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Technical Meeting on the Management of Spent Fuel
(Pebbles and Compacts) from High Temperature Reactors

HTGR SNF REPROCESSING TECHNOLOGY DEVELOPMENT IN RUSSIA

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Vienna, 7-11 of july 2025

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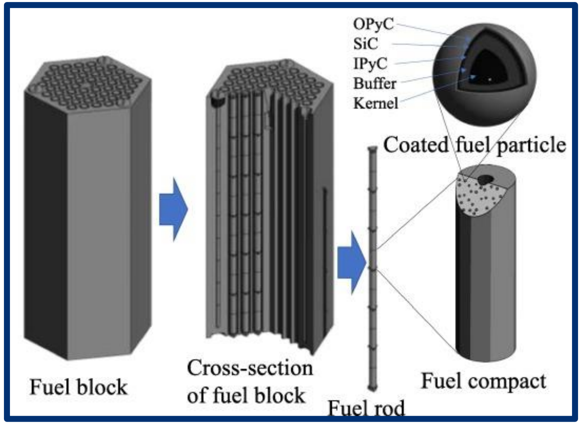
Owner and right-holder of exclusive rights of R&D results is JSC «TVEL».

HTGR is being developed within Hydrogen Energetics Project

R&D

«High temperature gas-cooled reactor SNF reprocessing and NM recycling technology development»

2022-2024 y.



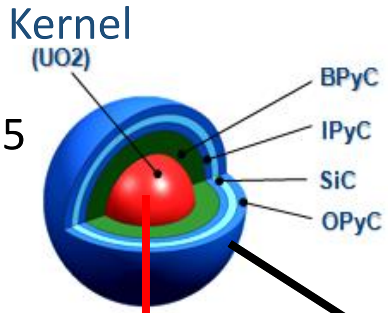
Composition of a prismatic type HTGR assembly

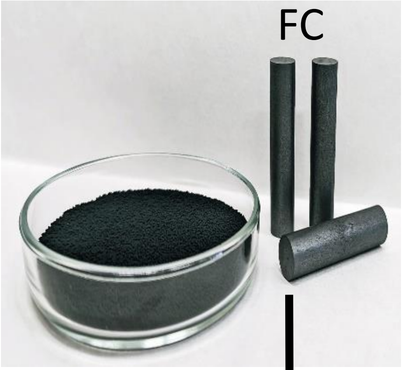
Fukaya Y., Goto M., Ohashi H. Feasibility study on reprocessing of HTGR spent fuel by existing PUREX plant and technology //Annals of Nuclear Energy. – 2023. – T. 181. – C. 109534.

HTGR fuel composition characteristics

	TRISO-particle	Fuel compact (FC)	Assembly
CM:	**Pyrocarbon, Silicon carbide**	**Graphite**	**Graphite**

18 %
U-235





Kernel reprocessing

Standard reprocessing technology for highly enriched oxide fuel

CM management

New processes for kernel extraction from assemblies and CM management

*CM – construction materials

Hydrometallurgical fuel reprocessing

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Adaptation of current extraction technology (PUREX) at operating or planned facilities

RT-1, PA «Mayak»
EDEC, JSC «SCC»
EDC, PA «MCC»

New facilities?

+

Additional facility for **head-end processes** of NM extraction and facility for **carbonaceous waste management**

Fundamental approaches to HTGR SNF reprocessing technology development

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VVER-1000		**HTGR**
~ 0,35	<	**~ 26**
tCM/tUO_2		tCM/tUO_2

