Ivanov V., Skupov M., Shadrin A.

Closed nuclear fuel cycle with fast reactors and dense fuel

Shadrin A., Dvoeglazov K., Ivanov V.

Reprocessing of spent mixed nitride U-Pu fuel from BREST-OD-300 reactor

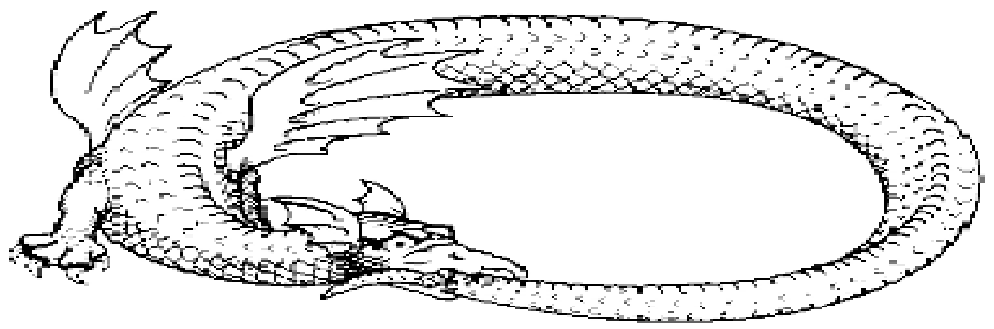
ROSATOM goal in the back-end is a closed nuclear fuel cycle

ЗСЖЦ
back-end

Очень велик
too long

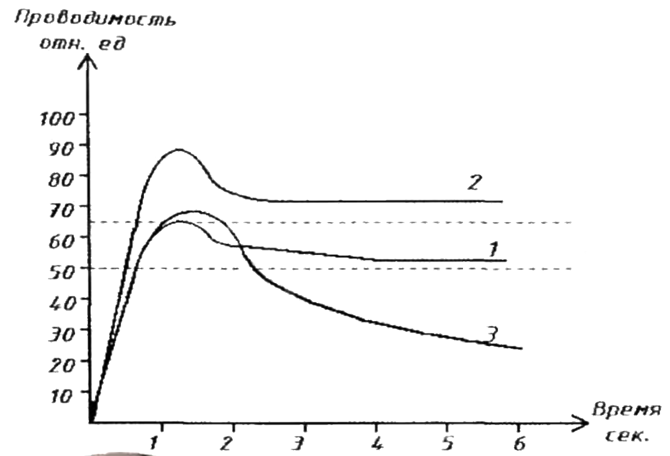
Отбросить?
to fall off?

Замкнуть!
to close!



Что делать с хвостом?
what to do with the back-end?

Сделать так, чтобы хвост не рос
to prevent SNF accumulation



Утилизировать наследие
to utilize the nuclear heritage

Вот, собственно, зачем мы создаем ту самую систему обращения с ОЯТ
that's why we develop the system of SNF management

Closed NFC whit Pu fuel

SNF accumulation

Cost of SNF storage (100 year) – around 200 - 400 USD for per kg

Recovered Pu storage – around 1 - 5 USD for 1 g per year
or – 100 - 500 USD for 1 g per 100 years

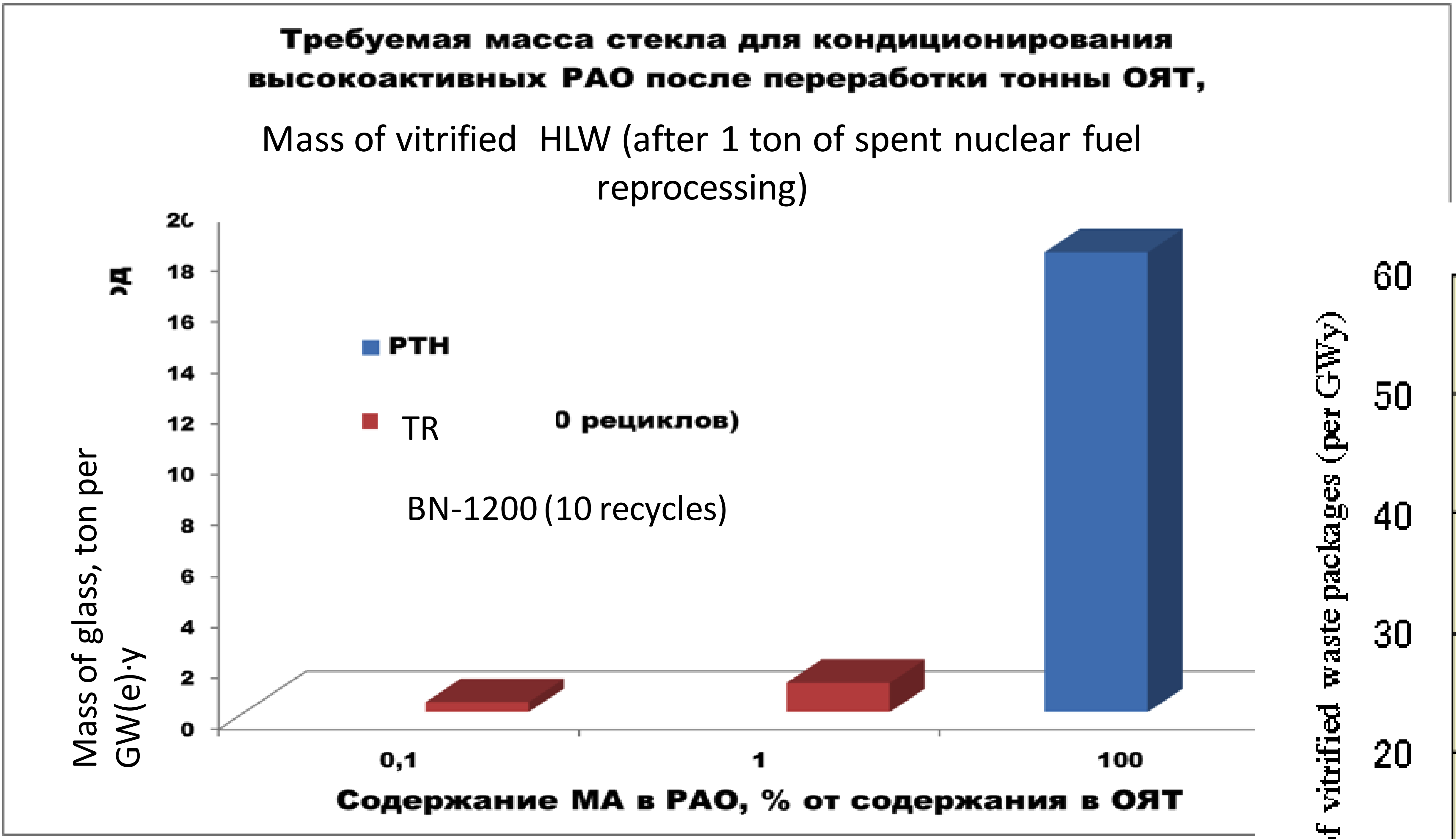
1 kg of terman reactor SNF contains several g of Pu

Main aim of Closed NFC is decrease of full expenses on SNF and Pu storage and radwaste treatment using Pu and MA as a fuel

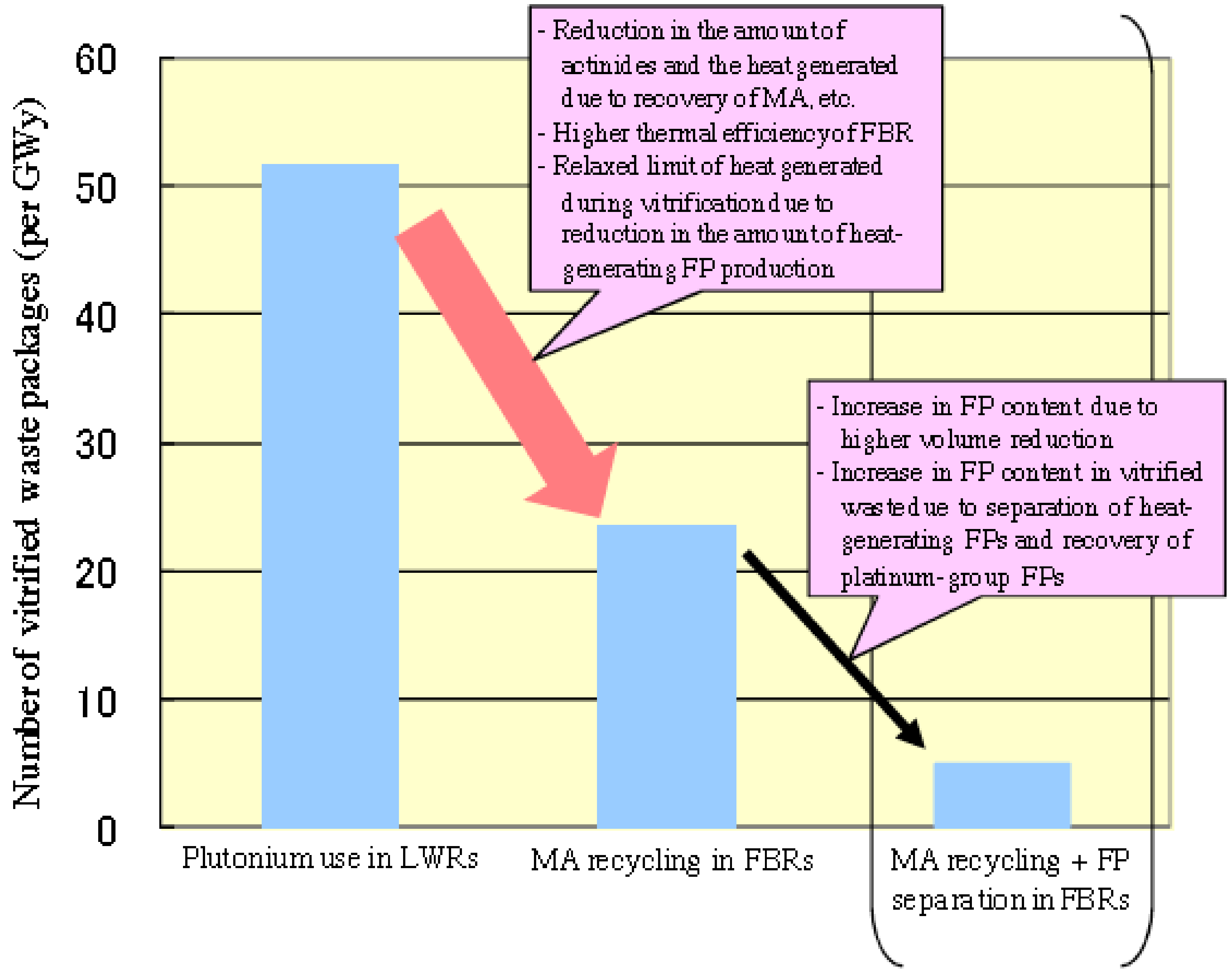
Options for closed NFC whit Pu fuel:

