ROSATOM

Fabrication and reprocessing of mixed uranium-plutonium nitride fuel for fast reactors

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Closed NFC with U-Pu fuel for fast reactor

- **U and Pu are involved in NFC and Np and Am will be involved**
- **Cm will be stored for long time and could be involved in NFC**
- **No limitation recycle of U and Pu**

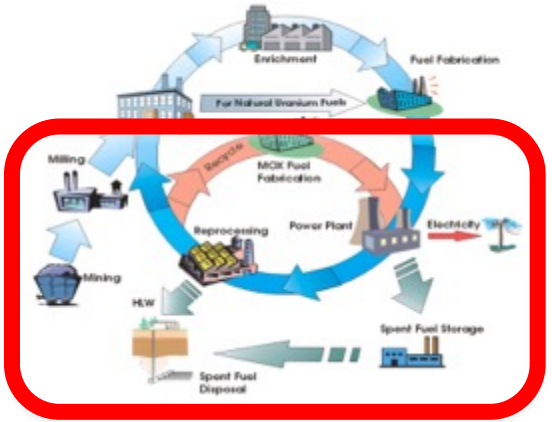
Main requirements for FR SNF reprocessing technologies

Imperative

- Safety
- Ecological acceptance
- Economic efficiency

Technical

- Ability to reprocess SNF with low cooling time and high burnup
- Observance of Non-Proliferation Treaty
- Pu loss less than 0,1 %
- End products suitable for fuel fabrication
- Low volume of high-level waste
- Partitioning



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Specificity of FR SNF reprocessing

- **High burn-up**
  average 12 % h.a (>100 GVt*day/t) instead of "comfortable" 45-55 GVt*day/t
- **Low cooling time – "hot" SNF and radwaste**
  1 year instead of "comfortable" 4-7 years. FP are concentrated in radwaste
- **High FP content**
  I, Ru, ^{14}C, Mo, Zr, Tc are not a micro-, there are a macro-components
- **Specificity of fuel – high content of Pu**
  Pu content (13-20%) leads to high capacity of Pu affinage line and to strong criticality control

Cooling time	1 year
Recycle of fissile materials	99,9 %
Type of SNF	Mixed U-Pu nitride or MOX
Separation U,Pu,Np	Not provided
U-Pu-Np purification coefficient	Up to 10^6
Transmutation of minor actinides	Homo- or heterogeniously
Capacity	5-10 t/year SNF

Main results of dense fuel research

Advantages of mixed nitride uranium-plutonium fuel (MNIT):

An compare with oxide fuel:	An compare with metal fuel:
▪ High density	▪ Acceptable compatibility with shell materials
▪ Higher thermal conductivity and low store of accumulated energy (advantage in emergency)	▪ Lack of the hard temperature restrictions

- MNIT fuel operation temperature is significantly low an compare with melting point
- Dense fuel is optimal for fast reactors from the safety and efficiency point of view.

Tests of MNIT fuel into BN-600. Main results

- Fabricated and put under irradiation 18 assemblers (> 1000 pins containing MNIT fuel (shells of austenitic and ferrite-martensitic steels).
- Successfully completed tests of 10 assemblers (max burn-up is 7.5% h. a.). 8 assemblers are still under irradiations. 1 pin had gas leak.
- Post irradiation tests are completed for 3 MNIT assemblers with BN-600 pin dimensions and 4 assemblers with BN-1200 and BREST pin dimensions.

The data necessary for fuel requirements, fuel codes, and fuel pins design for verification for BREST-OD-300 and BN-1200 first loading are obtained.

