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Current Status of Development in Dry Pyroelectrochemical Technology of Spent Nuclear Fuel Reprocessing

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CURRENT STATUS OF DEVELOPMENT IN DRY PYROELECTROCHEMICAL TECHNOLOGY OF SPENT NUCLEAR FUEL REPROCESSING (1)

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Strategy of Nuclear Energy Development in Russia

НИИАР

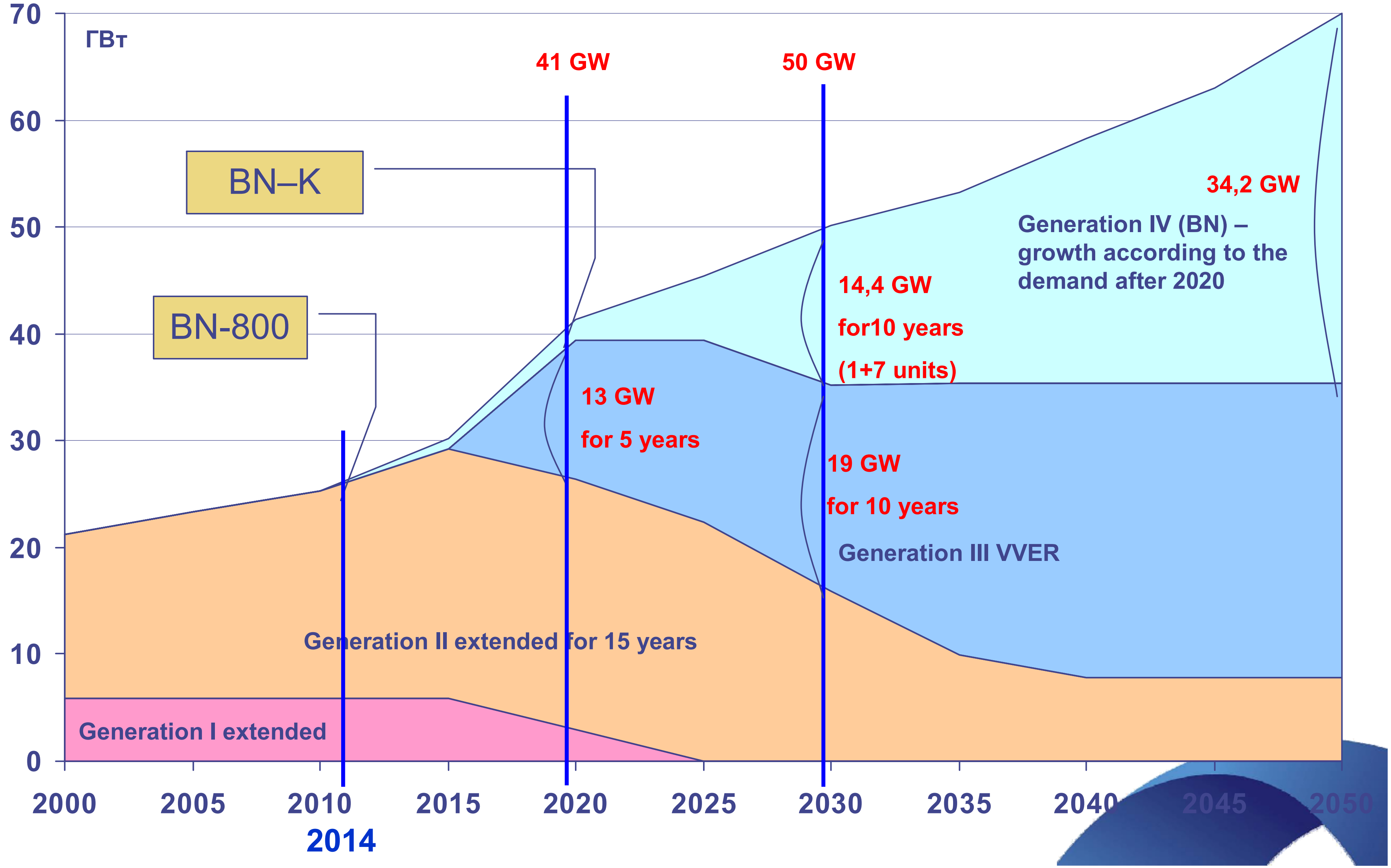
Russian Nuclear Power and Industry development is currently based on internal investment resources and on the two Federal Target-oriented Programs (FTP):

- FTP “Development of the Atomic Energy and Industrial Complex for 2007-2015 years” - *NPP construction*
- FTP “Assurance of Nuclear and Radiological Safety for year 2008 and till 2015” - *RAW Heritage*

FTP “New Generation Nuclear Energy Technologies” (2010-2020) – on final preparation Stage – and will support **Nuclear Innovations – New Technolgical Platform,** including:

– *Nuclear Closed Cycle on the basis of different fast reactors (Na, Pb, Pb-Bi)*
- *Dry technologies for recycling and new fuel*
- *New Experimental Facilities*
- *Fundamental studies, fusion developments etc.*

Forecast for Capacities of Russian Nuclear Power Industry till 2050

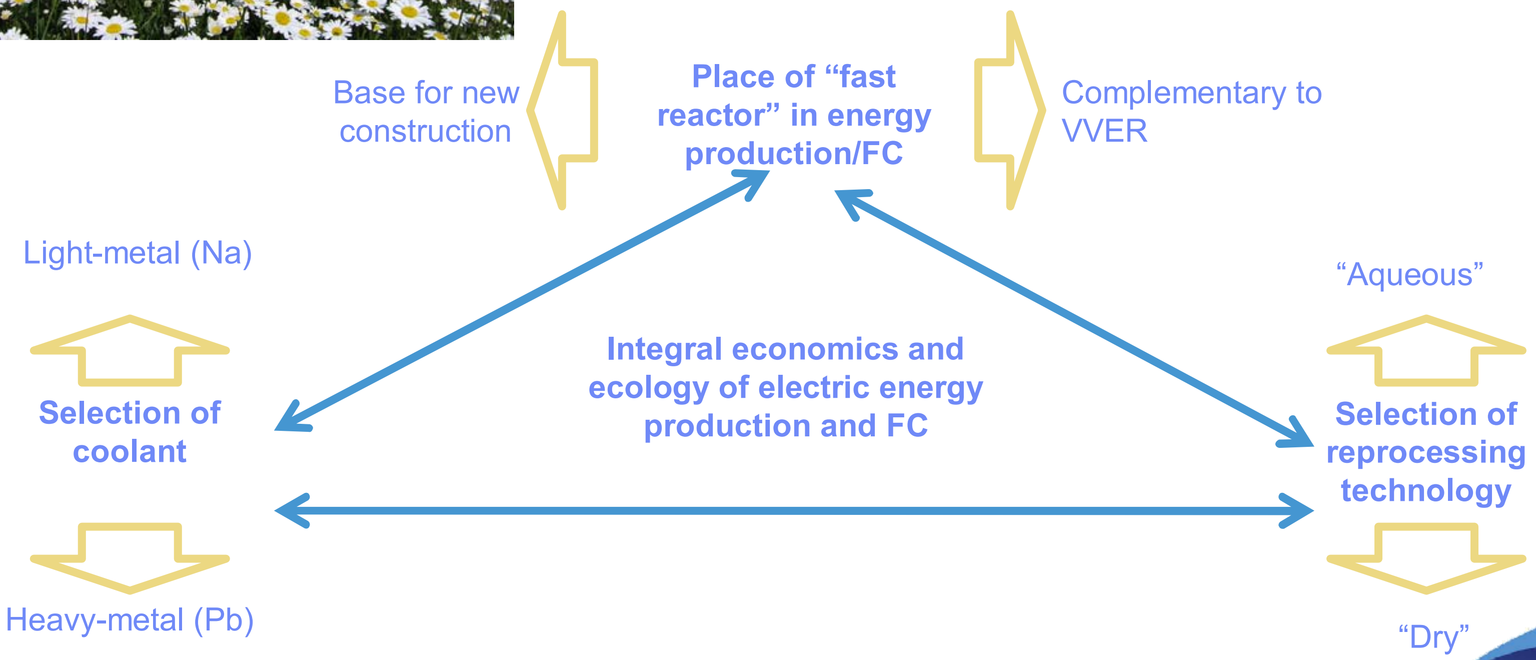


New Technological Platform

Beloyarsk 3, BN-600

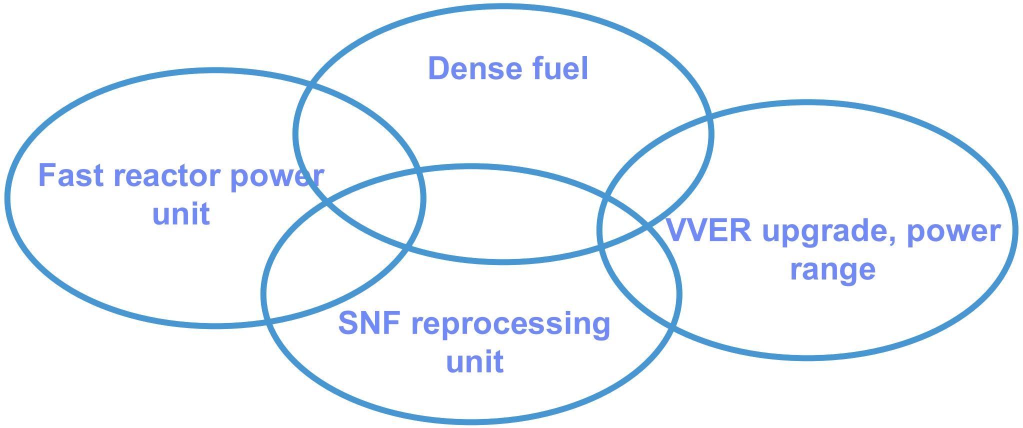
Na-related topic: BN-350, BN-600 (all facilities - 140 reactor-years)
Pb-related topic: floating reactors (Pb-Bi) on nuclear submarines
Mixed uranium-plutonium fuel
SNF reprocessing

Basic paths to arrange the architecture of CFC with fast neutron power units



New Technological Platform

Development of prototypes of CFC infrastructure key elements in Russia



Consolidation of competence and responsibilities for NTP

Model of new power engineering architecture in economic logics

Confirmation of technological readiness for industrial scaling

- **2014*** BN-800 and MOX fuel production startup
- **2014** Selection of base fast reactor technology and decision on VVER upgrade → **2020** Construction of power unit prototypes
- **2017** Establishment of “dense” fuel production
- **2018** Startup of SNF industrial reprocessing and RW disposal prototype
- **2019** Start of research reactor MBIR (RIAR) operation

2026 → Scaling of new technological platform

Development of New Technologies - key projects

New Type of NPP Power Units

Na Coolant Fast Reactors

- BN-800
- MOX fuel
- BN-K

Heavy Metal Coolant Fast Reactors

- BREST
- SVBR

Closed Nuclear Fuel Cycle Technologies

- Dense Fuel
- SNF Reprocessing
- RW Final Disposal

International Cooperation in the field of Energy Material Research

Multifunctional Fast Research Reactor MBIR

Controlled Fusion Synthesis and Energy Conversion

Fundamental Science

Research Base Development

Providing R&D

Conception of Federal Tasks Program "New Generation Nuclear Energy Technologies"

НИИАР

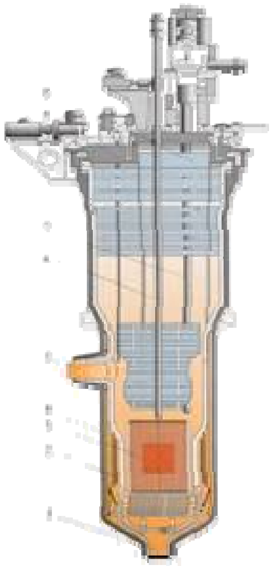
RIAR – main experimental site

- **Pilot Industrial Line for BN-800 (and BN-600) MOX Fuel Assemblies Manufacture**
- **Multi-functional Fast Test Reactor (MBIR) – 2018 →2020 (loops)**
- **Large Multi-Purpose Pyrochemical Reprocessing Complex -2015**
  - **Molten salt Reprocessing Facility for different type of fuel**
  - **Fluoride volatility Reprocessing Facility**
- **New Lab for Experimental and Innovative Fuel Production – 2010-1012 (incl. Fuel and Targets with MA)**
- **Demonstration of Closing Fuel Cycle based on Pyrochemical technologies - 2016-2020 - ... on a levels:**
  - **Up to 50 spent FAs of BN-600/800**
  - **Full scale closed fuel cycle for MBIR started initial fuel loading**
  - **Other experimental implementations**
- **Open for International Programs**

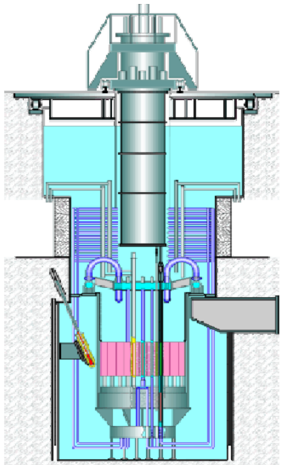
RIAR Site Today

Material Science Complex

Reactor complex



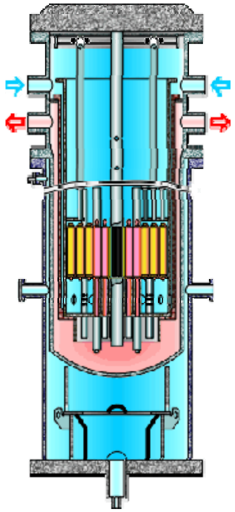
Experimental fast reactor
BOR-60



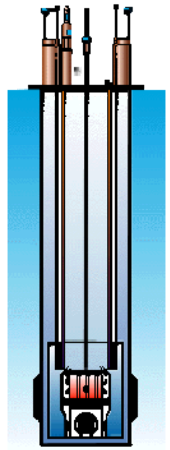
Multi-loop research
reactor MIR

Chemical Technological Complex

VK-50 reactor



High-flux reactor SM



Complex of pool-type
reactors RBT

New Russian Sodium Fast Research Reactor – Multi-functional Fast Test Reactor (MFTR)

НИИАР

Characteristic	Value
Maximum flux Фmax, n/cm2·sec	~ $6.0 \cdot 10^{15}$
Thermal power, MWth	~ 150
Electric power, MWe	~ 50
Number of independent experimental loops (~1 MWth, sodium, heavy metal and gas coolant + salt coolants)	3 (+1 behind reactor vessel)
Driven Fuel	Vi-pack MOX, (PuN+UN)
Core height, mm	400-500
Maximum heat rate, kW/l	1100
Fuel Cycle	Full Scale Closed FC based on Pyro Processes
Test Fuel	Innovative Fuels, MA Fuels and targets
Maximum fluence in one year, n/cm2	~ $1,2 \cdot 10^{23}$ (up to 55dpa)
Design lifetime	50 year
RR creation time (no more than, years)	**2018**

BN-800 and demonstration of CFC

- Support and recovery of technologies providing the design of fast sodium reactors (engineering tasks, fabrication of special-purpose equipment for Na-related work, Na-handling procedures, etc.)

- Mastering of industrial technology for MOX fuel production

- Demonstration of operation using reprocessed MOX-fuel

OBJECTIVES

Demonstration of competitiveness of the BN-800 operation to provide the development of the competitive “fast reactor” topic

Development of effective FC economics within the future Nuclear Power and Industry Complex and NTP

Long-term Objectives

НИИАР

Complete implementation of long-term objectives is efficient in case of large-scale operation of fast reactors

Design and operation of fast neutron reactors with CFC as a basis for the overall scenario of nuclear power engineering development using recycled and bred fuel

Basic principles of CFC:

- To minimize costs on fuel reprocessing, fuel elements fabrication and waste management
- To minimize RW volume and, if possible, complete recycle of MAs for transmutation in this reactor system
- To eliminate usage of pure fissile material, accommodation of productions in hot cells and remote-operated boxes

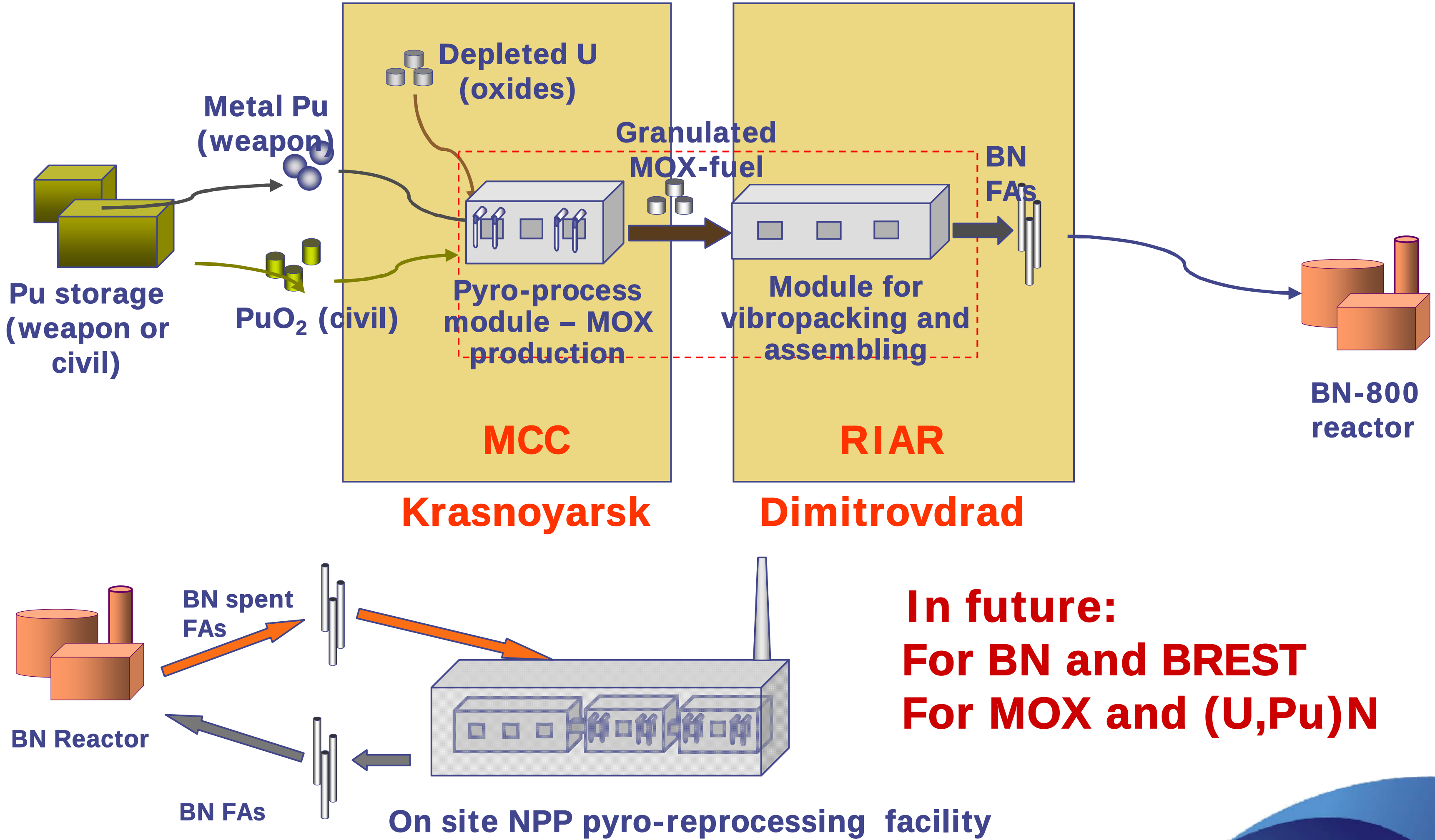
Application of advanced Russian technologies of world-level priority and ahead-of-time development of national processing and technical base

Nowadays Russia has an absolute technological priority in this field proved by the active Russian/Japanese cooperation related to the new FR CFC technologies.