- REMIX
- MOX for thermal reactors
- MOX for fast reactor
- MNIT for fast reactor

Way we need partitioning



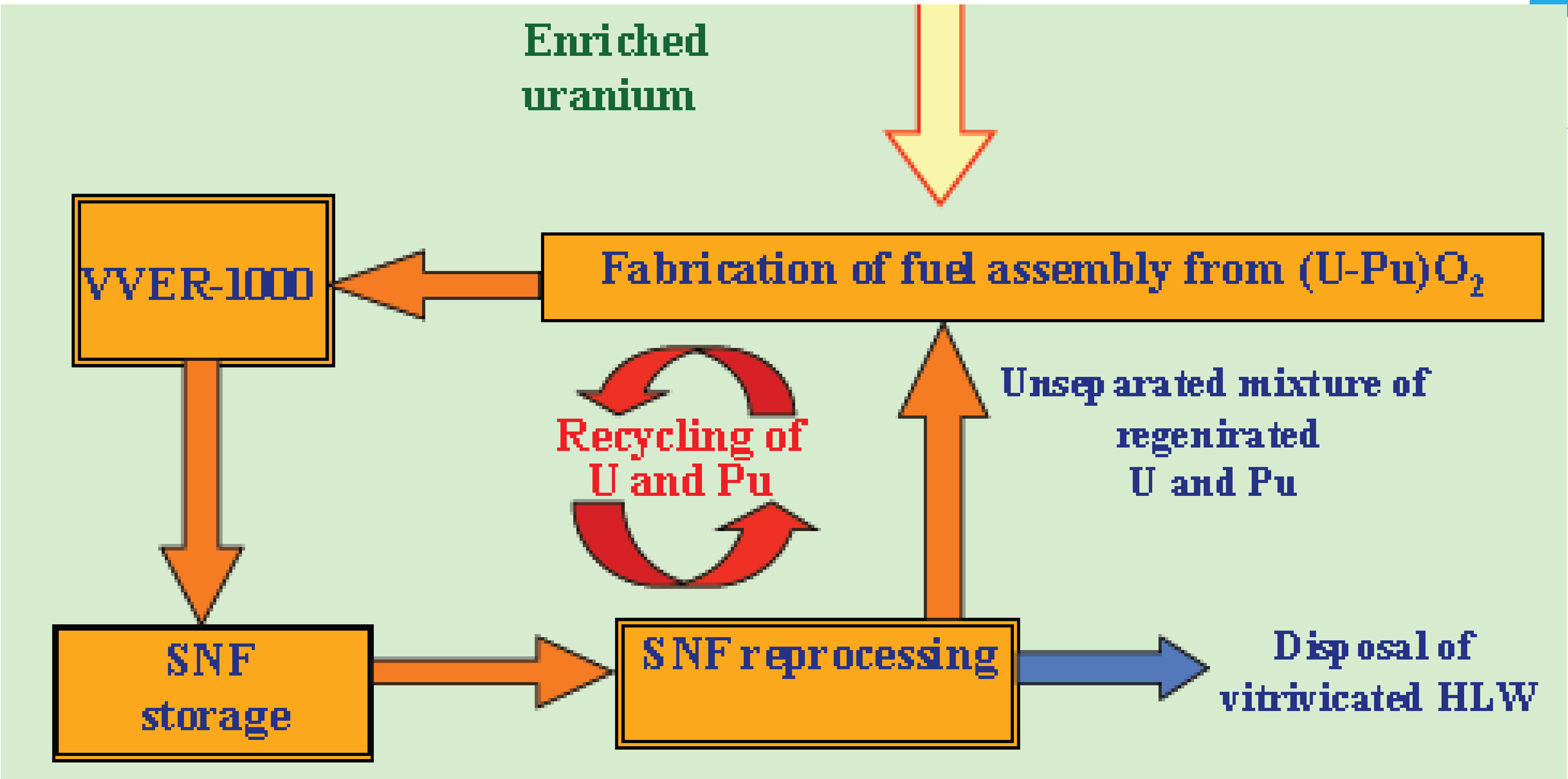
MA content in HLW, % of content in SNF



Volume of wastes containing MA for recycling in BR is negligibly small as compared with that from TR SNF reprocessing

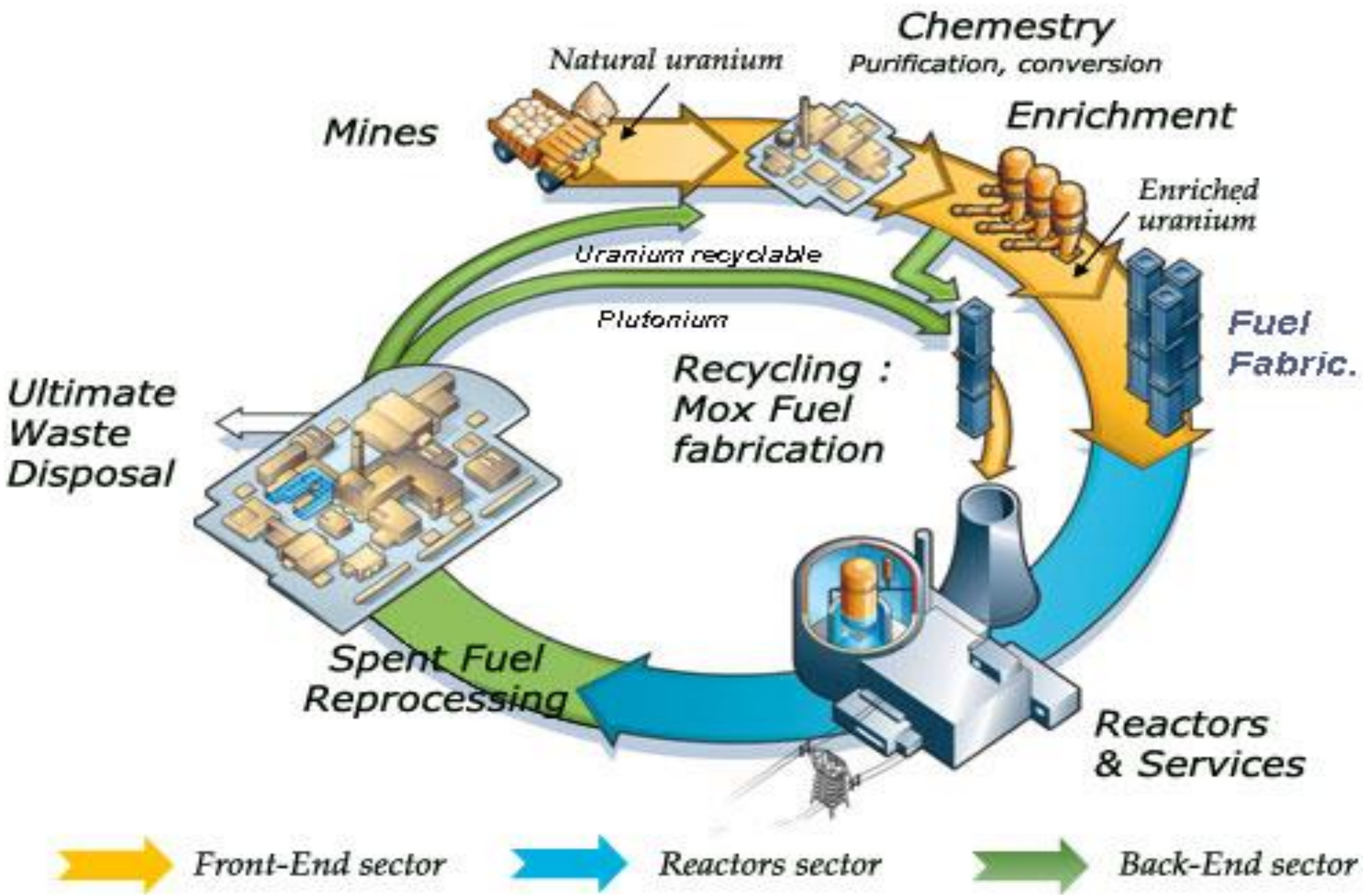
IKEDA, Yo., et al., "Overview of Fast Reactor Cycle System Technology Development Project (Fact) Phase 1 and Future Direction" , Global 2011 (Proc. Int. Conf., Makuhari, Japan, 2011), paper # 451660.

