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DEVELOPMENT OF VIBROPAC MOX FUEL PINS SERVICEABLE UP TP SUPERHIGH BURNUPS

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Abstract

The main results on investigations of fast reactor fuel pins with $(UPu)O_2$ vibropac fuel to substantiate their serviceability up to the super-high burnups are presented. The BOR-60 reactor fuel pins radiation behaviour in stationary, transient and designed emergency conditions has been determined from the fuel pins dimensional stability analysis having regard to the results of investigation fuel and cladding swelling as well as estimations of fuel and cladding thermal-mechanical and physico-chemical interactions. It is shown that the change of the outer diameter is minimum in fuel pins with VMOX fuel with a getter-metallic uranium powder and ferrito-martensite steel cladding, and the corrosion damage of the cladding inner surface is absent up to 26% h.a. The experiments with over-heating of the irradiated fuel pins cladding up to 850°C did not lead to any changes in pins integrity. The availability of the periphery area of the vibropac fuel core initial structure provides the minimum level of the thermal-mechanical stress at transient conditions of reactor operation.

Introduction

The most efficient way for improving the technique and economical characteristics of fast reactors fuel cycle is the increase of fuel burnup.

According to the estimations to compensate the high cost of fast reactor fuel component the maximum burnup must make up 20÷25 % h.a. When solving this task two problems are the most significant:

- choice of structural materials for fuel pins cladding and fuel assembly wrappers, possessing necessary level of heat-ressistance and an acceptable value of radiation swelling;
- provision of the minimum physical-chemical and thermal-mechanical effect of fuel column on cladding.

To realize this problems among the well-known grates of steels preference apparently should be given to ferrito-martensite class materials which demonstrate rather high size stability at moderate temperature levels of the cladding. As appears from the data of fig.1 where there is presented the dependence of the main cladding materials swelling on fluence, the best characteristics shows the American steel HT-9 [1,2].

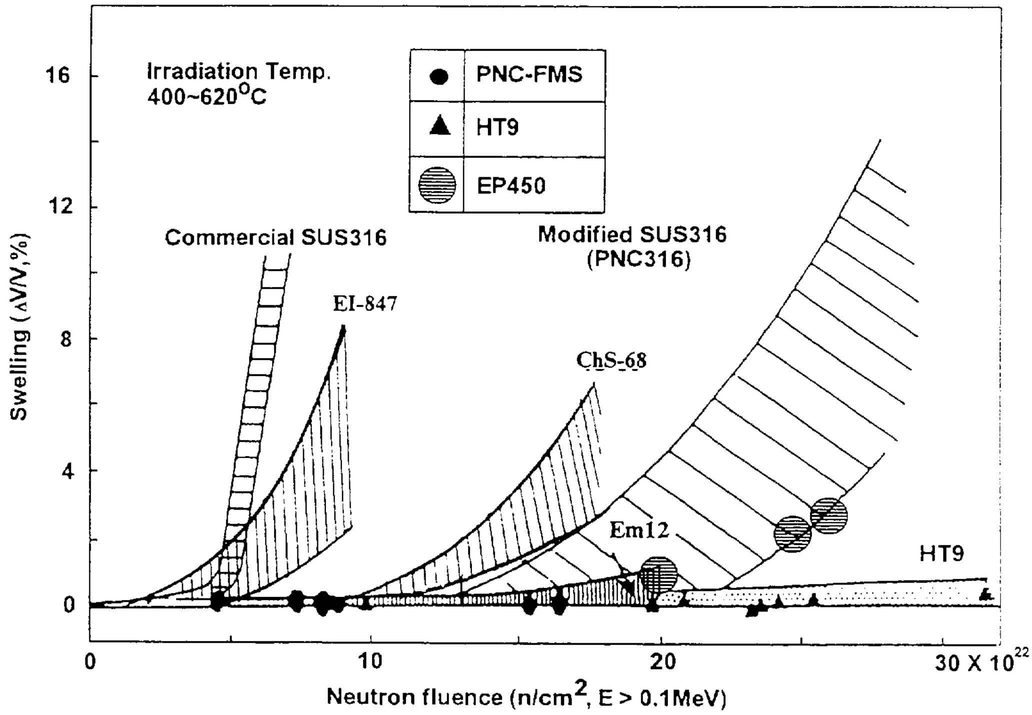


Fig. 1. Swelling of structural materials for FBR fuel pins.

EP-450 = Cr13Mo2NbVB,
EI-847 = Cr16Ni15Mo3Nb,
ChS-68 = Cr16Ni15Mo2Mn2TiBV,
Em12 = Cr10Mo2Mn,
HT9 = Cr12Mo1.

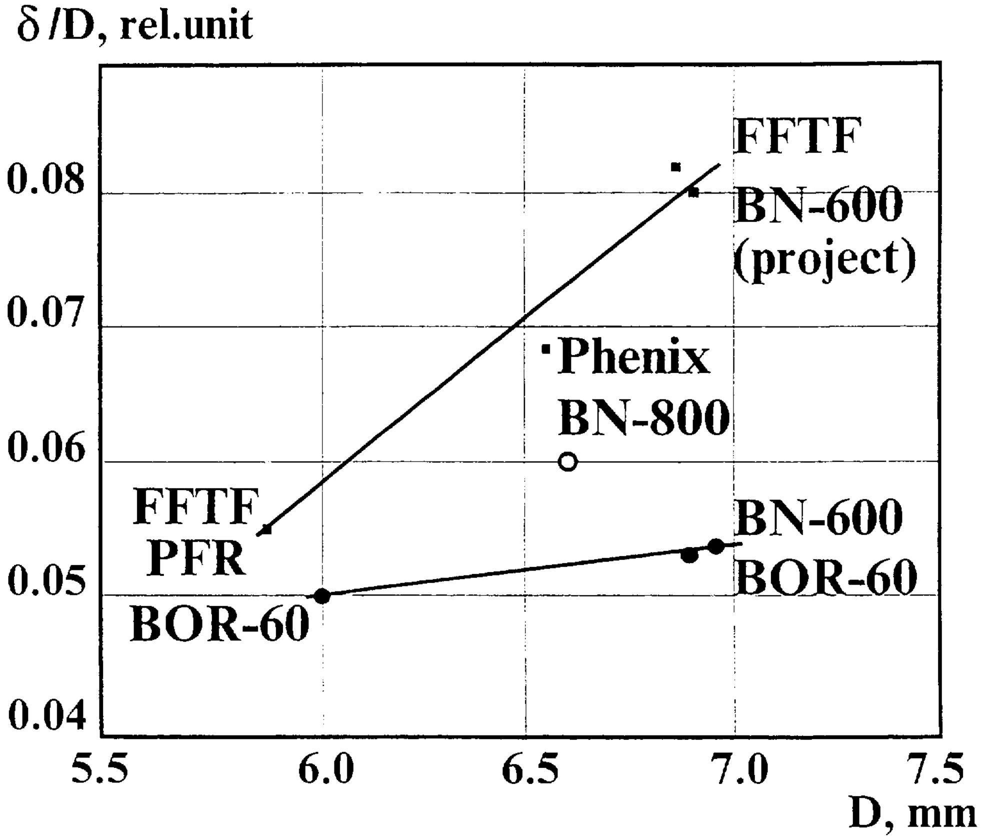


FIG. 2. Dependence the cladding relative thickness vs fuel pin diameter.

