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Current status of development in dryPyroelectrochemical technology of spent nuclear fuel reprocessing (2)

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CURRENT STATUS OF DEVELOPMENT IN DRY PYROELECTROCHEMICAL TECHNOLOGY OF SPENT NUCLEAR FUEL REPROCESSING

(2)
Experience in Vibropac Fuel Development for Fast Reactors

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Main trends of investigations

- Fuel cycle of fast reactors
  - Spent fuel recycling
  - Granulation of U- and U-Pu oxide fuel
  - Manufacturing of MOX fuel pins by vibropacking process
  - In-pile tests and PIE of vibropac MOX fuel pins

Outlines

- Purpose – fuel pin of Closed Fuel Cycle
  - pyrochemical («dry») processing
  - vibropacking of granulated fuel for fuel pin manufacturing
  - automated remotely-controlled equipment for manufacturing granulated fuel, fuel pins, fuel assemblies
- History
  - the 60-70s
    - development of Fuel Cycle concept
    - scientific research for substantiation of fuel pin design
    - OREL facilities on manufacturing of granulated fuel, fuel pins, fuel assemblies for the research reactor BOR-60
  - the 80s
    - irradiation of vibropac FAs in the research reactor BOR-60
    - semi-industrial complex for manufacturing granulated fuel, fuel pins, fuel assemblies for BN-600 (BNPP)
    - irradiation tests of experimental vibropac FAs in BN-350, BN-600
  - the 90s
    - irradiation tests of experimental MOX-vibropac FAs in BN-600
  - since 2000
    - continuation of irradiation tests of experimental MOX-vibropac FAs in BN-600

OREL facility

. Схема расположения оборудования для изготовления твэлов и ТВС в условиях защитных камер РФ-1 и РФ-2
1- бокс разделки твэлов; 2- подготовка гранулята; 3- виброуплотнение гранулята;
4- загрузка экрана; 5- загрузка верхней заглушки; 6- герметизация твэла;
7, 8, 9, 11, 16, 17, 18, 19, 20- хранение твэлов; 10, 13- транспортная система твэлов;
12- контроль герметичности твэлов; 14- контроль распределения компонентов топливного сердечника твэлов; 15- контроль геометрических размеров твэлов и их визуальный осмотр; 21- сборка ТВС; 22- сварка ТВС; 23- кантование ТВС;
24- контроль герметичности твэлов в составе ТВС; 25- измерение гидравлических характеристик ТВС; 26- контроль сварного шва; 27- визуальный осмотр ТВС;
28- радиографический контроль сварного шва; 29- сварка контровочной гайки;
30- хранилище ТВС.

Fluoride Volatility method for reprocessing of UO_2

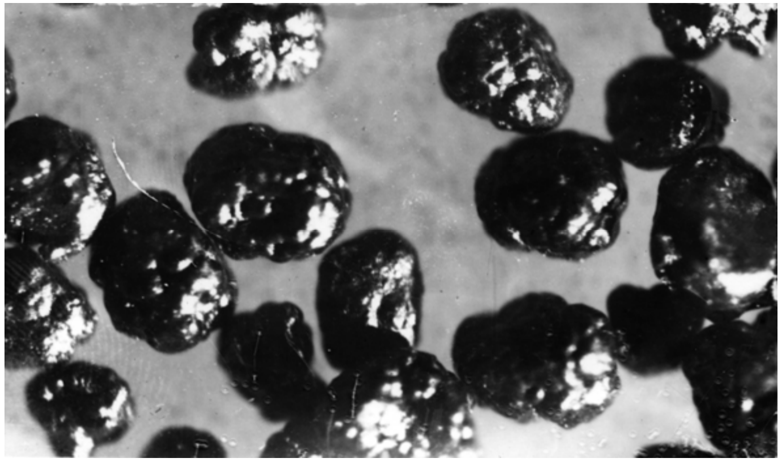
- Regeneration of spent BOR-60 fuel by gas-fluoride method (FREGAT-1)
- Fuel granulation by pyrohydrolysis of uranium hexafluorides
- Parameters of polydisperse granulated particles of UO_2:
  - density of particles ~ 10.7 g/cm^3
  - mass content of fluorine – less than 0.005 %
  - absence of contamination of the equipment structural materials with cruds

Fluoride Volatility method for reprocessing of UO_2

- Parameters of experimental fuel pins:
  - enrichment in U-235 – 90 %
  - smear density – max 9.3 g/cm^3
  - nonuniformity of density distribution along the fuel column length – within ± 5 %
- FA irradiation conditions:
  - irradiation duration – 1984 – 1990
  - maximal burnup – 14.8 % h.a.
  - maximal linear power generation – 42.2 kW/m
  - maximal cladding temperature – 711 °C

Fluoride Volatility method for reprocessing of $(U,Pu)O_2$

- Regeneration of spent BOR-60 $UPuO_2$ by gas-fluoride method (FREGAT-1, 2)
- Parameters of polydisperse granulated fuel:
  - output of the product:
    - Pu ~ up to 91 %
    - U ~ up to 99.3 %
  - purification factor:
    - Pu ~ $10^3 - 10^4$
    - U ~ 10^7
  - productivity – up to 3 kg/h