REMIX



- *U and Pu are involved in NFC*
- *Np, Am, Cm are in HLW jointly with fission products*
- *6 times recycle of U and Pu*

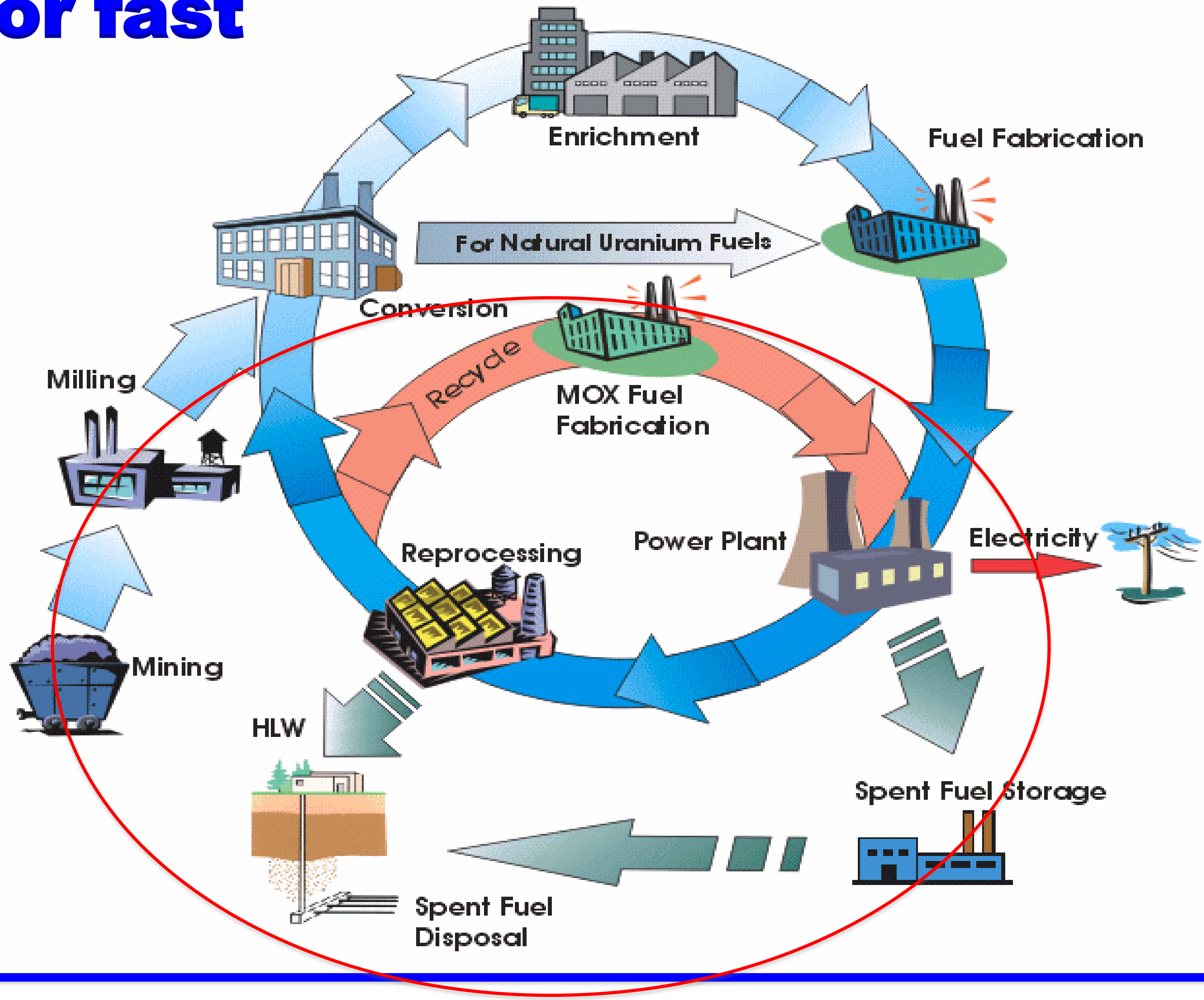
MOX for thermal reactors



http://www.laradioactivite.com/en/site/pages/Fuel_Cycle.htm

- *U and Pu are involved in NFC*
- *Np, Am, Cm are in HLW jointly with fission products*
- *1 or 2 times recycle of U and Pu*

MOX and MNIT for fast reactors

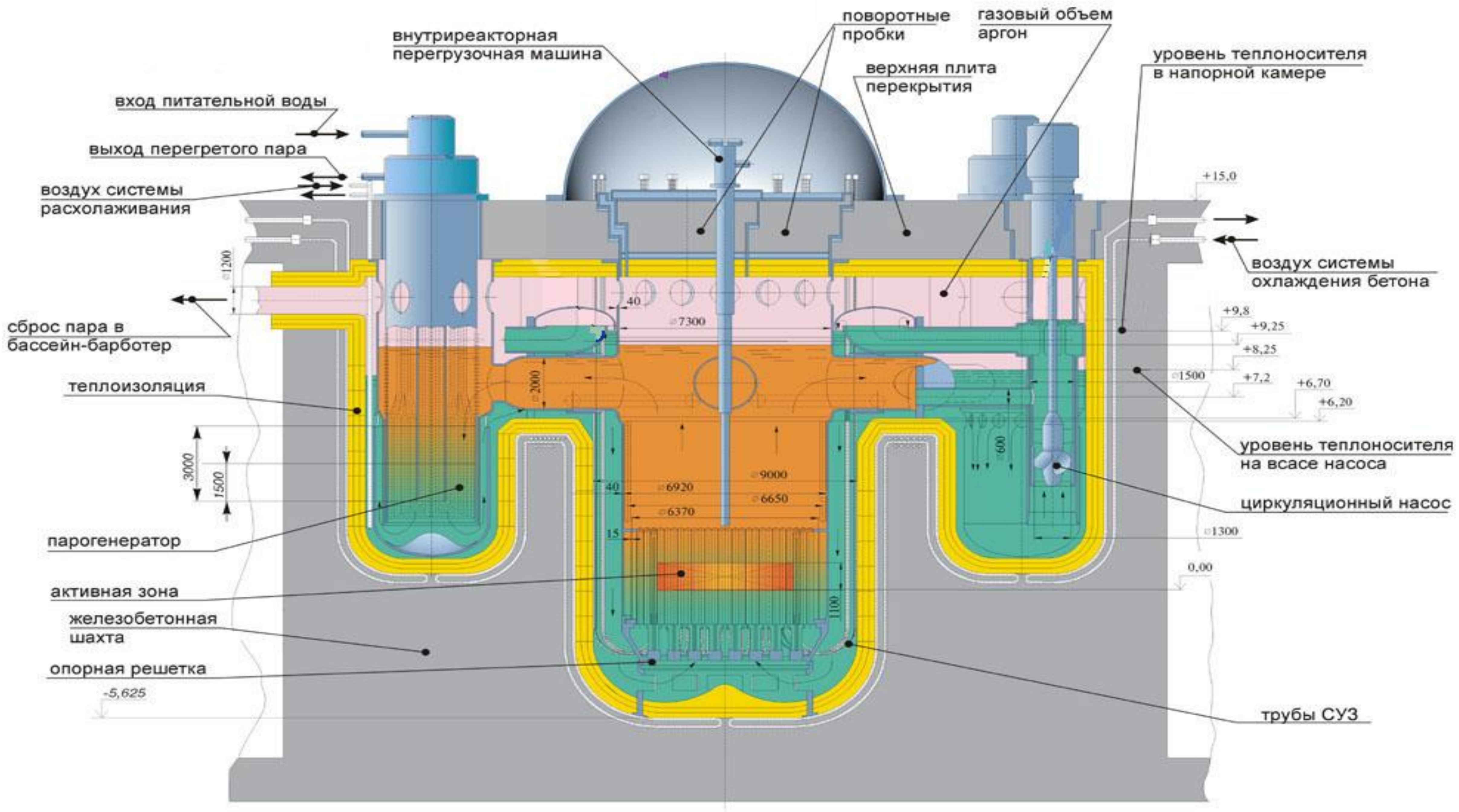


https://infcis.iaea.org/images/NFCISbackground.gif

- *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*

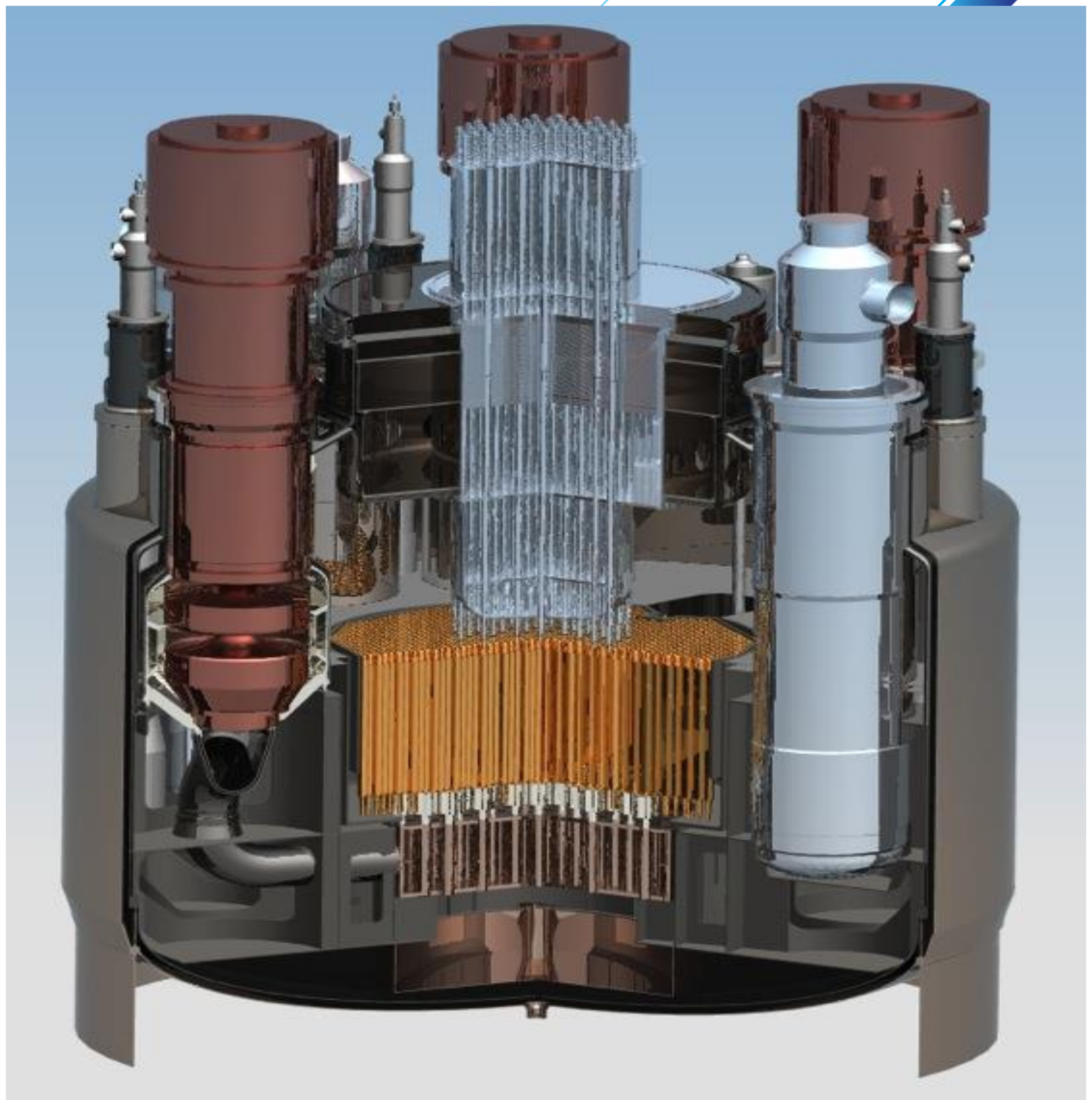
High capacity fast reactors

BREST-1200



Coolant – Pb
Fuel – MNIT (U-PuN)