Graphite accumulates C-14

↓

Incineration must be accompanied with CO_2 capture and immobolization

↓

Massive volume increase

↓

REJECTION OF GRAPHITE WASTE INCINERATION

Large volume of the waste

↓

Minimization of secondary contamination need

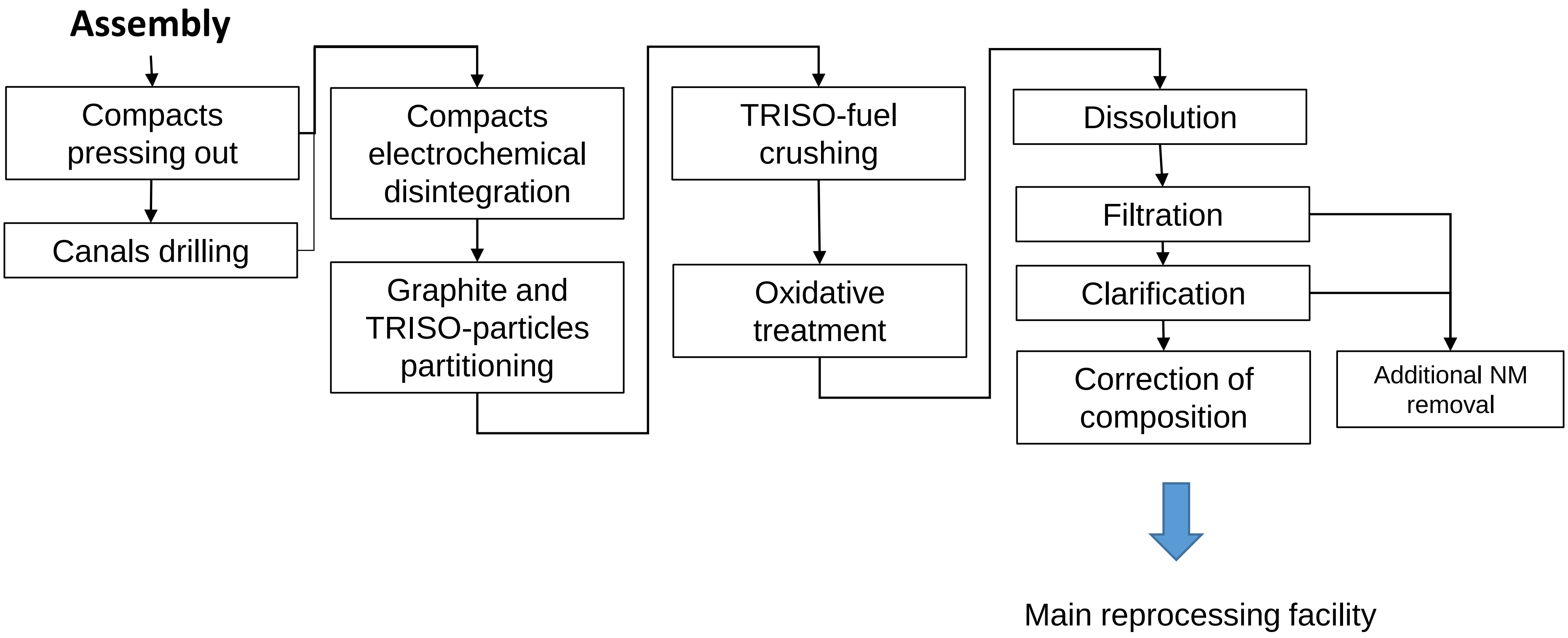
↓

«Step-by-step» approach to disassembling

↓

MAINTAINING INTEGRITY OF TRISO-FUEL LAYERS

HEAD-END HTGR SNF REPROCESSING OPERATIONS PRINCIPAL FLOW-SHEET



COMPACTS RECOVERY FROM ASSEMBLIES

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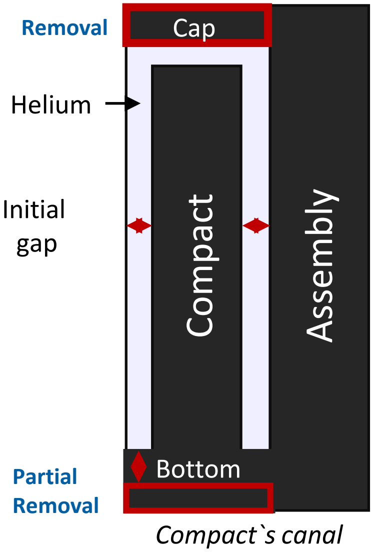
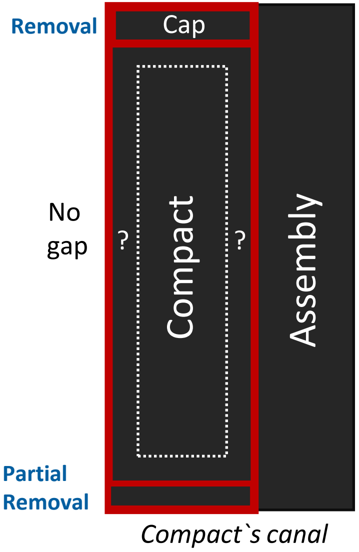
NORMAL GEOMETRY COMPACTS