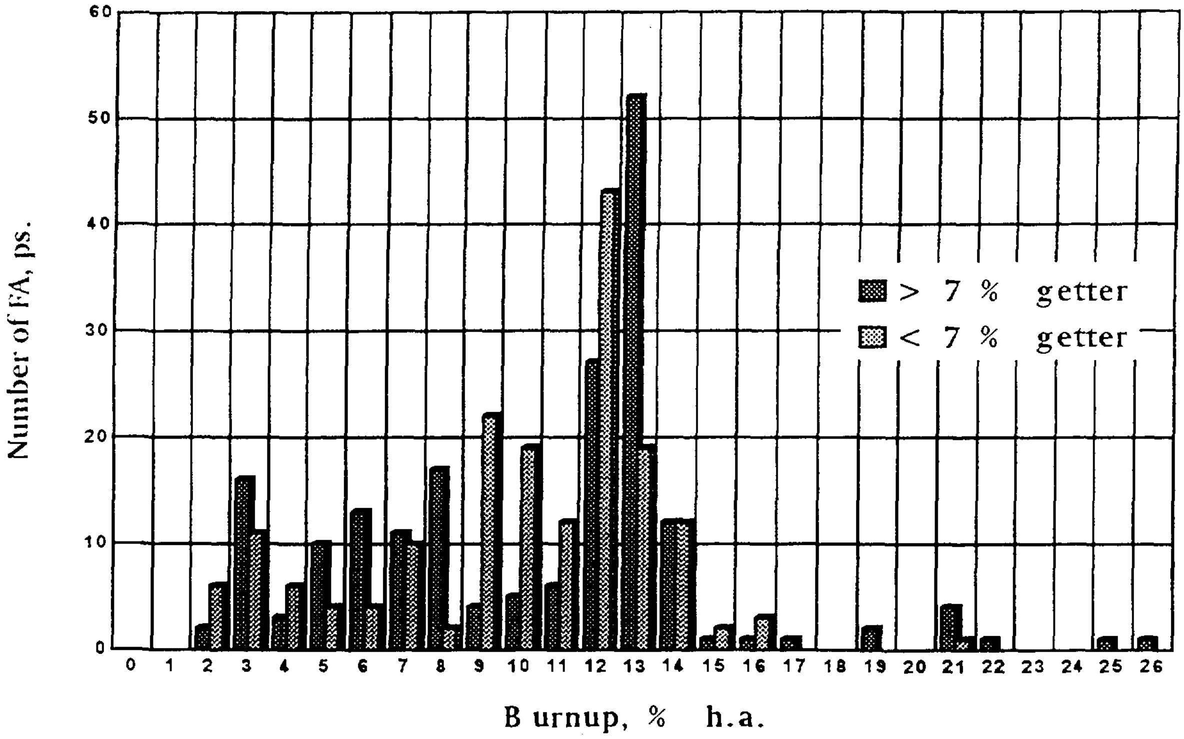


FIG. 3. FA distribution of the BOR-60 reactor versus burnup (wrapper Cr18Ni10, cladding Cr16Ni15Mo3Nb).

As for the problem of thermal-mechanical effect of the fuel column on cladding with minimum chemical interaction of U-Pu oxide fuel and cladding, then to increase the fuel size stability in the case of pellet fuel, the main accent is done on the cladding thickness increase, fig.2 [3,4] (FFTF, HT-9 cladding, burnup - 23,8 %, σ/d = 0,56/6,86 mm; PFR, cladding PE-16, burnup - 21,0 %, σ/d = 0,38/5,84 mm; BN-600, there is scheduled the cladding transfer from 6,9 x 0,55 mm of diameter and wall thickness). It is anticipated that the increase of cladding structural stength at the expense of its thickness increase 100 µm on the average, allows to minimise the corrosion factor effect.

For the last 15 years in RIAR in the range of the closed fuel cycle, based on the use of dry methods for nuclear fuel perfomed the intensive investigations on the creation of fuel pin design, adapted to the automated remotely-controlled technological process and possessing high operating

Table 1.1

Granulated Fuel $UPuO^2$ Features

Parameter	Value
Particle density, g/cm^3	10,7 ÷ 10,8
Fraction numberöèé	5
Particle size, mm	-1,00 + 0,63 -0,63 + 0,40 -0,40 + 0,25 -0,25 + 0,10 -0,10
Smear density, g/cm^3	
- fuel pin of FBR	9,1 , 0,2
- fuel pin of PWR	9,6 , 0,2
Content massÿ PuO_2, %	° 30
Isotope mass fraction, %	
^{238}Pu	0,2 ÷ 1,7
^{239}Pu	64,0 ÷ 98,5
^{240}Pu	3,3 ÷ 21,5
^{241}Pu	0,4 ÷ 9,0
^{242}Pu	0,2 ÷ 4,0
Enrichment UO_2, %	45 ÷ 90

Table 1.2

Production of Granulated Fuel

Type of facility	Fuel	Quantity	Period	Reactor
Granulated UO_2 fuel Facility	UO_2	900	1976÷1983	BOR-60
	UO_2	365	1983	BN-350
Granulated $UPuO_2$	$PuO2_2$	100	1980÷1982	BOR-60
	$UPuO_2$	550	1983÷1987	BOR-60
	$UPuO_2$	75	1984	BN-350
	$UPuO_2$	70	1987	BN-600
Pilot plant (Granulated Fuel Facility)	UO_2	120	1988	BN-600
	UO_2	535	1988÷1989	RPT-10
	UO_2	330	1989÷1994	BOR-60
	UO_2	374	1993	BN-350
	$UPuO_2$	325	1989÷1992	BOR-60
	$UPuO_2$	277	1989÷1992	FPS
	$UPuO_2$	300	1990	BN-600

characteristics. The result of these investigations has been vibropac fuel pin conception. The problems of thermal-mechanical and phisical-chemical fuel - cladding interactions have been solved in this conseption at the expense of vibropac fuel column. This column is a mechanical mixture of structural properties based on polydispers nonregular granular form and powder metalic uranium getter. The technological process of production and control of vibropac fuel pins from granulated $UPuO_2$ fuel is fully automated and is performed in hot cells RF-1 and RF-2 of the experimental-investigating complex of SSC RIAR [5]. In the reactor BOR-60, which has been operating with vibropac MOX fuel since 1981, there was achieved stable work of standard fuel pins with Cr16Ni15Mo3Nb steel cladding up to planned burnup 12-15 %, fig.3. Basing on fuel pins with VMOX fuel testings in the BOR-60, BN-350 and BN-600 reactors and their material science

Table 2.1.

The main features of BOR-60 fuel assembly with vibropac $(UPu)O_2$ fuel

Parameter	Values
Fuel composition	$UO_2 + PuO_2$ $+ U$
	$(UPu)O_2$
PuO_2 content, %	20-28
Getter mass fraction, %	3.....10
Clad diameter and thickness, mm	6.0 x 0.3; 6.9 x 0.4
Clading material	
	Cr16Ni15Mo3Nb (befor 1994)
	Cr16Ni15Mo2Mn3TiVB
Maximum linear power, kW/m	(after 1994)
Maximum clad temperature, C	52.0
Maximum fuel burnup, % h.a.:	720
- standard fuel assembly	
- experimental fuel pins	15.6
Fuel pins number, piecs,	28.0
having burnup:	
10-15 %	
15-20 %	6031
more than 20 %	185
	296

Table 2.2

Test Conditions in the BOR-60 Vibropacked Fuel Elements with Promising Cladding Materials.

Cladding Material	Number of the pins	Heat rate, kW/m	Temperature cladding, °C	Fluens, 10^{22} cm^{-2}	Burnup, % h.a.
Cr16Ni15Mo3NbB	214	44	610	24,3	21,6
Cr16Ni15Mo3NbB+C	10	37	660	11,1	9,9
Cr15Ni16Mo23MnTiVB	993	49	710	15,6	~16
Cr20Ni45Mo23MnTiVB	37	37	660	12,1	9,9
Cr20Ni45Mo4B+Y	37	40	690	10,6	12,9
Cr20Ni45Mo4NbBZr	443	48	690	28,2	~28
Cr13Mo2NbVB	74	46	670	3,3	4,3
Cr15Ni16Mo3MnTiNb	19	45	680	10,2	11,6

investigations there was created and varified the calculated program "VICOND" to predict their serviceability.

In this report there are presented the main investigation results for the progress of fuel pins with VMOX fuel program, referred to the super-high burnups achievement and substantiality of their seviceability in emergency conditions of reactor operation.

1. Granulated Fuel Features

The polydispers granulate obtained in the result of cathode deposite crushing after pyroelectrochemical reprocessing of nuclear fuel in malten salts on the base of alkali metal chlorides [6]. The main granulate characterictics and its operating time are presented in tables 1.1 and 1.2 respectively.