UO_2 pyrohydrolysis

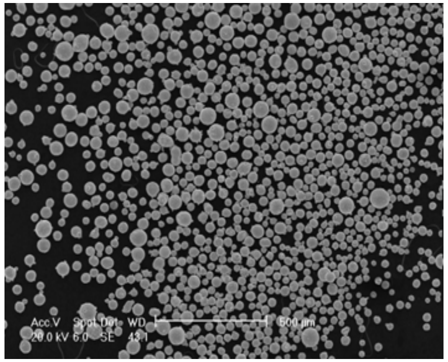
- Fuel granulation by pyrohydrolysis of uranium hexafluoride
- Parameters of experimental fuel pins:
  - enrichment in U-235: 90 %
  - smear density: 8.8 – 9.2 g/cm^3
  - nonuniformity of density distribution along the fuel column length: within ± 5 %
- FA irradiation conditions:
  - irradiation duration: 1991 – 1993
  - burnup: 3.7 – 10.5 % h.a.
  - linear power generation: 32.2 – 43.5 kW/m
  - cladding temperature: 584 – 655 °C

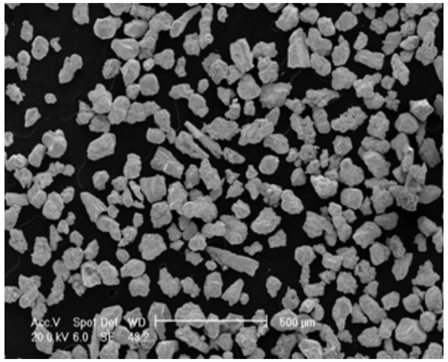
Sol-gel process

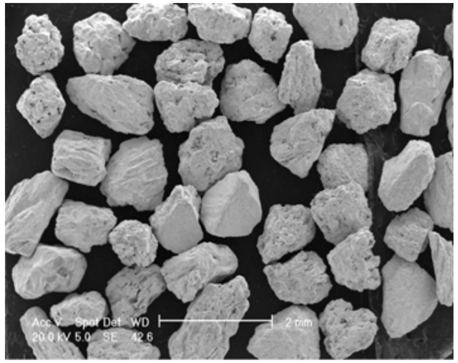
- UO_2 production by sol-gel process – VNIINM
- Manufacturing of fuel pins – RIAR:
  - packing of the coarse fraction
  - infiltration and compacting of the fine fraction
    - uniformity of density distribution is within ± 3 %
- FA irradiation conditions:
  - irradiation duration: 1984 – 1985
  - burnup: 5.7 % h.a.
  - maximal linear power generation: 54.0 kW/m
  - maximal cladding temperature: 750 °C

Electrochemical process

Metal content, % mass	87.75
Granule bottle density, g/cm^3	10.7
Bulk density of polydisperse granule, g/cm^3	6.0
O/M ratio in granulated fuel (oxygen ratio)	2.00 ± 0.01
Mass fraction of process impurities, %, including:	no more than 0.5
chlorine-ion	0.006
carbon	0.006







