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High burnup UO_2 fuel pellets with dopants for WWER

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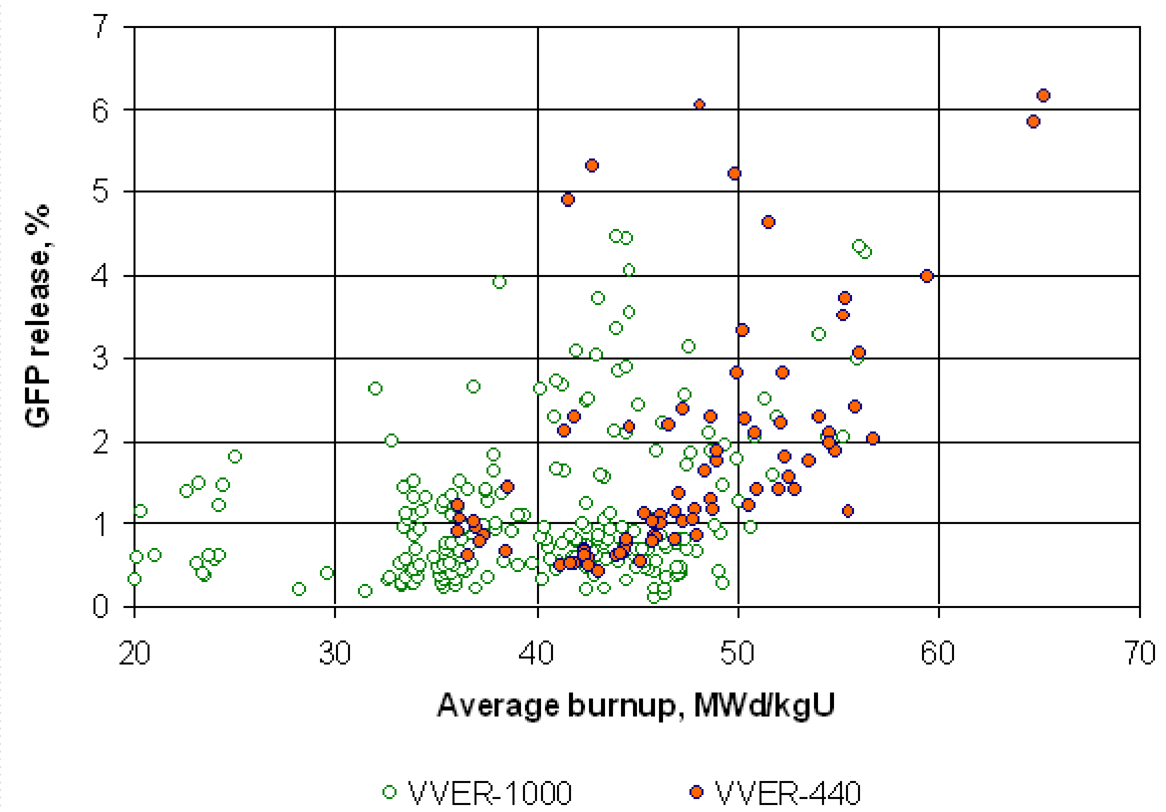
High burnup UO_2 fuel pellets with dopants for WWER

The currently achieved level of design and technology developments provided for the implementation of the fuel cycle (4x1) in WWER at the maximal design burnup of 56 MW·d/kgU per FA. Presently in Russia the program is under way to improve the technical and economic parameters of WWER fuel cycles characterized by an increased fuel usability.

To meet the requirements placed on the new fuel that ensures the reliable operation under conditions of higher burnups complex activities are under way to optimize the composition and microstructure of fuel pellets as applied to WWER.

This paper describes a general approach to providing the stimulated composition and microstructure of fuel via introducing various dopants. Aside from this, the paper presents the experimentally results of studies into the main technologic and operational characteristics of microdopants containing fuel pellets including higher grain sizes, pores distribution and oxygen to metal ratio.

Problems of high burnup



As the burnup increases (more that 50 MW·d/kgU) fission gas products (FGP) releases grow.