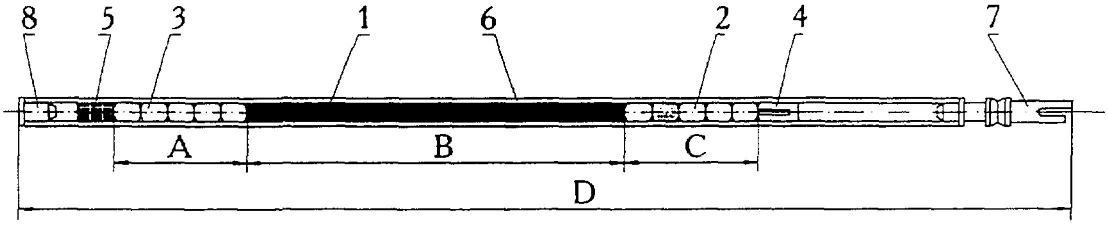
To realize the investigation programs, including Pu utilization, the experiments on obtaining granulate fuel with higher power Pu content were also carried out:

- 3,5 kg with 40 % of PuO_2 content (for testing in BOR-60 reactor);
- 0,2 kg with 56 % of PuO_2 content (for technological investigations);
- 0,2 kg 70 % of PuO_2 (for technological investigations).

The quality of granulate with high Pu content practically did not differ from the standard one.

2. The Desing of the Fuel Vibropac Oxide Fuel (VMOX) for Fast Reactor.

The design of the fuel pin with VMOX fuel for fast reactor is presented on fig. 2.1, the main technological and operating parameters of the BOR-60 reactor fuel pin are in table 2.1.
The base design of the fuel pin with VMOX fuel includs side areas of the blanket consisting of depleted or natural UO_2 isotope content pellets and U or U-Pu oxide vibropac fuel core. As the fuel pin design allows the avaiability of the compensation



Pos.	Designation
1	Fuel column
2	Lower blanket
3	Upper blanket
4	Supporting bushing
5	Holder
6	Cladding
7	Lower end plug
8	Upper end plug

Dimensions, mm

REACTOR	A	B	C	D
BOR-60	100	450	150	1083
BN-350	–	1060	400	1790
BN-600	350	950	350	2400

FIG. 2.1. The fast reactor fuel pin with vibropac [UPu}O_2 fuel.

FIG. 3.1. Microstructure of $UPuO_2$ vibropac fuel with burnup 26% of h.a.

volume in the fuel column is separated from the pellets of the blanket side area by gas-permeable element, preventing from granulate spill into the compensation volume when vibropacking.

Practically all the steels of different classes developed for fast reacors have been tested as the experimental fuel pins cladding material (Table 2.1).

More than 27000 of fuel pins have been produced during the whole period of accomplishing the complex program on fuel pins with VMOX fuel development (Table 2.3).

3. The Main Results of Tests and Investigations of Fuel Pins with VMOX Fuel

3.1. Fuel Pins Serviceability in Basic Conditions

The main factors influencing characteristics of fuel pins serviceability when reactor operates in statianary conditions are: fission gas products pressure, swelling fuel pressure and fuel - cladding chemical interaction as a result of formation corrosive fission gas products and oxygen, disengaged at U and Pu fission.

The analysis of fuel pins with vibropac MOX fuel serviceability has shown [7,9], that:

- the use of fuel composition with the addition of a getter - metalic uranium powder in the amount of 3-10 % mass allowed completely eliminated corrosion processes, induced by the presence of fission products such as Cs, I and processing impurities as Cl, F, CO_2. This fact practically removes the burnup limit because of physical-chemical fuel-cladding interaction. In none of the investigated fuel pin cross-sections up to 26 % burnup there were found any corrosion damage of the cladding inner surface, fig.3.1;

- the outlet of fission gas products from the oxide fuel under cladding at standard operation conditions of fast reactor fuel pins averages 50-70 % and practically does not depend on the type of fuel composition;

- the change of the fuel pin cladding diameter is induced in general by swelling of structural material. The contribution of inelastic deformation did not exceed 0,5 %. The change of the diameter of fuel pin cladding of steel Cr13Mo2 at doses up to 144 d.p.a. was ~ 1-2 %;

- the rate of pre-stoichiometric composition swelling, estimated by the fuel microstructure at 21, 24 and 26 % burnups was 0,6 +- 0,1 %/% burnup.

- the fuel column abnormal effective density (>9,0 g/cm^3), which is provided by the selection of optimal granulametric content at very hich pictometric particles density (table 1.1) allows to have sufficiante temperature supply up to the melting temperature (more than 400 °), (fig.3.2).

3.2. Fuel Pins Serviceability in Transient Conditions

To study the influence of transient conditions on fuel pins serviceability in BOR-60 reactor there have been performed experiments on replacing of fuel assembly with pellets as well as vibropac fuel (table 3.1).

The experiments of fuel pins with UO_2 pellet fuel shown [10]:

- all the 18 fuel assemblies, transfered from the centre to peryphery were tight when having reached 10 - 12 % burnup they were unloaded;

Table 3.1

Test Conditions of Subassemblies which were transfered in the core of BJR-60

Type of the transfere	Pellet fuel			Vibropac fuel		
	Number of the SA	Burnup, % h.a.	Number of the un-tight	Number of the SA	Bur-nup, % h.a.	Number of the un-tight
In the limit of one radius	4	10÷12	2	9	8÷24	2
From centre to peryphery	18	10÷12	-	23	7÷22	-
From peryphery to centre	4	12÷17	3	31	8÷18	-

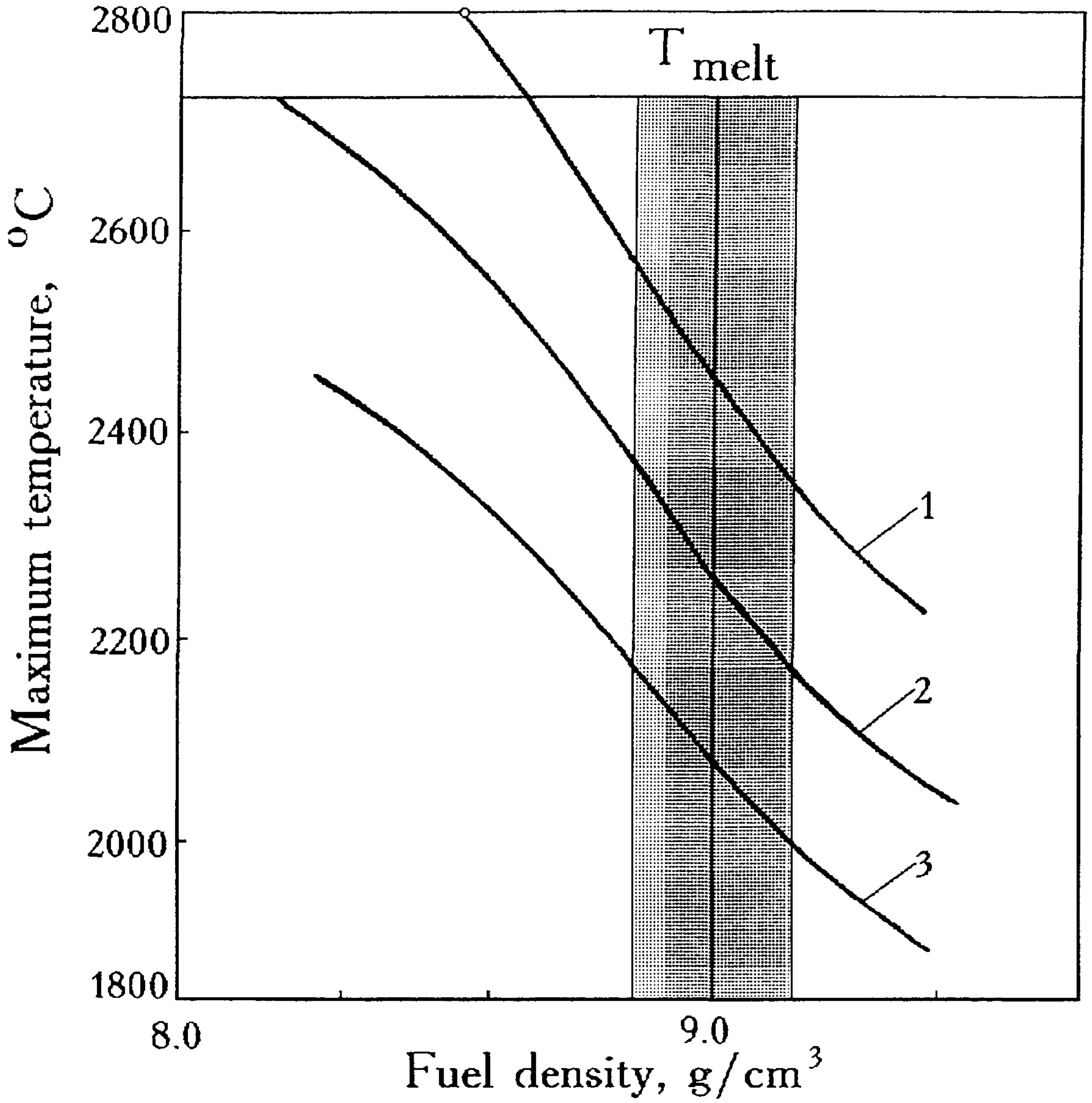


FIG. 3.2. Maximum fuel temperature versus the density of vibropac core and fuel element linear power.