MNIT fuel fabrication technology

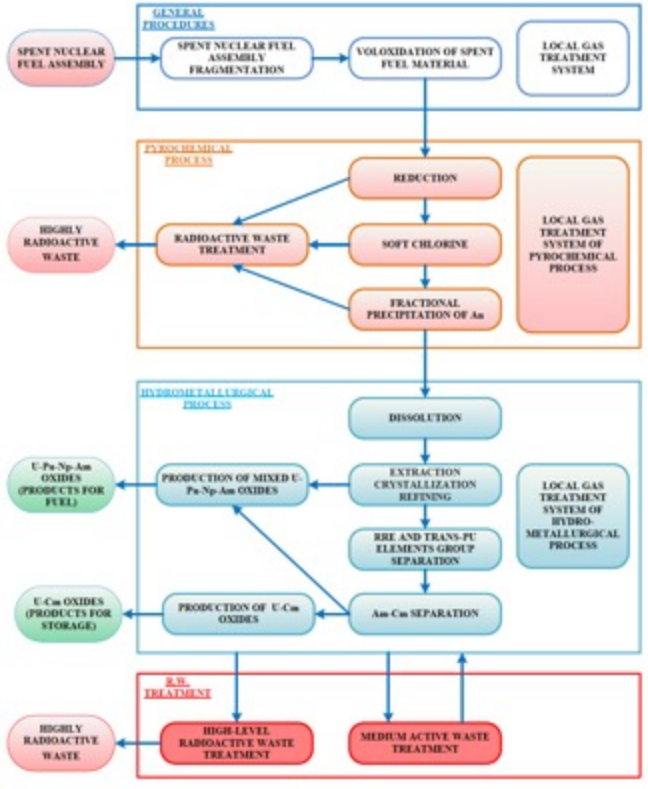
- MNIT fuel fabrication/refabrication technology is developed and tested on 21 assemblers for BN-600 and 11 assemblers for BOR-60.
- The technological and design solutions were tested. these data are the basis for the development of industrial technologies and design solutions for the MNIT fabrication pfor BREST-OD-300 and BN-1200.
- Since 2010, all stages from laboratory studies to industrial implementation have been completed, including the development of equipment prototypes.
- The unique automated experimental complexes allowing to produce nitride uranium-plutonium fuel in the conditions of completely drained nitrogen inner-box atmosphere are created.
- Technology and equipment were developed by cooperation of Bochvar Institute, Sverdniikhimmash, Siberian Chemical Combine, "Sosny" and many others.
- In 2018, the technological lines were supplied to SCC site. The commissioning is planned to perform in 2020.

PH-process is a combine technology for fast reactor SNF reprocessing (should be tested in industrial scale)

PH-process:

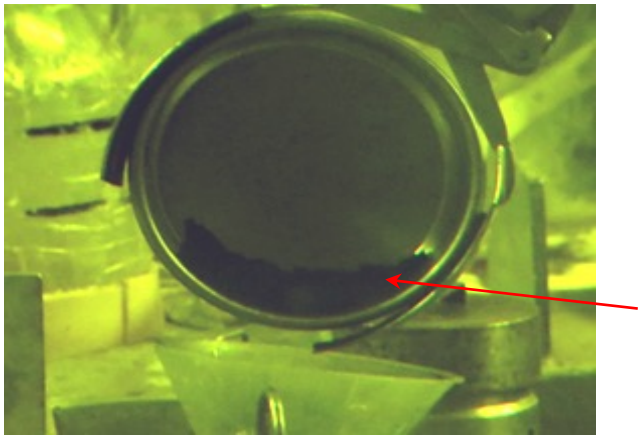
- treat of SNF with low cooling time and high content of fissile materials (10-15 %)
- purification coefficient is about ~10^6
- satisfied to nonproliferation treaty
- loses of actinides are ≤ 0,1 %
- recovery and separation of Am and Cm

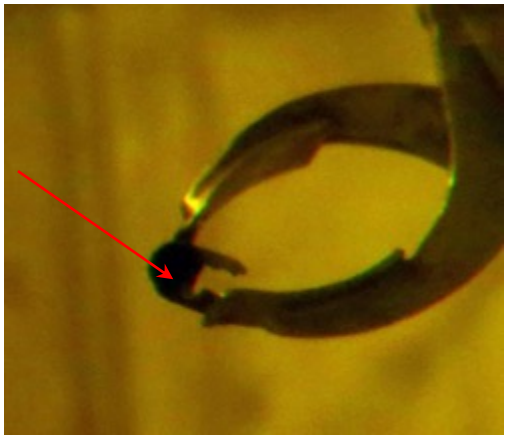
Hydrometallurgy part of PH-process is suitable for MNIT and MOX with 2 years cooling time and burn-up 6-8 % heave metal