COMPACTS PRESSING OUT

CHANGED GEOMETRY COMPACTS



WHOLE CANAL DRILLING

Compact`s or assembly`s graphite could change geometry

Compacts recovery unit

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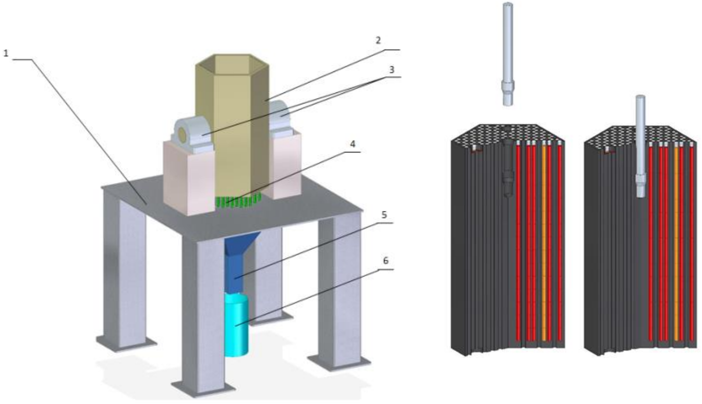
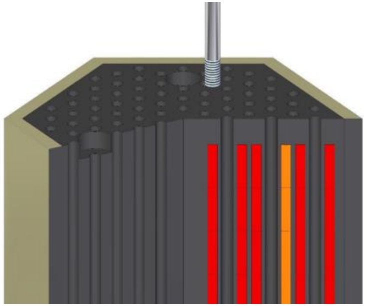
1.



1. Transportation

2.

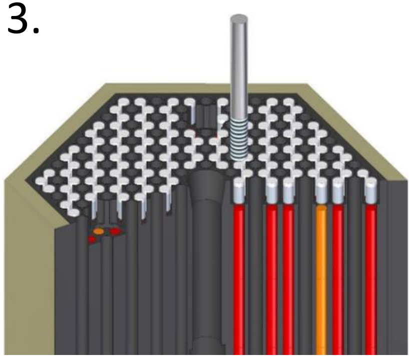


2. Partial bottoms removal

EXPERIMENTAL TESTING ON RBMK GRAPHITE

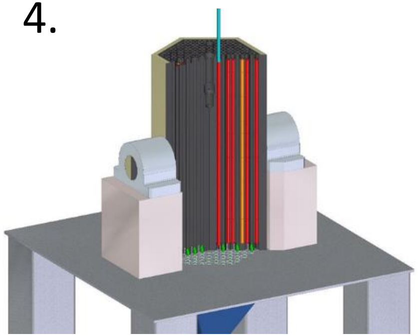
5.

3.



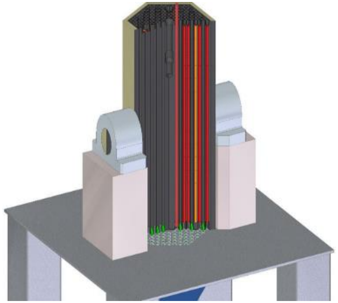
3. Caps removal

4.



4. Pressing out of normal geometry compacts

5.



5. Drilling of changed geometry compacts

5.

Electrochemical disintegration of fuel compacts

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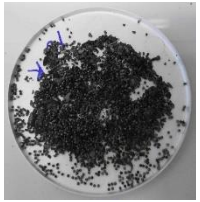
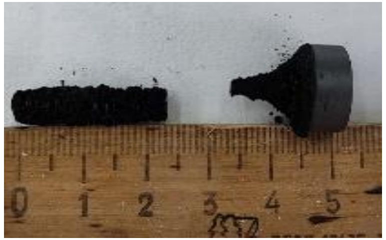
Process of **graphite matrix** destruction under electric current