BN-1200

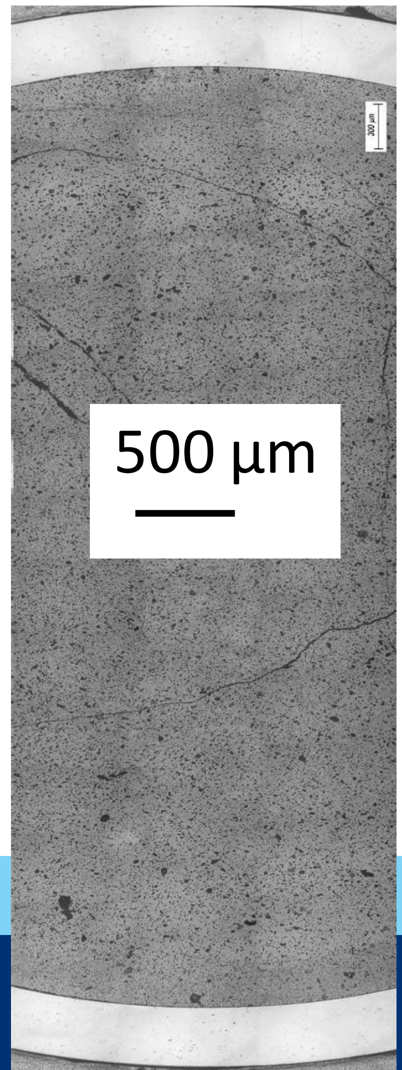


Coolant – Na
Fuel – MNIT (U-PuN)
MOX (U-PuO_2)

MOX or dense fuel?

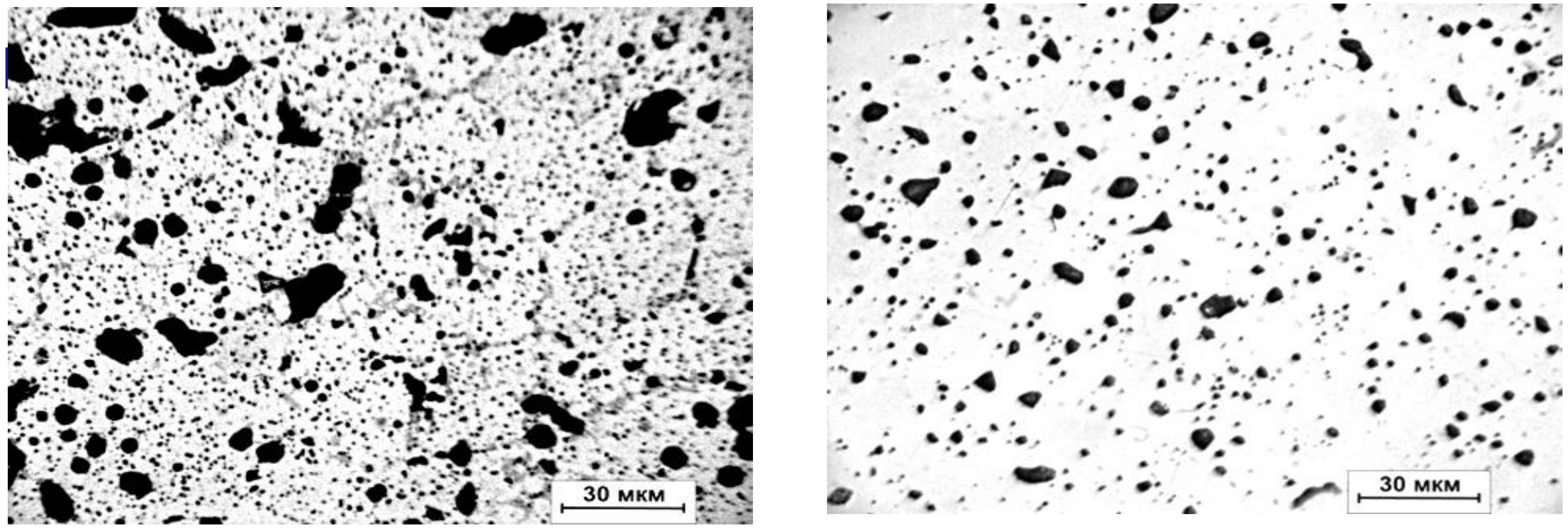
- Main questions
- Safety level
- Pu reproduction in active core

- Pu reproduction coefficient ~1.05 without blanket
- 0.5% ΔK/K during all company
- Compatibility of MNIT is shells material
- Compatibility of MNIT with Na and
coolant
- Experience of use U nitride fuel



Answer – dense fuel (metal, carbide, nitride) is better an compare with MOX.

However – MOX fabrication and MOX UNF reprocessing are industrial process



a *b*

Микроструктура (U,Pu)N топлива с выгоранием - 5 % т.а. (*a*) и 4 % т.а. (*b*)