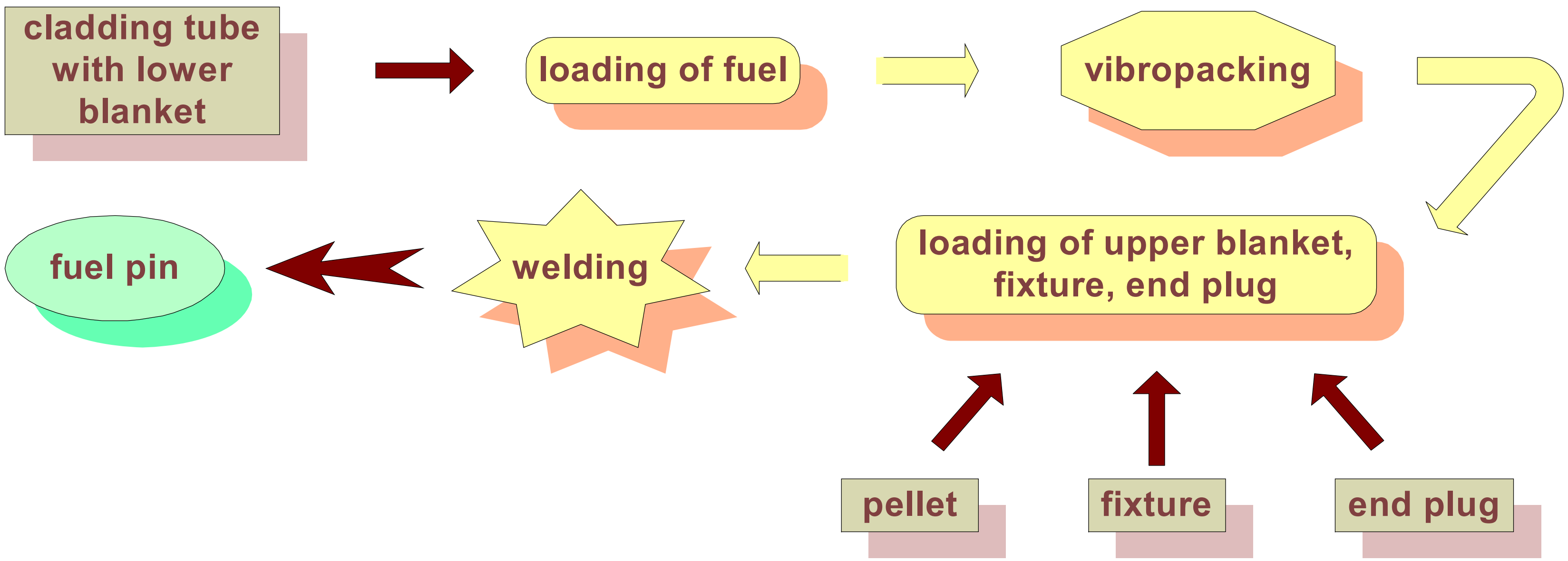
Preparation of granulated fuel

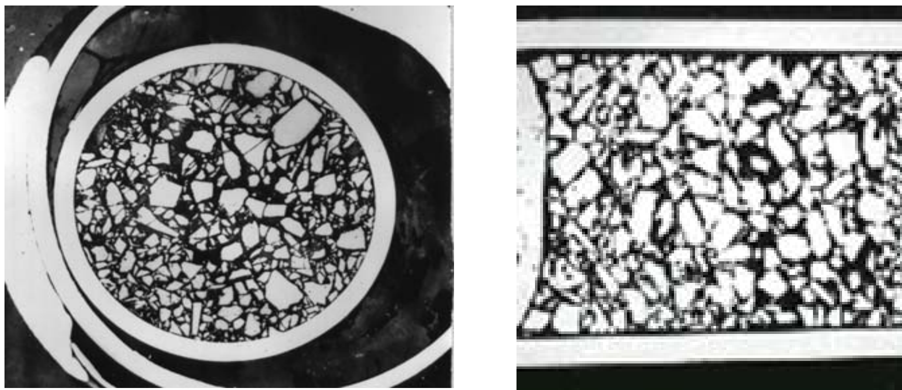
НИИАР

- Screen sizing of particles
  - 3, 4-fractional compositions
  - polydisperse composition
- Parameters of granulated fuel

Fuel parameters	Fractions of granulated fuel, mm			Polydisperse composition
	0.8 – 1.0	0.25 – 0.40	< 0.1	
Density, g/cm^3: bulk bottle	 4.6 – 4.9 10.8 – 11.0	 4.7 – 4.8 10.9 – 11.0	 4.9 – 5.1 10.9 – 11.0	 6.0 – 6.2 10.9
Yield, g/sec	18.5	17.0		21.0
Mass content, %: metal chlorine, $3 10^{-3}$ carbon $3 10^{-3}$	 87.9 ± 0.3 7 – 14 7 – 15	 88.0 ± 0.2 5 – 7 5 – 13	 87.8 ± 0.3 3 – 5 5 – 10	 87.6 5 – 6 8 – 12
Content of impurities, %	0,20	0,15	0,30	0,25

Manufacturing of fuel pins by vibropacking process





Macrostructure of unirradiated vibropack MOX-fuel

Manufacturing of fuel pins by vibropacking process

- Parameters and mixing techniques
  - Criteria
    - fuel column density
    - density and Pu distributions along the fuel column length
  - Investigations
    - mixer design
    - filling of the mixer
    - fuel type (homogenuous, heterogeneous)
  - Difficulties
    - bulk of portions
    - remote conditions

Manufacturing of fuel pins by vibropacking process

- Pouring parameters and techniques
  - Consecutive operations
    - mixing of portion
    - pouring
    - vibropacking
  - Synchronous batching
    - pouring
    - vibropacking

- Vibropacking modes
  - frequency range – 100…3000 Hz
  - maximal acceleration – up to 30g
  - vibropacking time – up to 120 sec

Manufacturing of fuel pins by vibropacking process

- Influence of features of fuel production and fuel pin manufacturing on operating parameters
  - Intercrystalline corrosion of the internal cladding surface due to increased humidity content in fuel
    - drying of cladding and fuel
  - Fuel-cladding chemical interaction (FCCI) on the fuel-cladding boundary due to accumulation of corrosion-active FPs
    - getter additive