Russia has developed processes to be a basis for CFC of fast neutron reactors, i.e. inter-related and inter-compatible pyrochemical reprocessing and vibropacking of fuel pins.

Implementation Pyroprocess for BN-800 Fuel Cycle

Combination of pyroprocess and vibropacking technology is the basis for BN-type MOX fuel production and recycling in different scenarios.



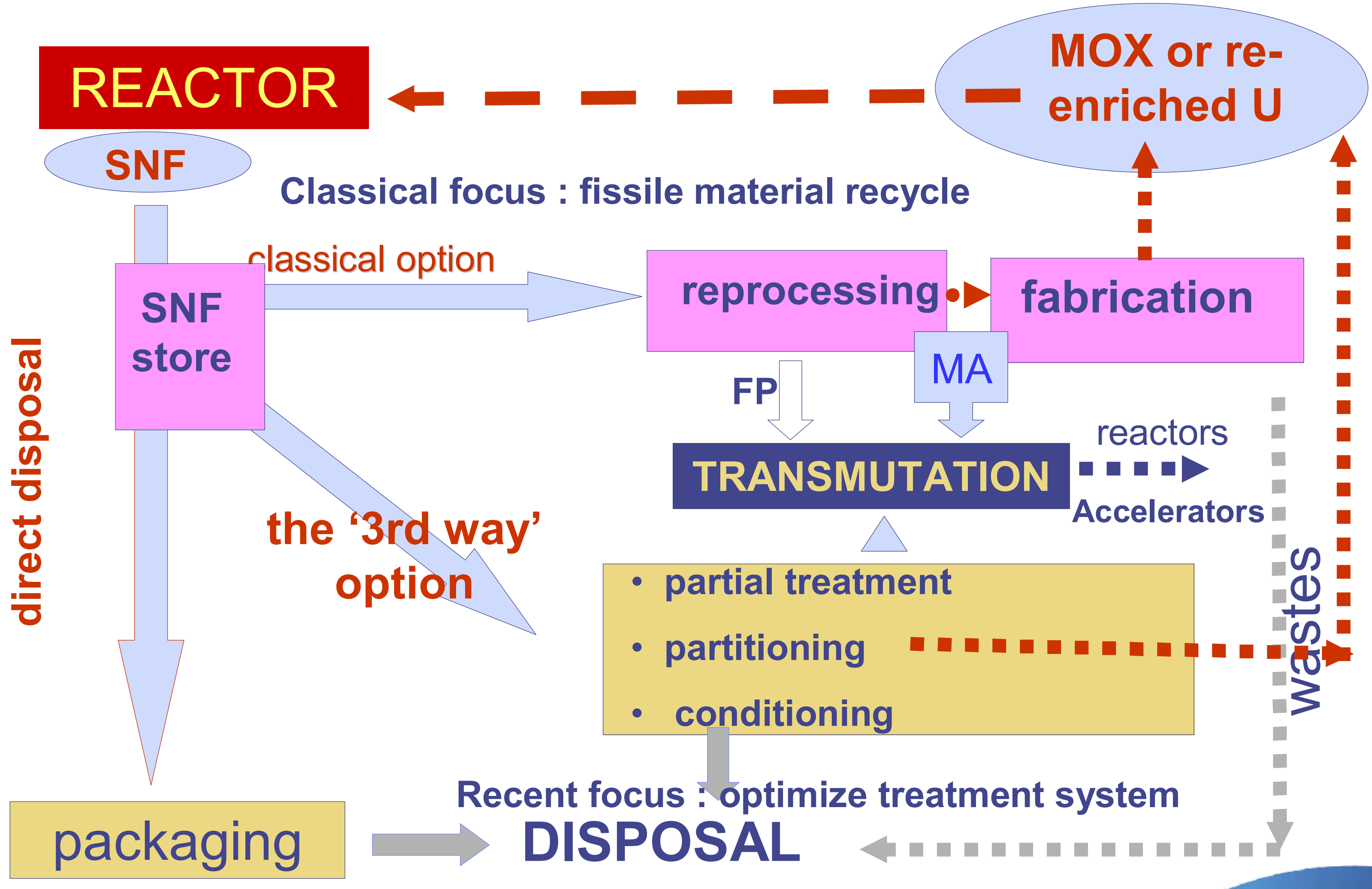
In future:
For BN and BREST
For MOX and (U,Pu)N

НИИАР

Key technologies of the Fast Reactor closed fuel cycle with MOX fuel

- Pyroelectrochemical reprocessing (recycling through molten salt)
- Vibropacking technology (crystalline particles with getter)
- Remote controlled automated technologies for fuel pins and fuel assembly manufacturing

Spent Fuel Management Options

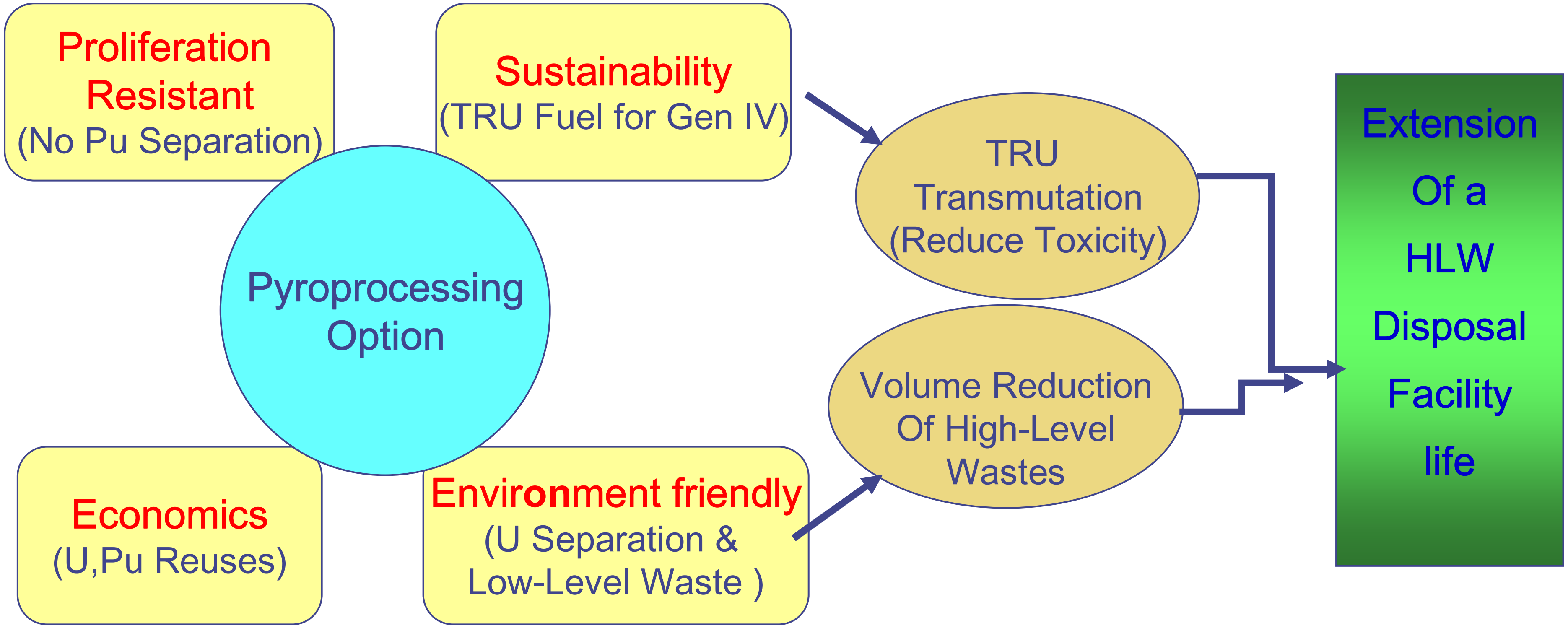


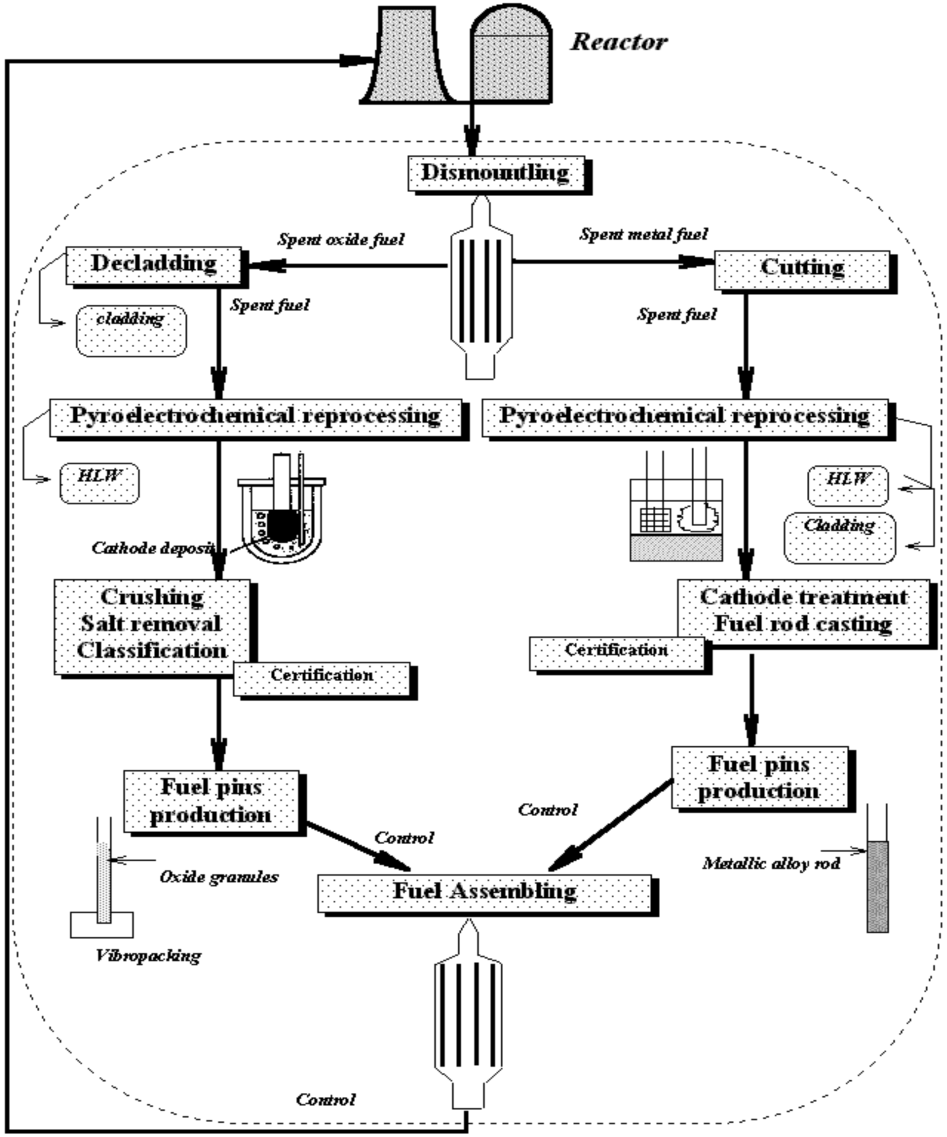
REPROCESSING AS AN OPTION FOR SFM

- EVOLUTION OF PURPOSE
  - *PAST : The classical option for spent fuel management (to recover pure fissile materials for recycle as MOX, especially in FBR)*
  - *PRESENT: A fraction of spent fuel inventory recycled to thermal reactors as MOX and enriched UOX (mainly in LWR)*
  - *FUTURE : Anticipation for innovative nuclear systems, P&T, simple recycling, etc*

- INDUSTRIAL MATURITY
  - *Currently, the only industrially available option (~1/3 of global inventory of spent fuel being reprocessed)*
  - *Technical and/or infrastructural base for future applications to other futuristic options (i.e., P&T)*

Advantages of the Pyroprocessing Option





Reactor
Dismountling
Spent oxide fuel
Spent metal fuel
Decladding
Cutting
cladding
Spent fuel
Spent fuel
Pyroelectrochemical reprocessing
Pyroelectrochemical reprocessing
HLW
HLW
Cladding
Cathode deposit
Crushing
Salt removal
Classification
Certification
Cathode treatment
Fuel rod casting
Certification
Fuel pins
production
Fuel pins
production
Control
Control
Oxide granules
Metallic alloy rod
Fuel Assembling
Vibropacking
Control

Non-aqueous methods in nuclear power engineering

Non-traditional SNF reprocessing methods

- Pyroelectrochemical processes in molten salts
  - Oxide type Fuel
  - Non-oxide
- Fluoride-gas technology
- Supercritical fluid extraction in CO_2
- Ionic room-temperature liquids

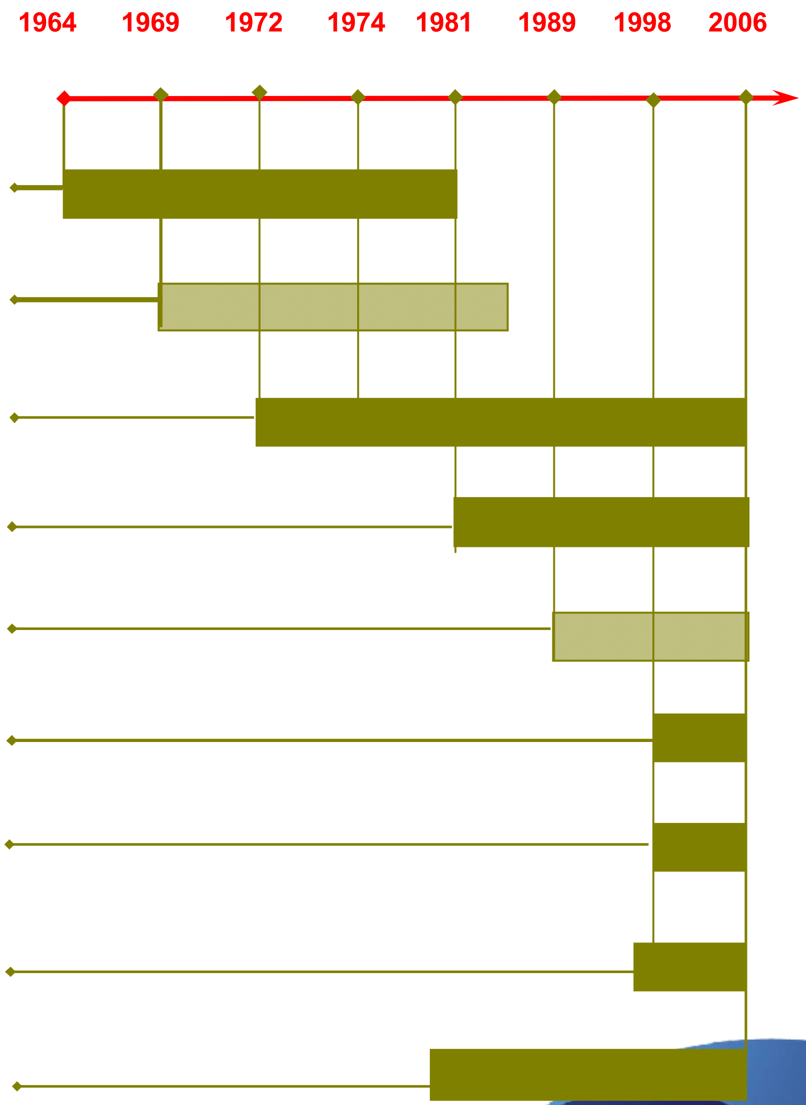
Molten salts in nuclear power engineering

- SNF reprocessing
- Reprocessing and partitioning of waste
- Use as liquid fuel (MSR)
- Use as a coolant

R&D on SNF Pyro Reprocessing in a World

- Oxide SNF reprocessing into Oxide – RIAR (Russia), JAEA (Japan)
- Oxide SNF reprocessing into Metallic – CRIEPI (Japan)
- Nitride SNF reprocessing – JAEA (Japan), RIAR, Bochvar Institute (Russia)
- Metallic SNF reprocessing – ANL (US), CRIEPI (Japan)
- SNF metallization – KAERI (Korea), CRIEPI, RIAR
- HLW partitioning in molten salts – CRIEPI, RIAR, KAERI, CEA (France), ITU (EU)
- Fluoride volatility processes – CRIEPI, Hitachi/TEPCO (Japan), Kurchatov Institute (Russia), RIAR, INR (Rez., Cech. Rep.)
- Others applications (RIAR, ANL, CRIEPI, CEA)

Main stages of RIAR activity in the Field of FR Fuel Cycle



Development of the pyrochemical technology for granulated fuel production and fuel rod fabrication by vibropacking

Construction and operation of the remotely controlled facility ORYOL (fabrication of the BOR-60 fuel rods and FAs)

Pyrochemical reprocessing of spent nuclear reactor fuel

Loading of vibropack MOX fuel into the BOR-60 reactor

Construction and operation of semi-industrial complex for the BN-600 fuel fabrication

Pyrochemical production of granulated MOX fuel based on the weapon-grade plutonium

Fabrication and irradiation of the experimental BOR-60 and BN-600 MOX FAs using weapon-grade plutonium

Fabrication and irradiation of vibropack fuel rods based on the fuel compositions with minor-actinides additives

Fabrication and irradiation of the experimental vibropack VVER fuel rods

Experience in Closed Fuel Cycle including pyrochemical processes

НИИАР

Research Institute on Atomic reactors – RIAR (Dimitrovgrad) is center of non-aqueous methods development:

- Pyrochemical investigation - from early 1960-s
- Demonstration of fluoride volatility reprocessing technology – 1970s
- Pilot facility for pyrochemical MOX-fuel production for fast reactor – from late 1970-s up to 1990-s
- Pyroelectrochemical reprocessing experience – 1990-2005
- Study on transmutation cycle, nitride fuel and others – from 1990s
- Start of industrial implementation of pyro-vipack MOX technology – 2008.
- Expected creation of “Test Demonstration Center – Dry technologies” 2009-2013

Current status of pyrochemical development for oxide fuel

- **Fundamental research**

 Properties of U, Pu, Th, Np, Am have been studied. Knowledge of physical chemistry and electrochemistry of basic FP is sufficient for processes understanding and modeling. The needed research lines – study of Cm and Tc chemistry. Development of nitride fuel recycle methods is carried out.