MOX and MNIT for fast reactor today in Russia

- *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*

Basic requirements for FR SNF reprocessing technologies

Imperative

1. ***Safety***
2. ***Ecological acceptance***
3. ***Economic efficiency***

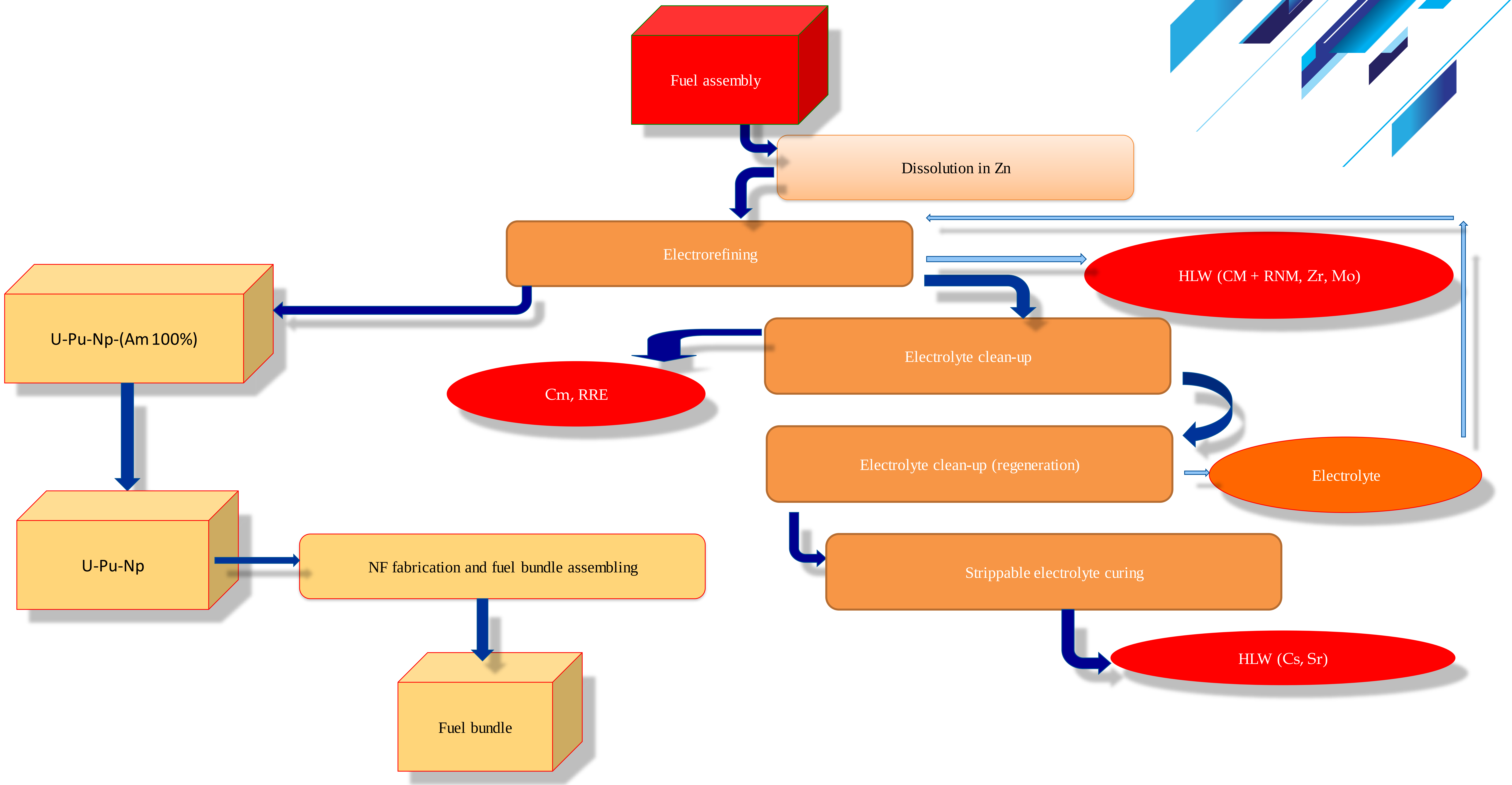
Technical

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

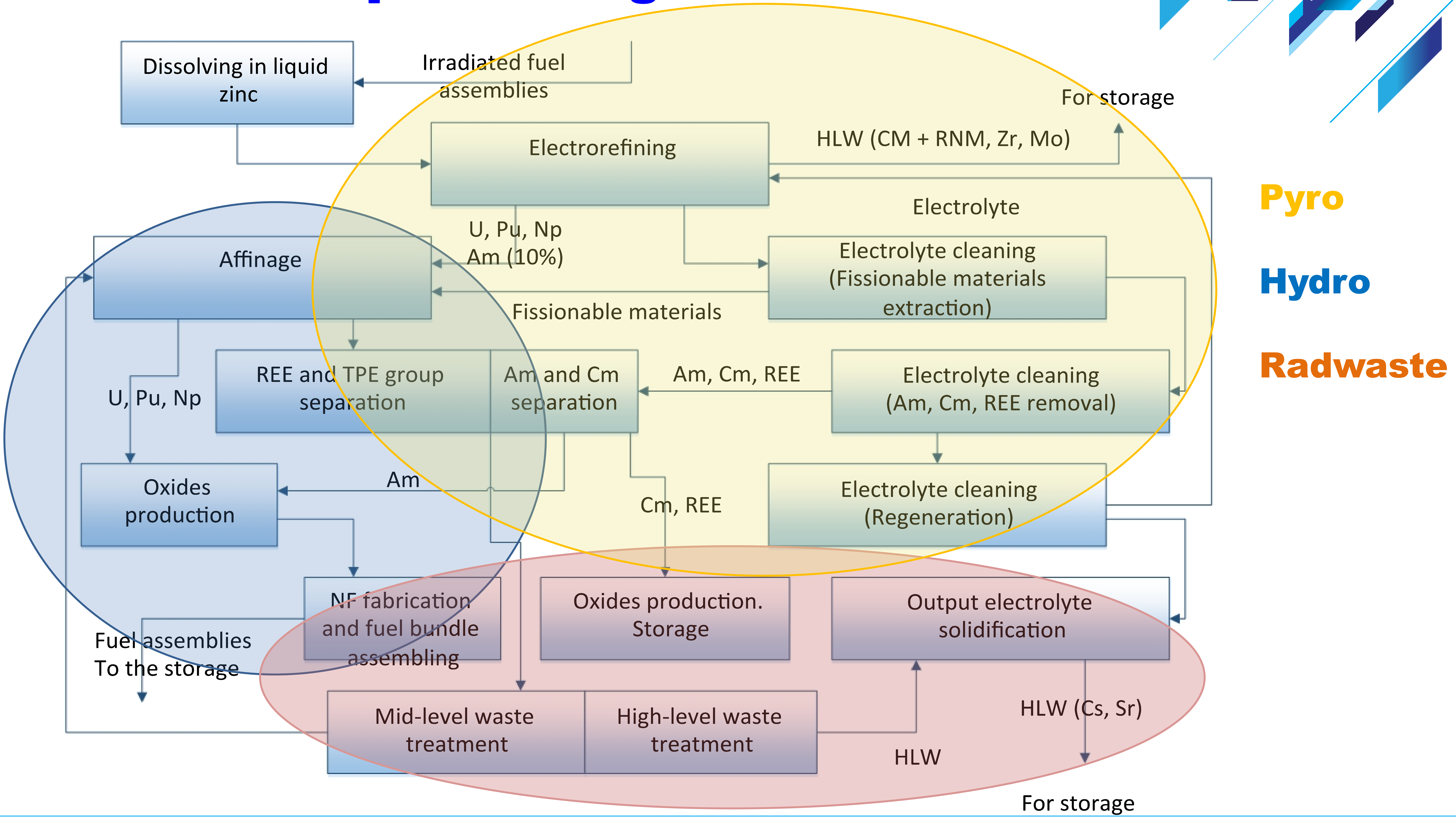
On-site reprocessing

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 from 10^3
Transmutation of minor actinides	Homogeneously or heterogeniously

Pyroelecrochemical reprocessing



PH-process is a combine technology for FR SNF reprocessing



Combine technology (PH-process) is a palliative solution

However, PH-process :

- **allows to reprocess SNF with low cooling time and high burn-up**
- **meets requirements of non-proliferation treaty**
- **allows to re-use > 99,9 % of fusible materials**
- **allows to produce mixed U-Pu-Np product of any purification grade**
- **Include Am and Cm recovery and separation**

PH-process shold meets requirements:

- ***Safety***
- ***Ecological acceptance***
- ***Economic efficiency***

Schedule for reprocessing facility (module) (RM) of pilot and demonstration energy complex (PDEC)

Pilot scale experiments

"Cold", "warm" and "hot" experiments at RIAR, PA "Mayak", Siberian Chemical Combine, Bochvar Institute
(HYDRO)

"Cold" experiments at RIAR
(PYRO)

Combine test of technology

Equipment manufacturing

MR Design

RM construction

Start of operation and tests

2014 2015 2016 2017 2018 2019 2020 2021 2022

PYRO

Technology and equipment

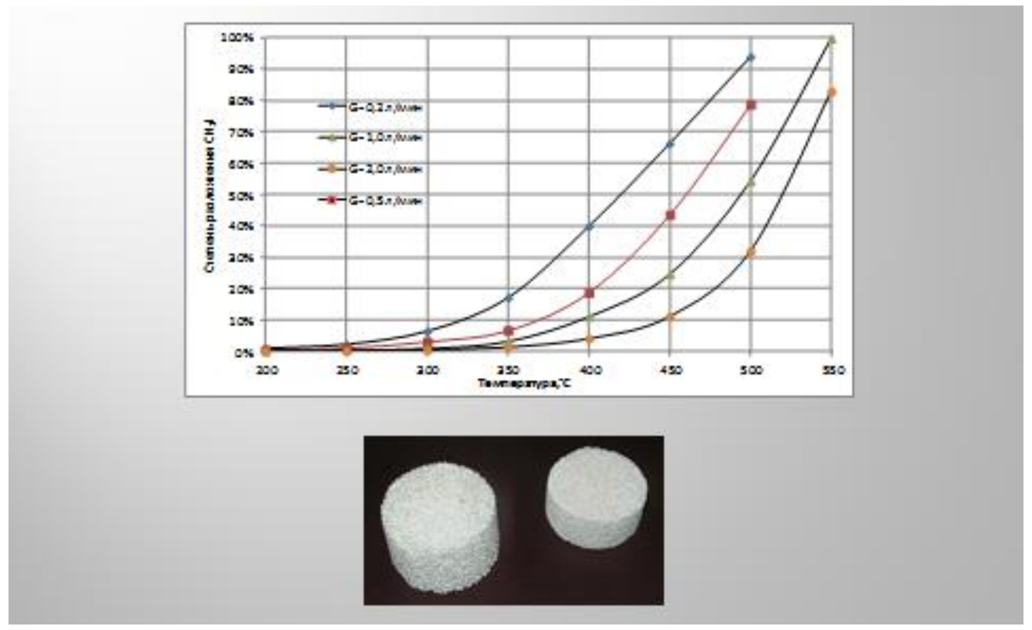
Up today following operation have been tested with simulated in irradiated fuel in lab scale:

- Shell removal
- Distillation of Zn/Cd/salt
- Pyroelectrorefining of MNIT
- Off gas treatment
- Salt purification and recycling

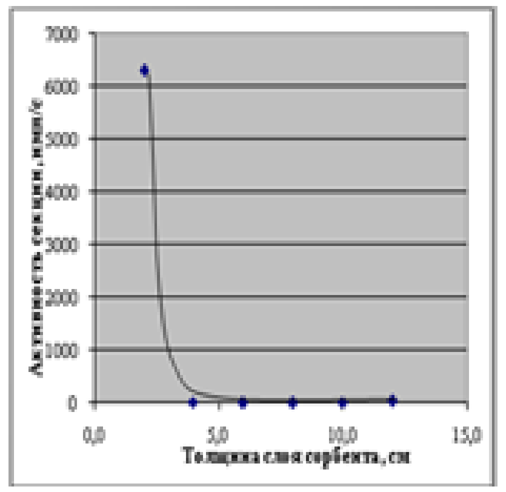
Tests of pilot equipment and study of process conditions using full scale simulant MNIT SNF 2016-2018