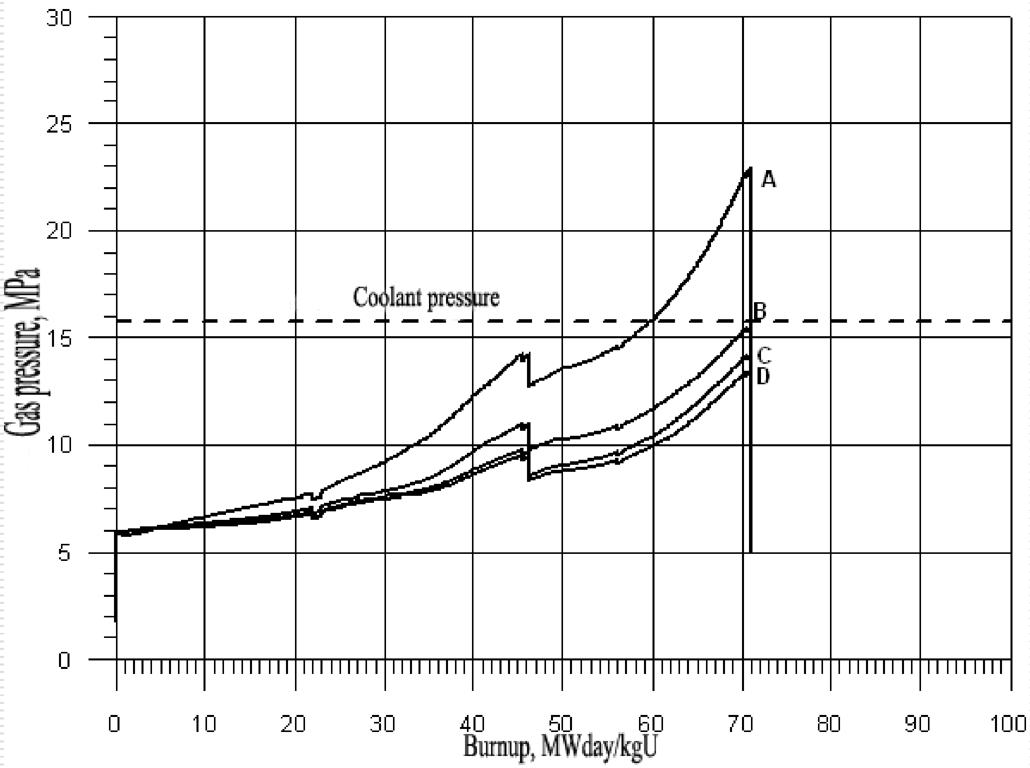
Pimenov Yu.V. , Smirnov V.P., Markov D.V. et al PIE results of high-burnup VVER FA. IAEA Technical co-ordination meeting High burnup experience and economics. Sofia (2006)

Ways of optimizing UO_2 fuel microstructure to provide for higher burnup

The possible way of resolving the adverse problems relating to a higher burnup is to use fuel having larger grain sizes and the optimized pores structure that is capable of retained fission gas products within pellets.

Lysikov A.V., Novikov V.V., Kuleshov A.V. et al. Modified fuel for WWER-1000 reactors to assure high burn-up and optimization of fuel cycles. Nuclear and Radiation Physics (Proc. 6th Int. Conf., Almaty, 2007).
Novikov V.V., Bibilashvili Yu.K., Reshetnikov F.G. et al. Development of low-strain resistant fuel for power reactor fuel rods. IAEA. Technical Committee Meeting on Improved Fuel Pellet Materials and Designs. IAEA-TECDOC-1416. Vienna (2003) 297-306.

Design analisis of influence produced by initial technologic characteristics of fuel material on gas pressure in fuel rod



A – standard fuel (dg=8 mkm, Popen=1 %, x=0.003)

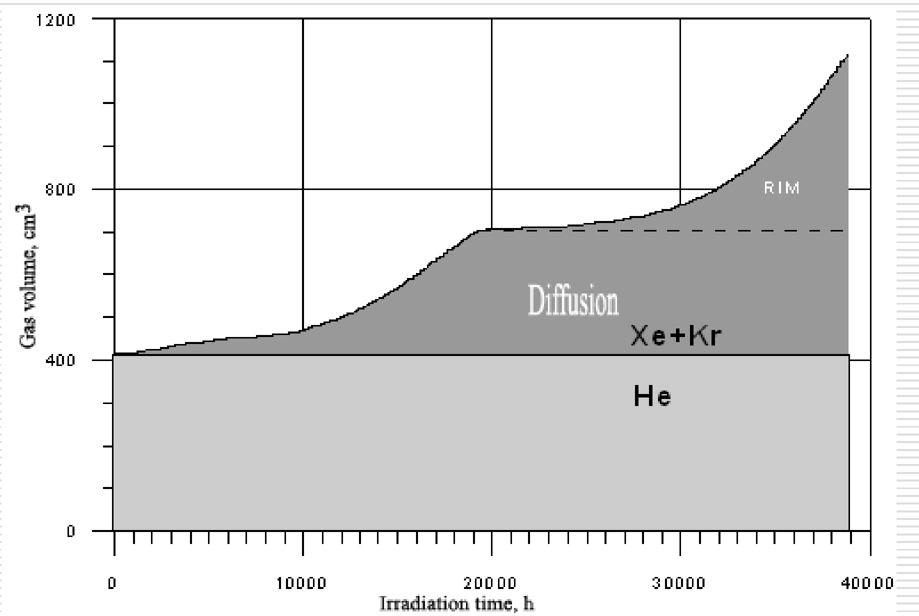
B – modified fuel (dg=25 mkm, Popen=1 %, x=0.003)

C – modified fuel (dg=25 mkm, Popen=1 %, x=0.001)