- **Development work**

 All technological steps and equipment have been developed for the oxide fuel reprocessing and fabrication processes. The process was tested more than to **7200 kg of fresh fuel** for different reactors and up to **40 kg** of BN-350 and BOR-60 **irradiated fuel**. The essentials of technology have been elaborated and feasibility study has been completed for the BN-800 large-scale CFC plant. **More than 45 000 fuel pins and more than 1000 FAs**

- **Industrial implementation**

 As the readiness of technology is high, work is underway on industrial implementation of U-Pu fuel. The BOR-60 operates on vi-pack fuel. The design of the CFC facility is in progress. 30 FAs have been tested and irradiated in BN-600. **These technologies are under implementation as basic for BN-800 industrial MOX fuel production.**

Pyrochemical processes

Basic research of the molten salt systems allowed for the development of technological processes for production of granulated uranium and plutonium oxides and mixed uranium and plutonium oxides. A distinctive feature of the pyrochemical technology is a possibility to perform all the deposit production operations in one apparatus - a chlorinator-electrolyzer

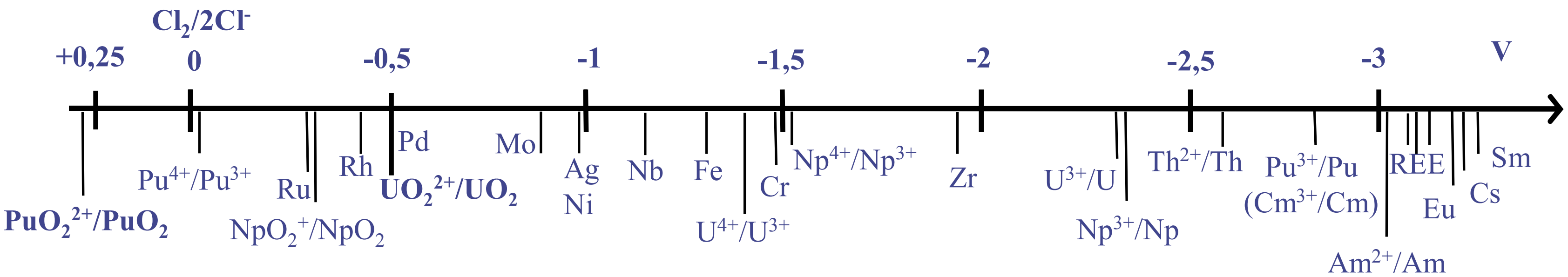
Pyrochemical reprocessing consists of the following main stages:

- *Dissolution of initial products or spent nuclear fuel in molten salts*
- *Recovery of crystal plutonium dioxide or electrolytic plutonium and uranium dioxides from the melt*
- *Processing of the cathode deposit and production of granulated fuel*

CHEMISTRY

UO_2 PuO_2 $(U, Pu)O_2$ MA FP

Potentials row for actinides and fission products in molten 3LiCl-2KCl under 773 K



Basis of “oxide electrolysis” in molten chlorides

- From electrochemical point U and Pu oxides behave like metals. They are forming the complex oxygen ions MeO^{2n+}, which are reduced on cathode up to oxides.
- Under high temperatures (> 400°C) UO_2 are electrically conductive.
- In the molten alkali chlorides uranium has the stable ions U(III), U(IV), U(V), U(VI). Highest states of Pu oxidation Pu(V) and Pu(VI) are stable only in the definite field of ratios for oxidation reduction potentials of the system.
- From any oxidation state plutonium can be conversed into oxide by changing of the oxidation-reduction potential of the system.
- UO_2 and PuO_2 are reduced in the electropositive area. The majority of fission products are reduced at more negative potentials.

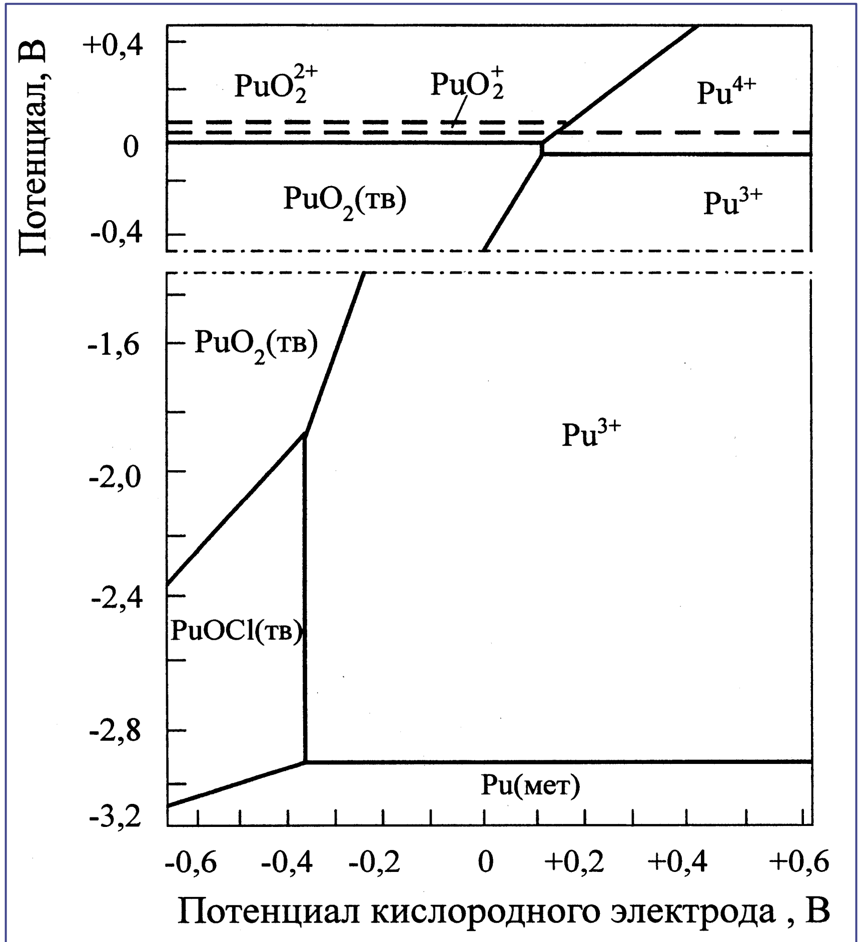
CHEMISTRY

UO_2 PuO_2 $(U, Pu)O_2$ MA FP

The potential/pO^{2-} (or potential of oxygen electrode) diagram of plutonium

in NaCl-2CsCl melt at 863K

- From any oxidation state plutonium can be conversed into oxide by changing of the oxidation-reduction potential of the system.



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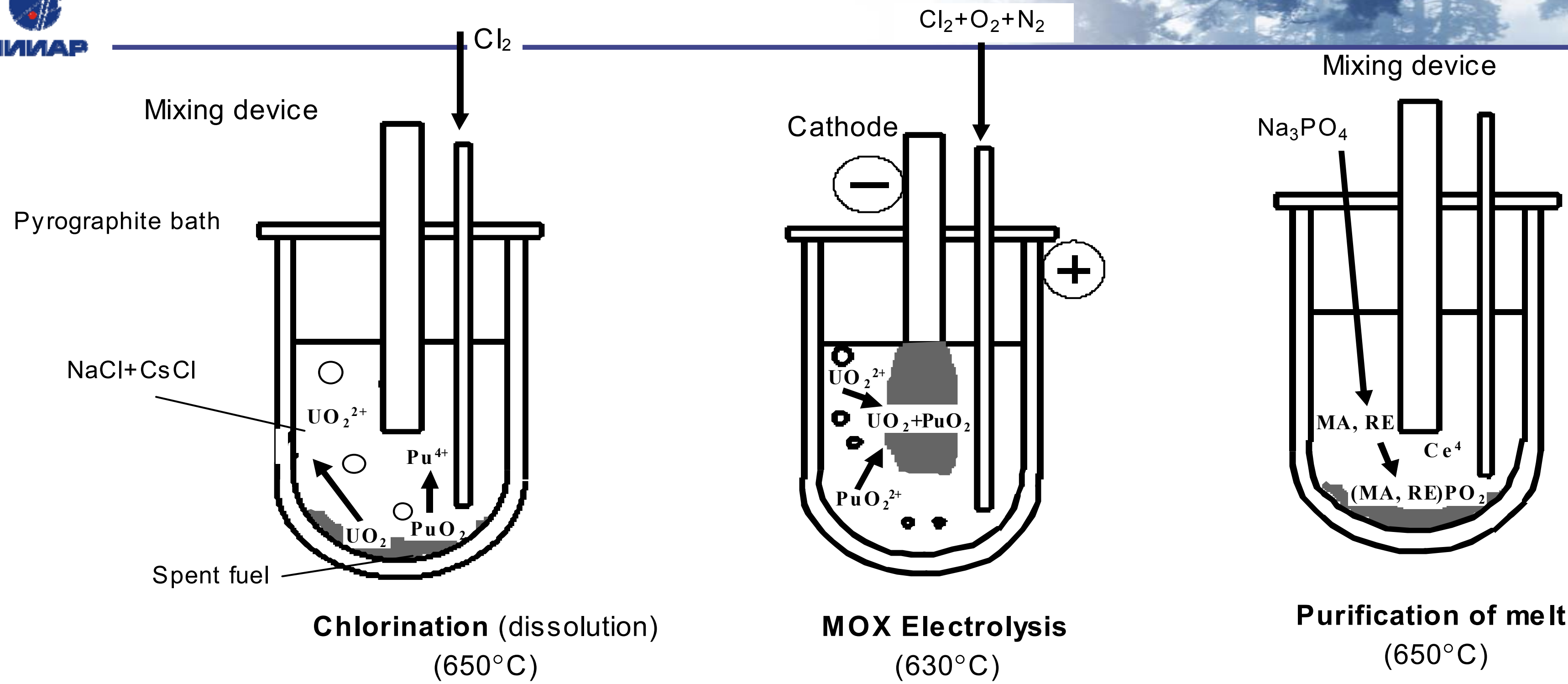


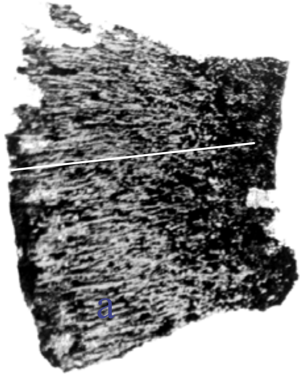
Cathode: $UO_2^{2+} + 2e^- \rightarrow UO_2$

$PuO_2^{2+} + 2e^- \rightarrow PuO_2$

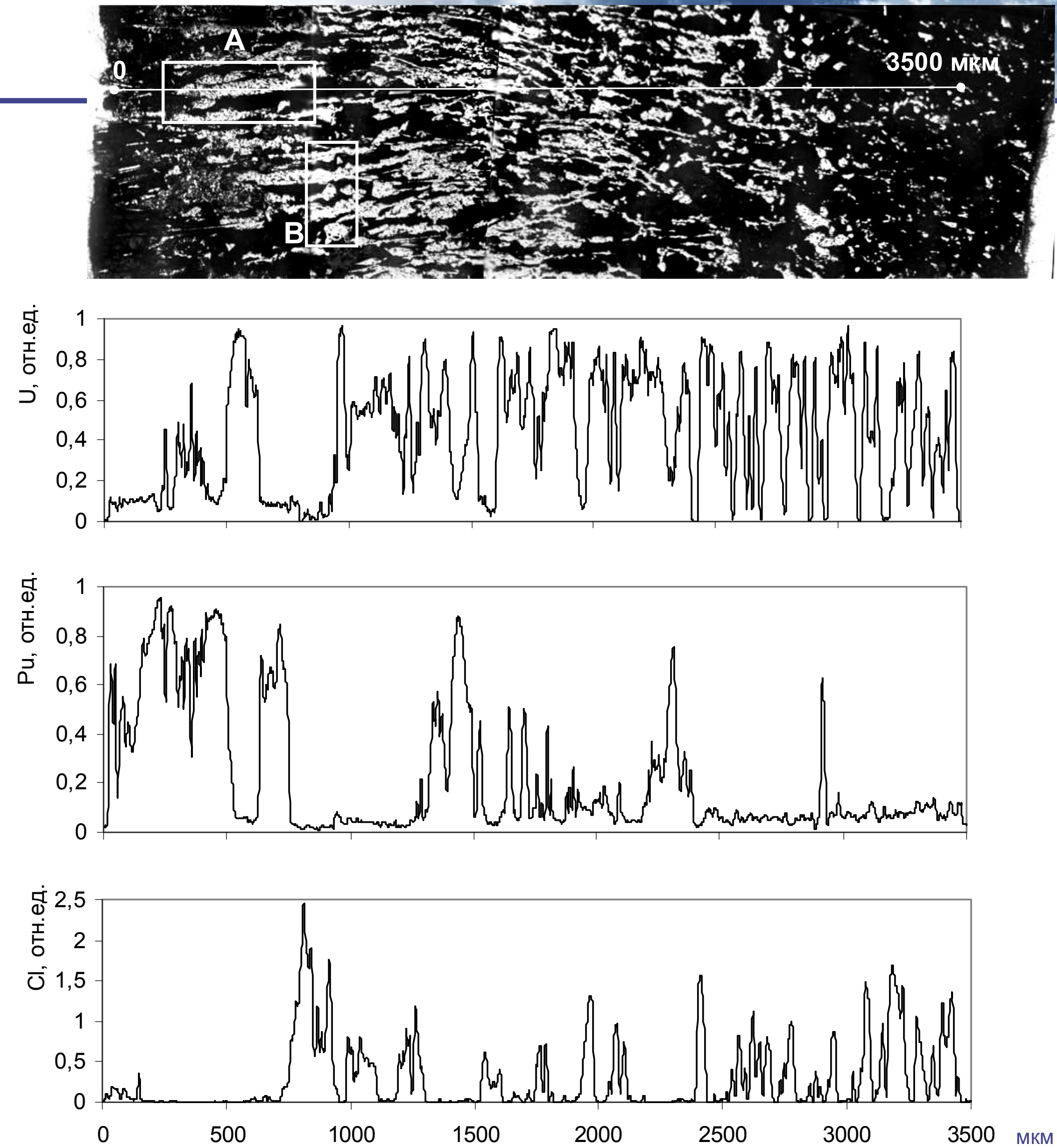
Anode : $2Cl^- \rightarrow Cl_2 + 2e^-$

Sequence of operations for pyroelectrochemical reprocessing of spent fuel in MOX-fuel.

Oxide fuel deposit on cathode



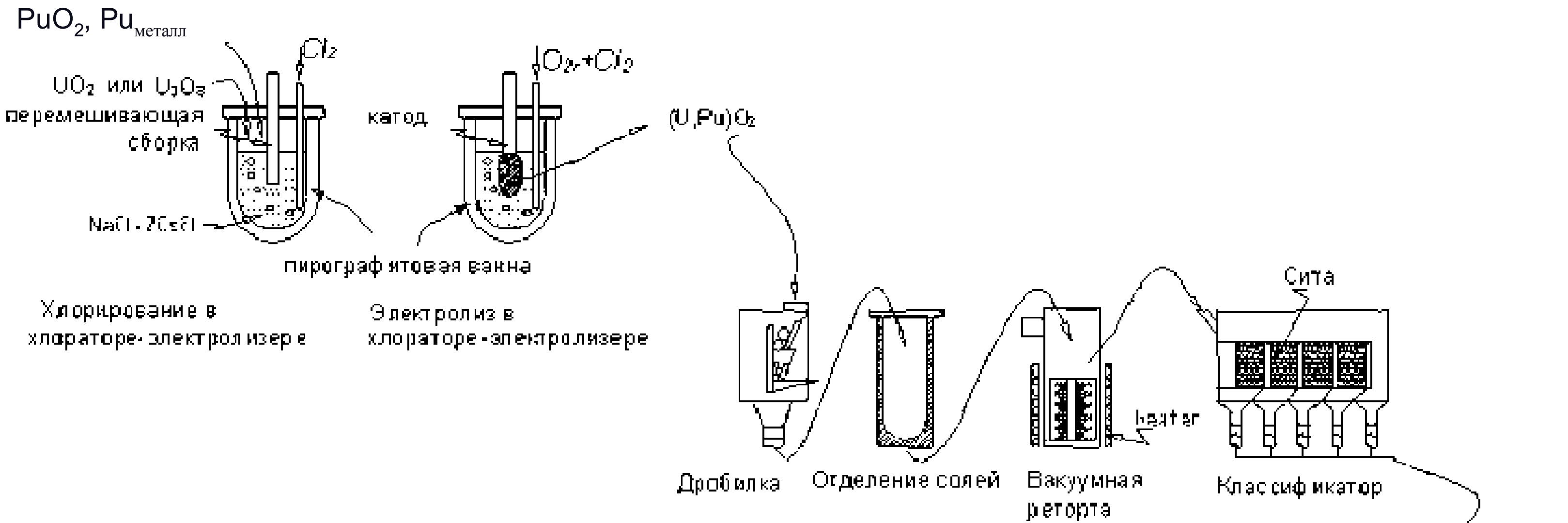
а) Microstructure of $(U,Pu)O_2$ cathodic deposit (×10)



б

б) Microstructure of $(U,Pu)O_2$ and distribution of U, Pu, and Cl on scaning line