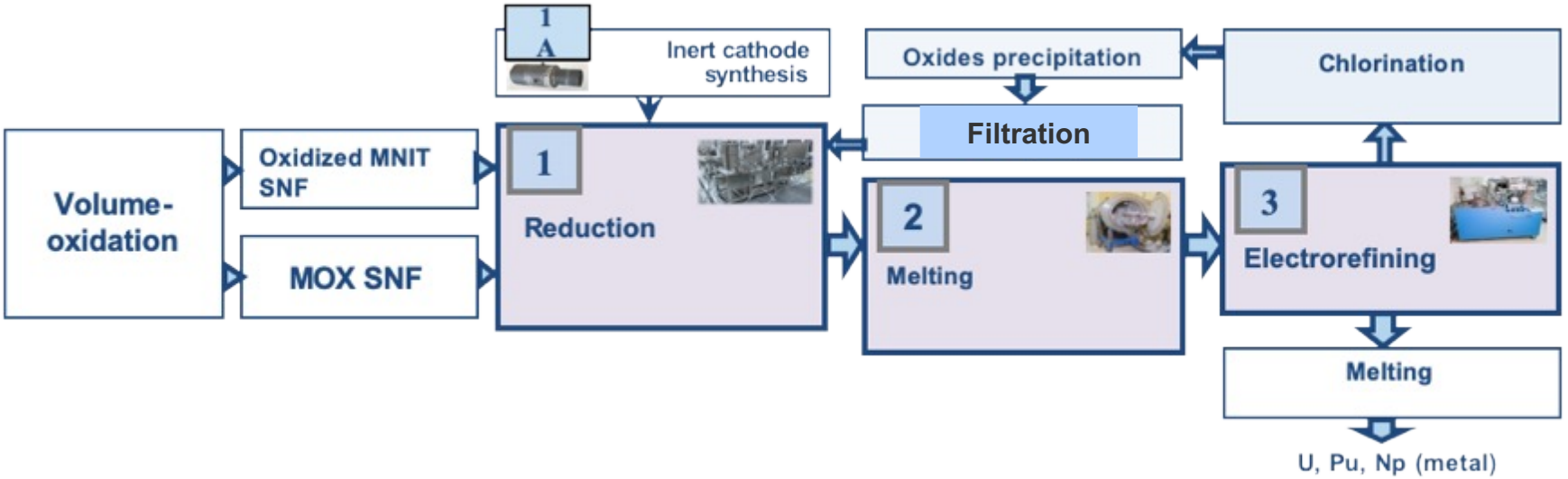
Waste minimization (head-end operation)

- MNIT SNF BN-600 with burn-up 5,45 % h.a. was oxidized in air
- Fuel was separated from shell
- ^{3}H recovery > 99,8%
- ^{14}C recovery > 98,4%





Pyrochemical operations (IHTE RAS, RIAR, Siberian Chemical Combine)



Compact and universal (for MOX and MNIT) technology
Suitable for combine (pyro + hydro) and for ”pure” pyrochemical technologies

Dissolution and clarification

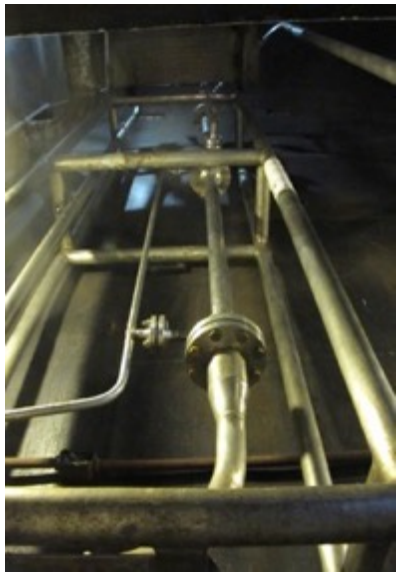
The chemical and electrochemical dissolution of simulated oxidized (15 % of Pu) MOX or MNIT SNF with burn-up > 12 % h.a. were tested

Retention of Pu with Mo-Zr residue was 0,008 % initial amount of Pu

Cross-flow membrane clarification were tested for 200 hours

The final solid concentration 103 g/l was achieved

There is no solids were observed (detection limit is < 0.1 g/l)

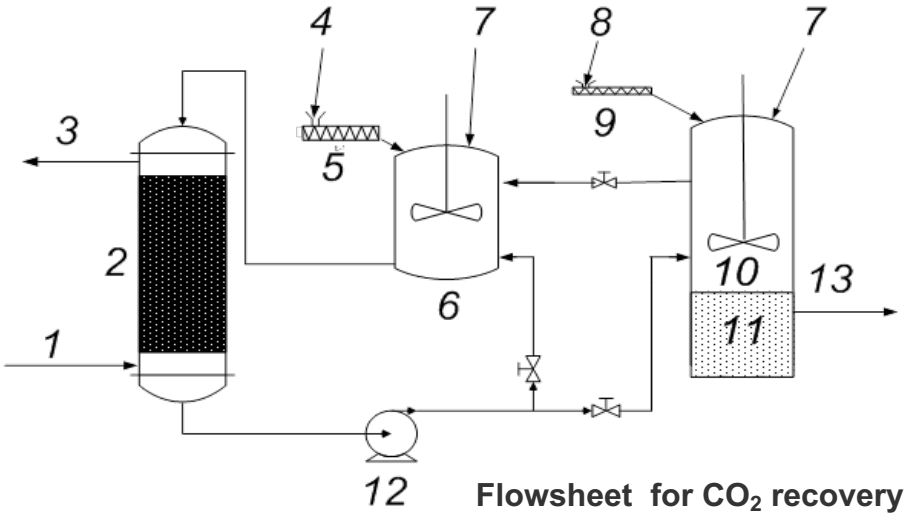


”Mayak” clarification set-up”