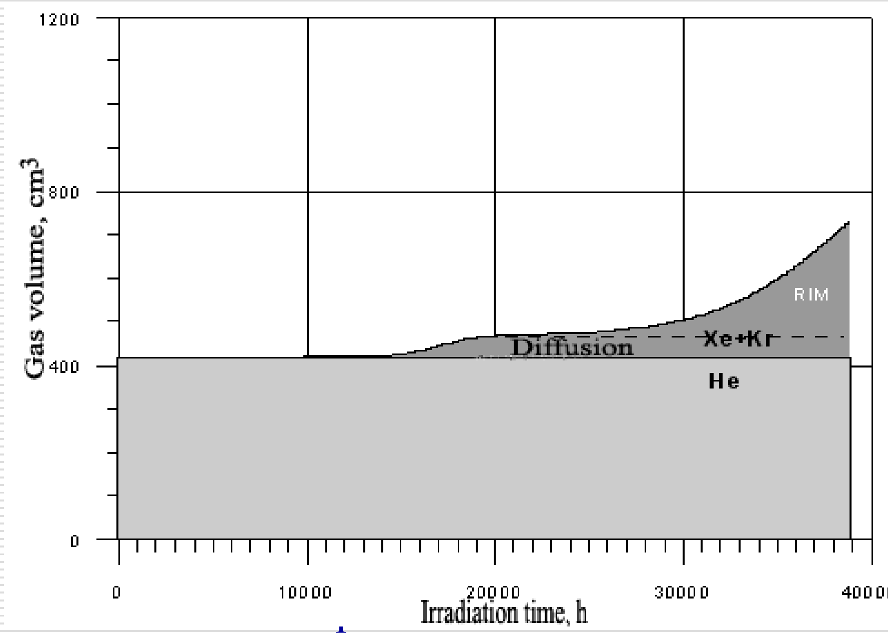
D – modified fuel (dg=25 mkm, Popen=0.05 %, x=0.001)

Khvostov G., Novikov V., Medvedev A., Bogatyr S. Approaches to Modeling of High Burn-up Structure and Analysis of its Effects on the Behaviour of Light Water Rector Fuels in the START-3 Fuel Performance Code. (Proc. 2005 Water Reactor Fuel Performance Meeting. Kyoto, 2005). 992-1009.

Design analisis of contribution made by thermal diffusion and low temperature mechsnisms of gas releases into composition of mixed gases under fuel rod cladding for fuel produced by standard and promising processes



Standard fuel



Promising fuel

Khvostov G., Novikov V., Medvedev A., Bogatyr S. Approaches to Modeling of High Burn-up Structure and Analysis of its Effects on the Behaviour of Light Water Rector Fuels in the START-3 Fuel Performance Code. (Proc. 2005 Water Reactor Fuel Performance Meeting. Kyoto, 2005). 992-1009.

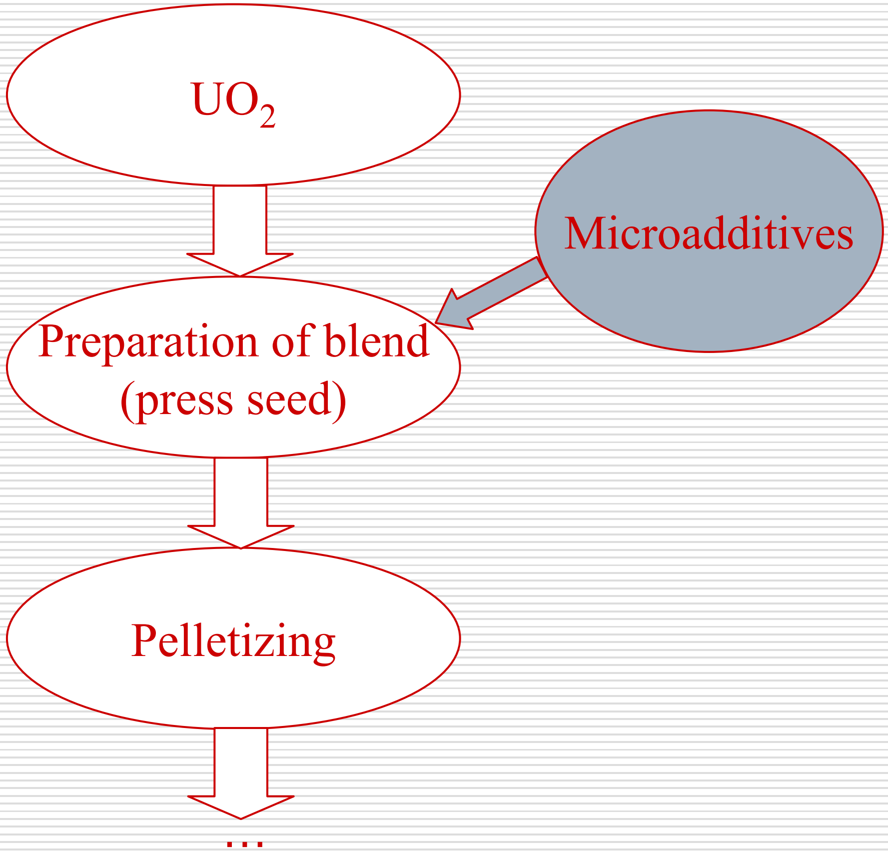
UO_2 fuel microstructure optimization to provide for higher burnup

The most suitable of changing grain sizes is to apply various microadditives that accelerate growth of grains.

In view of this at JSC "VNIINM" a series of activities were accomplished to search for additives, their preparation, technologic means of their introduction into UO_2, to study the new fuel properties as well as the controlling procedures.

Several types of oxide additives and the method of their introduction during the blend preparation were selected.

The results of the investigations are given below.



Lysikov A.V., Novikov V.V., Kuleshov A.V. et al. Modified fuel for WWER-1000 reactors to assure high burn-up and optimization of fuel cycles. Nuclear and Radiation Physics (Proc. 6th Int. Conf., Almaty, 2007).