Design characteristics of vibropac fuel pin

Parameter	Value						
	BOR-60		BN-350		BN-600	
Length of fuel pin, mm	1080	1050	1790		2440	2400
Diameter × thickness of fuel pin cladding, mm	6.0×0.3	6.9×0.4	6.9 × 0.4		6.6 × 0.4	6.6 × 0.4; 6.9 × 0.4
Material of fuel pin cladding	EI-847, EP-172, ChS-68, EP-450		EI-847		EP-172	ChS-68
Height of fuel column, mm	450		1060		950	950; 1030
Fuel column composition	UO_2; UO_2 +U; $UPuO_2$+U		UO_2 +U	$UPuO_2$+U	$UPuO_2$+U	$UPuO_2$+U
Smear density of fuel column, g/cm^3	8.3…9.5		8.9…9.1	8.4…8.9	8.9…9.1	8.8…9.2
Plutonium content, %	15…40		-	20	22	25
Enrichment in U-235, %	45…90		24	10	0,7	0.7
Enrichment in Pu-239 %	60; 95		-	95	95	95
Getter content, %	3…10		5	5	10	10
Relative non-uniformity of smear density along the fuel column, %	± 5					
Relative non-uniformity of plutonium content distribution along the fuel column, %	± 5					

Vibropac fuel in BOR-60 (1)

- Problems of fuel elements serviceability during the initial period:
  - intercrystalline corrosion of the cladding
  - lower smear density
  - insufficient reliability of the welded joint "cladding –upper endplug“

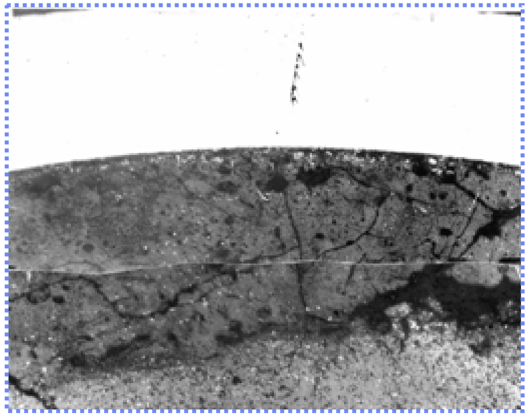
- Solution of problems
  - Getter additives in the form of metal U particles- 5-10 % wt.
  - Granulated fuel improvement
  - Special preparation of cladding and granulated fuel

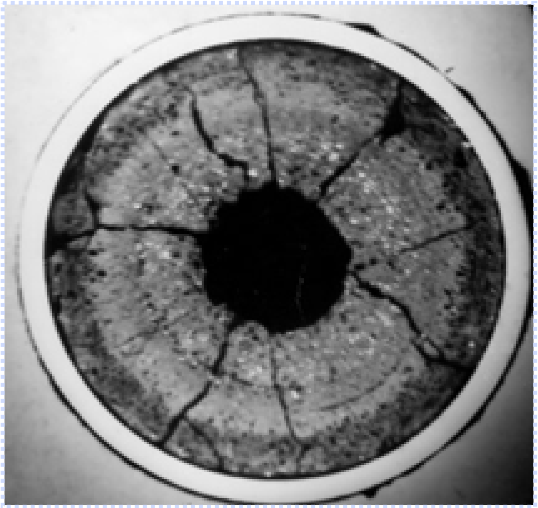
Vibropac fuel in BOR-60 (2)

Maximum parameters of irradiation

Maximum linear power, W/cm	510
Maximum cladding temperature, °C	722
Maximum fuel burnup, % h.a.	
- standard FA	18.0
- experimental FA	30.0
- experimental fuel elements	32.3
Quantity of FA with burnup (pieces)	
- 10 – 15% h.a.	279
- 15 – 20% h.a.	25
- > 20% h.a.	10

Vibropac fuel in BOR-60 (3)