1 - q_l = 55 kW/m;
2 - q_l = 50 kW/m;
3 - q_l = 45 kW/m;
▭- permissible range of the density change.

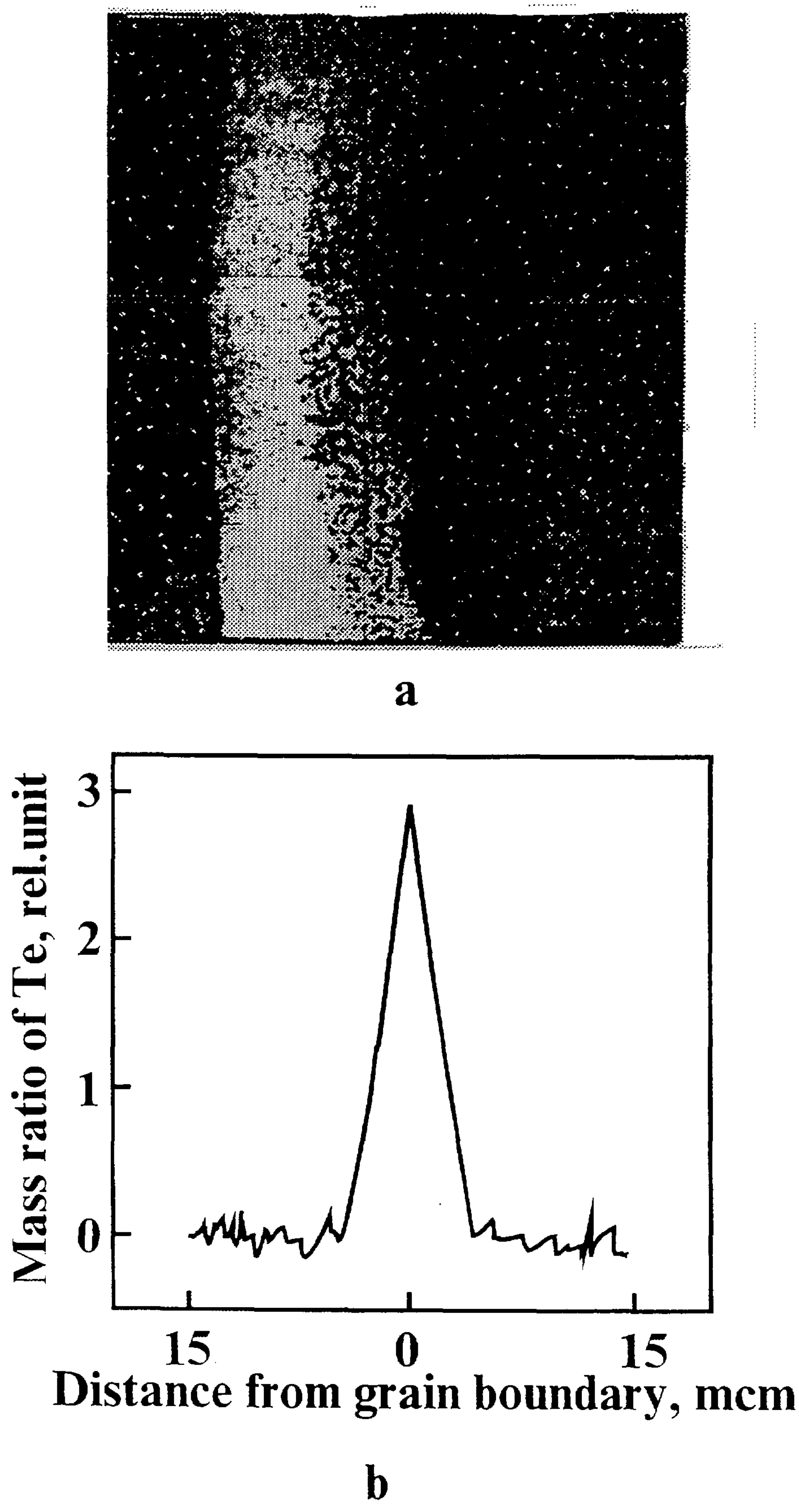


FIG. 3.3 Corrosion of the cladding (Cr20Ni45Mo4Nb):

a - macrostructure, x100;
b - distribution of Te.

- when one fuel assembly was transfered from the fourth row to the sixth one and then back it remained tight;
- four fuel assemblies were transfered in the limit of one radius, where they were installed, two of them turned out to be untight;
- four fuel assemblies were transfered from periphery rows to the centre and three of them turned out to be untight. Two fuel assemblies of this serie have been studied (Table 3.2).

The reasons of cladding untightness of these fuel assemblies, for which the liner power excess was up to 36 % of the initial level were investigated.The investigations have shown the availability of considerable intergrains corrosion with great Te and also Cs content on the corroded grain boundaries, fig.3.3. This type of corrosion was observed on cross-sections with the maximum temperature of fuel pin core surface. The untightness of two fuel pins with vibropac fuel at 20 and 24 % burnup (one from each assembly) was not connected with the change of power since it was detected two campaigns after fuel elements transfer. As the material science investigation have shown the untightness was caused by the exhaustion of cladding material resource character istics due to its excessive radiation swelling and creep.

Parameters of 17 standard fuel assemblies with vibropac fuel, which were transfered from periphery to the central rows are presented in table 3.3. The transferes in the reactor core with the power increase up to 80 % do not influence on the vibropac fuel pins serviceability. This fact testifies that the lowed temperature of the periphery layer does not allow tellurium

Table 3.2

Tests Conditions Examinated
Subassemblies of the
BOR-60 with Pellet UO_2 Fuel

Number of the SA	Cladding Material	Burnup, % h.a.	Cladding tempera-ture, ^{o}C	Heat rate, kW/m
Ȧ-613	Cr16Ni15Mo3NbB	12,6	670	37÷46
ĨĪ-30	Cr20Ni45Mo4Nb	16,9	700	31÷49

Table 3.3

Tests Conditions of the Subassemblies with Vibropac Fuel, with were transfered in the core of the BOR-60

Num-ber of the SA	Bur-nup,% h.a.	Heat rate, kW/m	Change of the row	Heat rate, kW/m		State of SA
				initi-al	finish	
Î-215	8,1	131	6 → 1 6	202	333	herm.
Î-220	13,0	111	→ 2	224	335	herm.
ÎÃ-31	12,8	211	6 → 2	264	475	herm.
ÎÃ-44	12,0	169	5 → 2	311	480	herm.
ÎÃ-50	11,5	136	5 → 2	350	486	herm.
ÎÃ-52	11,9	170	5 → 1	312	486	herm.
ÎÃ-53	12,1	143	6 → 3	279	422	herm.
ÎÃ-55	11,2	176	6 → 1	288	464	herm.
ÎÃ-56	12,5	174	5 → 1	320	494	herm.
ÎÃ-57	12,7	172	6 → 2	289	461	herm.
ÎÃ-59	11,7	155	5 → 1	351	506	herm.
ÎÃ-60	11,7	154	5 → 1	350	504	herm
ÎÃ-65	11,5	157	5 → 1	356	513	herm.
ÎÃ-66	11,5	183	5 → 1	332	515	herm.
ÎÃ-71	13,9	113	5 → 1	330	443	herm.
ÎÃ-72	11,7	158	5 → 2	354	512	herm.
ÎÃ-77	12,7	118	6 → 4	293	411	herm.

"to reach" cladding and the presence of the initial structure of this layer provides "soft" thermo-mechanical fuel column effect on cladding at transient conditions. The typical vibropac fuel structure, perfect from the point of view of minimum thermo-mechanical effect on cladding, is presented in fig.3.4.

3.3. Serviceability of Fuel Pins at Cladding Overheating

Two types of experiment have been perfomed: in-pile, when the claddings had high temperature and after irradiation - to study the reliability of pins at emergency over-heatings.