Off-gas cleaning

R&D are completed for SNF oxidation, dissolution, denitration on mixed actinide product, extraction and crystallization operations

The equipment for recovery aerosols, recovery of NO, NO_2, CO_2 (^{14}C), I_2, CH_3I, RuO_4 and destruction of N_2O were tested



Flowsheet for CO_2 recovery

Recovery of ^{14}C was 99,99 %

Solid ^{14}C (Na_2CO_3) could be cemented

2,72 t of cement compound for 1 t of SNF

1 – off gases;
2 – absorber;
3 – clean gases;
4 – NaOH, Na_2CO_3;
5 – NaOH feed-screw; Na_2CO_3;
6 – mixing tank;
7 – H_2O;
8 – $Ca(OH)_2$;
9 – $Ca(OH)_2$ feed-screw;
10 – $CaCO_3$ sedimentation tank;
11 – $CaCO_3$ collecting vessel;
12 – pump;
13 – $CaCO_3$ pulp for cementing

Liquid/liquid extraction for U-Pu-Np recovery and crystallization affynage

For MNIT SNF reprocessing

- recovery of U and Pu 99,97 %,
- decontamination factor from

  Cs – 10^6,
  Sr – 10^3,
  Zr-Mo – 10^3,
  rare earth elements – 10^4

extraction set-up

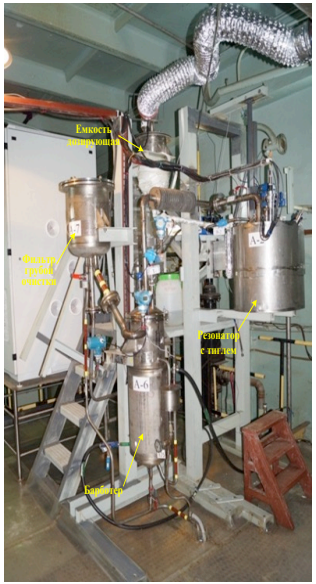
Joint crystallization of U and Pu with decontamination factor of rare earth elements 100 was experimental confirmed in semi-industrial scale

The volume of the mother-wash solution was decreased (25 % of feed flow)

Crystallization purification provides a technological barrier to the spread of nuclear materials.

crystallization set-up

Mixed actinide oxides preparation



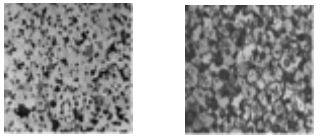
SCC Microwave denitration set-up

There is no mother solutions from microwave-denitration
Mixed U-Pu oxides (150 g) twice were obtained using laboratory equipment (RIAR)

U oxides and U-Ce (imitator of Pu) oxides (1 kg each) were prepared by SCC set-up. UN and U(Ce)N pellets were prepared from these powder.

Physic and chemical properties of UN and U(Ce)N pellets are satisfied to MNIT fuel requirements

