reassemblings	Achieved B^{max},% h.a.	Note
VS-26E	$UPuO_2$**	4	13,2	Clad. EP-450
VS-27E	$UPuO_2$**	3	11,6	-/-
VS-103E	$UPuO_2$**	2	15,5; 32,3	-/-
VS-114E	$UPuO_2$**	2	29,2	-/-
VS-216E	$UPuO_2$*** $UPuO_2$** $UNpO_2$	3	9,5 10,1 20,0	Recycled PuO_2 -|- Burn. MA
VS-217E	$UPuO_2$**	-	6,1	45% PuO_2
VS-263E	UPuN*; ZrPuN*; PuO_2*+MgO	-	6,1	40…60% Pu

Conclusion

The engineering capabilities and the previous experience to produce granulated oxide fuel (MOX, AMOX, etc), fabricate oxide fuel pins and oxide FAs, irradiate them into reactors and carry out their post irradiation examinations in the hot cells of the SSC RF RIAR – all is used for solving the problems of modern nuclear power engineering and advanced nuclear reactors of IV-th generation.

References

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