Compact – anode
Electrolyte – nitric acid 3-8 mol/l

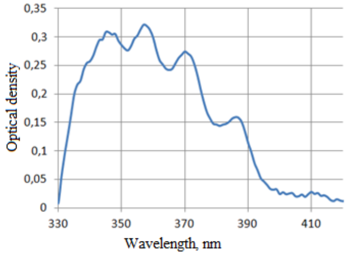
Products



TRISO intact and graphite particles



Non-desintegrated parts



Electrolyte with HNO_2, WSOC
water-soluble organic compounds

Electrochemical disintegration of fuel compacts

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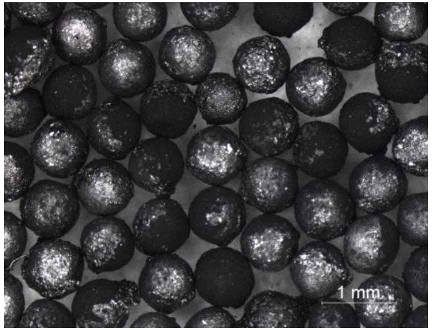
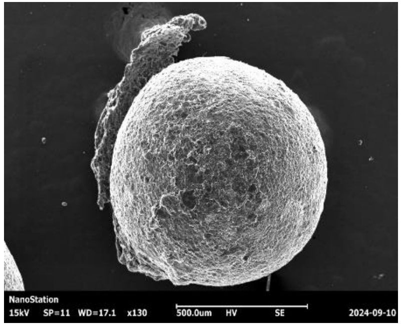
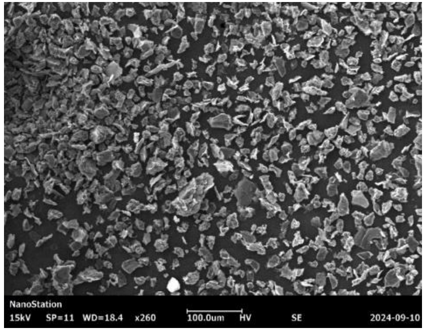
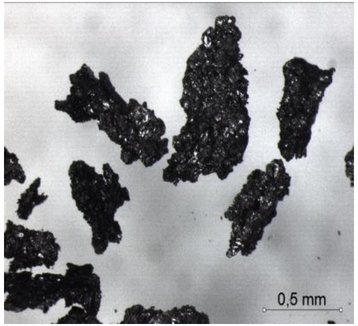
Analytical control





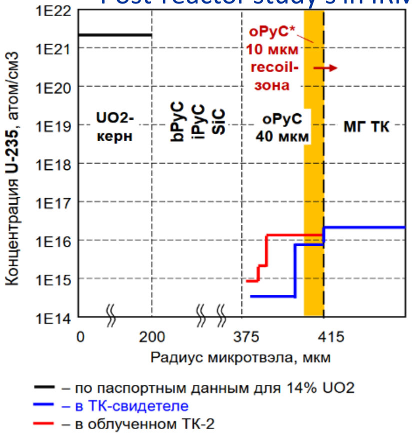




Materials irradiaton was conducted in «dry» canal AK-1 in active zone of reactor IVV-2M (JSC «IRM»)

Concentration g ^{235}U/ml **electrolyte**	Concentration g ^{235}U/g **graphite**	Concentration ^{235}U, nuc/cm^3 **OPyC**
$5{,}5\cdot10^{-10}$	$(2{,}0 \pm 0{,}2)\cdot10^{-7}$	$4{,}7\cdot10^{15}$
$6{,}2\cdot10^{-10}$	$(1{,}3 \pm 0{,}2)\cdot10^{-7}$	$1{,}9\cdot10^{15}$

Post-reactor study's in IRM



«Yield» of U due to production circumstances, not disintegration

Сквозная проверка головных процессов – Схема экспериментов

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I Several compacts disintegration in a row

II Modeled TRISO SNF crushing

↓

Oxidative treatment

↓

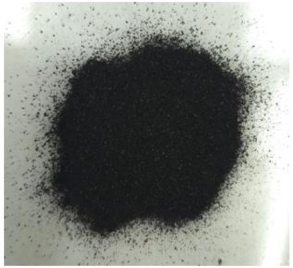
Dissolution

↓

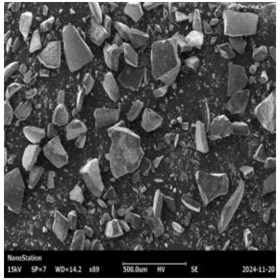
Clarification

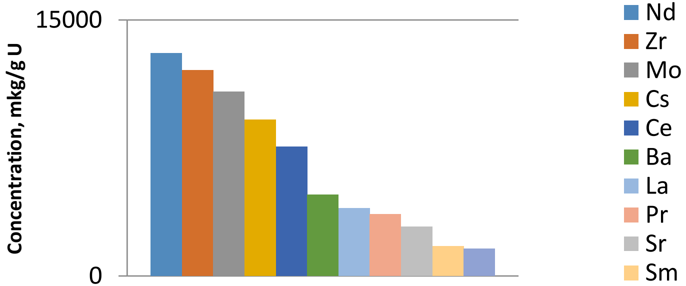
Modeled SNF HTGR fuel was synthesized in a form of kernel
It was then coated with **TRISO layers**.