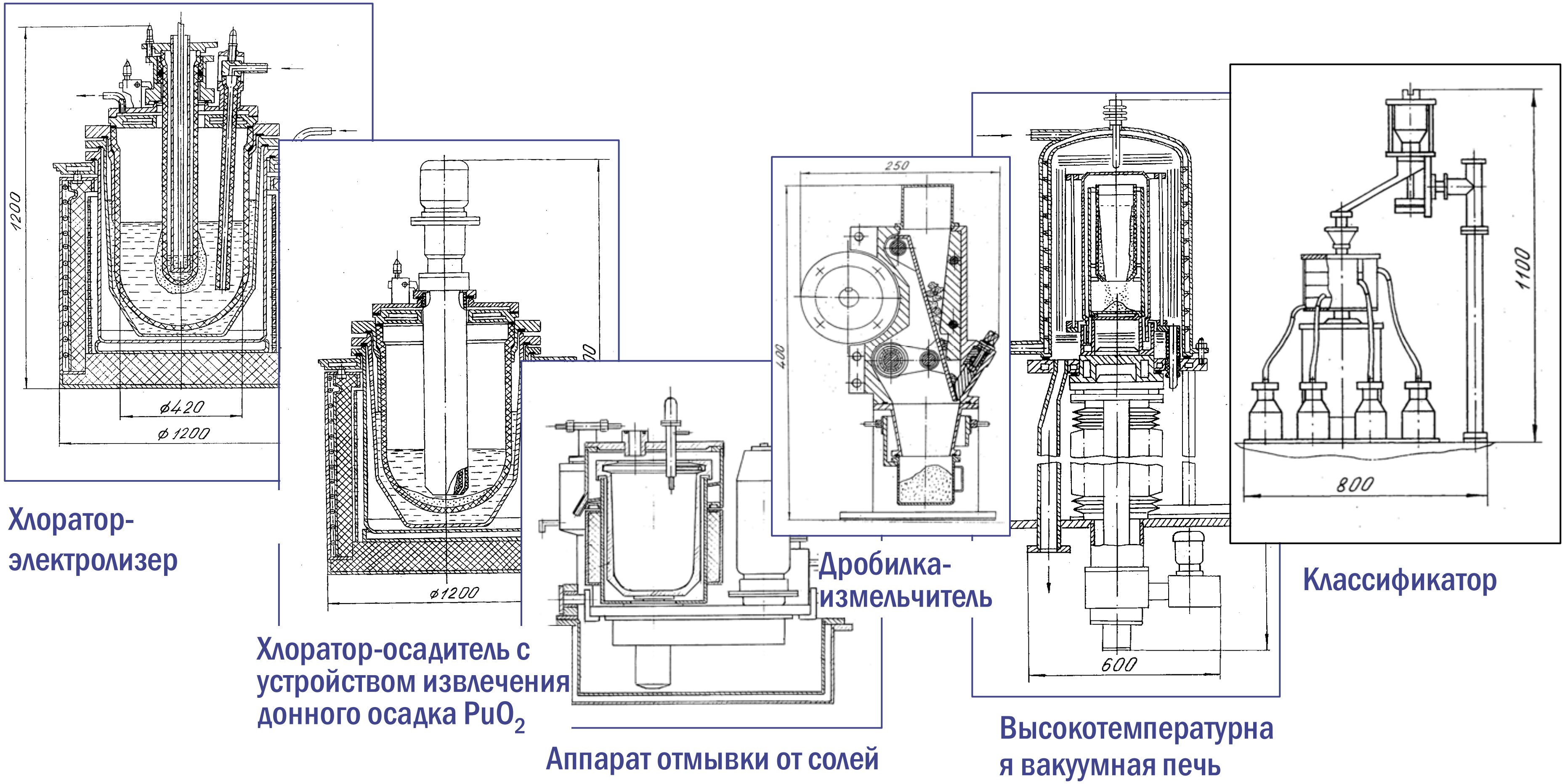
Flow-sheet of MOX fuel production



Technological process - periodical

Final products – granulated oxide fuel in the form of oxides of U and Pu or codeposited oxides of Pu and U

Equipment for pyroprocess

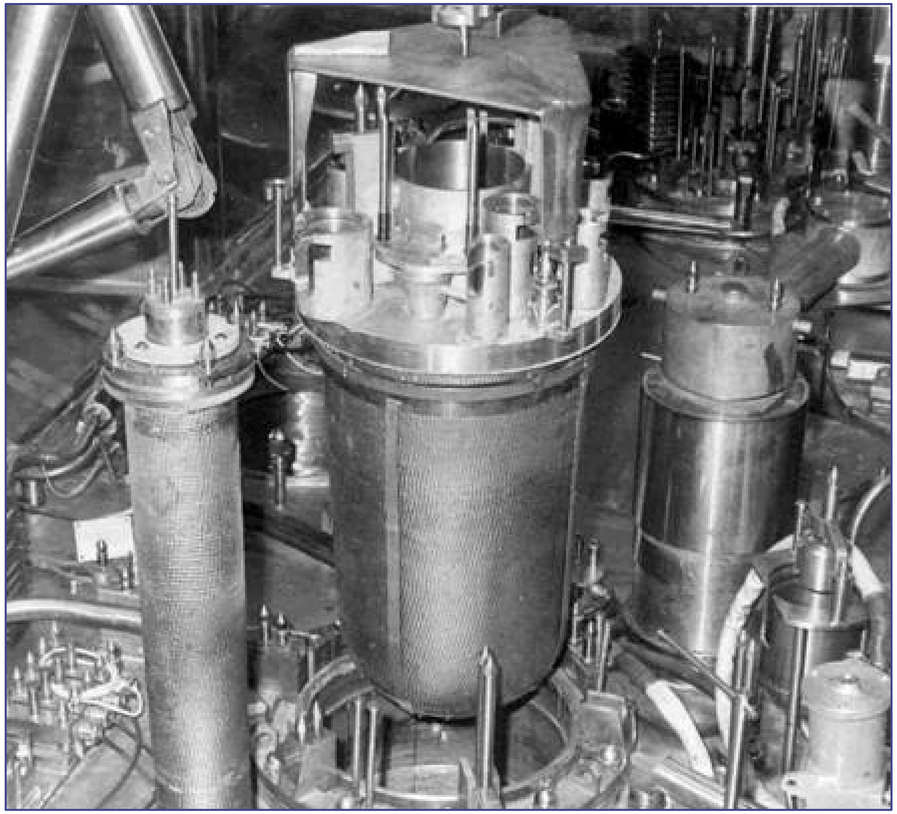


MOX-fuel

30 kg MOX-fuel

6 kg MOX-fuel

Crucible diameter 250 mm

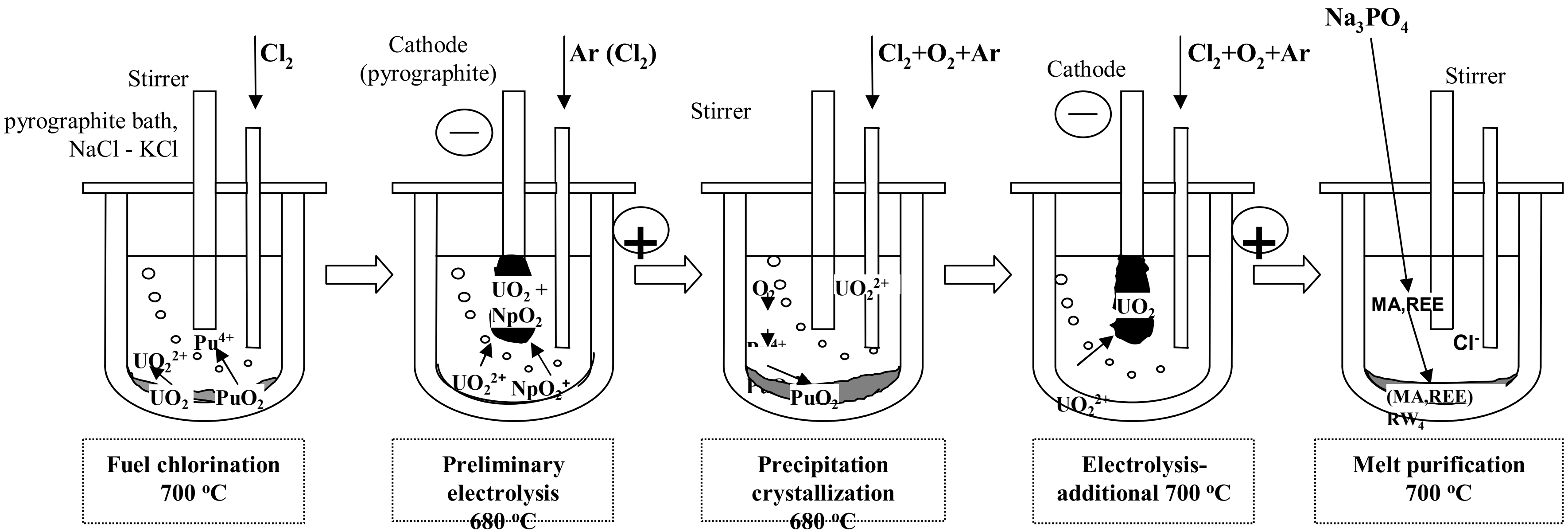


Crucible diameter 380 mm

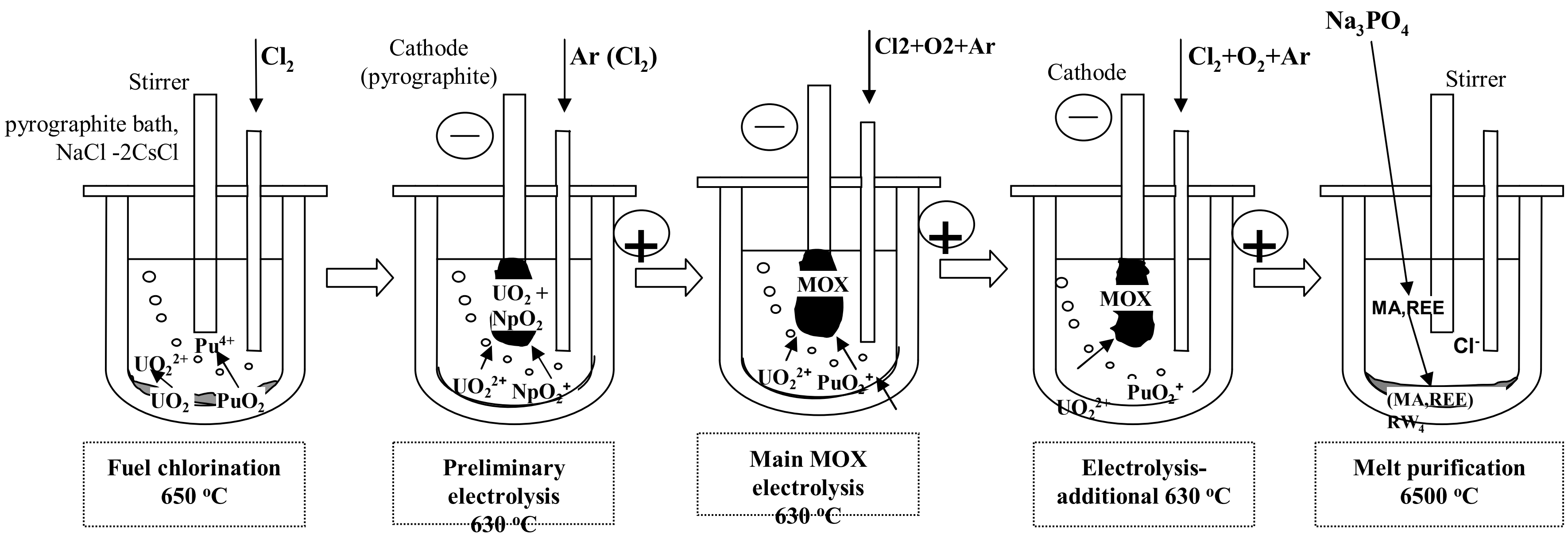
Mass balance on products

(mass. %) for UO_2-PuO_2 granulation (on batch of 30 kg)

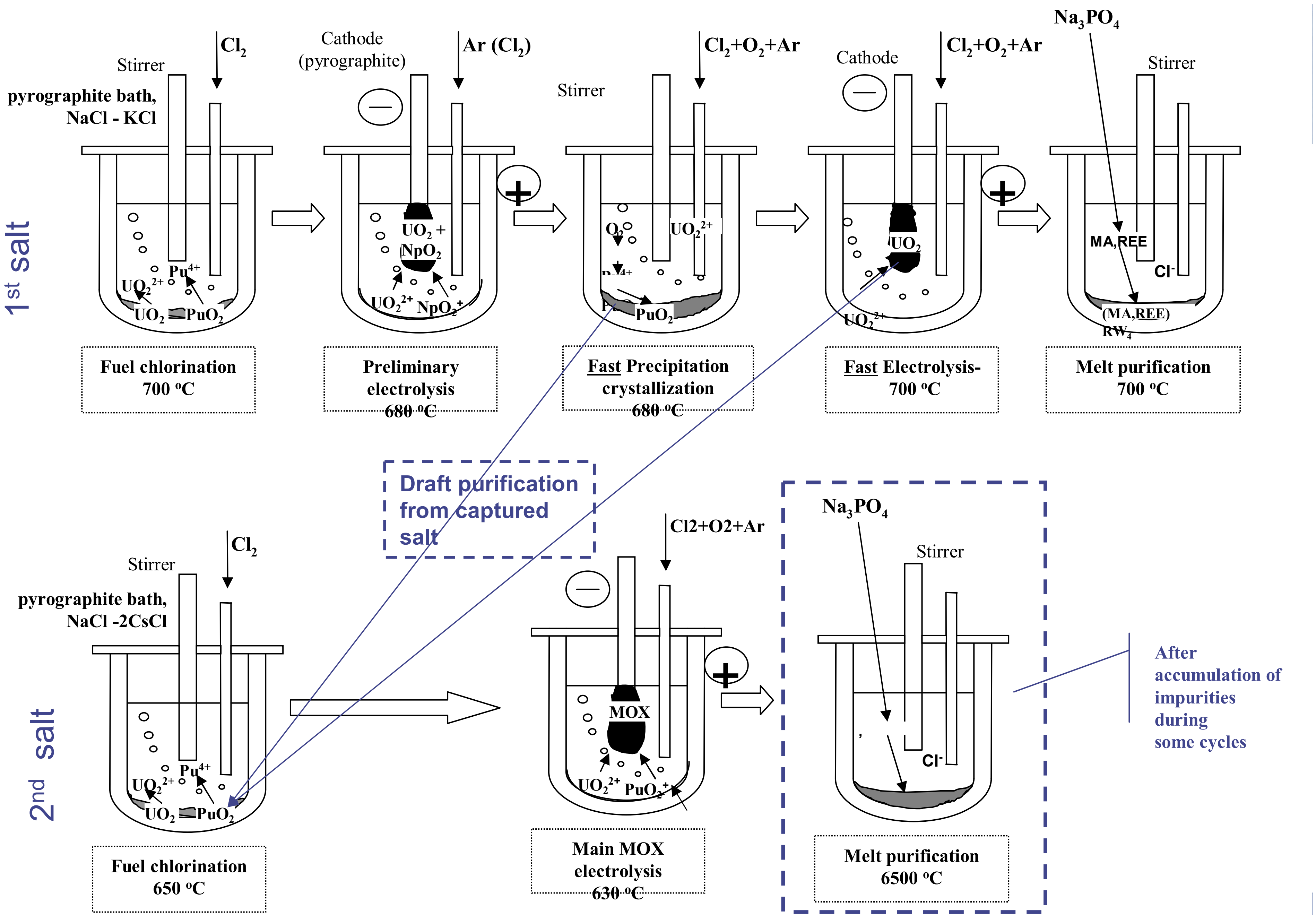
	Direct yield after basic	Recycled products		Losses	
		for direct return to process head	for return after treatment	portion	type
U+Pu	97.90±0.30	1.31±0.08	0.57±0.03	0.12±0.004	samples for analysis,
U	97.87±0.34	1.36±0.07	0.56±0.03	0.101±0.003	sorption on equipment,
Pu	98.04±0.15	1.08±0.11	0.59±0.06	0.20±0.02	slime after salt refining



DDP MOX→PuO_2 flow sheet



DDP MOX→MOX flow sheet



DDP Double Salt flow sheet

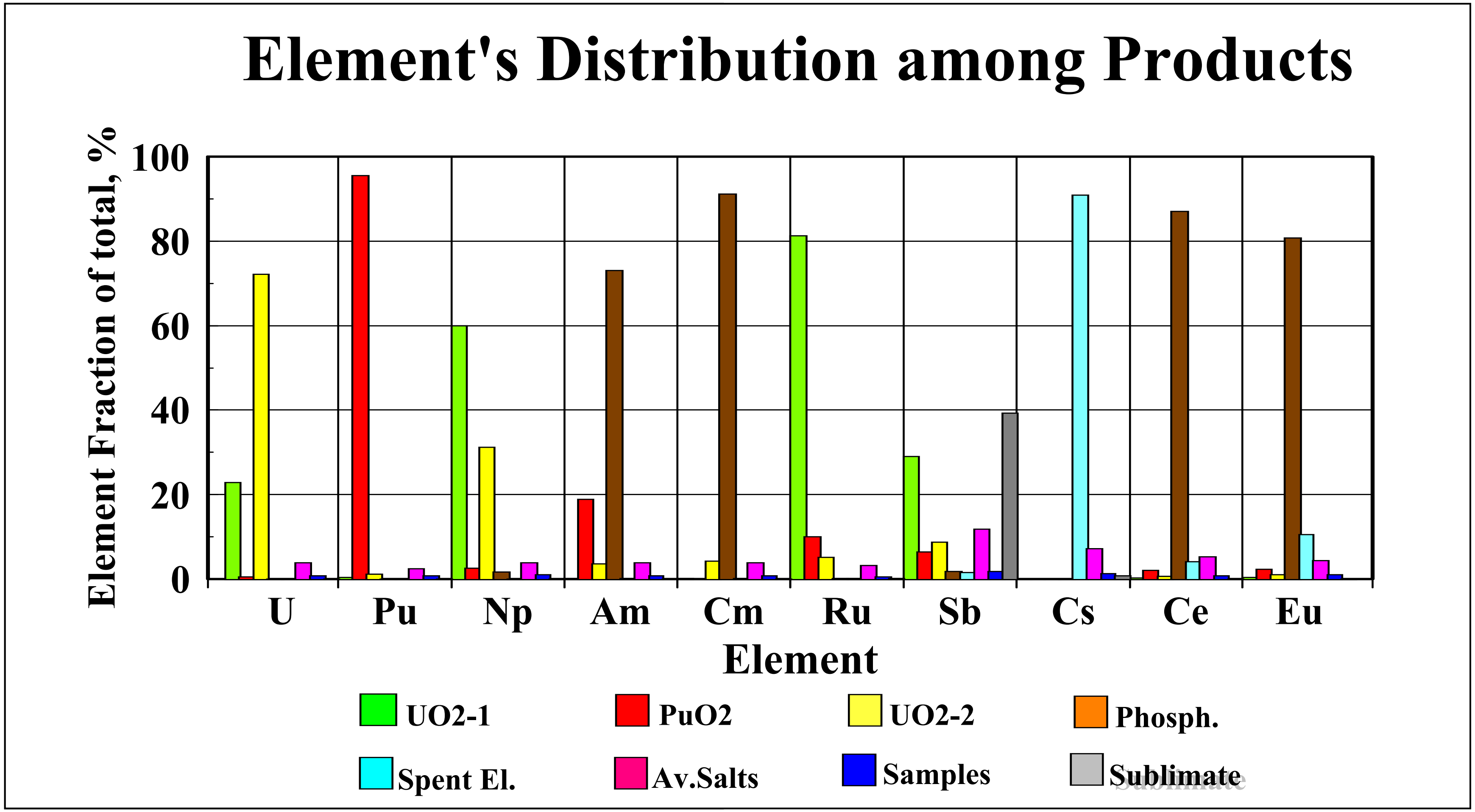
RIAR experience in reprocessing of spent fuel of the BOR-60 and BN-350 reactors

Fuel type	Burn up ,%	Mass, kg	Period	Reactor
UO2	7,7	2,5	1972..1973	BOR-60
$(U,Pu)O_2$	4,7	4,1	1991	BN-350
(U,Pu)O2	21..24	3,5	1995	BOR-60
UO2	10	5	2000	BOR-60
(U,Pu)O2	10	12	2000…2001	BOR-60
(U,Pu)O2	16	5	2004	BOR-60

Decontamination factors (DF) from main FPs

Fuel type	Main FPs				
	Ru-Rh	Ce- Pr	Cs	Eu	Sb
PuO_2 for BN-350 (test, 1991)	50	220	> 3000	40	200
PuO_2 for BOR-60 (test, 1995)	33	40..50	4000	40..50	120
UO_2 for BOR-60 (test, 2000)	> 30	~	> 4000	> 200	~
$(U,Pu)O_2$ for BOR-60 (test, 2001)	20 - 30	25	~ 10000	> 100	~

Mass-balance of Actinides and FP after the BOR-60 Fuel Reprocessing (1995)



MOX-MOX reprocessing experiments

2004

Main MOX - 3 400 g,

Pu content - 30 %wt .