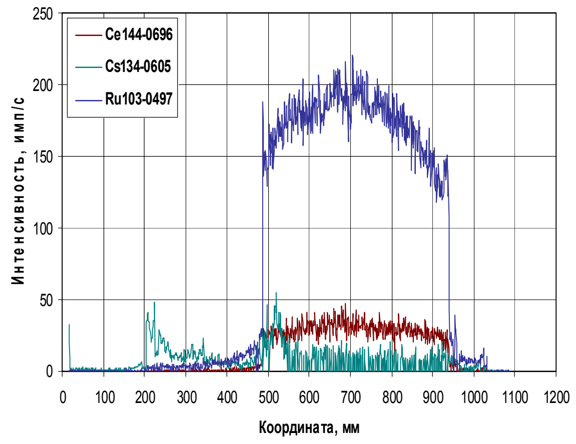


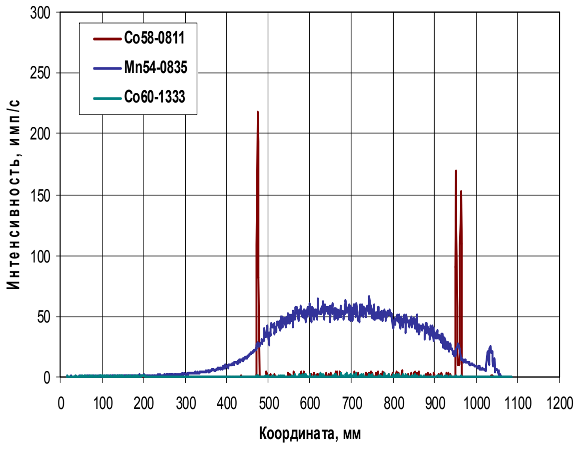


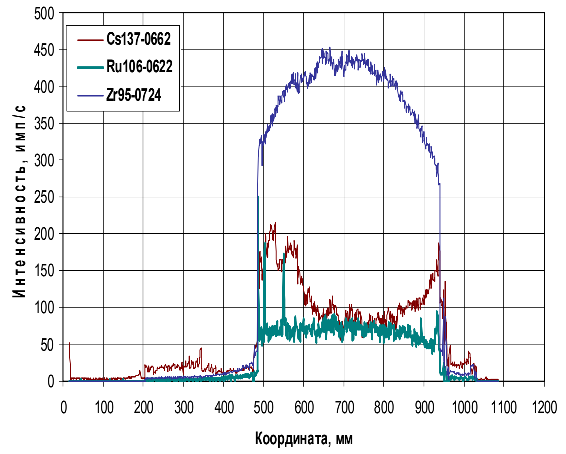
During 1977-1984 more than 190 FA for BOR-60 were fabricated at the OREL facility.

Total quantity of the BOR-60 FA is more than 420.

Vibropac fuel in BOR-60 (4)







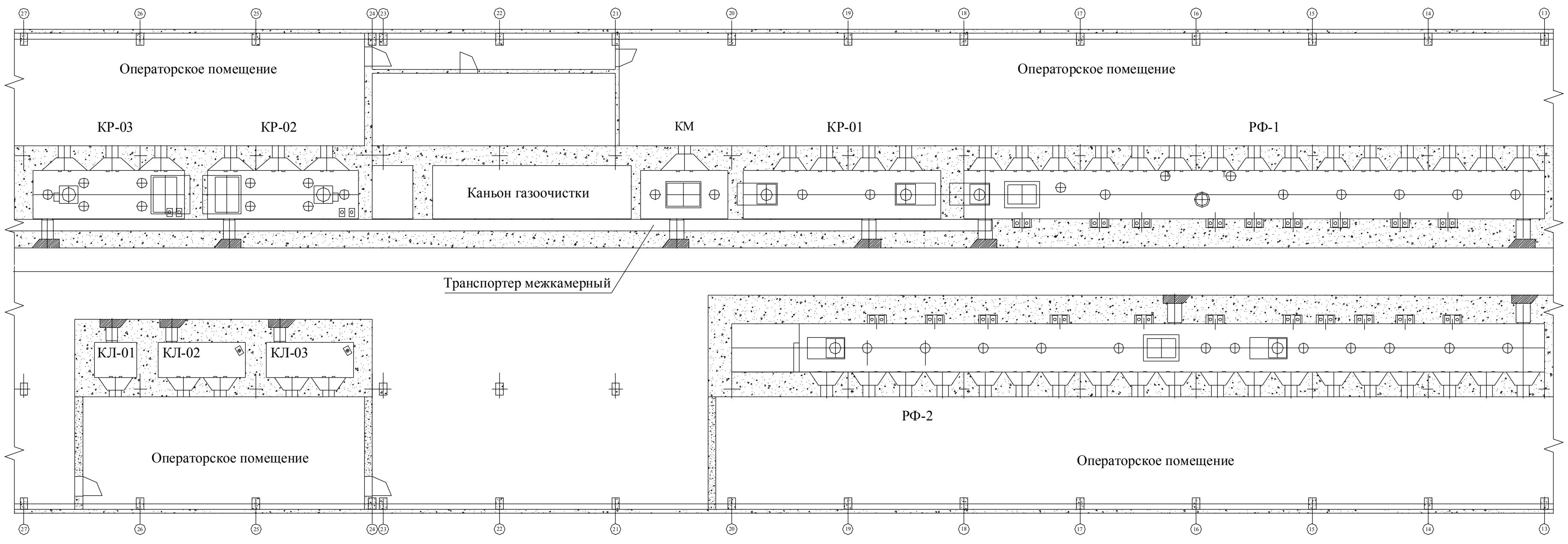
Vibropac fuel in BOR-60 (5)

Pins Requirements and Operating Limits

- Fuel smear density
  - 9±0,2 g/cm^3
- U metal content
  - 3…5 %
- Density and Pu distribution
  - ± 5 %
- Cladding material
  - Stainless steel + c.w.