Tests with irradiated MNIT would be done on EDEC reprocessing facility

Experimental equipment for off gas treatment



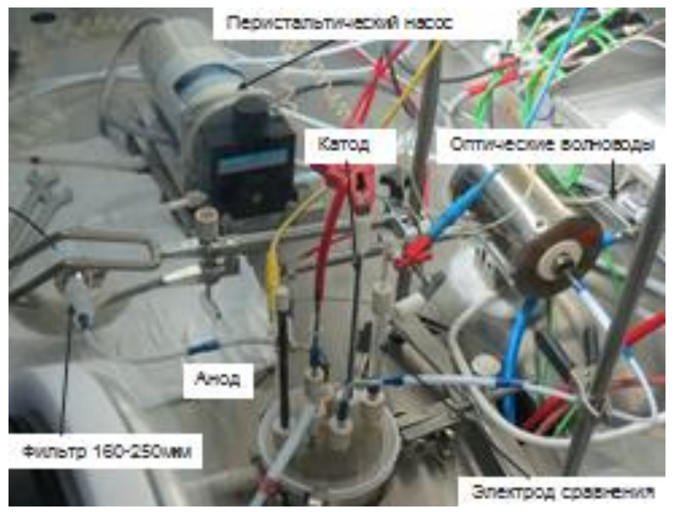
Removal of CH_3I



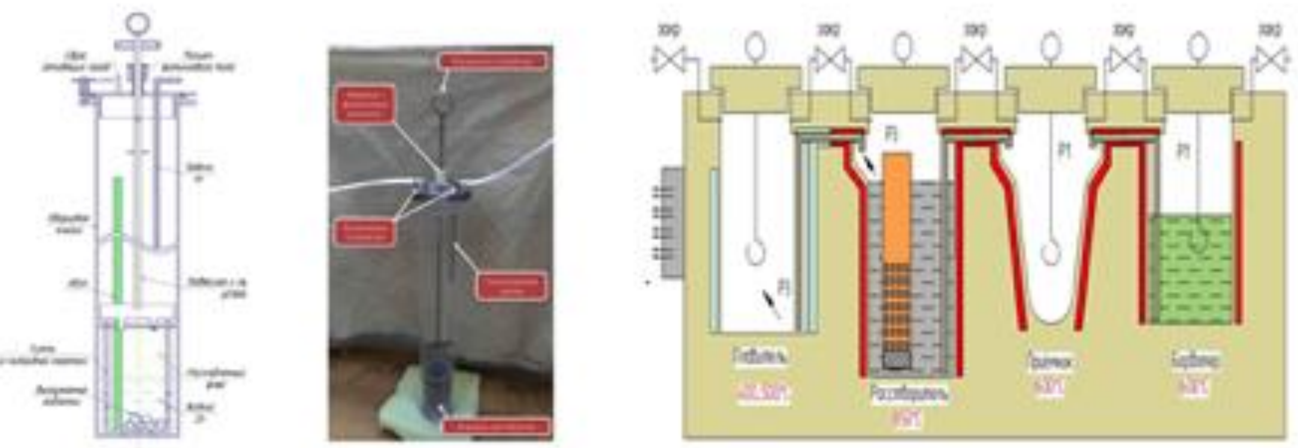
Removal of I_2

Experimental equipment for salt crystallization purification

Experimental equipment for shell removal. Zn after tests



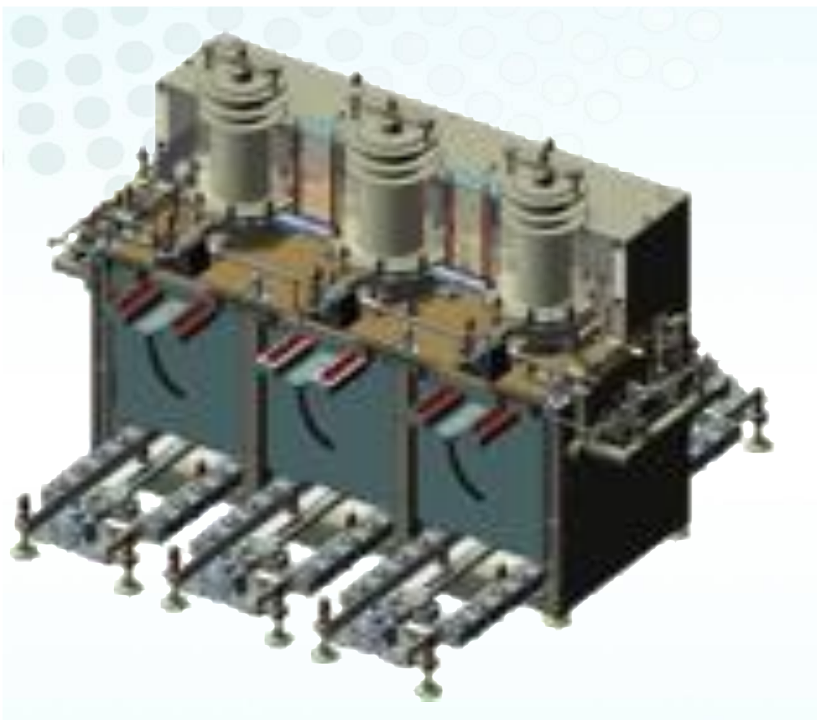
Tests of permanent pumping of liquid metal (Gas-In) and salt (LiCl-KCl-CsCl-$NdCl_3$, 330 °C, 200 hours



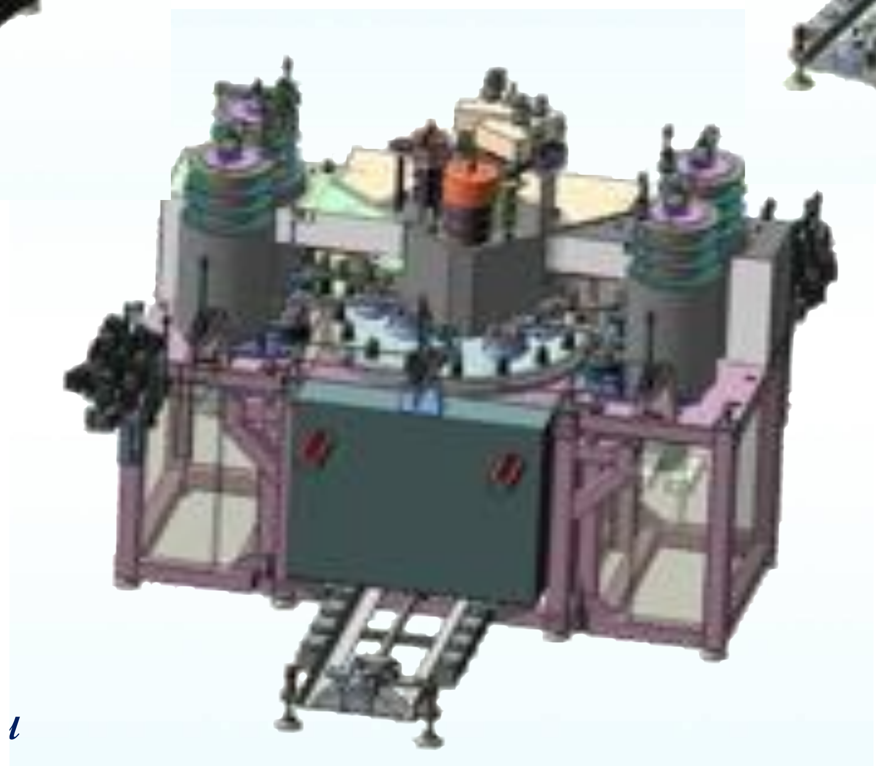
Experimental equipment for shell removal. Zn after tests