Investigation of modified fuel technologic properties

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First of all the important properties of fuel such as its density and thermal stability (resintering) were investigated.

The density of fuel pellets was studied by immersion technique.

Parameter	Standard	+ dopants 1 (Al-Si-Fe-O)	+ dopants 2 (Al-Si-O)	+ dopants 3 (Al-Nb-O)
Density, g/cm^3	10,55	10,52	10,54	10,56
Resintering, %	0,215	0,175	0,121	0,113

It is evident from above given results that the selected additives that meet the specified requirements for fuel pellets do not lead to substantive changes in their properties. The lower resintering of the pellets containing the additives is explained by the effect produced by larger grain sizes.

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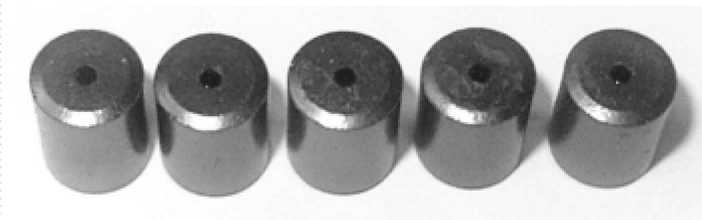
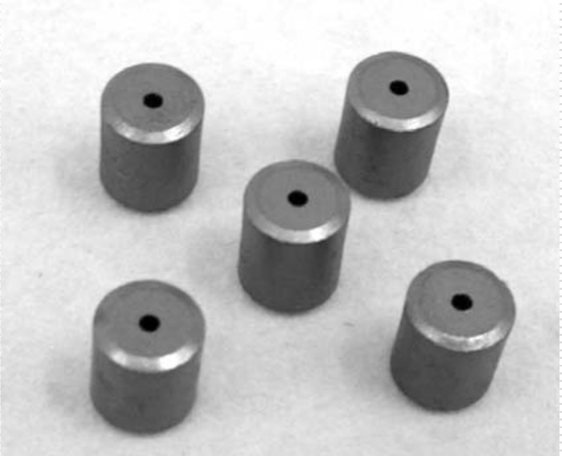
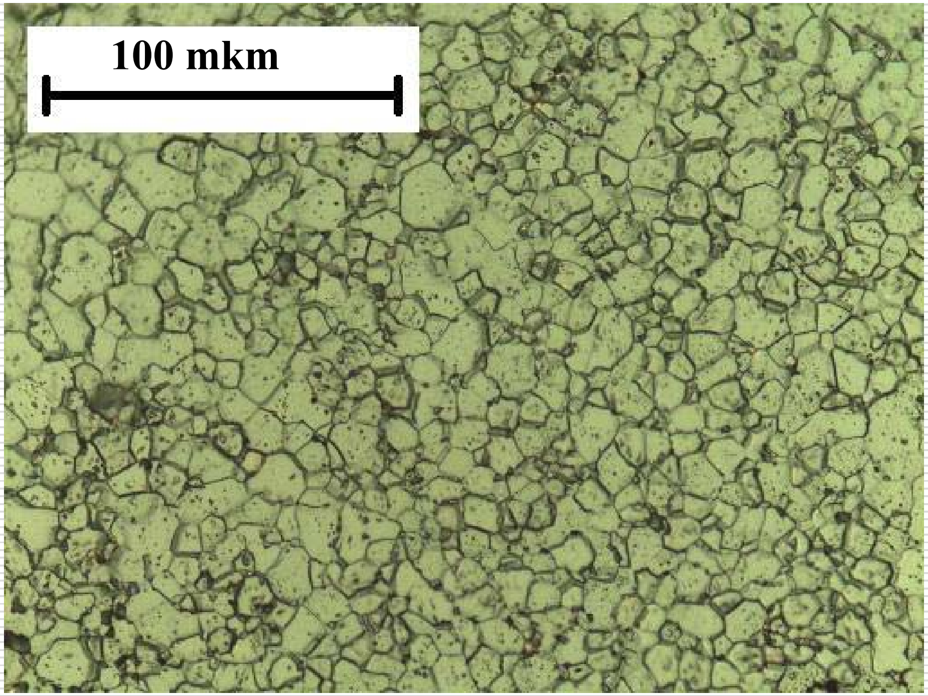
Investigation of modified fuel technologic properties. Appearance.