- Linear power rate
  - 50 kW/m
- Cladding temperature
  - 710 °C
- Damage doze
  - 70 dpa
- Burnup
  - No limit

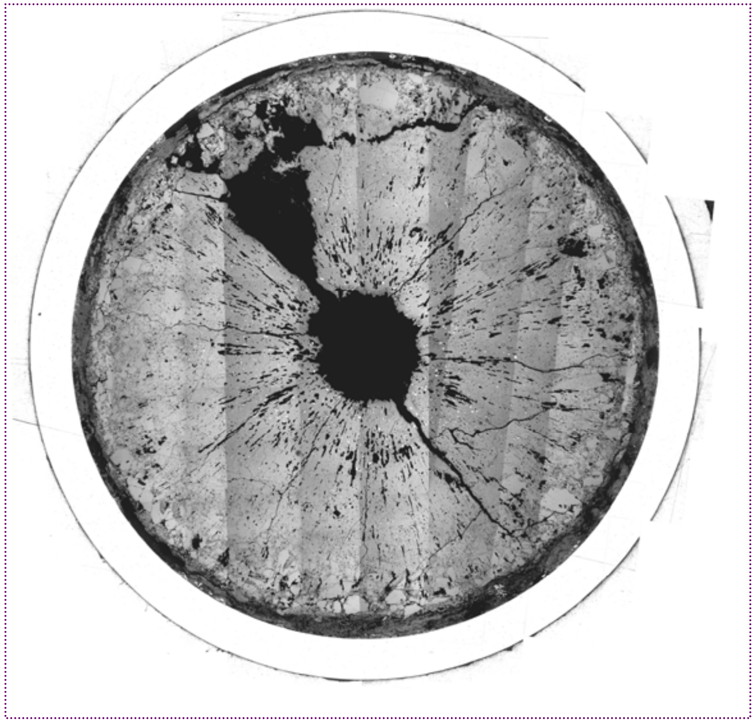
Semi Industrial Complex



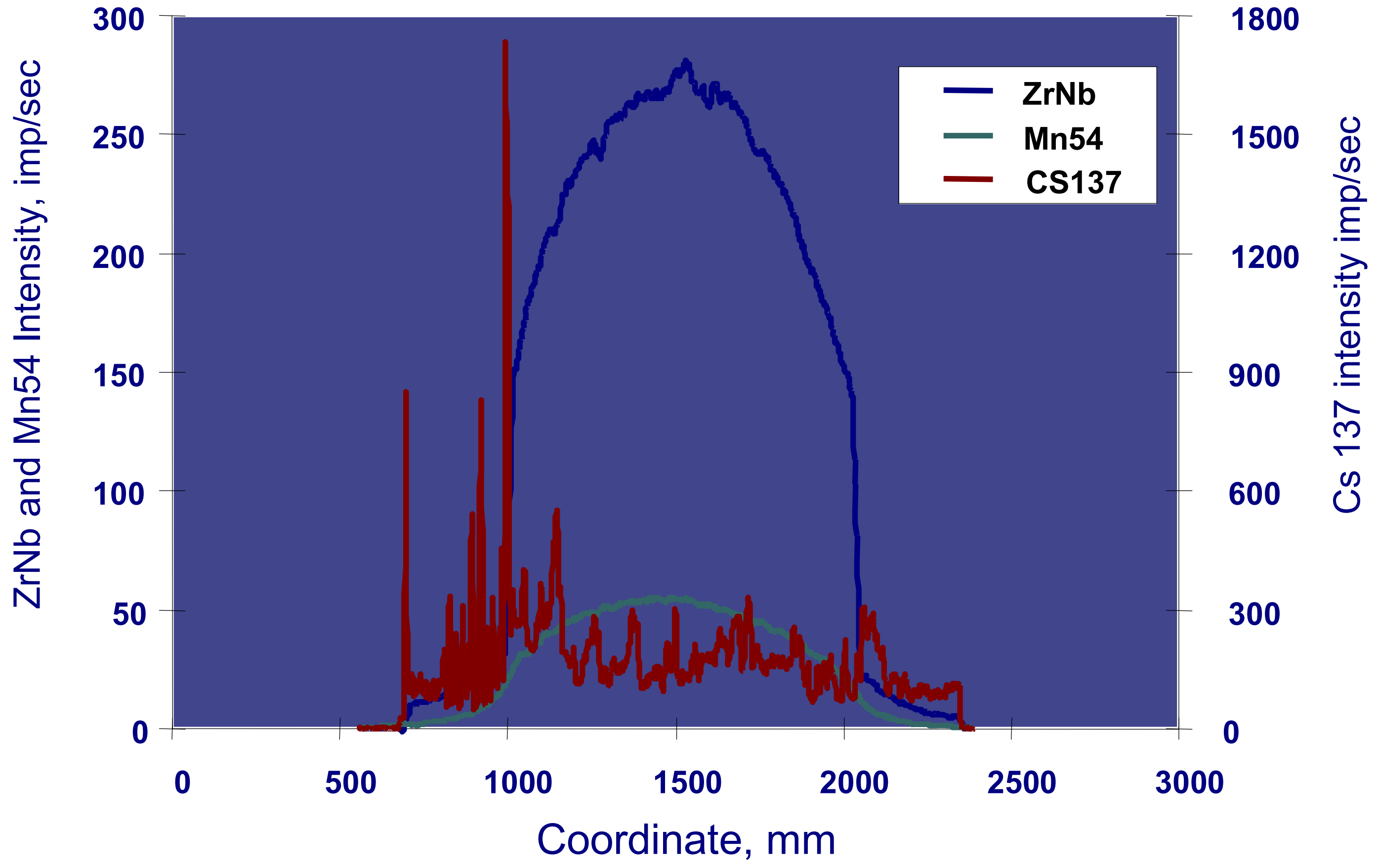
Vibropac fuel in BN-600 (1)