Current efficiency – 35 %

2000

1st Main MOX - 3 200 g,

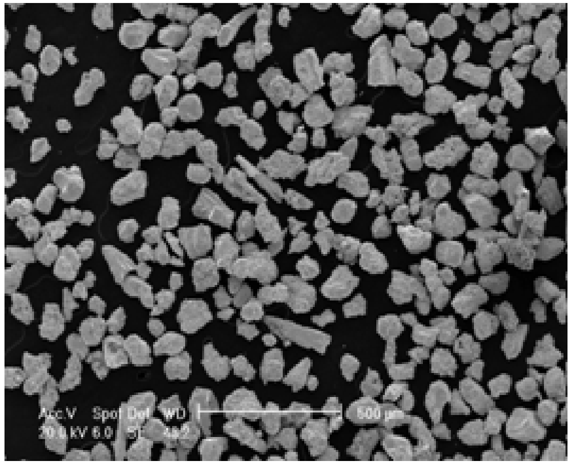
Pu content - 10 %wt .

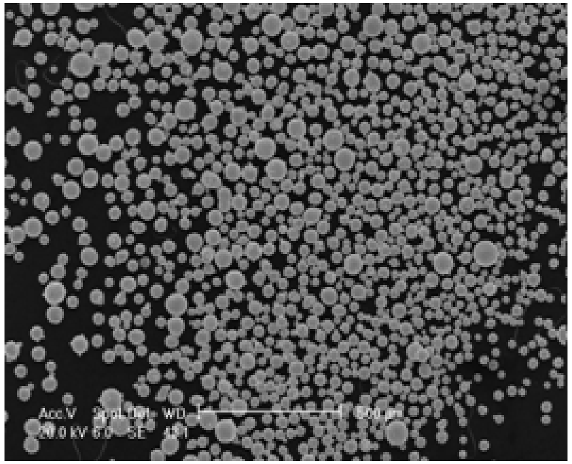
Current efficiency – 15 %

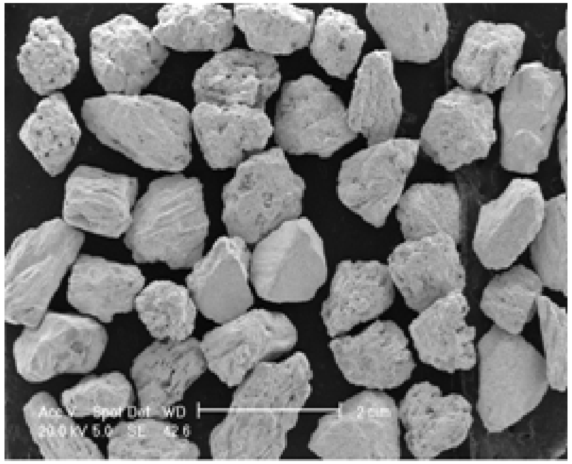
MOX cathodic deposit just after pyro-process

Salt ingot after reprocessing test with the BOR-60 fuel

Granulated MOX-Fuel







Metal content, %wt	87,75
Pyknometric density of granules, g/cm^3	10,7
Bulk density of polydispersed granulate, g/cm^3	6,0
O/M ratio (oxygen ratio)	$2{,}00^{+0{,}01}$
Mass fraction of process impurities, %:	
chlorine – ion	0,006
carbon	0,006

Parameters of demonstration experiment

on reprocessing of spent UO2 and MOX fuel

Parameter	$UO_2 \rightarrow UO_2$ process		MOX → MOX process	
	Experiment	Continuous-running process	Experiment	Continuous-running process
Nuclear materials in target products, %	95,91	>99,6	94,83	>99,5
Nuclear materials in recyclable products, %	2,9	In process cycle	3,9	In process cycle
Loss, %	1,19	< 0,4	1,27	< 0,5
Decontamination factor				
cesium	10000		>1000	
REE*	>100		>100	
noble metals*	~10		~10	

* **estimation based on the previous laboratory studies and demonstration experiments**

Methods for separation of MA and LLFP

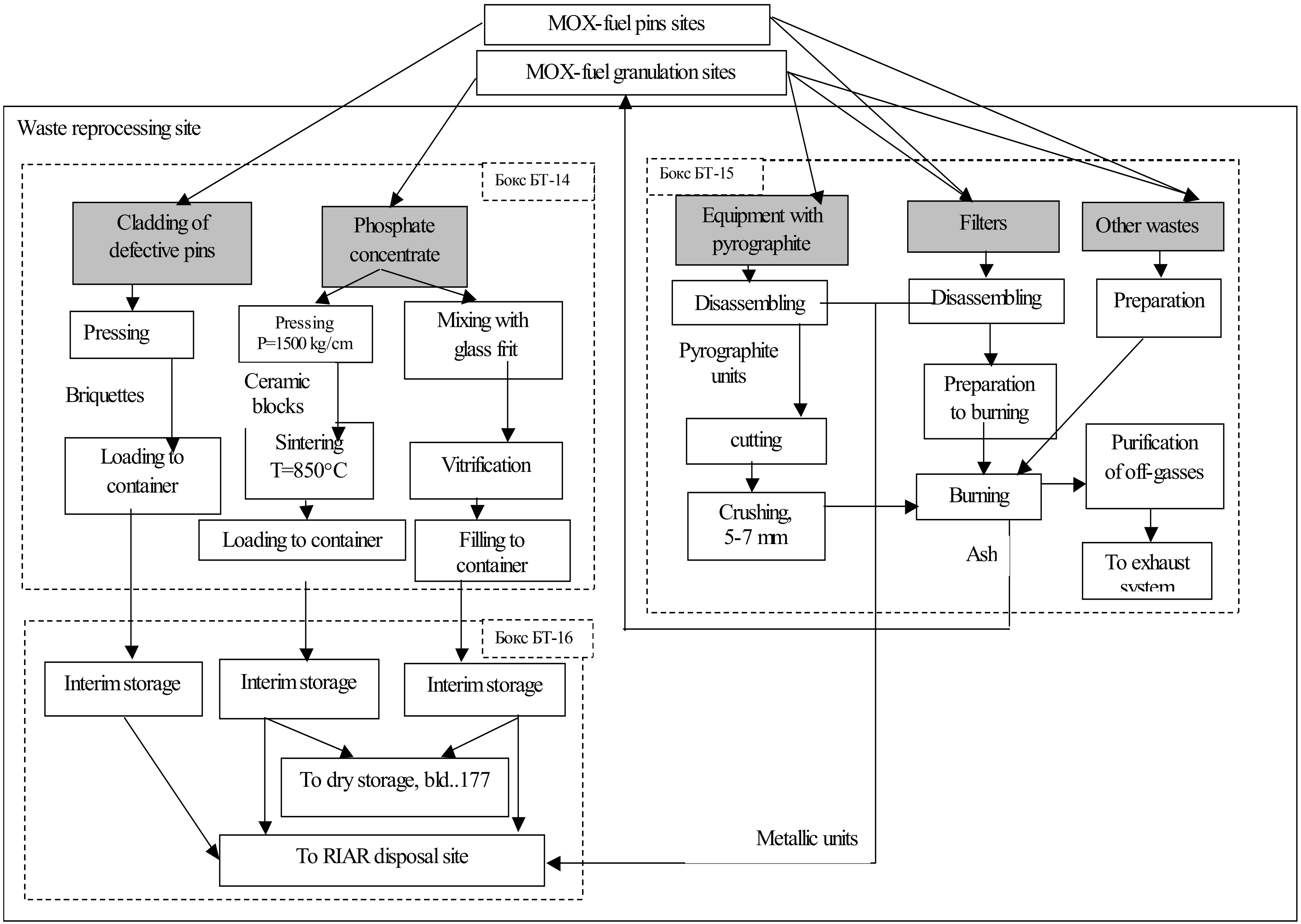
During solid fuel reprocessing by molten halide salt methods:

- Cs, Sr, I move to component of salt
- Np, mainly, move with U and Pu
- Am and Cm accompany REE
- Tc collected as part of noble metals fraction
  - (Tc and I can moved in gas phase during chlorination or fluorination)

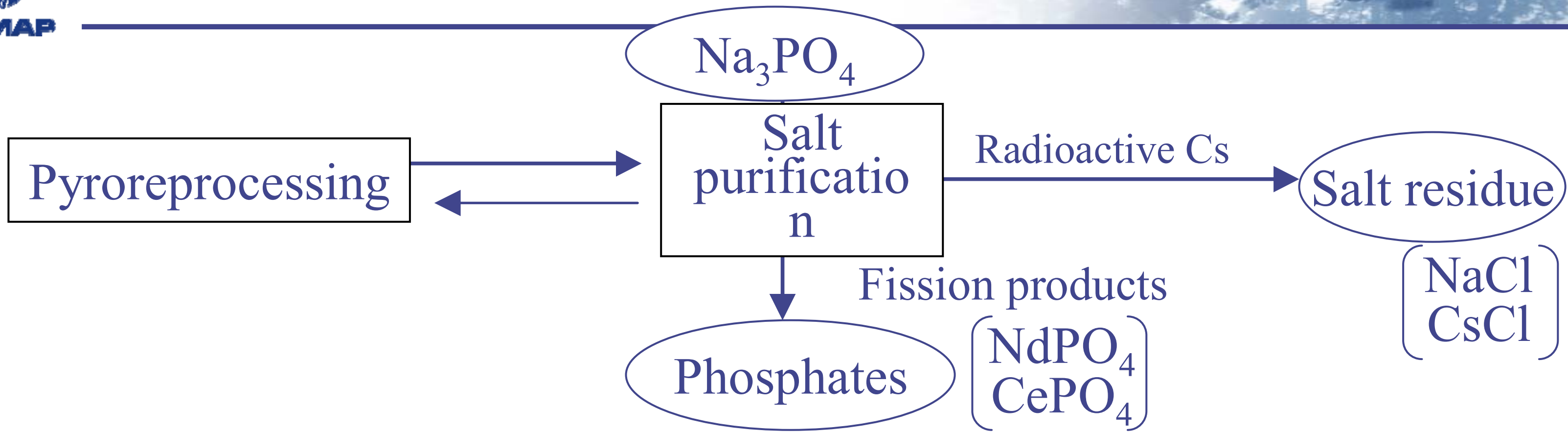
Waste treatment site

Solid waste characteristics formed on MOX-facilities

Type of wastes	Specific amount, kg on 1 kg of fuel	Maximum specific activity, Bq/kg wastes
On MOX-fuel facilities		
Phosphate concentrate	0,013	$1{,}5 \cdot 10^{9}$
Pyrographyte units	0,2	$2{,}3 \cdot 10^{8}$
All filters (cell and boxes)	0,13	$1{,}5 \cdot 10^{8}$
Other wastes (polyethelen, cloths etc.)	0,02	$1{,}0 \cdot 10^{8}$
On fuel pins facility		
Cladding of defective fuel	0,04	$9{,}3 \cdot 10^{7}$
Other wastes	0,02	$1{,}0 \cdot 10^{8}$


MOX-fuel pins sites
MOX-fuel granulation sites
Waste reprocessing site
Бокс БТ-14
Cladding of defective pins
Phosphate concentrate
Pressing
Pressing P=1500 kg/cm
Mixing with glass frit
Briquettes
Ceramic blocks
Loading to container
Sintering T=850°C
Vitrification
Loading to container
Filling to container
Бокс БТ-15
Equipment with pyrographite
Filters
Other wastes
Disassembling
Disassembling
Preparation
Pyrographite units
cutting
Preparation to burning
Purification of off-gasses
Burning
Crushing, 5-7 mm
Ash
To exhaust system
Бокс БТ-16
Interim storage
Interim storage
Interim storage
To dry storage, bld..177
To RIAR disposal site
Metallic units

Pyrochemical Wastes treatment



Waste	Phosphates	Salt residue
Special features	contain fission products	Alkaline metal chlorides, high activity, significant heat release
Basic elements	11 wt.% Nd 4,4 wt.% Ce	81,96 wt.% CsCl 18,04 wt.% NaCl
Quantity	<0,15 kg/kg of fast reactor SNF	<0,03 kg/kg of fast reactor SNF

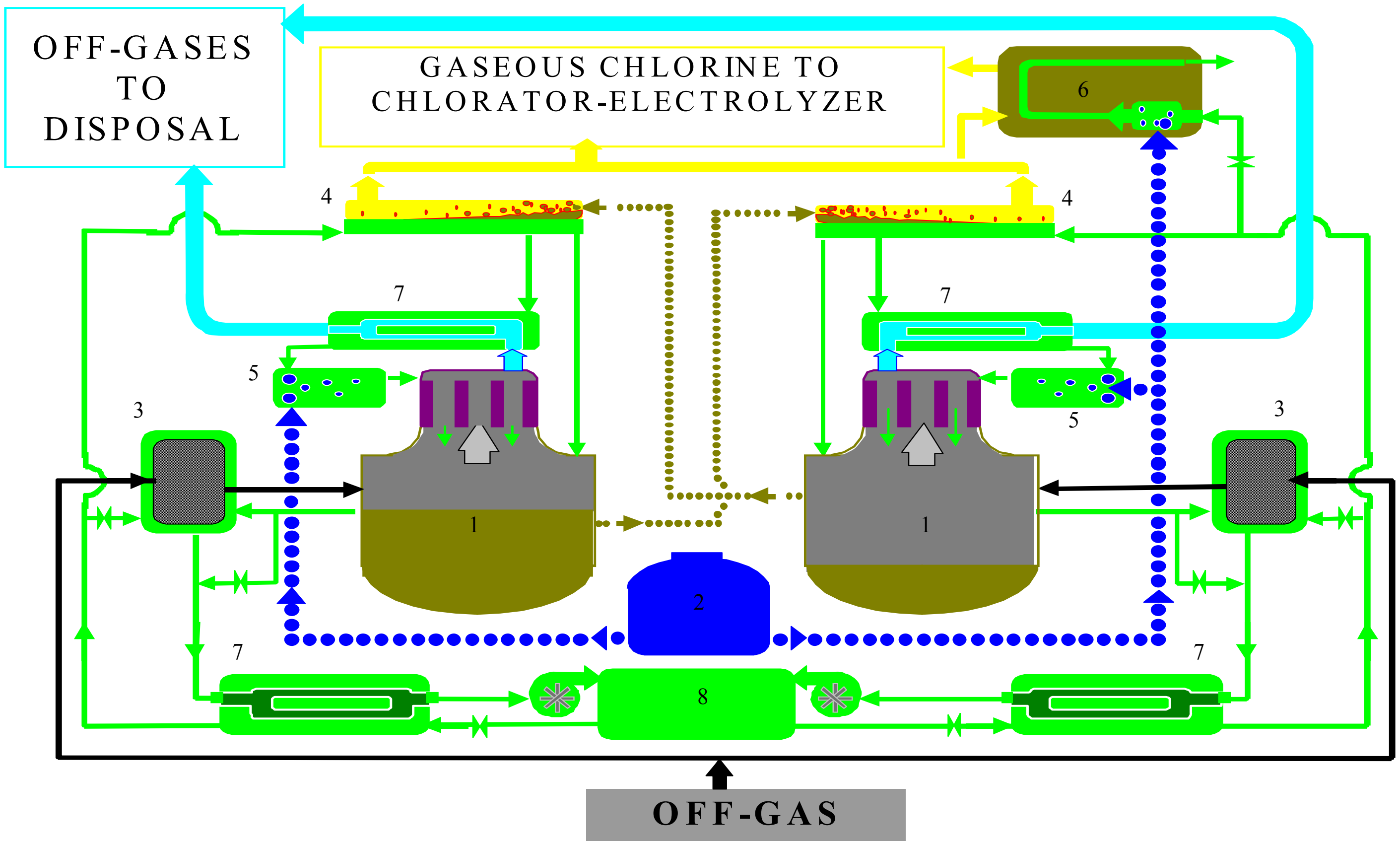
Evaluations by Toshiba

Vitrification of HLW from pyrochemical process

Characteristic	HLW type		
	Phosphate precipitate	Spent salt electrolyte	Phosphate precipitate + spent salt electrolyte
Glass matrix type	$Pb(PO_3)_2$ $NaPO_3$	$NaPO_3$, AlF_3 Al_2O_3	$NaPO_3$, AlF_3 Al_2O_3
Introduction method	vitrification, $T=950^0C$	vitrification without chloride conversion, $T=950^0C$	vitrification without chloride conversion, $T=950^0C$
Introduced waste amount, %	28	20	36
^{137}Cs leaching rate as of the 7^{th} day, g/cm^2 * day	$7*10^{-6}$	$7*10^{-6}$	$4*10^{-6}$
Thermal resistance, ^0C	400	400	400
Radiation resistance	10^7 Gr (for γ and β)		10^{18} α-decay/g

Ceramization of pyroprocess HLW

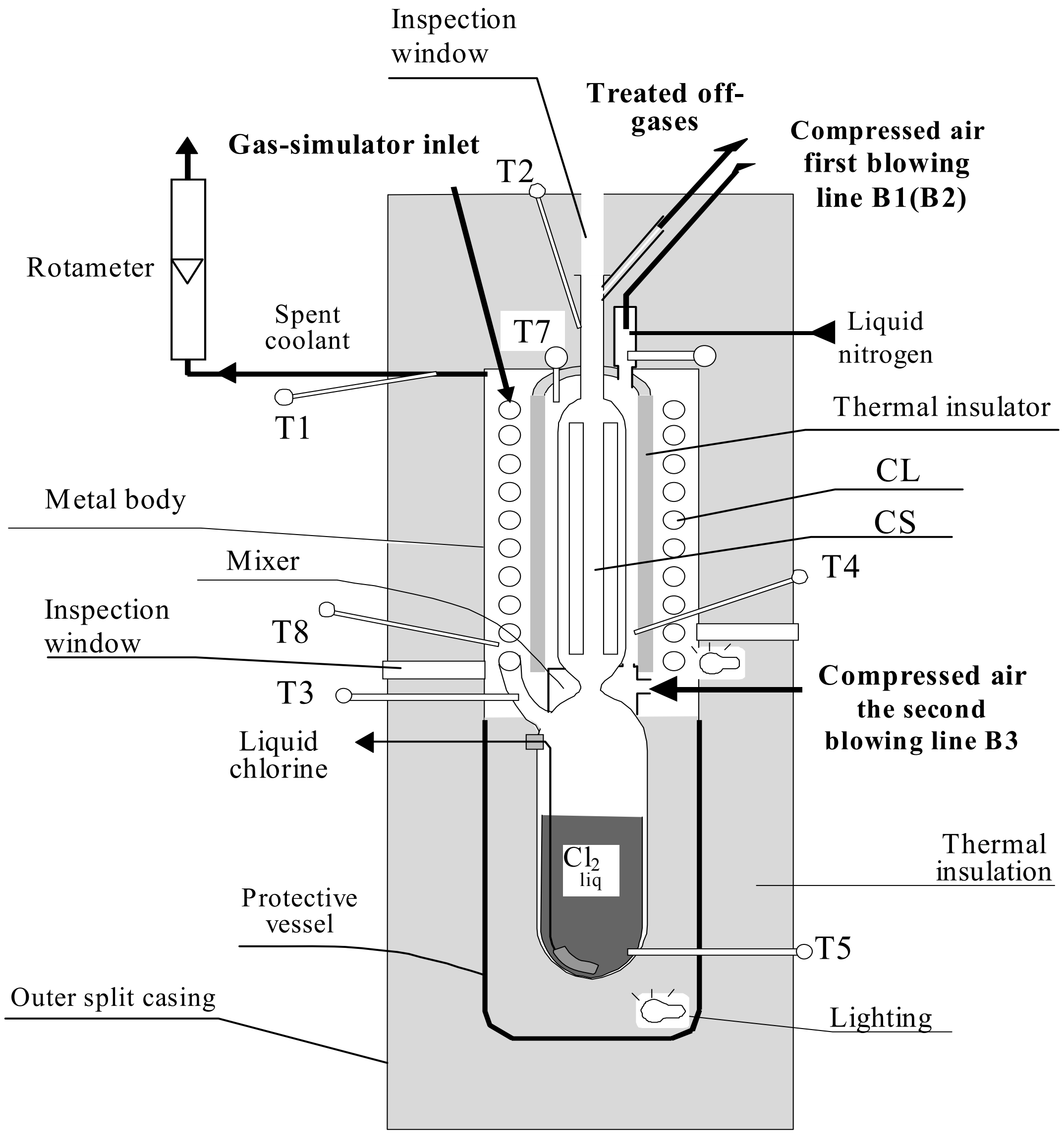
Characteristics	Type of high-level wastes	
	Phosphate concentrate	Spent salt electrolyte
Type of ceramics	monazite	Cosnarite (NZP)
Method of introduction into ceramics	pressing, calcination , $T=850^0C$	Conversion to NZP from the melt or aqueous solution, pressing, calcination , $T=1000^0C$
Quantity of waste introduced into ceramics, %	100	30..40
Leaching rate of ^{137}Cs on 7-th day, g/cm2 * day	$1*10^{-6}$	$3*10^{-6}$
Thermal stability, ^0C	850	1000
Radiation resistance	$5*10^8$ Gy(for γ and β)	10^{19} α- decay/g



off-gas ( ); chlorine: solid ( ),
liquid ( ) and gaseous ( );
nitrogen: liquid ( ) and gaseous ( );
spent coolant ( )

1- combined condensers;
2- liquid nitrogen supply unit;
3- Drier – adsorption zeolite column;
4, 5- liquid nitrogen and chlorine evaporators;
6- Chlorine storage block;
7- Cold exchanger;
8- Gaseous nitrogen recycle.