The main parameters of the experiments are presented in table 3.4.

The post-irradiation examinations of the cladding of fuel pins with pellet fuel from OP-25 assembly have shown matrix and

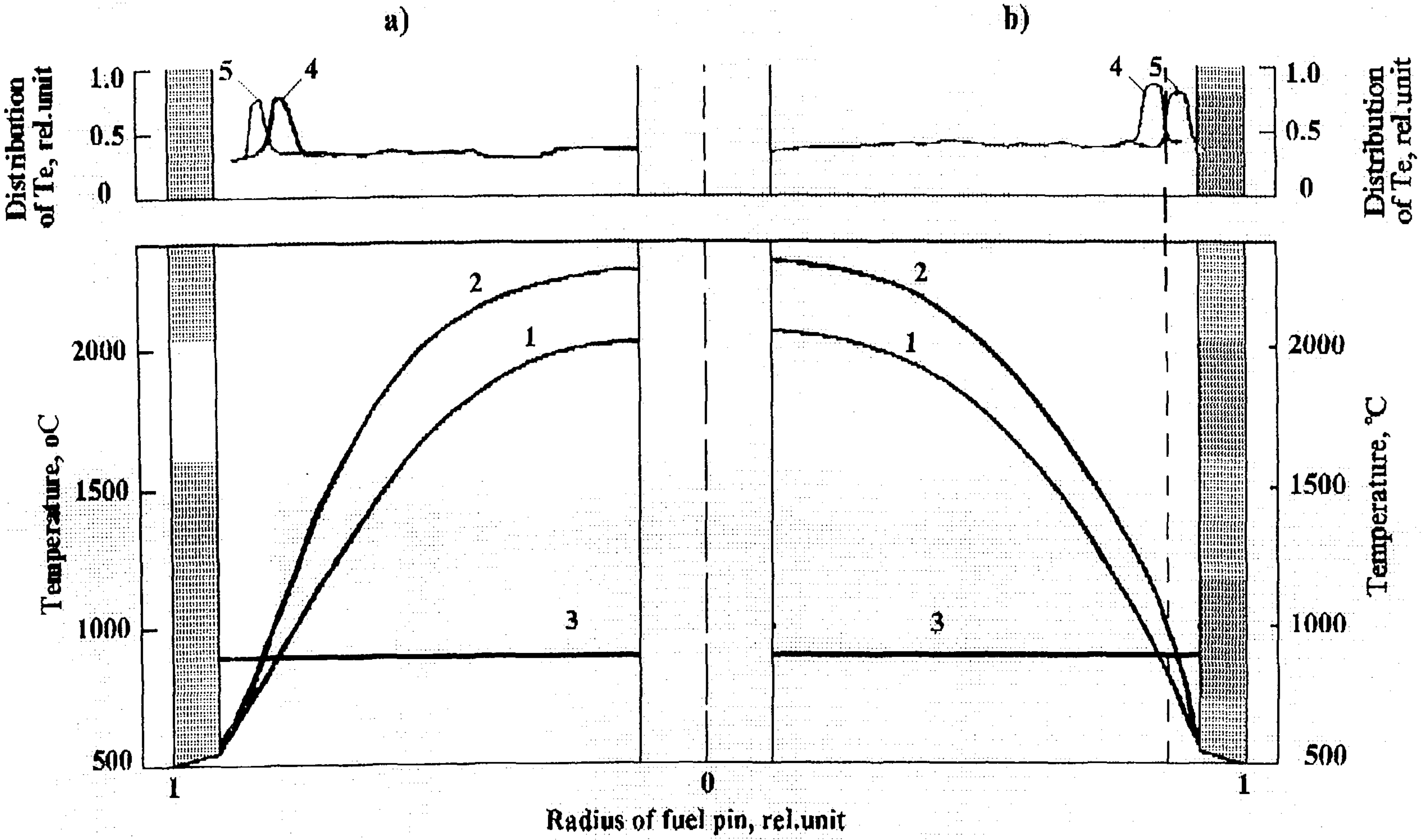


FIG. 3.4. Behaviour of Tc in the vibropac (a) and pellet (b) fuel:

1,4 - temperature and Te distribution in the basic regime;
2,5 - temperature and Te distribution at 20 % power ramp;
3 - initial temperature of Te vaporization (990oC).

Table 3.4

Tests Conditions of the BOR-60 Subassemblies under Ylgher Parameters

Number of the SA	Materials		Burnup, % h.a.	Heat rate, kW/m	Cladding temperature, °C	Postreactor tests conditions		Depth of the corrosion, mkm
	Fuel	Cladding				Tclad.	—min	
Ĩĺ-25	UO2 pellet	Cr13Mo2NbVB	12,6	44,4	740	-	-	200
ÎÃ-35	UPuO2 vibro	Cr16Ni15Mo3Nb	5,4	60,0	740	-	-	-
ÎÃ-73	UPuO2 vibro	Cr15Ni15Mo3Nb	7,0	40,1	661	850	90	-
ÎÃ-115	UPuO2 vibro	Cr13Mo2NbVP	21,0	48,2	687	850	90	-

intergranular corrosion in the upper sections of the column part, caused by cesium and iodine interaction. A large amount of tellurium was also observed in the interaction products. The results obtained testify that high temperature of the cladding of pellet fuel pin causing high temperature of the column periphery zone influences greatly on the tellurium radial distribution and thus on its with cladding interaction. The irradiation of fuel pins with a vibropac $UPuO_2$ + U (10 % mass) fuel composition under very hard conditions (Q_l up to 60 kW/m, $T_{clad.}$=740 °C) did not involve any chemical fuel-cladding interaction. The same result was obtained when fuel pins with vibropac $UPuO_2$+U fuel irradiated in BOR-60 reactor up to 21 % burnup were heated up to 800-850°C for 1-1,5 hour not in reactor. At these testing conditions also there were not found any evidence of corrosion damage of the inner cladding surface.

3.4. Serviceability of Fuel Pins with High Plutonium Content.

To study radiation aspects of plutonium utilisation there was developed the granulate production technology and were fabricated experimental fuel pins with $UPuO_2$+U fuel composition containing 40% of Pu. The fuel assembly was tested in the BOR-60 reactor up to 4,7 % burnup at maximum linear rate 46 kW/m and cladding temperature up to 650 °C [11].

Plutonium isotope composition, % : 238; 239; 240; 241; 242 = 0,5; 71; 19; 7,5; 2,0 , U-235 enrichment was 64,5.

Post-irradiation material science examinations showed that the radiation behaviour peculiarity of the fuel pin with ~ 40 % Pu content is the increase of its concentration on periphery in the central maximum liner rate part of the column. This became the reason of cladding frontal corrosion damidge 70mm depth in some fuel pins. There were not founded chemical fuel-cladding interaction in the high-temperature part. Taking into account the importance of this problem,additional testings and investigations on parameters optimisation and fuel column initial characteristics up to superhigh burnups are scheduled.

3.5. The BOR-60 Reactor Fuel Pins to Study Superhigh Burnups

Successful tests of standard fuel pins with Cr16Ni15Mo3Nb steel cladding and Cr18Ni10Ti steel wrapper tube up to 15% h.a. burnup, solution of the thermal-mechanical and physical-chemical vibropac fuel pin core-cladding interaction allowed to begin to realise qualitatively new stage - the study of the limit burnup

Table 3.5.