PYRO
Equipment design

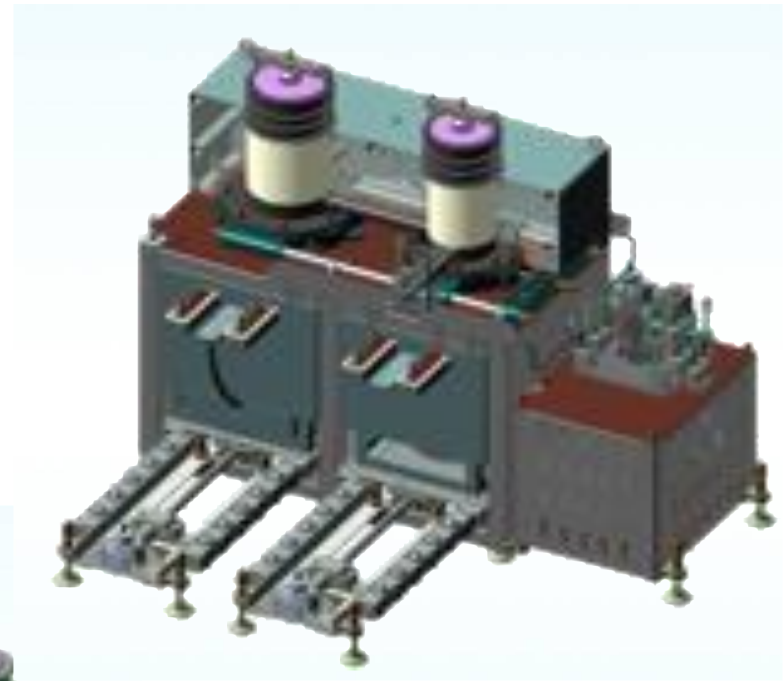
Experimental equipment



Shell removal

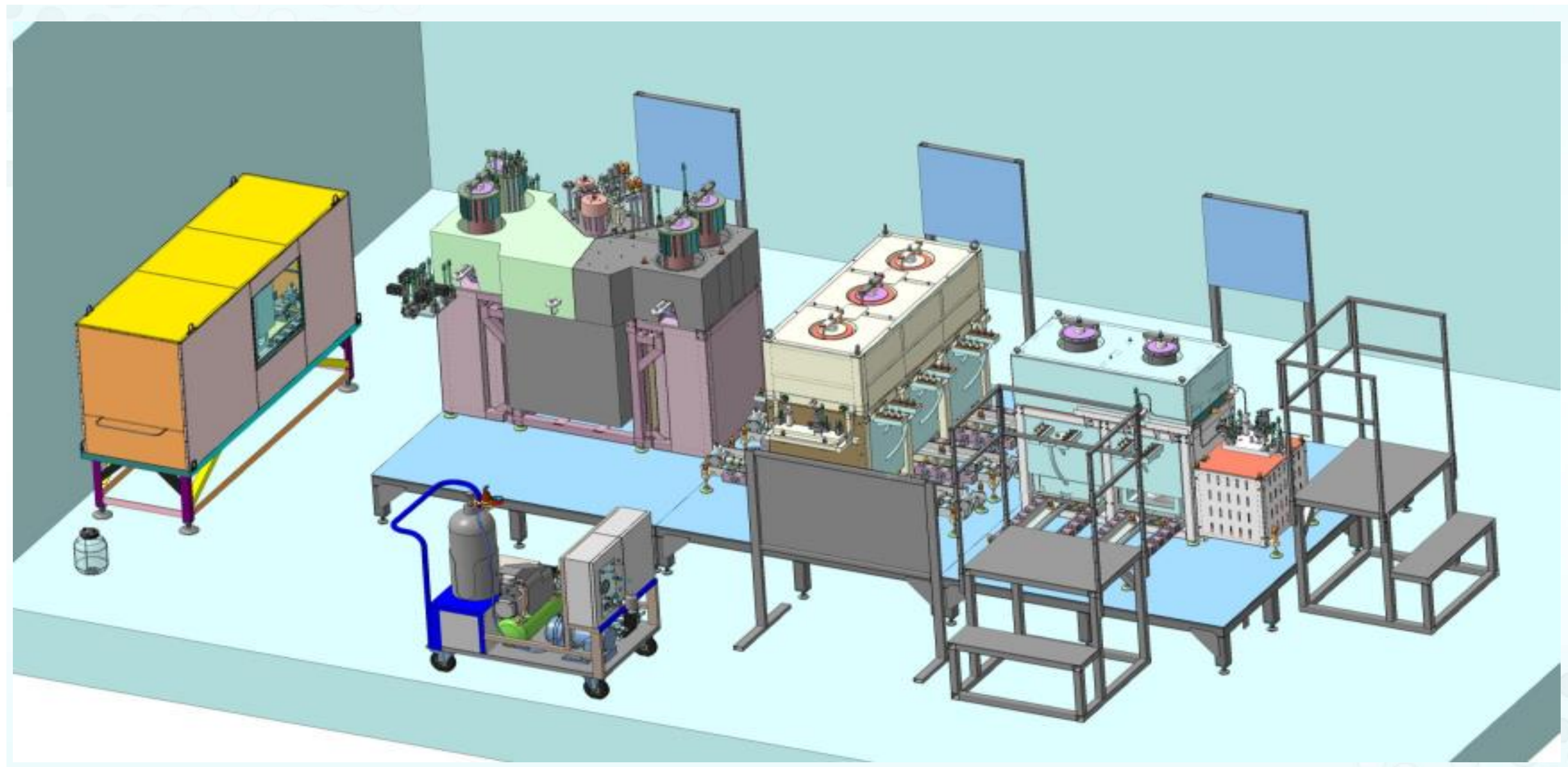


Electrorefining



Distillation of Cd

Argon cell should be put in operation in end of 2015



Design of industrial equipment should be completed in 2015

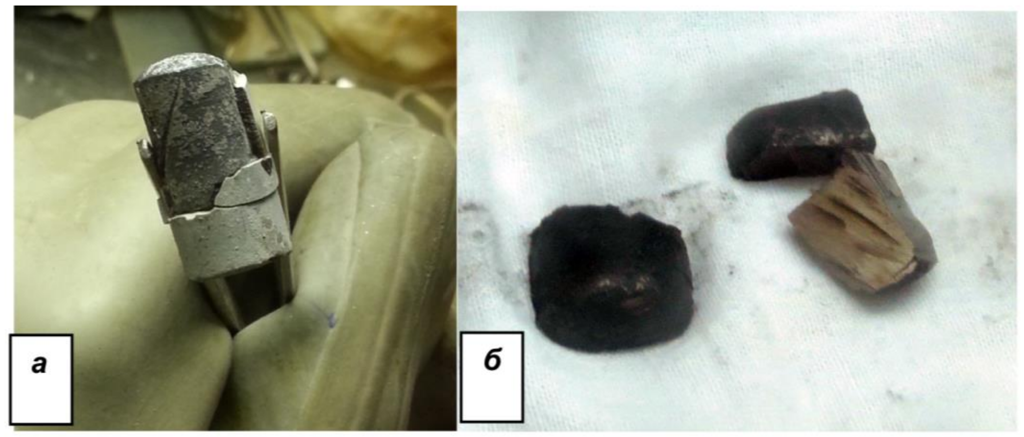
HYDRO Main results up today

Tested with simulated and irradiated fuel:

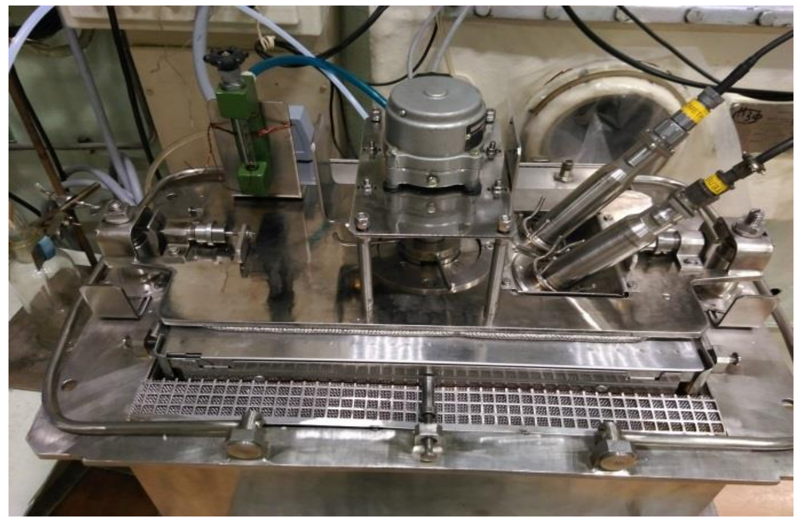
- **Dissolution of U-Pu-Np ingot**
- **Flow (membrane) clarification**
- **Partitioning**
- **Preparation of actinide oxides**
- **Intermediate and high level radwaste**

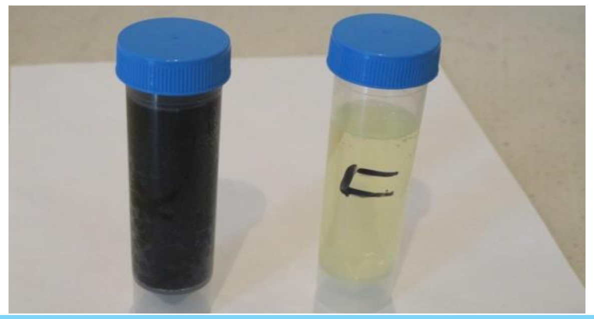
Desruction of NH_4NO_3 during distillation

2015-2018 task is to test all operation using pilot scale (prototype) equipment



а – ingot U-Pu-Np
б – ingot U-Pu-Np separated in 3 parts



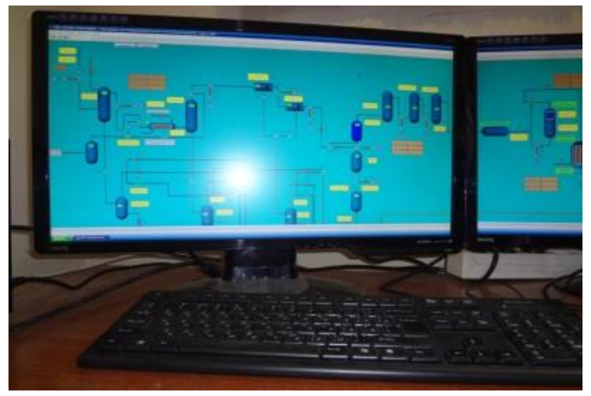


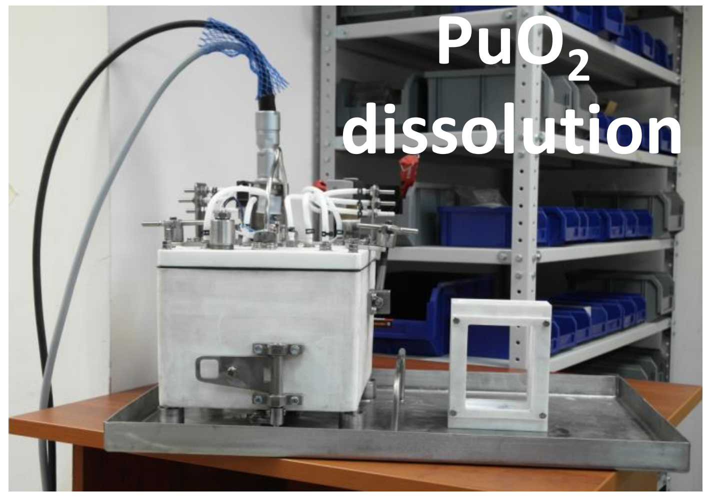
Oxide of actinides

HYDRO

Laboratory and pilot mock-up for hydrometallurgy

Laboratory and hot cell set-ups





High temperature treatment including oxidation

Pilot mock-up

Main tasks

Initial task – there is no the industrial technology for treatment of radwaste from BREST-300-OD MNIT SFF reprocessing

Reasons:

- *Low time of SNF cooling;*
- *Loses of fissile materials with radwaste < 0,1%;*

Solution – use of compact equipment with low capacity

Important – all technical solutions should not increases the time needed for achievement of radioecology equivalency

Main results up today

- Principal design of equipment
- Crystallization and glass verification were selected as basic methods
- Principal design of container for all kind of filters, including HLW filters for liquid metals and melted salt

Tasks 2015-2017:

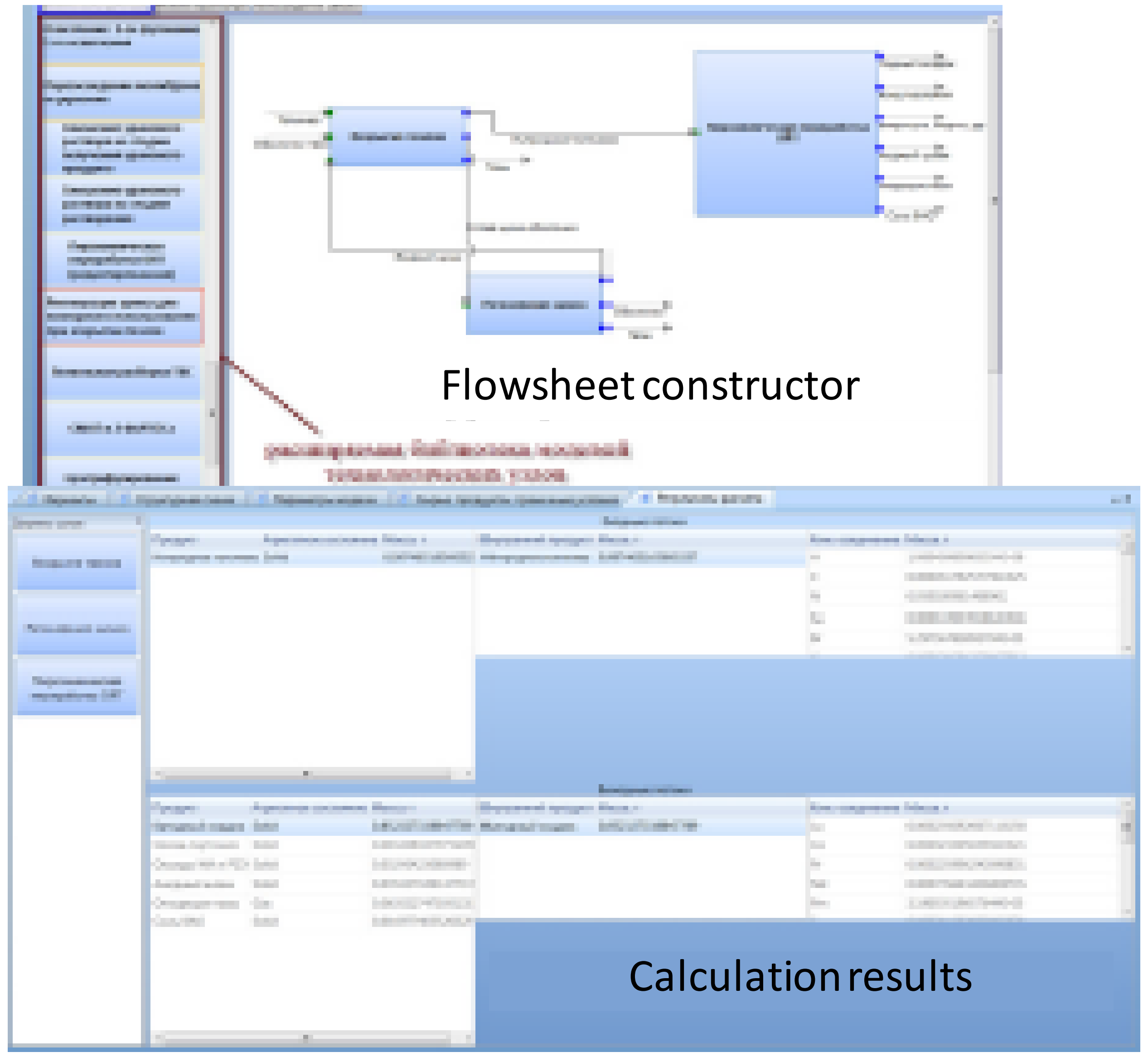
- Test of full-scale crystallization set-up
- Test of full-scale cold crucible
- R&D for basis of process safety