Flow sheet of low-temperature chlorine recycle facility



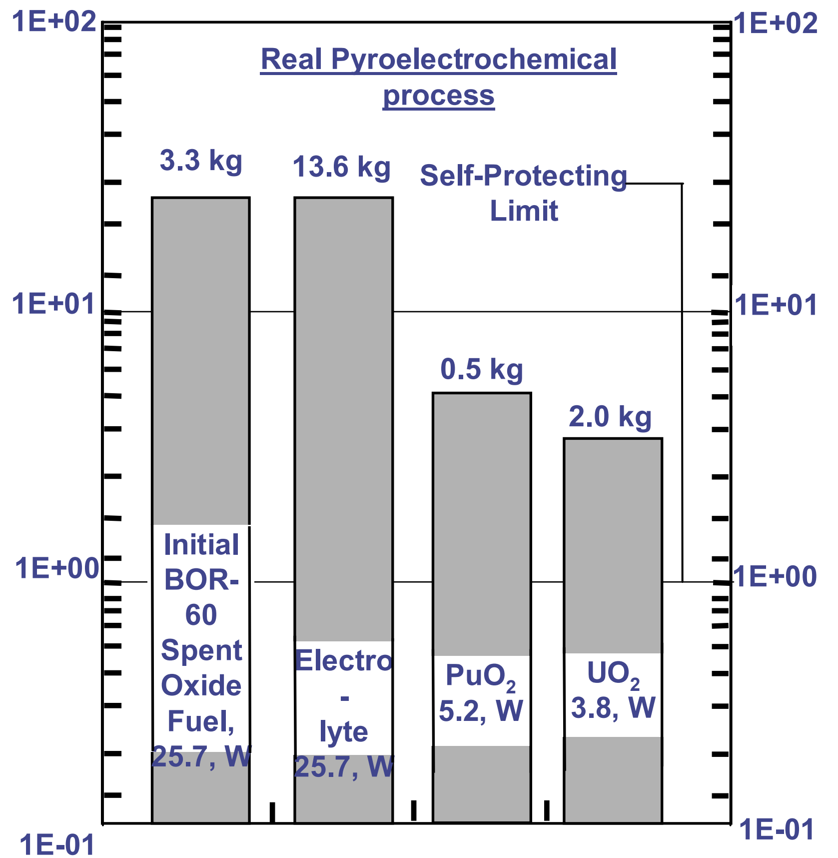
Concept scheme of OCRFM apparatus

(CL – Condenser of liquid-phase deposition; CS – condenser of solid-phase deposition)

Excluding of pure plutonium

For utilization of Pu in Fast reactors:

- High DF no necessary
- Additional treatment in closed cycle of Fast reactor
- Possibility of recycle of other TRU (*Np, Am, Cm*)



Self-Protection of BOR-60 spent Fuel Reprocessing by Gamma Radiation .

What we have now on Dimitrovgrad Dry Process (DDP) development?

- Three processes combined from the same operations (dissolution and recovery)
- Equipment and ways for improvement
- New understanding of MA behavior and methods for their partitioning
- Initial data on wastes (glass form and ceramic as additional option)
- Understanding of decladding procedures (but only old demo-tests)
- Methods for refabrication (some technical arrangements)
- Tested methods and new ideas for analytical control

Vibropacking technique

Fuel rods with granulated fuel are fabricated by vi-pack technique according to the standard procedures (in glove boxes or hot cells) that has been used at RIAR for 30 years.

The main advantages of the vi-pack technique and vibropacked fuel rods are the following:

- Simplicity of the process due to the reduced number of process and control operations, that makes the automation and remote control of the process easier
- Possibility of usage of the granulate in any form; both in the form of a homogeneous composition and mechanical mixture
- Reduced thermo mechanical impact of vi-pack fuel on the cladding (as compared with a pelletized core).
- More flexible requirements for the inner diameter of the fuel rod claddings

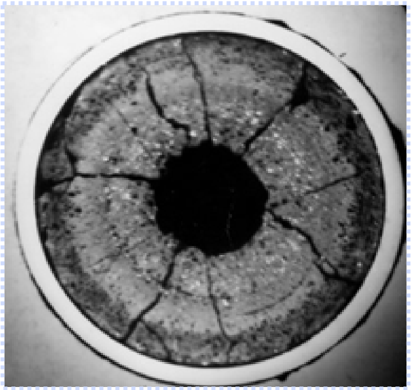
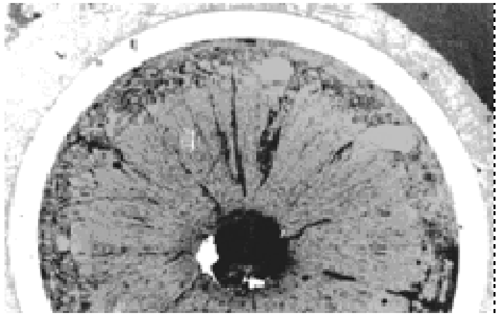
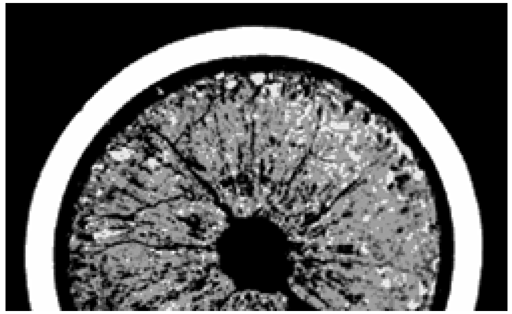
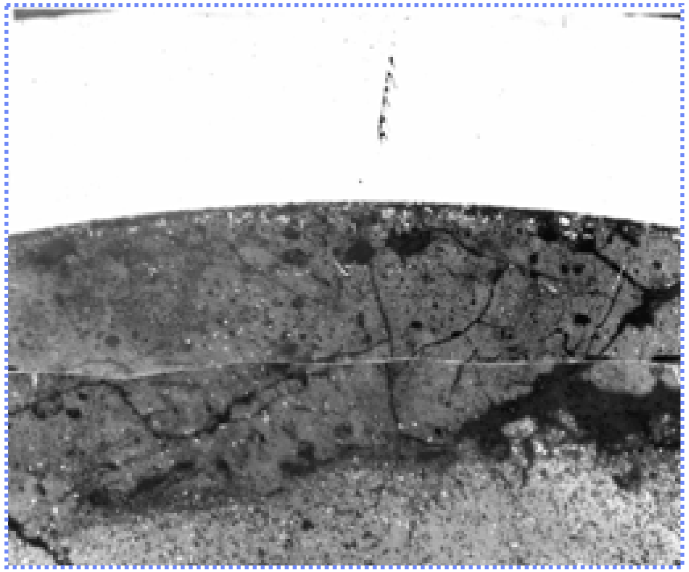
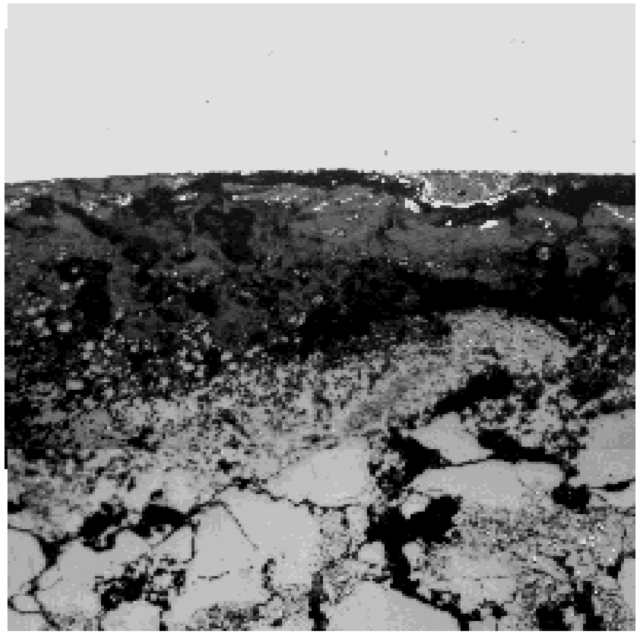
To correct the oxygen potential in the fuel and eliminate the process impurities effect, *getter* based on U metal powder is introduced into the granulated fuel

Production and testing of vibropacked fuel rods on the basis of MOX-fuel

Fuel type		Number of fuel assemblies	Burnur, max.%	Load, kW/m	Temperature, ^0C	Reactor
$(U, Pu)O_2$	Weapon grade, power grade	330	30,3	51,5	720	BOR-60
$UO_2 + PuO_2$	Weapon grade, power grade	132+20	14,8	45	705	BOR-60
$(U, Pu)O_2$	Weapon grade	30	10,5	46	680	BN-600
$(U, Pu)O_2$	power grade	4	development of the production technique			BN-600

Results of the material science studies of vibropacked fuel pins

Micro- and macrostructure of the cross section of the **BOR-60** fuel rod with **$UPuO_2$** fuel (the burnup of 32% h.a.) and **BN-600** fuel rod (the burnup of 10.5 %)

Experience in application of new technologies for the fuel cycle of the BOR-60 and BN-600 reactors

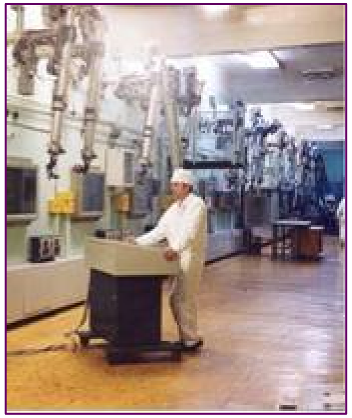
Semi-Industrial realization of remote controlled methods for manufacturing of fuel pins and assemblies of the BOR-60, BN-350 and BN-600 reactors:

- ORYOL facility (1977 - 1986),
- Semi-Industrial Complex (1989-1997)
- pilot facility “Kolibry” (1992-1997).

25 year experience allow to formulate main principles for design and services of fuel and fuel pins production in remote controlled conditions.

The 3rd generation facility is under construction from 2001.

Experience in operation of automatic facility for the BOR-60 fuel rods and FAs fabrication



Fuel type	Mass, kg	Period
UO_2 90% enriched in ^{235}U	98.85	1977…1987
$(U, Pu)O_2$	816.71	

Irretrievable loss of the fuel composition during the whole period of the facility operation is **0.12 kg**, that makes **0.013 per cent** of the total amount of the fuel reprocessed at this facility.

Oxide fuel

Granulated fuel production
Recovery ~99,5 %

FAs production
$K_1 = 0{,}98$ $K_2 = 0{,}97$

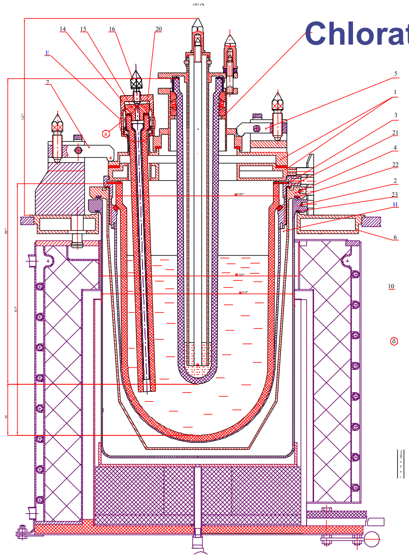
Control of fuel rods with vi-pack fuel
$K_1 = 0{,}85$ $K_2 = 0{,}95$

Fabrication of fuel rodsi with vi-pack fuel
$K_1 = 0{,}93$ $K_2 = 0{,}95$

K_1 – **reliability factor** *(ORYEL 1)*

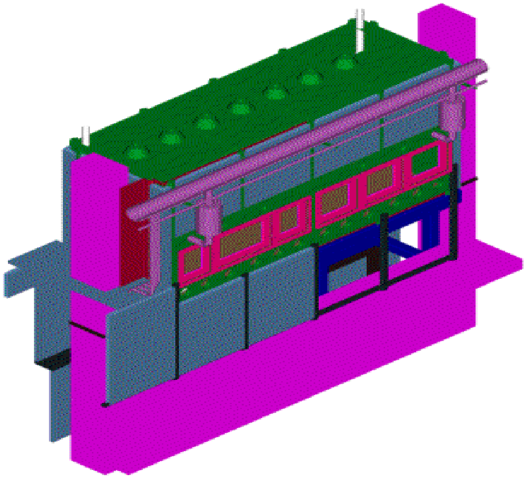
K_2 – **reliability factor** *(ORYEL 2)*

Equipment for the pyrochemical process and vibropacking

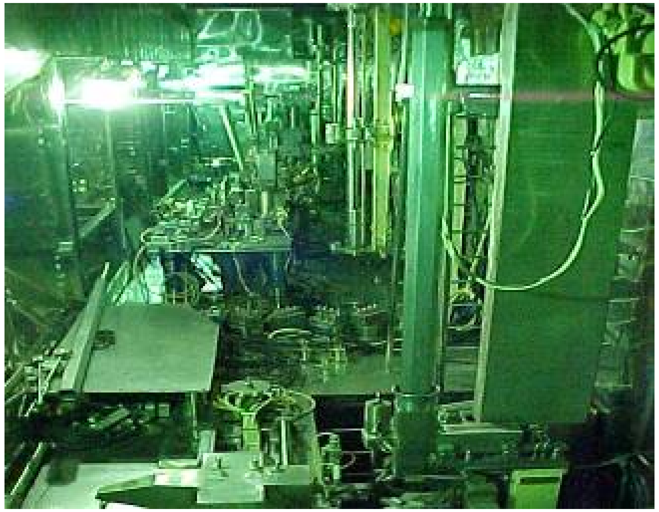


Chlorator-electrolyzer

Automatic fuel pins line



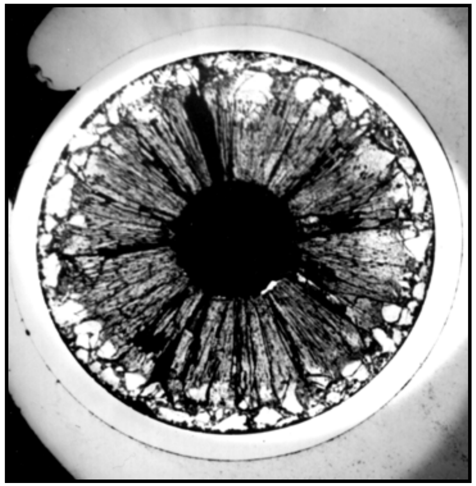
Hot shielded box

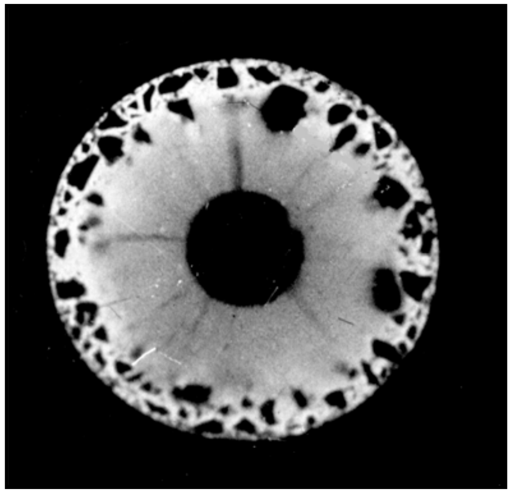


Assembling line

Recycle of reprocessed fuel in the BOR-60 reactor in vibrocompacted mode

- Fuel UO_2+PuO_2 (mechanical mixture) has burn-up about 17%,
  - Some fuel pins were under PIE (b.u.4,8 - 9,8 %)
- MOX reprocessed fuel used for new fuel pins production in 2002 and under irradiation in the BOR-60 from 2004 (burnup 15%)