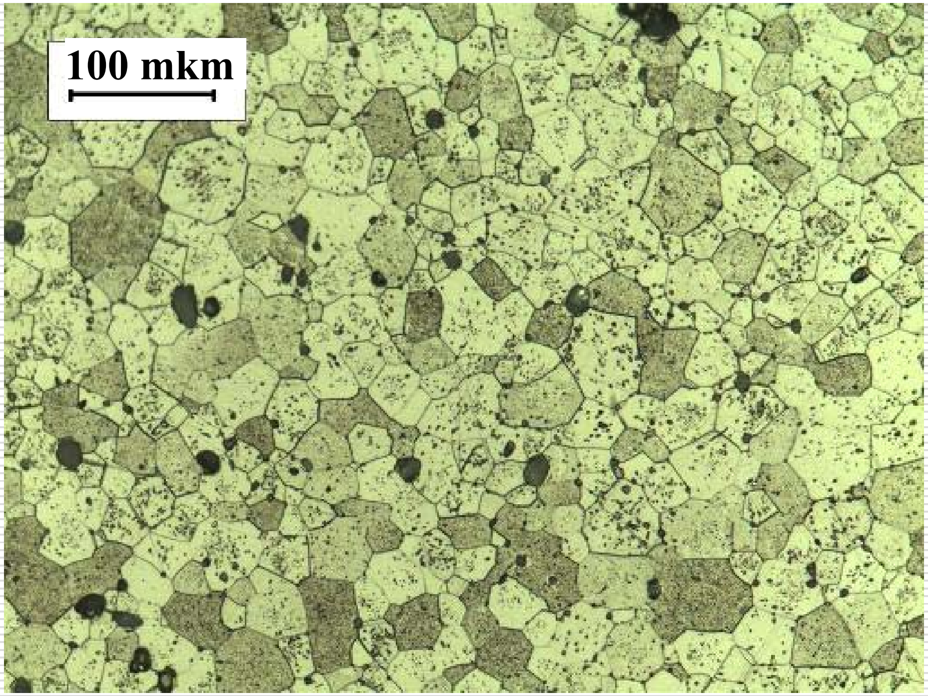




The process operations were optimized that are suitable for additives containing pellets. Their appearance meets the standard requirements for fuel pellets.

Investigation of modified fuel properties. Microstructure (metallographic analysis).





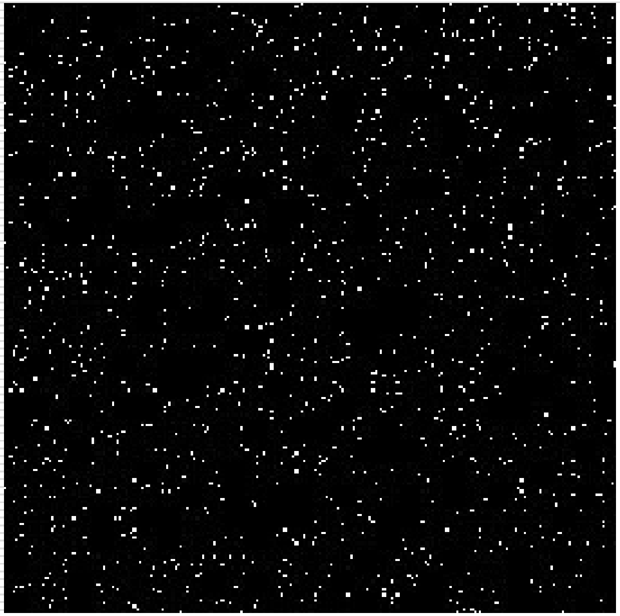
d = 10 mkm

d = 28 mkm

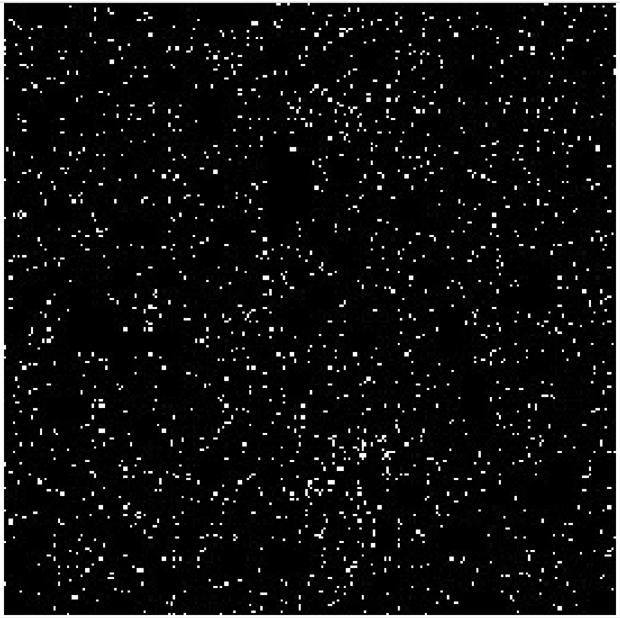
The average grain size is given in the linear dimension

Investigation of modified fuel properties. Microstructure (X-ray analysis).

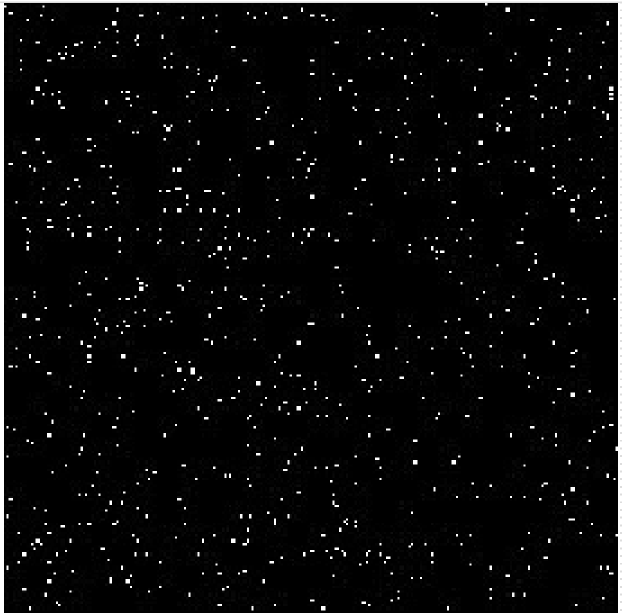
The image of the scanned surface in the characteristic X-ray radiation.