Modeled kernel crushed



Modeled TRISO crushed





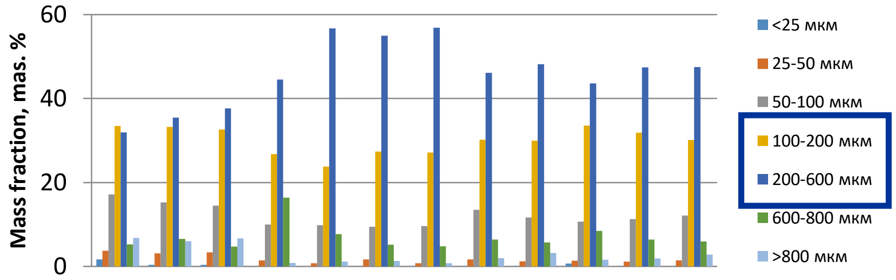
Compacts disintegration in a row

3 pcs.

5 pcs.

5 pcs. U

Series	Experiment	$[HNO_3]$, mol/l	V_{HNO3}, ml	Time, min
1	1	5,1	450	63
	2	5,0		53
	3	5,0		53
2	4	4,9		56
	5	4,8		48
	6	4,8		52
	7	4,7		52
	8	4,7		59
3	9	4,7		50
	10	4,7		47
	11	4,7		47
	12	4,6		45
	12	4,6		48



- Single electrolyte volume (3 l.)

↓

- Average time – 52 min
- No significant differences between experiments

Electrolyte

HNO_3, mol/l

5,1 → 4,6

HNO_2, mmol/l

0 → 12

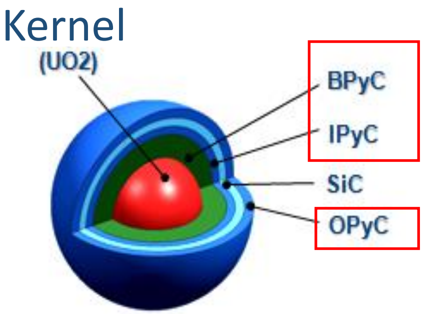
COD, mgO/l

0 → 130

COD – chemical oxygen demand

Construction materials. Pyrocarbon.

Same problems as for carbide fuel



Component	U	UO_2	**PyC**	BPyC+IPyC	OPyC	SiC
Mas. %	36,8	41,8	**34,8**	18,0	16,8	23,4

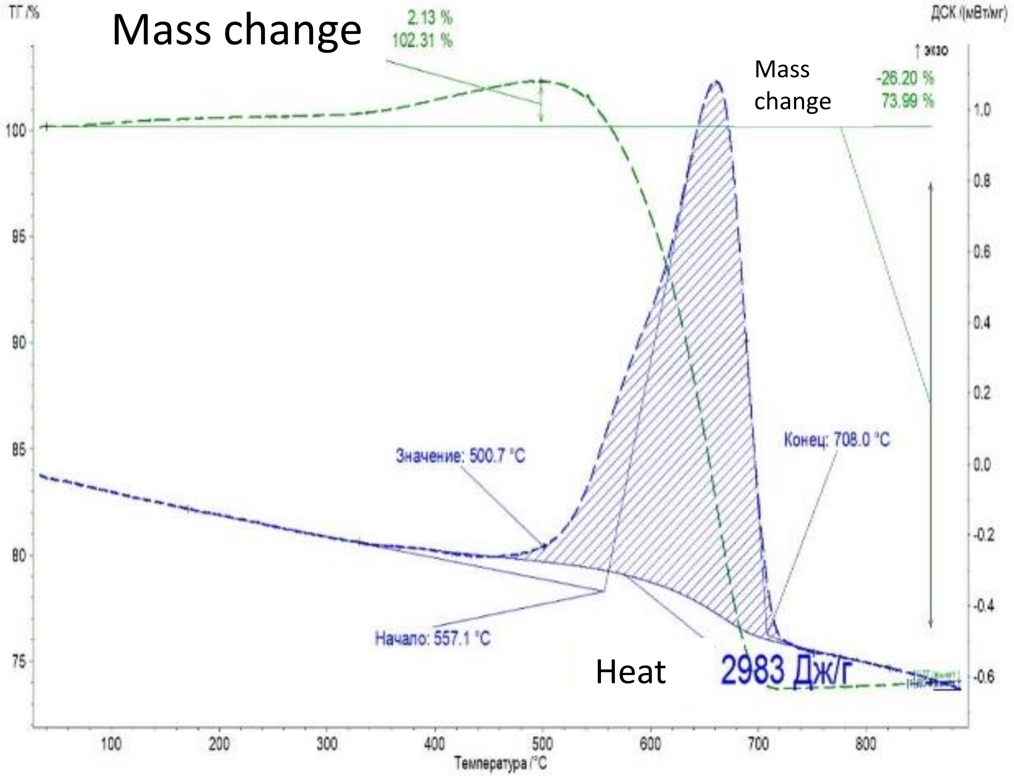
Pyrocarbon forms WSOC, films and overall worsens physical and chemical properties of solutions