Laboratory equipment for microwave denitration

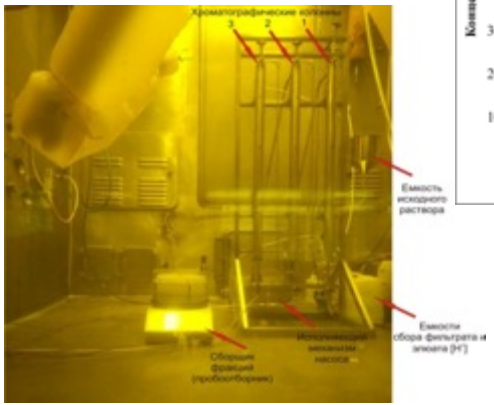


Microstructure of UN and U(Ce) N pellets

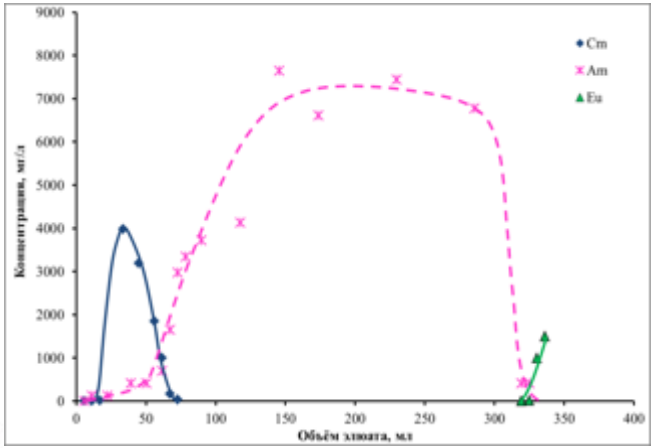
HLW partitioning - recovery and separation of Am and Cm

The recovery of Am and Cm by TODGA from real Purex raffinate were tested at "Mayak". Recovery of actinides > 99,9 % were achieved.
Separation of Am and Cm by using a cation exchange resin was successfully tested. This technology is effective but generates significant amounts of secondary radioactive waste (used resin).

Set-up for high pressure liquid chromatography for separate Am and Cm was tested with rare earth elements (Frumkin and Bochvar Institutes). Use of HPLC could reduce volume of secondary radioactive waste by more than 100 times. Safety requirements for HPLC separation process are determinated.



Elution of Am – Cm – Eu



Cm – 0,124 g (97%)
Am – 1,463 г (103%)

“Cold” crucible for HLW vitrification

Full-scale layout of cold crucible for vitrification of HLW from MNIT reprocessing using combine technology was made and tested

7 kg of glass per hour

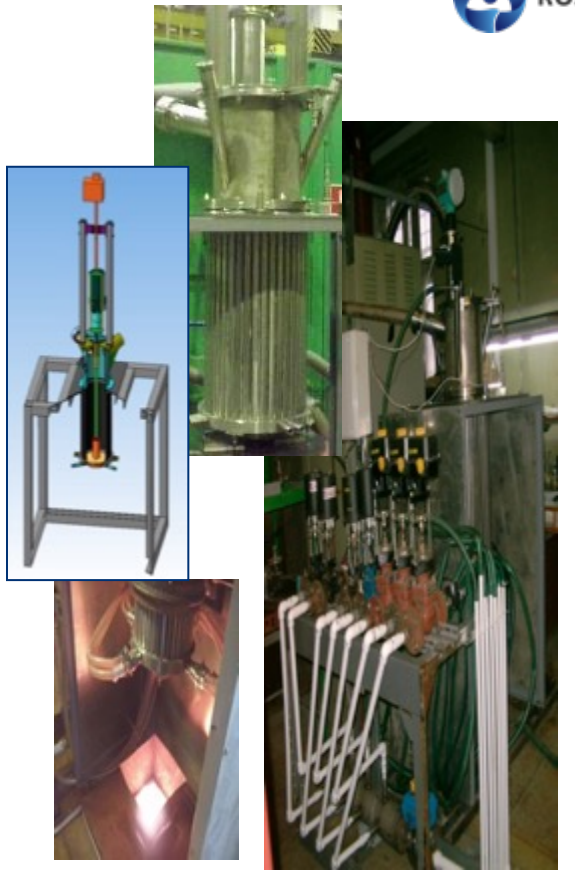
Remote control and feed systems

Remote repairing and equipment parts change

Same equipment for pyro- and hydro wastes

Borophosphate glass for pyrochemical HLW vitrification

Borosilicate glass for hydrometallurgy HLW vitrification



Conclusion

R&D on MNIT fuel fabrication and SNF MNIT reprocessing has so far shown experimental demonstration of technical feasibility:

- Production of MNIT fuel for fast reactors
- The synthesis of MNIT fuel containing MA
- Oxidation of SNF MNIT (dry separation of SNF and fuel assemblies' shells, removal of more than 99.9% tritium and more than 98% of ^{14}C from SNF)
- Extraction and crystallization refining of the undivided U+Pu+Np mixture (confirmed total purification factor of $5 \cdot 10^6$)
- Achieving the depth of actinide extraction (more than 99.9%) during SNF MNIT reprocessing for radiation-equivalent disposal of fission products remaining in RAW
- Obtaining mixed oxides of U+Pu+Np, U-Am, U-Cm and pure U (tested for U and Ce) by microwave denitration
- Extraction of REE-TPE sum and separation of Am and Cm

Thus, the PRORYV project creates a prototype of the fast-neuron reactors fuel cycle.

Thank you for your attention

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