Program to Achieve Super High Burnups and Damage Doses in the BOR-60

No	Material		Number of fuel pins	Burnup(forecast), % h.a.						
	Fuel pin cladding	FA Wrapper		1995			1996			
				2	3	4	1	2	3	4
1 3	Cr13Mo2NbVB	Cr13Mo2N-bVB	185	19...24				24...29		
2	Cr13Mo2NbVB Cr16Ni15Mo3VB c.w.	Cr13Mo2N-bVB	74	26						
3	Cr13Mo2NbVB		6*	28 (155 dpa)		29...31		33		35 (190 dpa)

* Refabricated fuel pins having the burnup from 21 to 26 % of h.a. in dismountable FAs

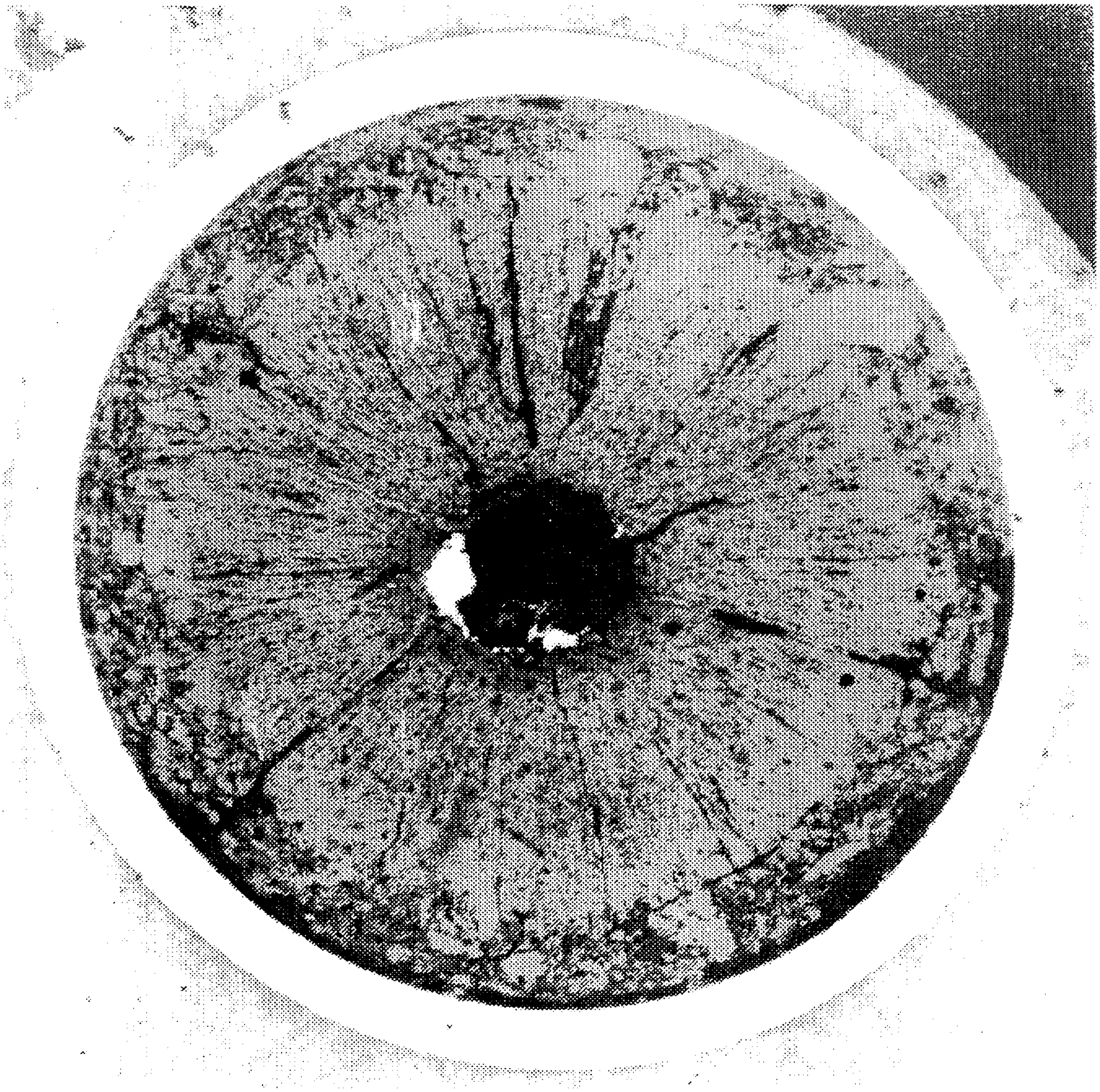


FIG. 3.5. Macrostructure of the central cross-section of the BN-600 fuel pin (x25).

and dose characteristics of fuel pins and structural materials. The program of experiments on the base of standard design as well as on the base of the BOR-60 reactor dismountable fuel assembly was developed for this purpose. The program provides testings of standard fuel assemblies with promissing structural materials and additional irradiation of refabricated fuel pins in a dismountable assembly (Table 3.5).

The results of cladding materials swelling (see Fig.1) illustrate the best size stability of ferrito-martensite steels,

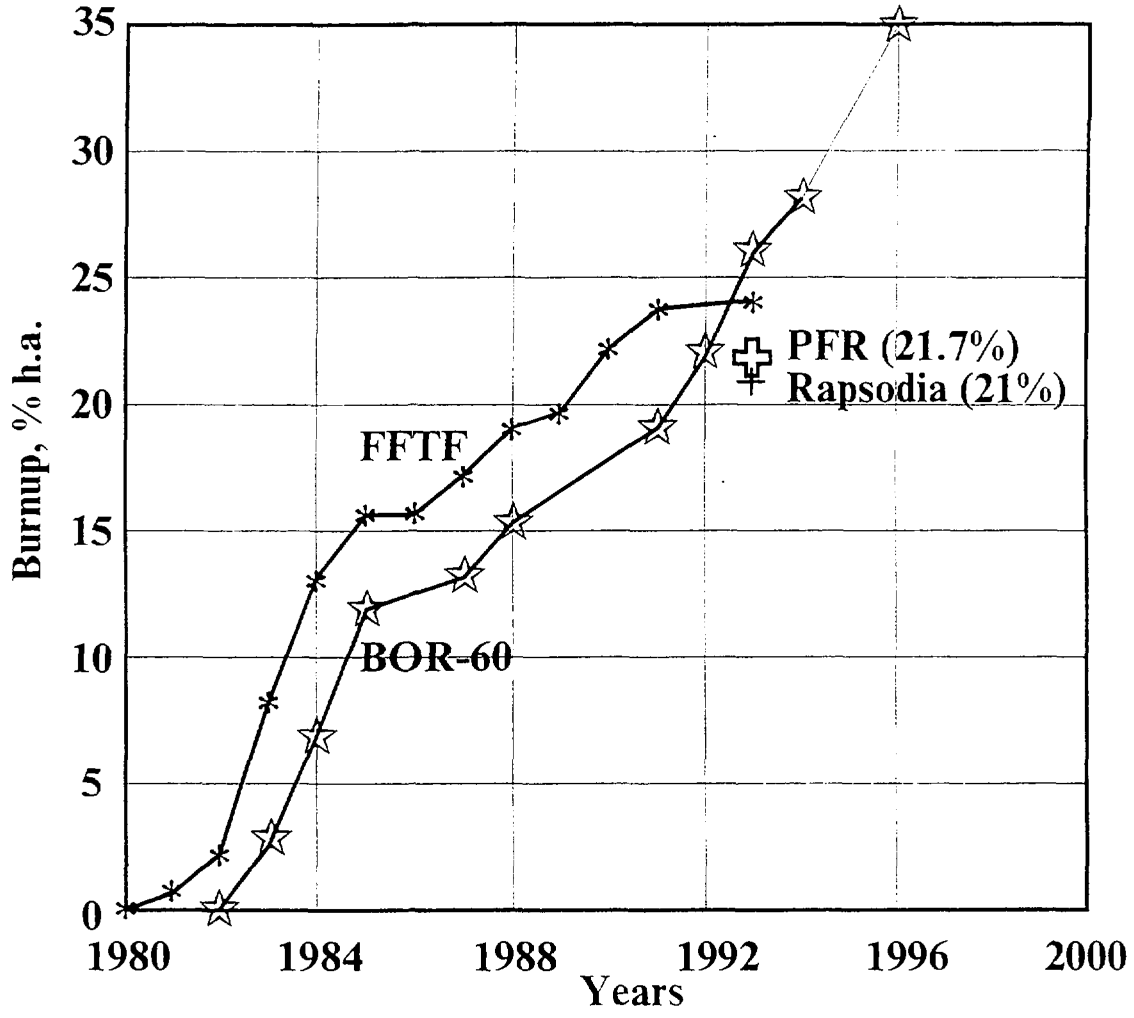


FIG. 3.6. Burnup achievements in UPuO2 fuel in fast breeder reactors.

Cr13Mo2NbVB Russian steel in particular. That is why the main emphasis was given to ferrito-martensite steels, despide the fact of their ralatively low heat-resistance in the experiments on achieving super-high burnups of vibropac oxide fuel. Data are as of May,1995 when there was achieved the world record burnup 28% on the experimental fuel pins with Cr13Mo2NbVB steel cladding in the reactor BOR-60, (Fig. 3.5). The tests of these fuel pins are continued.