*WSOC – water-soluble organic compounds

Oxidative treatment

TRISO

Fraction 50 – 100 micron, 3 К/min in 17,5 vol. %
oxygen in nitrogen atmosphere



- Modeled TRISO SNF oxidation starts at 516 ± 9,5 °C
- Ends at 709,2 ± 13,3 °C
- Heat release 3027 ± 293 J/g.
- Loss of mass 27,41 ± 0,70 %.
- No significant differences between experiments with different particle fractions

Dissolution without preliminary oxidative treatment

S(kernel) : L = 1 : (3-6), $[HNO_3]$=8,2 mol/l

COD~300 mgO/l

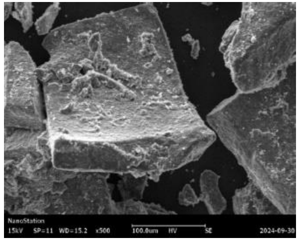
As for:
COD for oxalic acid solution
3 mmol/l
Or acetic acid solution
5 mmol/l

WSOC formation is **much lower** than expected for untreated TRISO

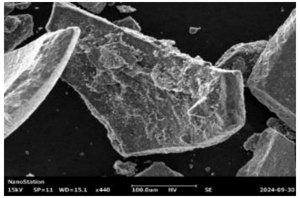
Dissolved Modeled SNF
After clarification

Kernels

TRISO



Undissolved particles at the surface of a SiC particle layer

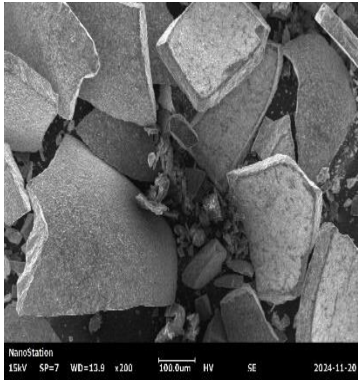


COD – chemical oxygen demand

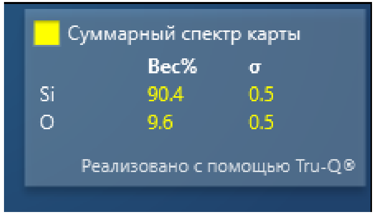
Dissolution after preliminary oxidative treatment

Filtrate

COD ~ 2 times lower in comparison to untreated TRISO



SiC and undissolved residue



Суммарный спектр карты

	Вес%	σ
Si	90.4	0.5
O	9.6	0.5

Реализовано с помощью Tru-Q®

Qualitatively U not found

Суммарный спектр карты

	Вес%	σ
Si	77.7	1.1
O	17.6	0.9
Mo	4.7	0.9

Реализовано с помощью Tru-Q®

Experiments should be conducted on U-235 enriched materials

Carbonaceous radioactive waste solidification. «Conventional» approaches

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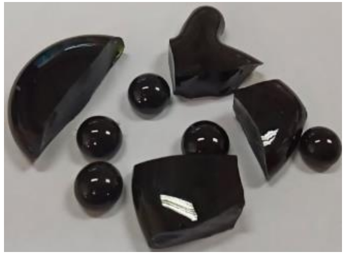
8 borosilicate glass compositions for SiC vitrification were studied. All compositions meet the requirements of NP-019-15 (leaching rate, hydrolytic stability, mechanical strength, homogeneity).