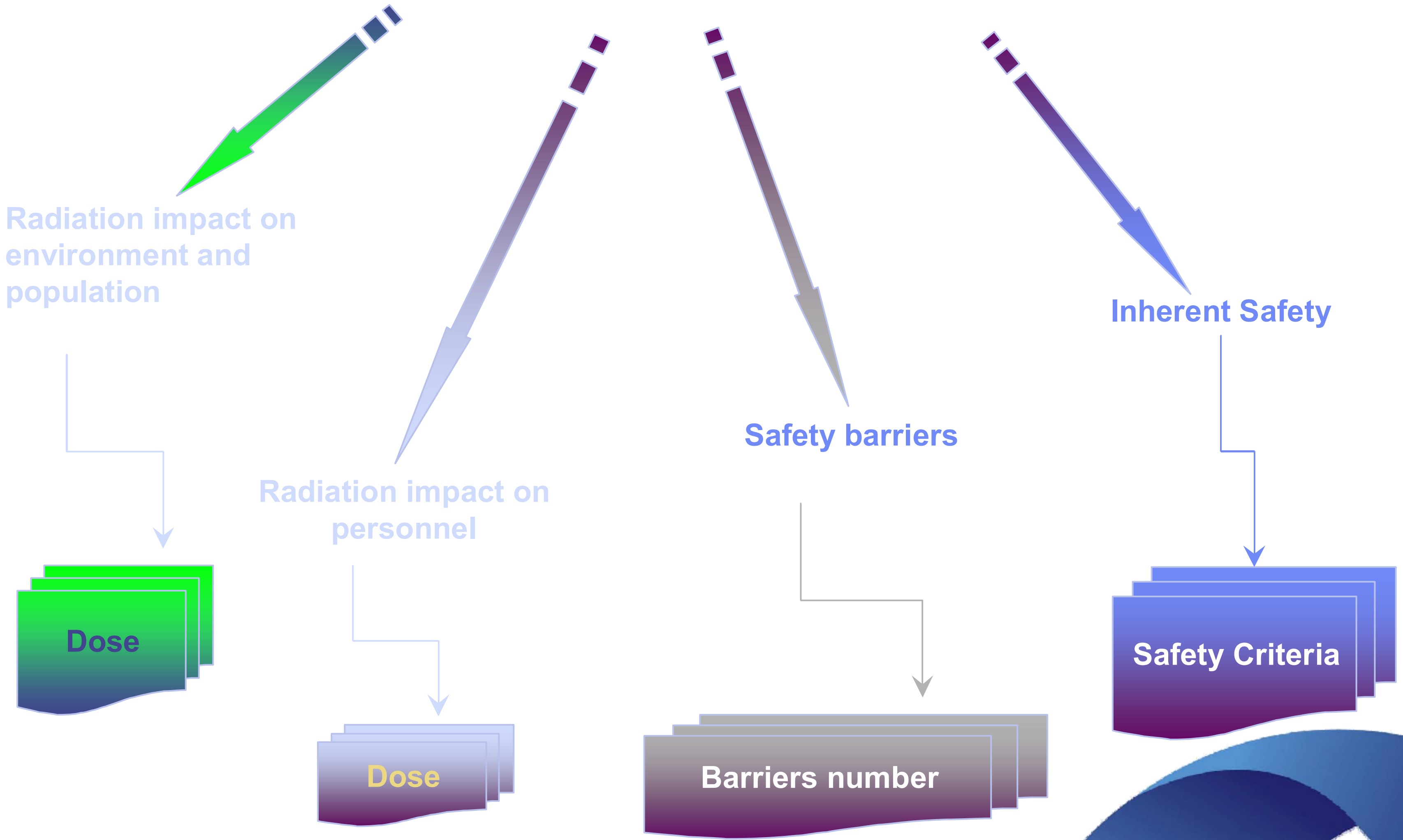
Other processes and fuels which are under R&D in RIAR

- Nitride fuel – recycling by pyro-process and simplified pelletizing
- Metallic fuel (U-Pu-Zr, U-Al, U-Be) reprocessing
- RBMK Spent Fuel conditioning (metallization by Li/or electrochemical)

- Different fuels/targets with Np, Am, Cm
- Treatment of non-traditional fuel (coated particles (UN covered by W, U-Mo alloy, UC, Pu alloy, PuO_2 etc.)
- Molten salt fuel - (study of reprocessing and MA behavior)

“Investigation and evaluation of radiation and environmental safety of engineering processes of the nuclear fuel cycle at SSC RF RIAR ”

integrated task-oriented Program has been pursued since the 90-s



Estimation of radiation safety of fuel cycle technological processes (RIAR)

✓ Direct recovery rate of fuel	99,3...99,7%
✓ Losses of fuel	0,1..0,2%
✓ Radiowastes volume	0,2 kg/kg
✓ Safety (explosion, fire)	high
✓ Possibility of accidence per year	< 0,01 в год

Radiation doses

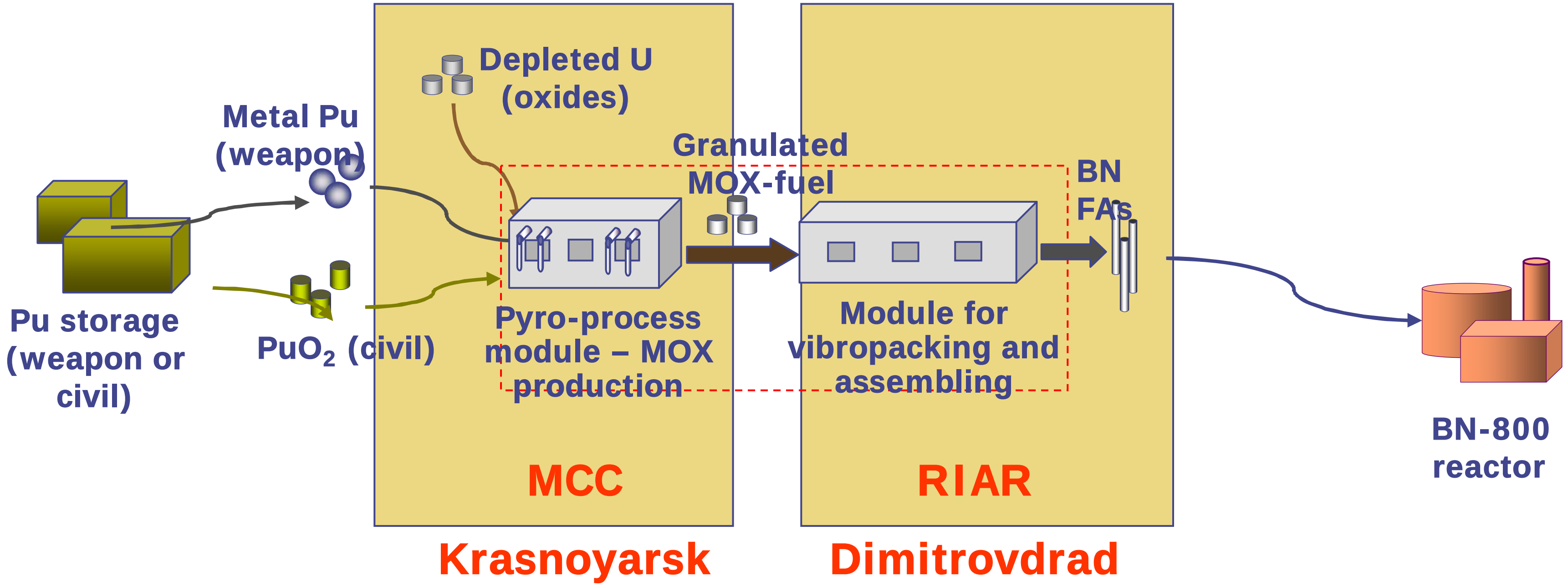
- ✓ Effective annual dose for Pu operation personnel 0,60 mSv
- ✓ Effective collective dose 0,06 man*Sv/year

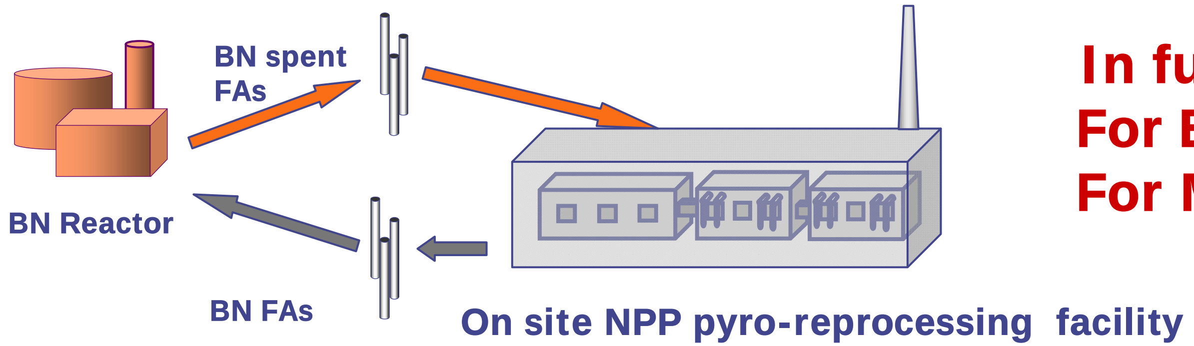
Radiation effect on environment and population

- ✓ Effective total dose for population from realizes of radionuclides through exhaust system - 2,5 mkSv/year (2,5% of permitted level)
- ✓ Pu content in air, soil, river bottom precipitates, plants in 10..1000 times less of permitted level

Implementation Pyroprocess for BN-800 Fuel Cycle

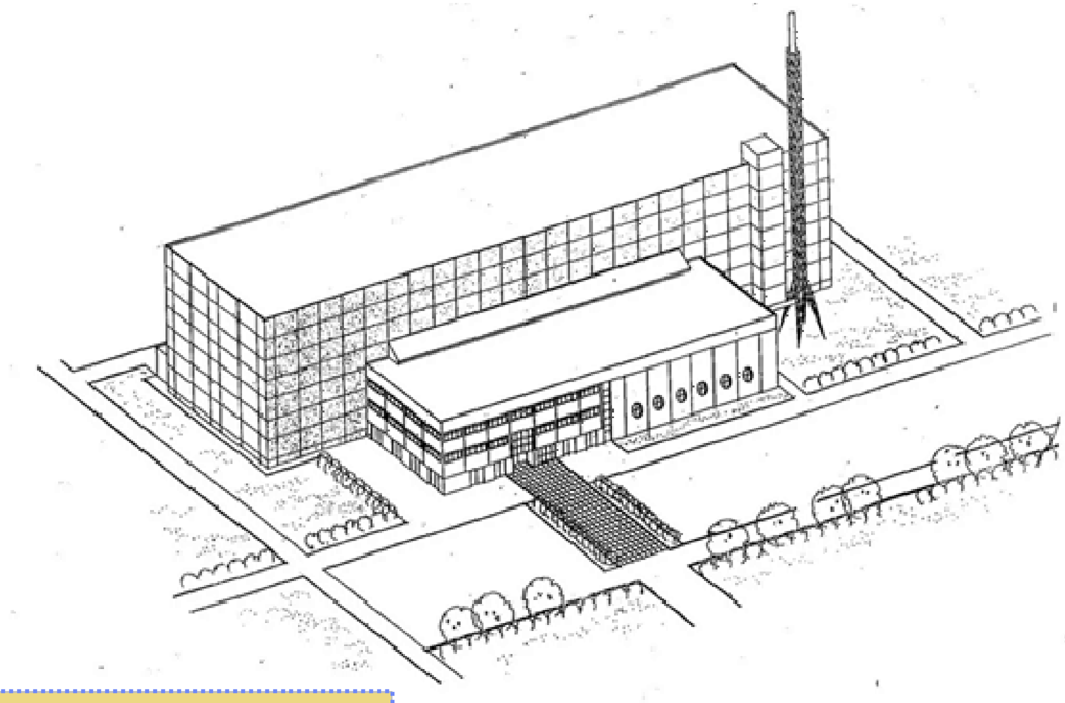
Combination of pyroprocess and vibropacking technology is the basis for BN-type MOX fuel production and recycling in different scenarios.

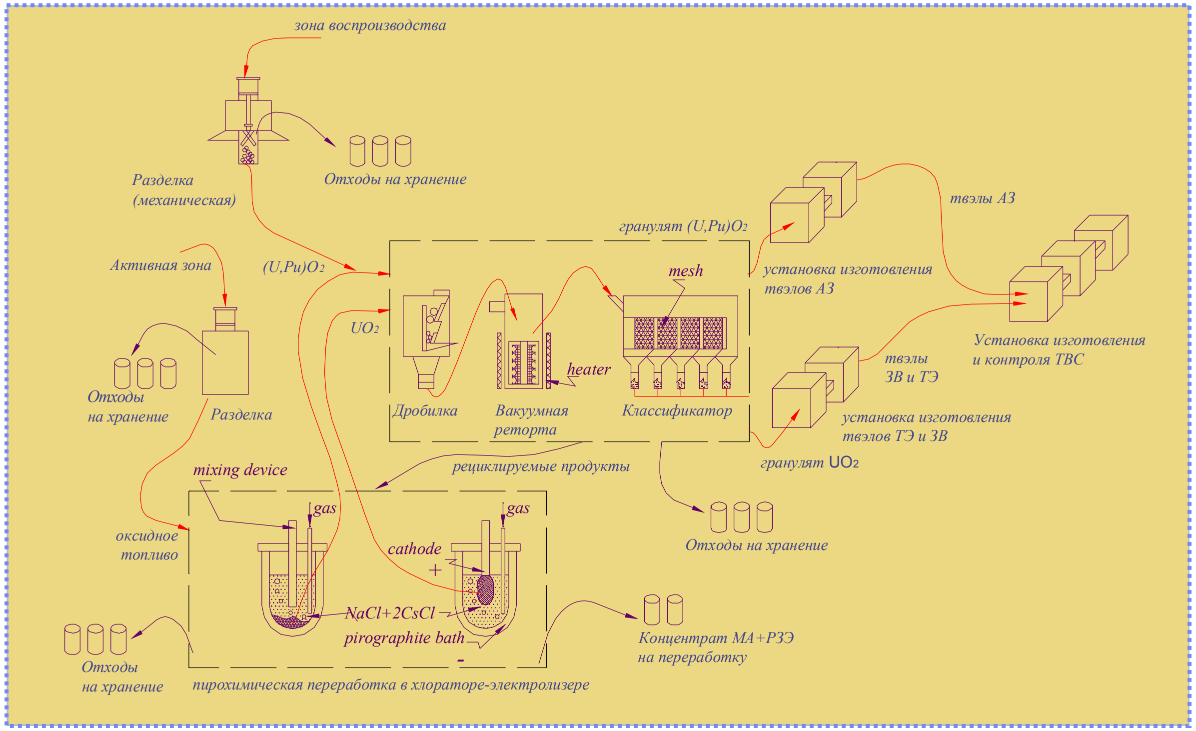




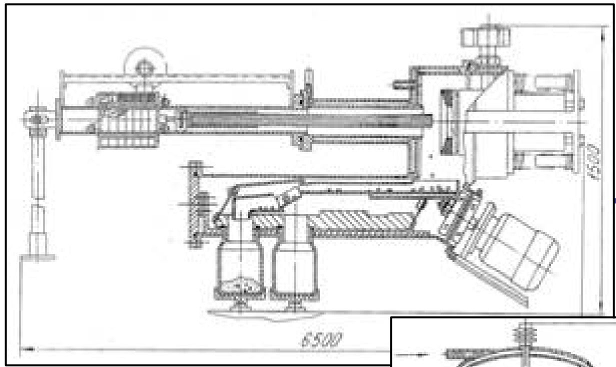
In future:
For BN and BREST
For MOX and (U,Pu)N