The post-irradiation examination of the BOR-60 reactor fuel pin claddings with 21.0; 24.4 and 26.0% burnup fully confirmed the technical solutions of the design and promissing estimations of their serviceability, carried out by "VICOND" program. In none of the investigated cross-sections there were found any indications of the fuel-cladding chemical interaction. Typical macrostructures of the irradiated vibropacked fuel column at

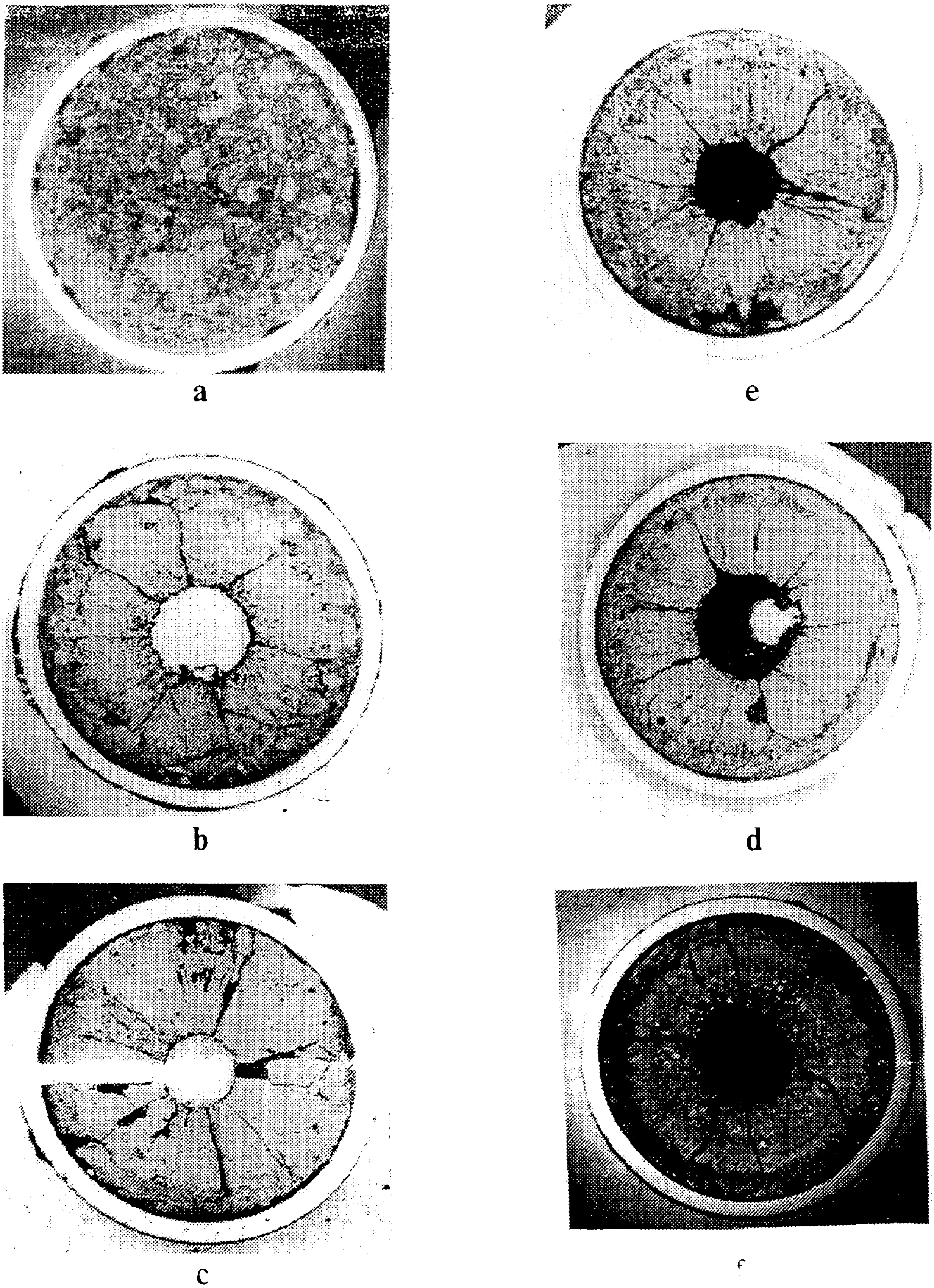


FIG. 3.7. Macrostructure of the vibropac fuel column

a) initial | *b) 12% burnup*
c) 21% burnup | *d) 24% burnup, center A.C.*
e) 24% burnup, upper A.C. | *f) 26% burnup, center A.C.*

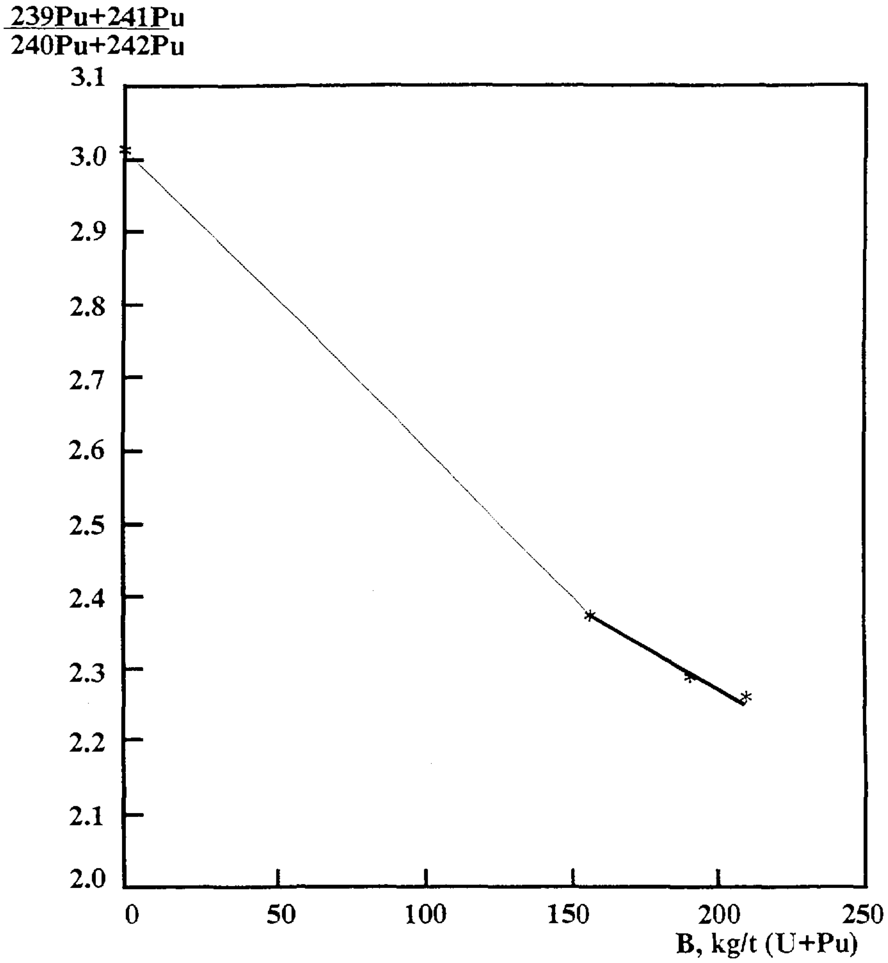


FIG. 3.8. Dependence of ratio even and odd Pu isotopes change vs burnup.