SiC was vitrified into borosilicate glass on a full-scale model of the CCIM at 1200°C. The time it took for SiC to melt was 1 hour, and 20 kg of glass were produced.



- SiC – **5 %** in borosilicate glass (waste class 2)
- SiC – 30 % in cement (waste class 3)
- Graphite – 25 % in cement (waste class 3)

Portland cement without additives

5 % SiC immobilization – unacceptably low
+-45 % SiO_2 immobilization – pre-oxidation or oxidation during vitrification is of interest

Carbonaceous radioactive waste solidification. SiC oxidation

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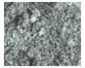
Oxidation of SiC to SiO_2

Pre-oxidation

Initial composition	Components molar ratio	Temp, °C/ time, hrs	Before	After	Composition of reaction products, wt. %	
NaOH, SiC, O_2	4 : 1, 1 г SiC	650 / 3,5			Na_2SiO_3 Na_2CO_3 SiC	22,86 48,83 23,31
NaOH, SiC, O_2	4 : 1, 1 г SiC	855 / 2			Na_2SiO_3 Na_2CO_3 $Na_2Si_4O_9$ $Na_2Si_2O_5$ $Na_6Si_6O_{19}$	16,05 57,45 4,80 15,40 6,30
Na_2CO_3, SiC, O_2	1 : 1, 1 г SiC	890 / 4			Na_2SiO_3 Na_2CO_3 SiC	72,32 18,50 9,18
Na_2CO_3, $Na_2B_4O_7$, SiC, O_2	1 : 0,03 : 1, 1 г SiC	890 / 3			Na_2SiO_3 Na_4SiO_4 Na_2CO_3 SiC	63,63 6,84 16,86 12,67
Na_2CO_3, SiC, O_2	2 : 1, 1 г SiC	890 / 4			Na_2SiO_3 Na_2CO_3 SiC	13,52 75,80 10,68
Na_2SO_4, SiC, O_2	1,1 : 1, 1 г SiC	920 / 2			Na_2SO_4	100
NaOH, SiC, O_2	2 : 1, 2 г SiC	830 / 0,4			Na_2CO_3 SiC	78,68 21,32
NaOH, SiC, O_2	4 : 1, 2 г SiC	830 / 0,5			$Na_2Si_4O_9$ Na_2CO_3 SiC	15,99 70,75 13,26

SiC < 5 wt. %

Oxidation during vitrification

MnO_2, CrO_3, LiOH or **LiF**

- All additives reduce oxidation time in laboratory conditions
- Glass properties meet the requirements of NP-019-15
- **LiF** – minimum holding time

At the full-scale model of the CCIM at JSC "VNIINM" **25 kg of borosilicate glass** with inclusion of **20 wt. % SiC** were produced. At the same time, the **holding time of the melt for SiC oxidation was 3.5 hours**

Carbonaceous radioactive waste solidification. Graphite cementation

Graphite

Expanded graphite*

Experiment on immersion of spent fuel assemblies simulators in cement

before

50 % dipping

90 % dipping

after

Waste content in matrix

- Graphite from compacts with particle size up to 1 mm – **28 wt. %.**
- Graphite from gas purification system filters – **20 wt. %;**
- Expanded graphite – 1 wt. %;

* Expanded graphite is one of the possible forms of graphite that forms during electrochemical disintegration of compacts

Future tasks and plans

- **Experimental testing on irradiated materials**
- Pilot scale stand development
- Overall stands development
- Testing on pilot volumes
- Feasibility study
- Facilities consideration for first HTGR reactor SNF reprocessing.
  Most promising – first testing facility of EDC, PA «MCC»

Main factors:

The Compacts pilot production line «Luch»

- Single source of materials
- Testing on rejected/discarded materials?

Compacts irradiation in IRM and/or NIIAR
A Stand for irradiated materials testing development

- Behavior of NM, FP and CM can`t be modeled
- Stand facility?

Conclusions

1. Head-end HTGR SNF reprocessing processes scheme was designed and rationalized by fundamental approaches;
2. Fundamental approaches include rejection of graphite waste incineration and maintaining integrity of TRISO-fuel layers during their recovery from assemblies;
3. Feasibility of main head-end operations was confirmed on non-irradiated TRISO-fuel, modeled spent fuel and imitators on lab-scale tests;
4. Real SNF testing of obtained operation regimes should be carried out for further technology development.

Thank you for your attention

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