FA No	Year of fabrication	Maximum linear power, W/cm	Maximum cladding temperature, C	Burnup, % h.a.
WG0187	1987	450	670	6,8
WG0287	1987	450	670	10,8
03, 04, 05,06	1990	425…450	680…690	9,0…9,3
01.99, 02.99, 03.99	1999	360…400	670…680	10,2…10,5
04.01, 05.02, 06.02	2001, 2002	453	694	~ 10
07.03, 08.03, 09.03	2003	450	690	7,4…7,8 (under irradiation)
10.05, 11.05, 12.05	2005	Are transported for irradiation		

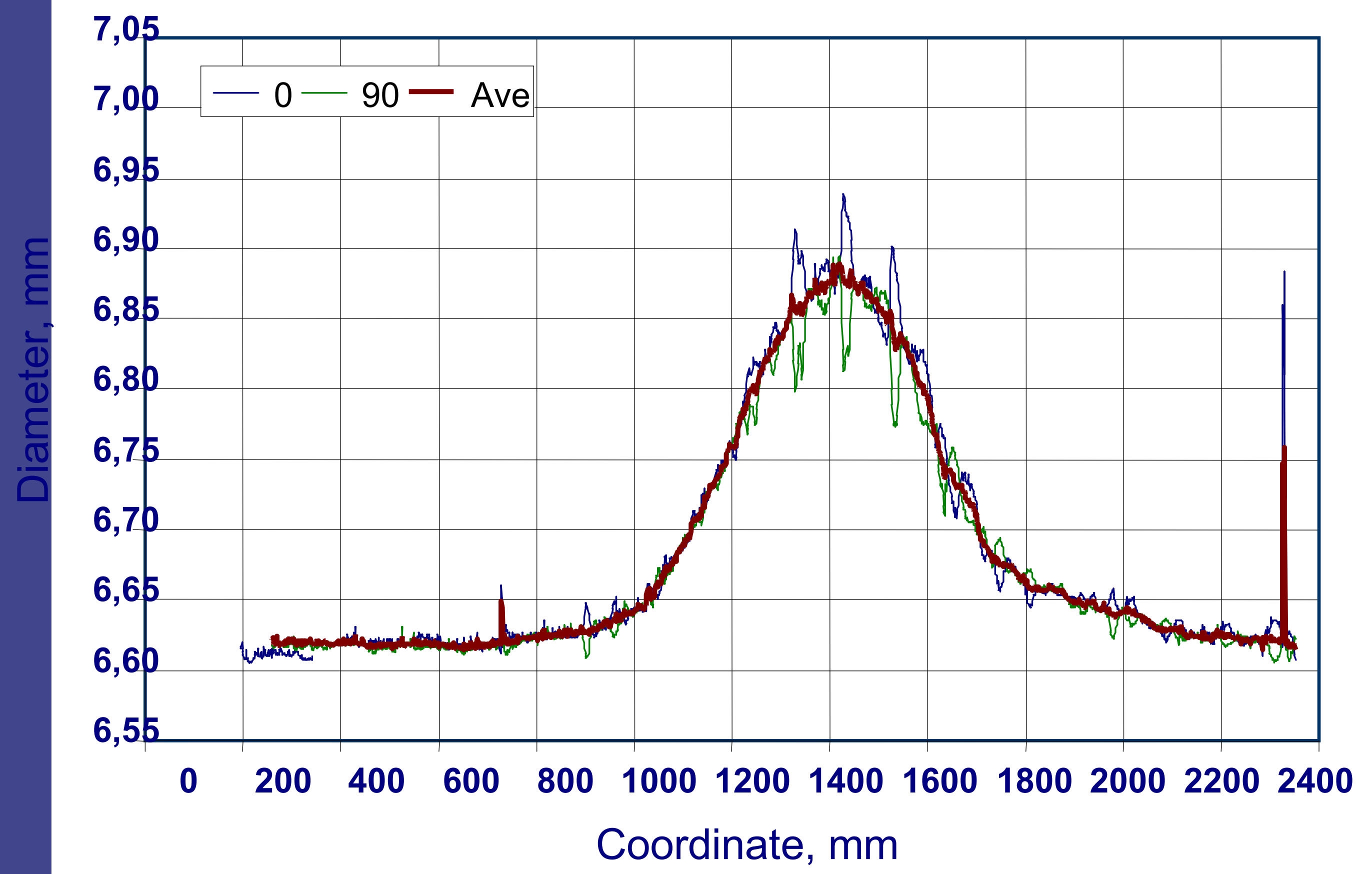
Vibropac fuel in BN-600 (2)



Vibropac fuel in BN-600 (3)



Vibropac fuel in BN-600 (4)



Vibropac fuel in BN-600 (5)

- No specific differences in radiation-thermal effects were observed in fuel pins and FA tested in BOR-60, BN-350 and BN-600.