Al-Si-Fe-O



Al-Si-O



Al-Nb-O

It is evident from the above data that the microadditives is uniformly distributed within the fuel pellet volume.

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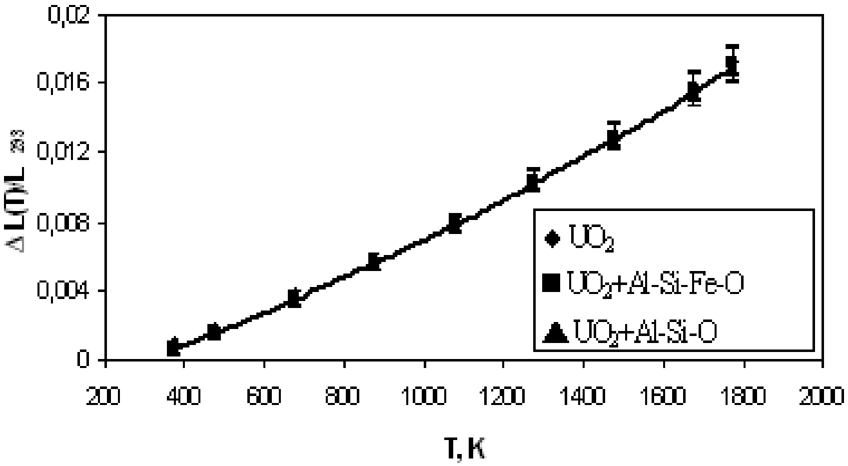
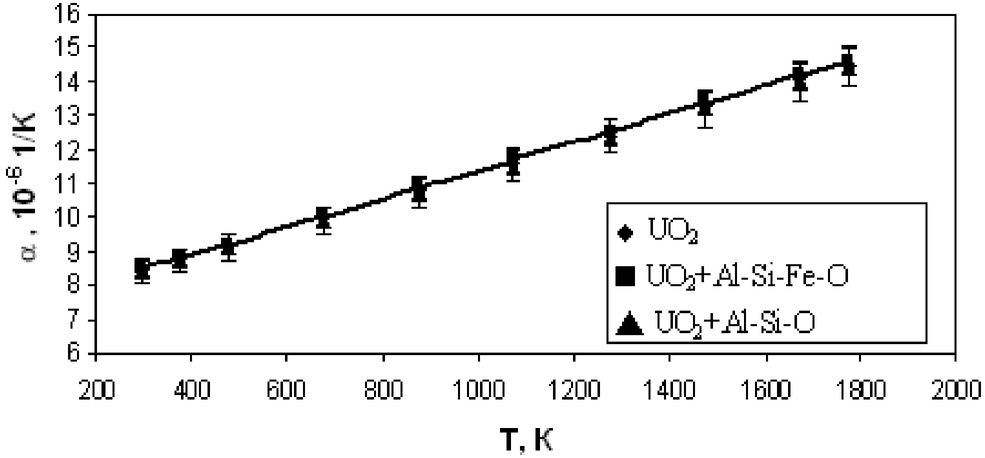
Investigation of modified fuel thermo-physical properties. Linear thermal expansion.





T = 293 - 1775 K;

Linear thermal expansion – $(\Delta L(T)/L_{293}) = A + BT + CT^2$;

L_{293} – length of sample at room temperature;

T – temperature of investigations;

$L(T)$ – length of sample at temperature of investigation;

$\Delta L(T) = L(T) - L_{293}$ – elongation of sample at temperature of investigation;

Coefficient of linear thermal expansion – $\alpha = (1/L_{293})\cdot(dL(T)/dT) = d(\Delta L(T)/L_{293})/dT = B + 2CT$

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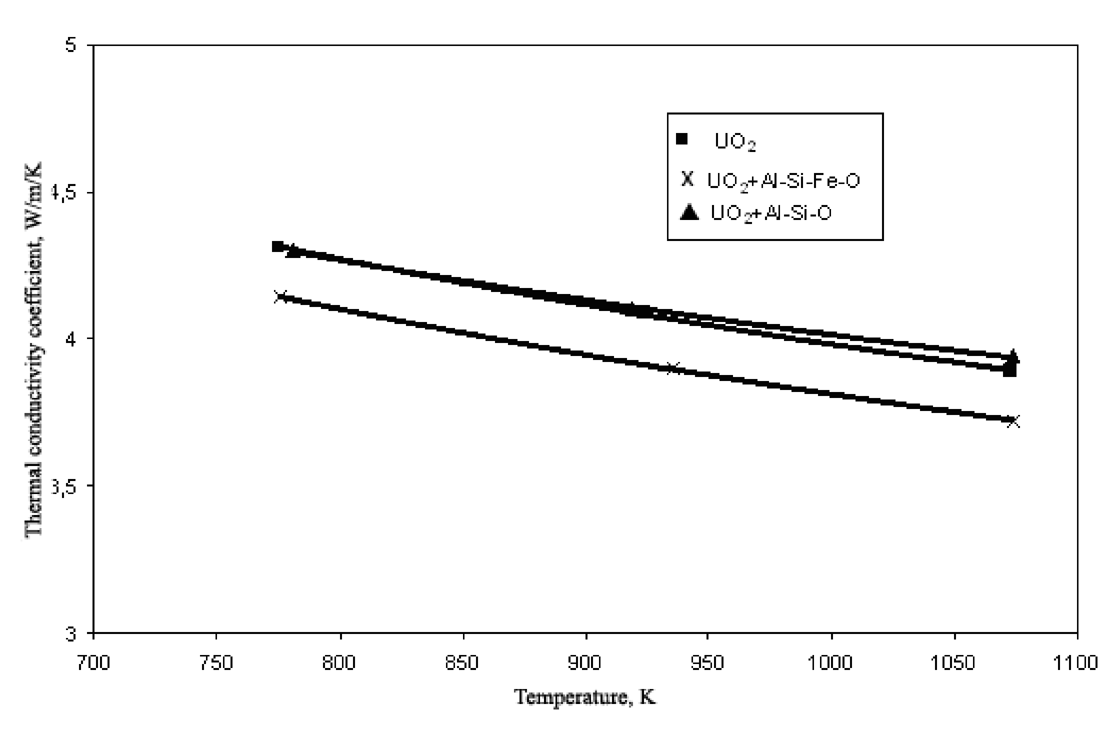
Investigation of modified fuel thermo-physical properties. Thermal conductivity.