Computer codes for nuclear fuel cycle technologies and objects development

BALANCE MODELS OF INF REPROCESSING, NUCLEAR FUEL FABRICATION/REFABRICATION AND RADIOACTIVE WASTE TREATMENT

Objectives:

Evaluation feasibility of technological solutions while developing flow sheet; balance calculations of material flows and generated waste; flow sheets optimization

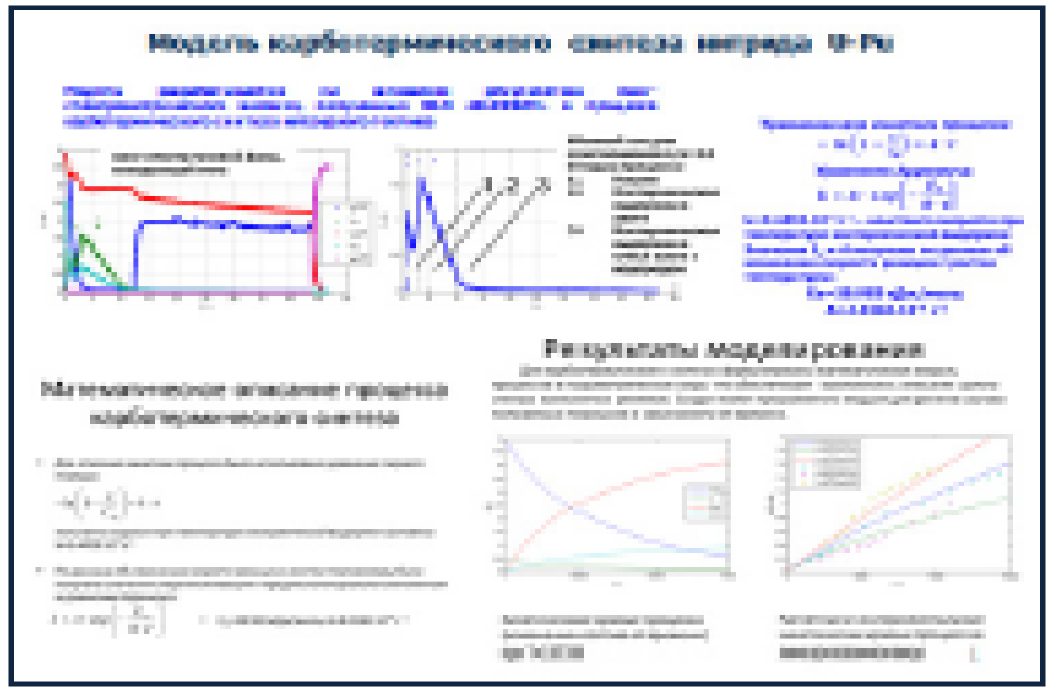


This mathematical tool significantly decreases time and resources required for calculations and comparison of multiple flow sheet options

SIMULATING KEY TECHNOLOGICAL PROCESSES OF CLOSED NUCLEAR FUEL CYCLE

Objectives:

Calculation and optimization of processes operation modes, substantiation design decisions, emergency modes description

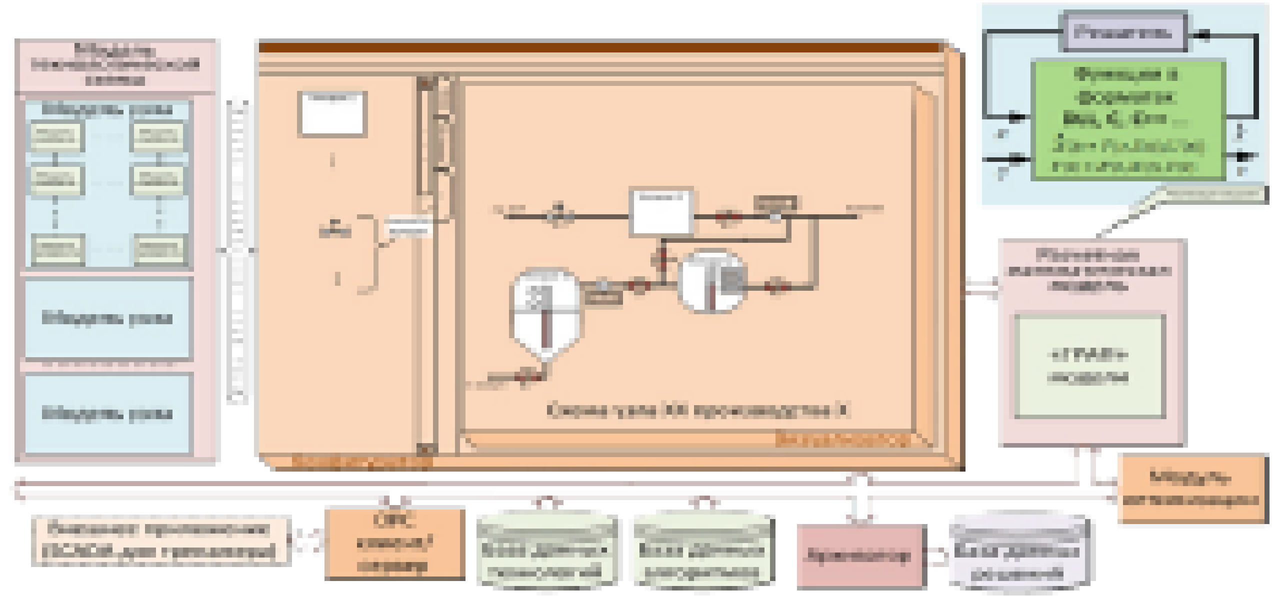


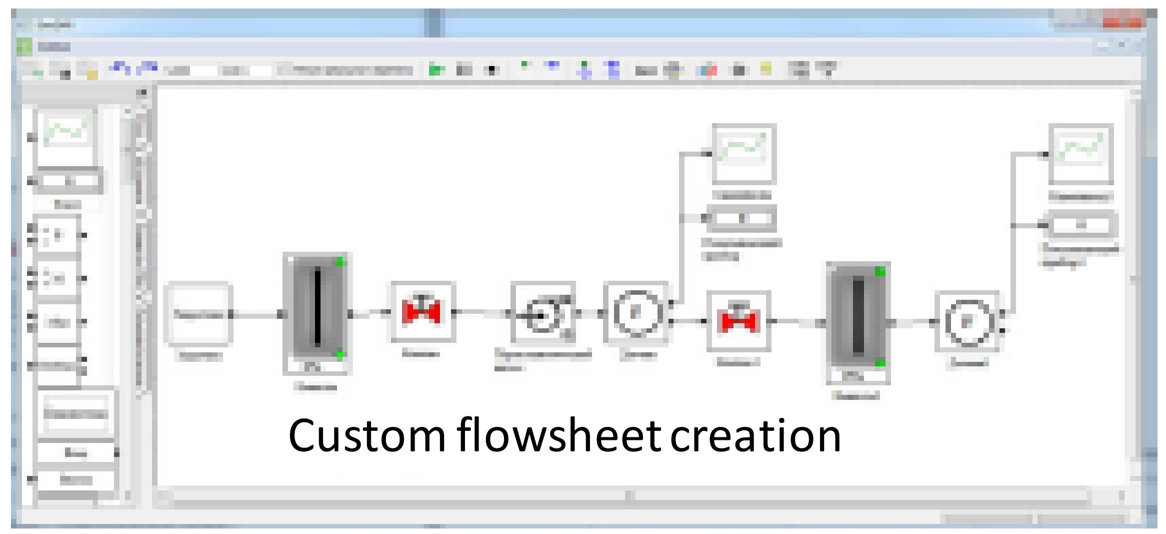
COMPUTER CODE FOR OPTIMIZATION AND DIAGNOSTICS OF TECHNOLOGICAL PROCESSES (COD TP)

Objectives:

Simulation of On-Site NFC flow sheet operation for investigation of operability and controllability and optimization as separate processes, technological nodes and setups, so the whole On-Site NFC flow sheet. Also the COD TP is purposed for simulation of control and operation of the whole flow sheet or separate elements with further usage of the simulation results for creating real APCS

Structural scheme of COD TP





Conclusion (1)

There are several options for closed NFC whit Pu fuel:

- REMIX
- MOX for thermal reactors
- MOX for fast reactor
- MNIT for fast reactor

The high density fuel is the only type of nuclear fuel which is able to provide CNFC realization.

CNFC with MNIT and PH-process allows:

- reprocessing of FBR SNF with high burn up and low cooling time;
- decrease the volume and time of SNF storage
- to reprocess any type of SNF;
- to prepare the final uranium – neptunium – plutonium product running the requirements for fabrication of the final pelleted mixed (U,Pu)N fuel.

Conclusion (2)

- By now following basic technological operations have been tested in laboratory conditions on real products:
  - steel cladding removal by dissolution in molten Zn;
  - pyroelectrochemical recovery of U, Pu and Np;
  - extraction refining of U, Pu and Np;
  - separation of rare earth elements and transplutonium elements.
- Experimental set-ups to test engineering solutions for pyroelectrochemical equipment should be installed in argon cell in 2015
- The installation for test of innovative systems for hydrometallurgical operations was completed 2014
- Design of MNIT SNF reprocessing and waste treatment unit was started in 2015

Conclusion (3)

At present time design of the pilot demonstration power complex (Seversk, Siberian Chemical Combine) for fuel fast reactor fabrication and FR SNF reprocessing is started.

The complex includes
- **reactor**
- **fabrication and refabrication facility**
- **reprocessing of SNF and waste treatment facility.**

Operation start:
- **Fuel fabrication - 2018**
- **Reprocessing of SNF and waste treatment – 2021**
- **Refabrication of MNIT fuel – 2024.**