Vibropac MOX-fuel in BN-600 (6)

Main project characteristics

Characteristic	Value
Type of fuel	MOX
Density of fuel column, g/cm^3	9,0±0,2
Content of metal U in fuel, %	5…10
Cladding Material	c.w. stainless steel
Density and plutonium distribution, %	± 5
Maximum burnup, % h.a.	10,7
Maximum damage dose, dpa	84,3
Maximum linear heat power rate, kW/m	47,6
Maximum Cladding temperature, ˚C	710

Current Status (1)

- Fuel pin design, technologies for granulated fuel production and fuel pins fabrication are ready for industrial application;
- After modernization SIC will have annual productivity 50 FA for BN-600;
- RIAR technologies are under implementation for BN-800 fuel supply.

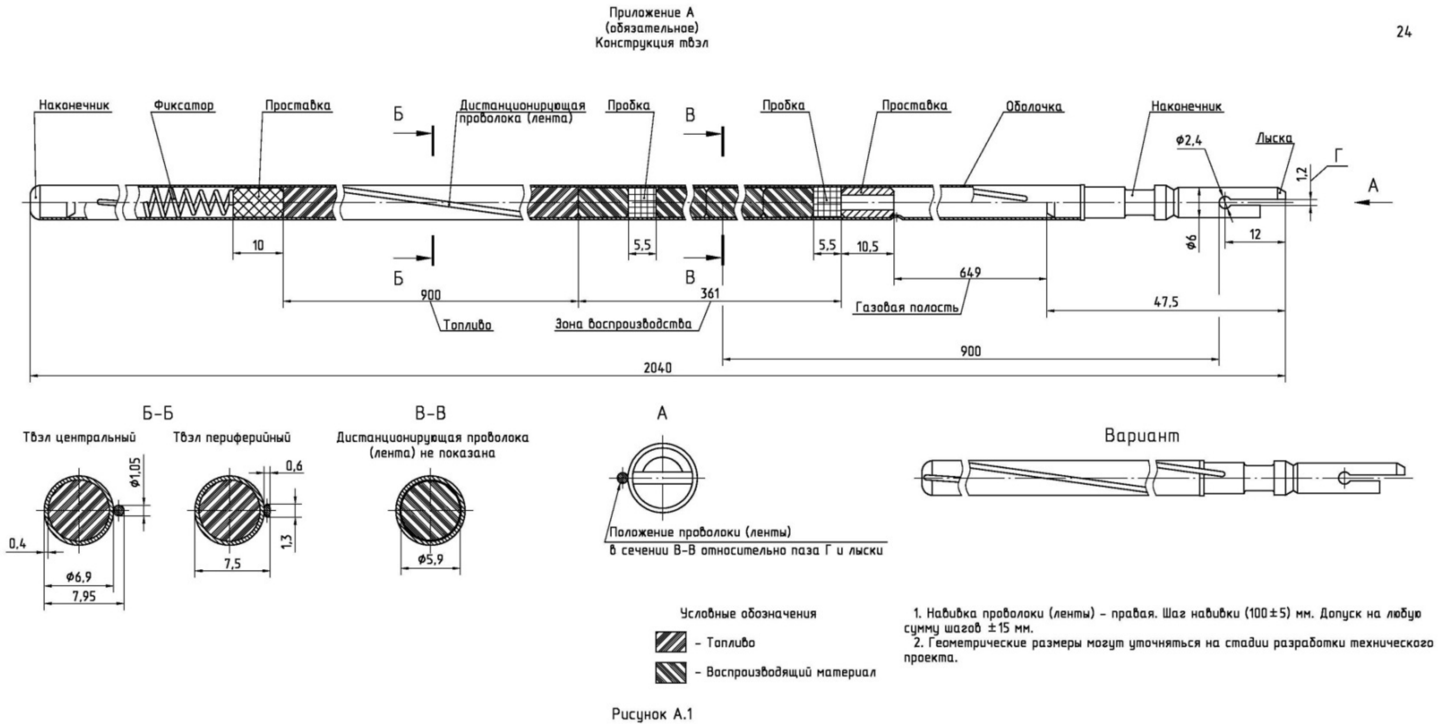
Current Status (2)

Scientific investigations

No significant influence of used MOX-fuel of the following grades was observed:

- UO_2+PuO_2 mixture or co-precipitated fuel $UPuO_2$;
- Pu of various grades (weapon, power generating or recycled);
- fuel with PuO_2 content up to 45 wt. %;
- fuel with NpO_2 content up to 5 wt. %;
- fuel with residual FPs content up to 8 wt. %

Fuel pins for BN-800



Thank you for your attention!

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