The thermal conductivity of the fuel pellet samples having microadditives was investigated by the laser burst method (Parker pulse method).

The results on the pellets containing microadditives are about similar (within the error of the method).

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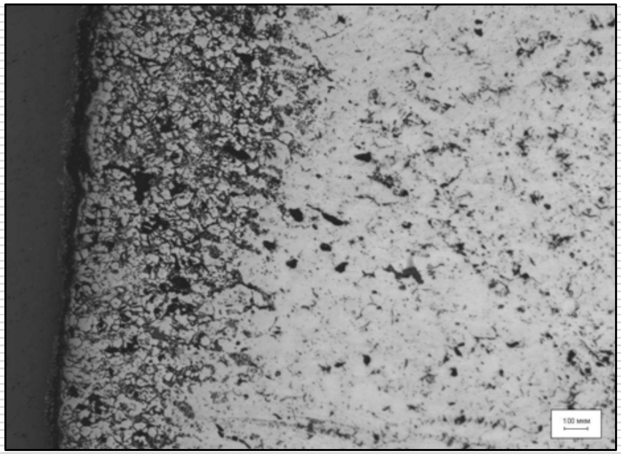
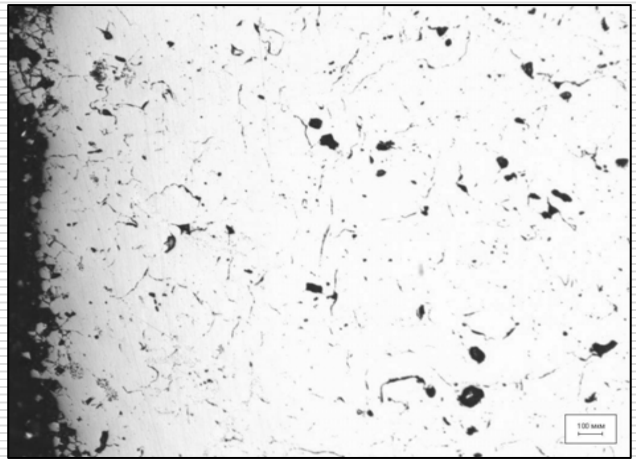
Investigation of modified fuel technologic properties. Corrosion resistance.

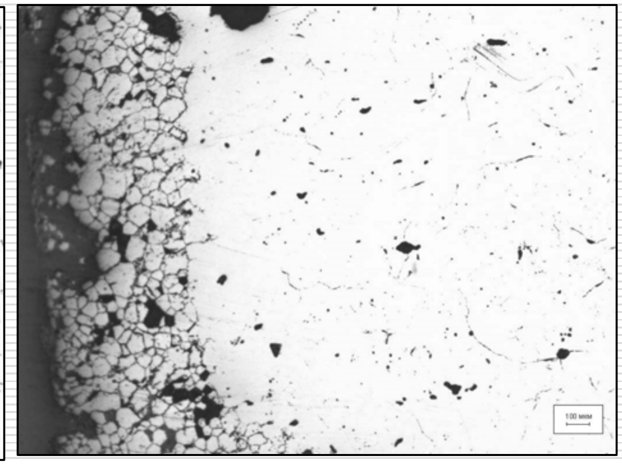
The investigation were carried on the WWER water chemistry mode during 500 h.



Non doped



+ Al-Si-Fe-O



+ Al-Si-O

The investigations attest that modified microadditive containing fuel pellets feature stronger corrosion resistance when interacting with a coolant (thermal carrier). The depth of a corrosion induced fracture of those pellets is less than that of the standard pellets not containing microadditives.

Lysikov A.V., Novikov V.V., Samokhvalov A.N. Corrosion resistance of doped pellets.(Proc. 2008 Water Reactor Fuel Performance Meeting. Seoul, 2008), (CD-Rom, Paper No. 8017).