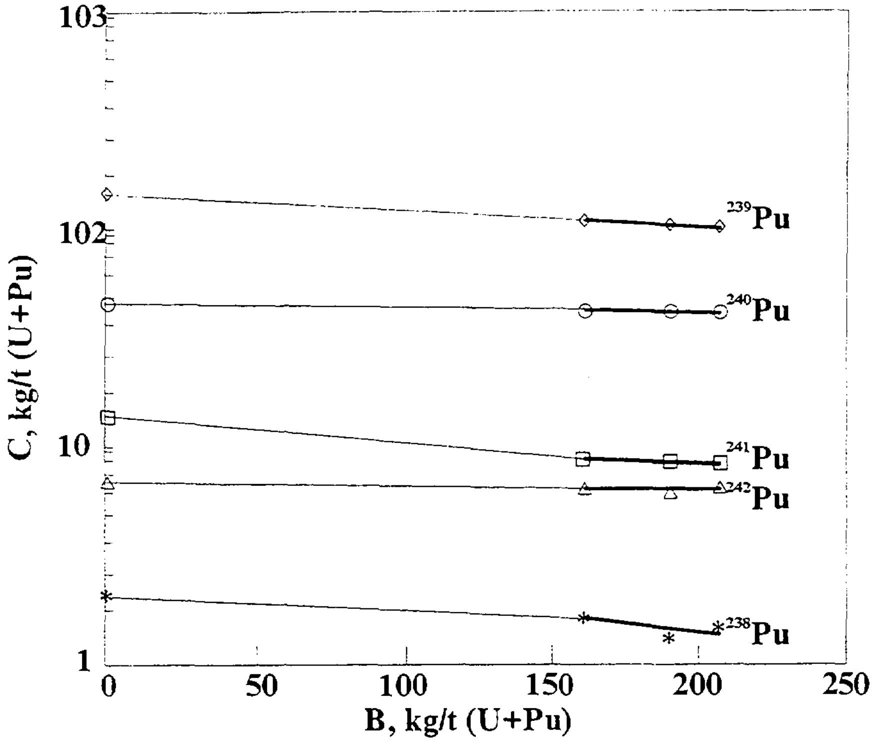


FIG. 3.9. Content of the Pu isotopes as a function of burnup.

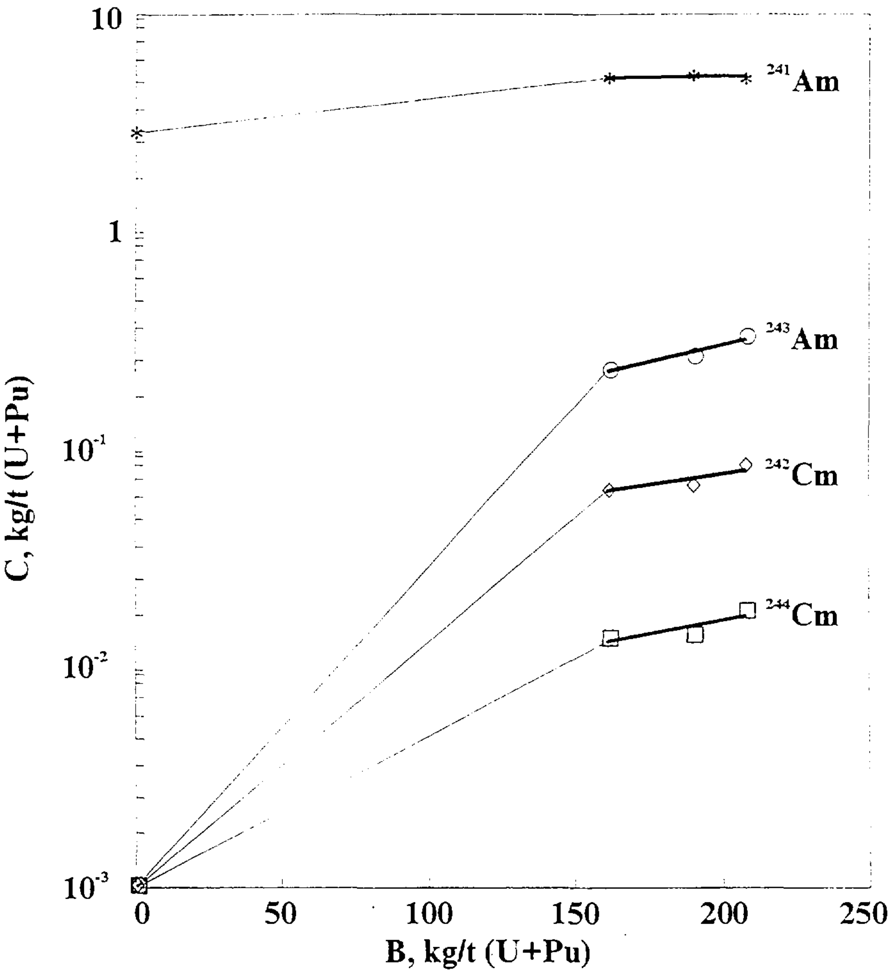


FIG. 3.10. Content of MA as a function of burnup.

different burnup are shown in Fig.3.6. The analysis of stressed-strained state of the fuel pin claddings of fuel assemblies with more than 20% burnup, estimation of their mechanical characteristics have given possibility to plan further experiments on fuel pins of this very design for achieving more high burnups. The radiochemical analysis of the $UPuO_2$ fuel isotope composition, irradiated up to 21.0% h.a. burnup allowed not only to precise the calculated values of the fuel burnup, but to estimate kinetics of content changes of the main isotopes presented in Fig. 3.7 - 3.9. In Fig.3.7 there is seen a clear tendency for decreasing even and odd Pu isotopes correlation due to burnup in the BOR-60 reactor spectrum and for increasing curium isotopes consentration. All these data in combination with the next radiochemical investigations of fuel isotope content with 26% burnup, which are carried out now will allow to precise the programs for calculation the minor-actinides transmutation in the BOR-60 reactor spectrum.

CONCLUSION

Large-scale testing of the BOR-60 reactor fuel pins with vibropac uranium-plutonium oxide fuel confirmed high operation characteristics of these fuel pins in standard and transient conditions, as well as in experiments with cladding overheating. The addition of a getter - metallic uranium powder to the fuel composition allowed to suppress completely physical-chemical fuel-cladding interaction and eliminate the burnup due to this factor.

Considering the shown advantages and successful tests of fuel pins with vibropac MOX fuel and Cr13Mo2NbVB steel claddings in the BOR-60 reactor up to 28% burnup there are planned tests of similar fuel pins with $UPuO_2$ + U fuel in the BN-600 reactor.

REFERENCES

1. R.D.Legget, L.C.Walters "Status of LMR fuel development in the United States of America" J.Nucl.Mat., 204(1993) 23-32.

2. M.Katsuragawa, H.Kashihara, M.Akebi "Status of liqiud metal fast breeder reactor fuel development in Japan" J.Nucl.Mat., 204(1993) 14-22.

3. R.B.Baker et al "Status of fuel blanket and absorber testing in the fast flux test factility" J.Nucl.Mat., 204(1993) 109-118.

4. C.Brown, A.Languille, G.Muchling "Status of LMR fuel development in Europe" J.Nucl.Mat., 204(1993) 33-38.

5. O.V.Skiba, A.A.Mayorshin et al "Development and Operation Experience of the Pilot Plant for Fuel Pin and Subassembly Production Based on Vibropac Uranium-Plutonium Fuel"
/Proc.Int.Conference on Fast Reactors and Related Fuel Cycles,
October 28-November 1, 1991, Kyoto, Japan, N2, R15-4.

6. O.V.Skiba, Yu.P.Savochkin et al "Technology of Pyroelectrochimical Reprocessing and Production of Nuclear fuel"/ Proc.Int.Confernce on Future Nuclear Systems: Emerging Fuel Cycles and Waste Disposal Options Global - 93, September 12-17, 1993, Seatle, WA. ANS 1993, r.z.p. 1344-1350.

7. R.Herbig, O.V.Skiba, A.A.Mayorshin et al "Vibrocompacted Fuel for the Siquid Metal Reactor BOR-60" J.Nucl.Mat. 204(1993) 93-104.

8. A.A.Mayorshin, A.A.Petukhov et al "Development af Vibropac Oxide Fuel Element for Fast Reactor"/ Int.Conference Global-93. Seatle, USA, September 12-17, 1993.

9. A.A.Mayorschin, V.A.Tzykanov et al. "The Features of Radiation Behavior of Fuel Elements with Vibropac MOX Fuel", Proc.Int. Conference, Alushta, May 22-25, 1990, v.4, pp. 90-97.

10. V.K.Shamardin, F.N.Kryukov at al. "Effect of Tellur on Corrosion of Fuel Pin Clads for Fast Breeder Reactor" Preprint, RIAR-8(791), Dimitrovgrad, 1990.

11. A.A.Mayorshin, O.V.Skiba et al "Production and irradiation of $UPuO_2$ fuel with 40% of Pu in BOR-60. Vibrotechnology application for utilization of Plutonium and Minor Actinides"/ Int. CAPRA Seminar, Karlsruhc, September 21-22,1994.