In-pile investigations of high-burnup fuel properties

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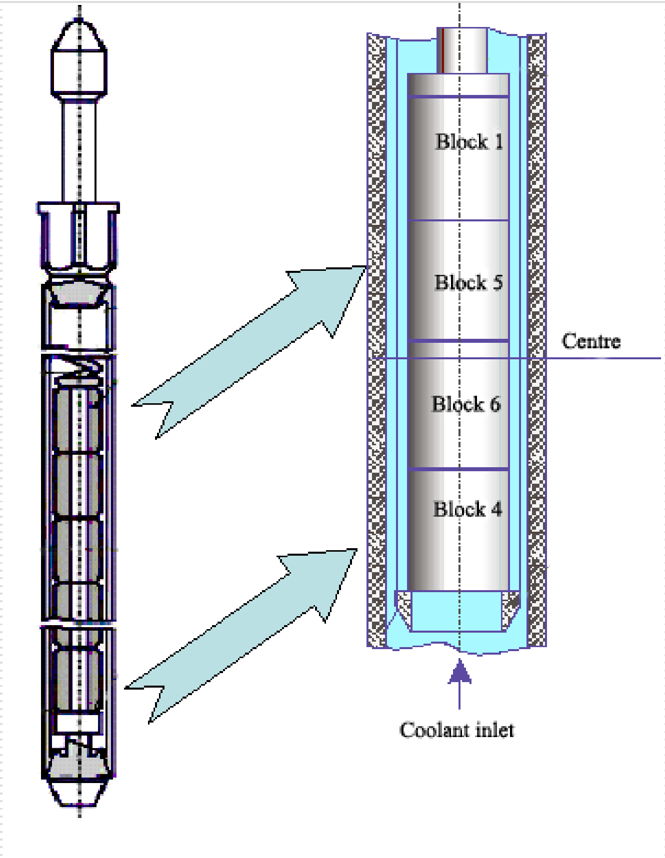
JSC "VNIINM" together with JSC "SSC RIAR» have investigated the properties of the high burnup fuel in the research reactor "MIR" at a power ramp.

The power ramp tests of the fuels involved a preliminary irradiation stage to reach the specified burnup and a ramp of the power followed by holding it at a higher level.

The particular experiment used the RIAR developed procedure of testing the WWER-100 fuels under conditions of power changes.

Three types of fuel containing microadditives and the standard fuel were investigated.



a) b)

a) – experimental fuel rod
b) – irradiation device

Novikov V.V., Bibilashvili Yu.K., Mikheev E.N. et al WWER fuel behavior with additive elements. Atom Energy 105/4 (2008), pp.205-210.

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In-pile investigations of high burnup fuel properties

The facility with the fuels to be investigated were installed into a loop facility channel where the coolant parameters corresponded to those in WWER. The reactor was brought to the power level that provides for the needed initial experimental conditions in the loop channel. In this case the controls that are close to the loop channel were in the lower position. After all the parameters were stabilized and the equilibrium states were reached at this power level the power was increased in ramps at the needed amplitude. With this aim the nearest controls were removed and the introduced positive reactivity was compensated via inserting the controls in fuel other parts of the care.

Novikov V.V., Bibilashvili Yu.K., Mikheev E.N. et al WWER fuel behavior with additive elements. Atom Energy 105/4 (2008), pp.205-210.

In-pile investigations of high burnup fuel properties. The acquired results.

Point number	T_{inlet}, °C	T_{outlet}, °C	ql_5, W/cm	ql_6, W/cm
1	255	278	314	242
2	273	303	583	448
3	281	316	611	470
4	289	320	472	360
5	294	324	450	341

In the experiment under consideration the fuel containing aluminum silicate did not lead to losses of tightness by the fuels. The particular fuels remained serviceable under the conditions of the experiment.

The acquired data also evidence a lower coefficient of xenon diffusion within points to the releases of FGP and the fuel swelling. Larger grain sizes have also to promote those effects.

Novikov V.V., Bibilashvili Yu.K., Mikheev E.N. et al WWER fuel behavior with additive elements. Atom Energy 105/4 (2008), pp.205-210.

Conclusion

• Activities were implemented to study the properties that involved in-pile investigations of fuel pellets with microadditives that increase the grain size to more then 25 mkm.

• The process was designed to manufacture fuel pellets with microadditives that increase the grain size to more than 25 mkm.

• The properties of fuel pellets containing microadditives have been studied.

• The implemented investigations of the microstructure of the modified fuel evidence that the selected additives increase grain sizes and are uniformly distributed in the fuel pellet volume.

• The carried out investigations of the thermal physics properties of the modified fuel (linear thermal expansion, thermal conductivity) have demonstrated that the introduced microadditives do not deteriorate those properties.

Conclusion

•The corrosion resistance of the fuel pellets containing microadditives was investigated under the conditions have shown that the modified fuel pellets containing microadditives have a higher corrosion resistance when interacting with coolant.

• Additives were selected (aluminum silicates that comply with the requirement specified for fuel pellets and do not lead to substantive changes in their properties).

• The acquired experimental results allowed the development of semi-commercial process of modified fuel fabrication, the manufacture of pellet batches to semi-commercially operated in NPP with WWER.

• Batches of pellets were manufactured to be semi-commercially operated at NPP with WWER.

• Since 2005 the semi-commercial operation of the fuel containing microadditives has been commenced in NPP with WWER-1000, WWER-440. The burnup of 56 MW·d/kgU was reached.

Thanks for your attention