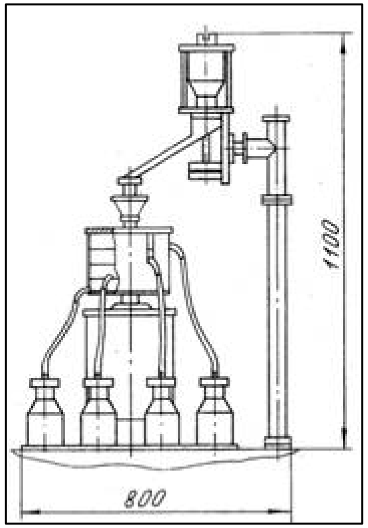
Reprocessing Plant for Two BN-800

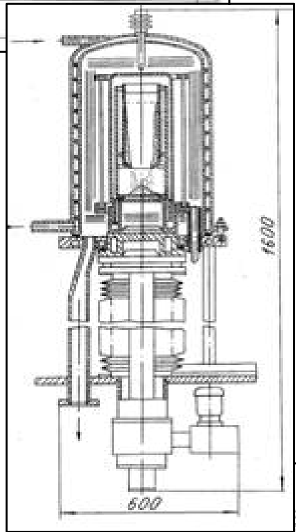


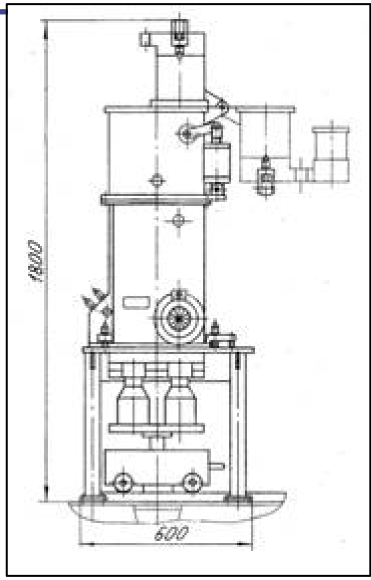


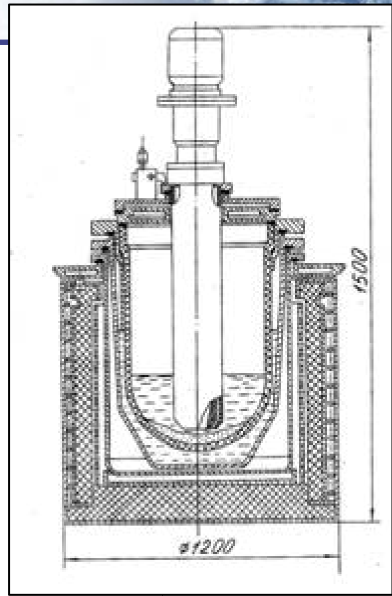
Reprocessing Plant for Two BN-800

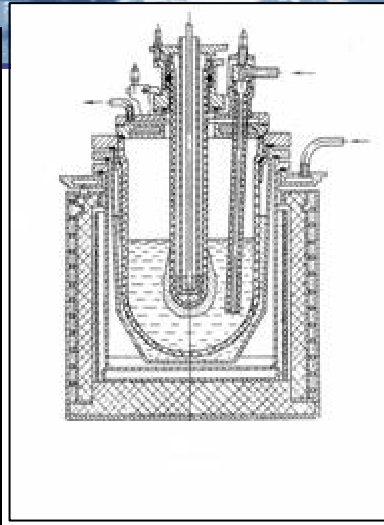


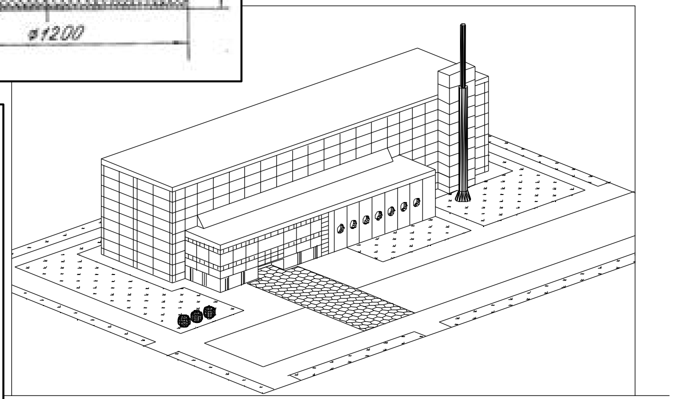


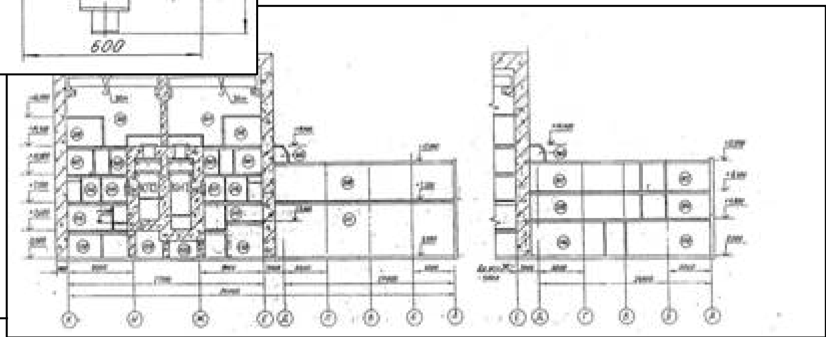


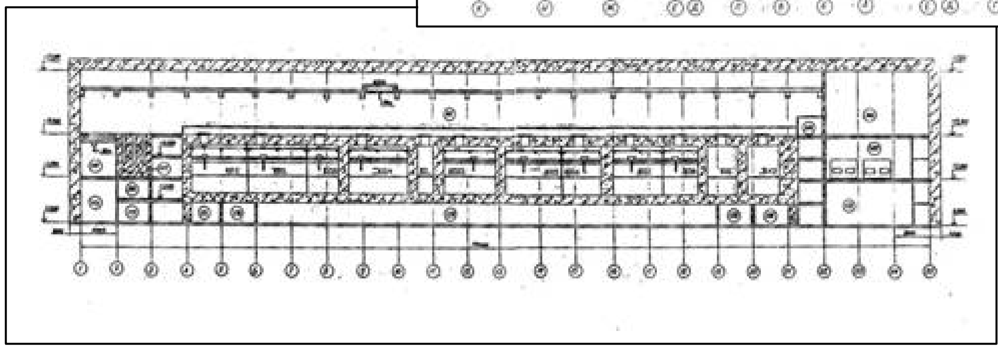


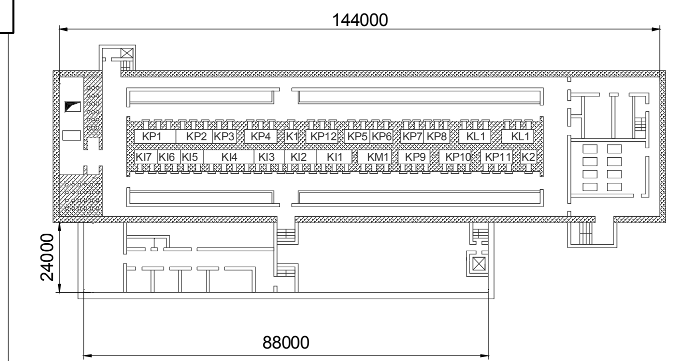




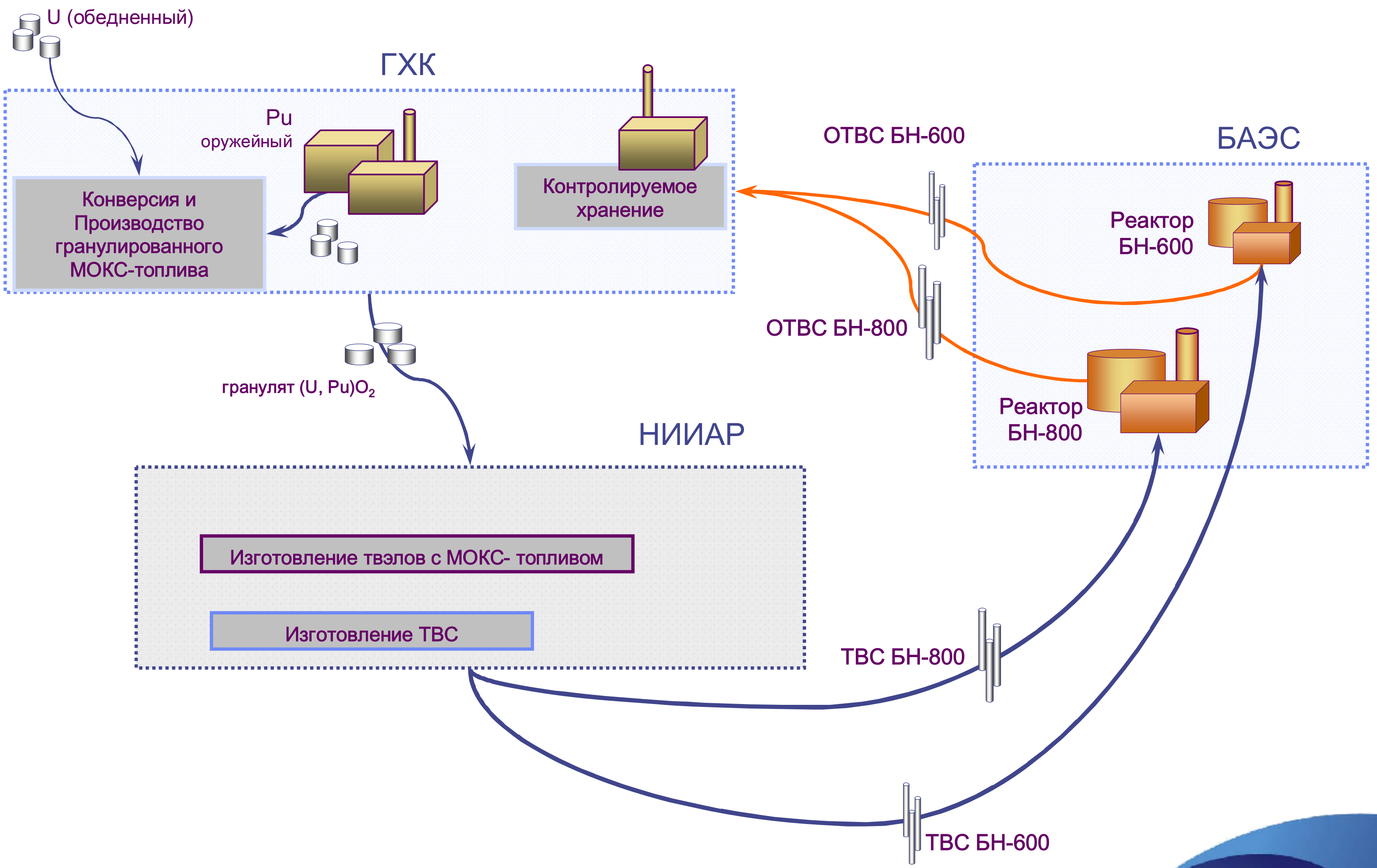




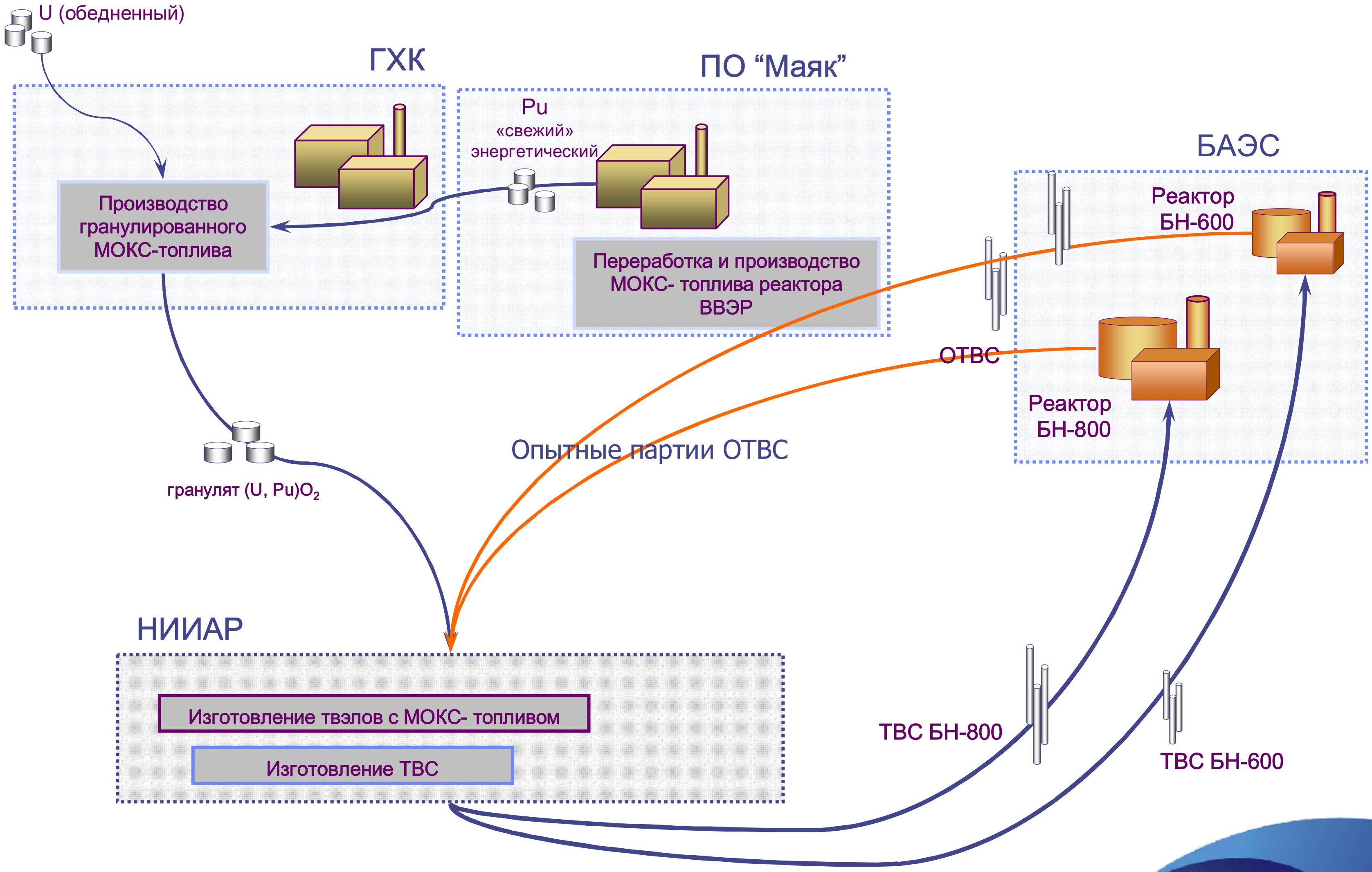




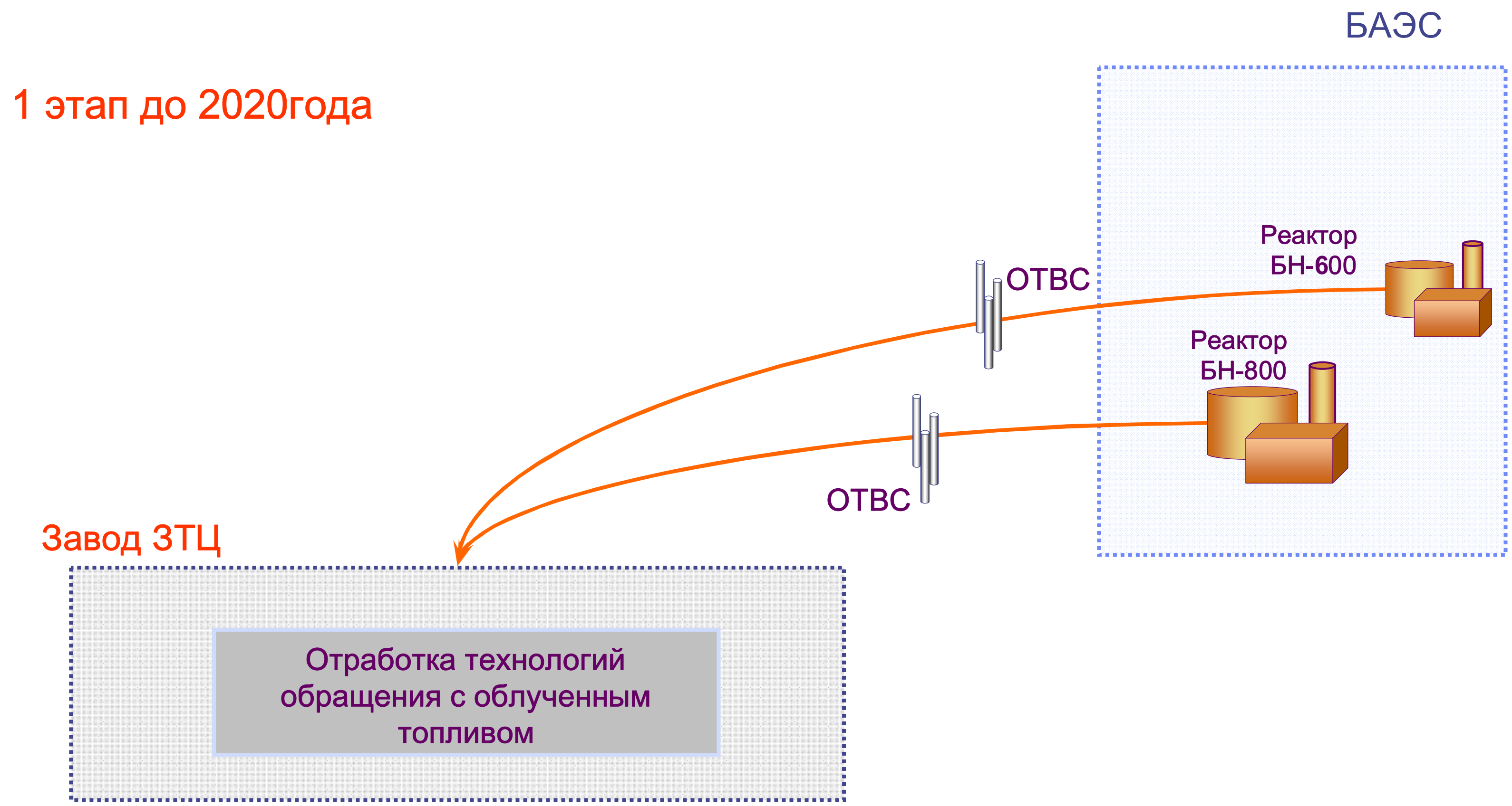
Introduction into plutonium power energy and CFC.
1st Step – Weapon Pu disposition



Introduction into plutonium power energy and CFC.
2nd step – semi-industrial testing of CFC elements with power grade Pu

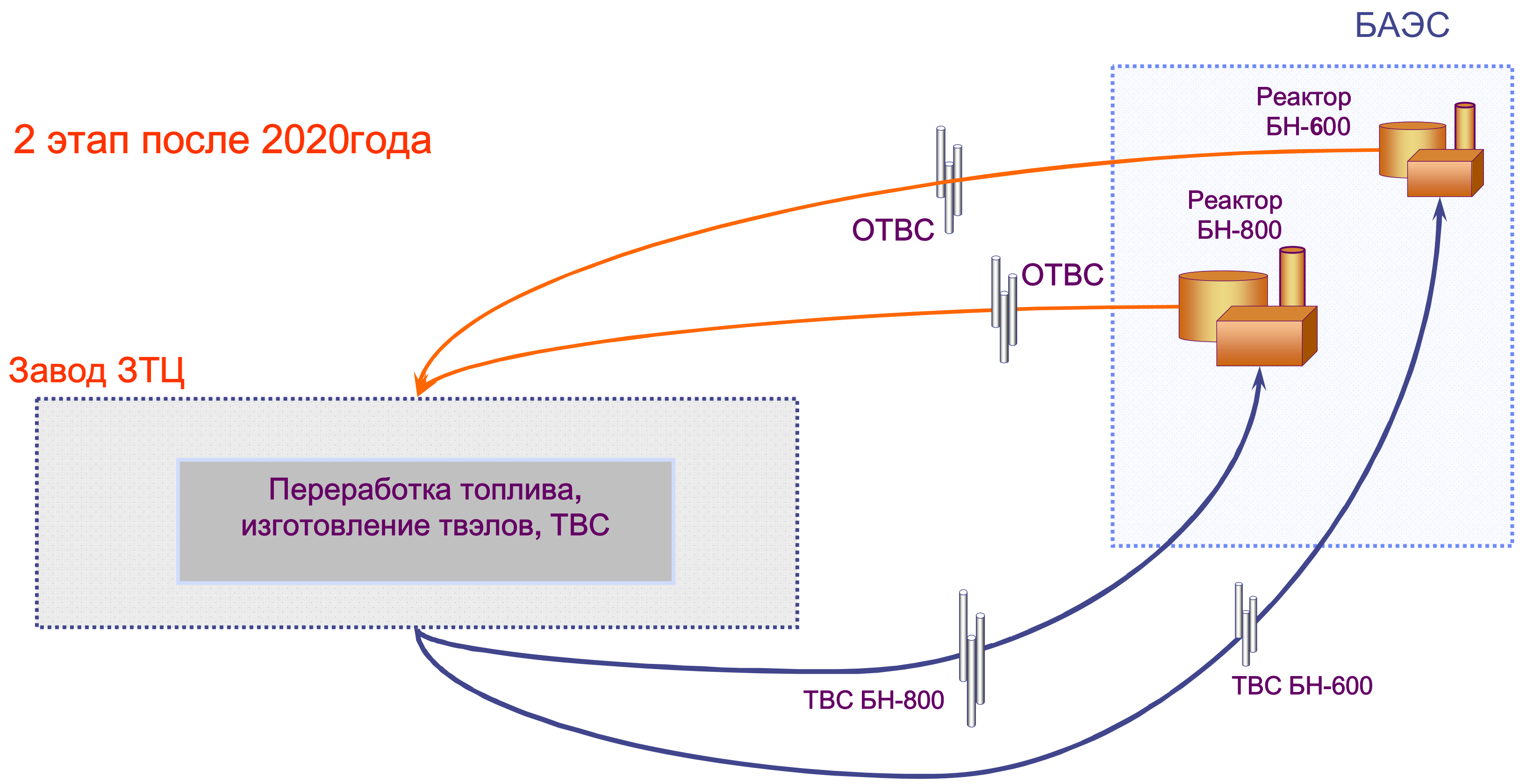


Introduction into plutonium power energy and CFC.
3rd Step – Closed fuel cycle plant for recycling of BN-800 fuel with remote technologies



In parallel: Krasnoyarsk EDRC is under operation:
-Testing of VVER and RBMK SNF reprocessing
- Utilization of new Pu (U-Pu-Np) in BN fuel

Introduction into plutonium power energy and CFC.
4th Step – Closing of BN-800 fuel cycle



Decision on construction of VVER and RBMK SNF reprocessing plant

Concept of the closed fuel cycle Plant for reprocessing and production of (U,Pu)N fuel (for the BREST reactor)

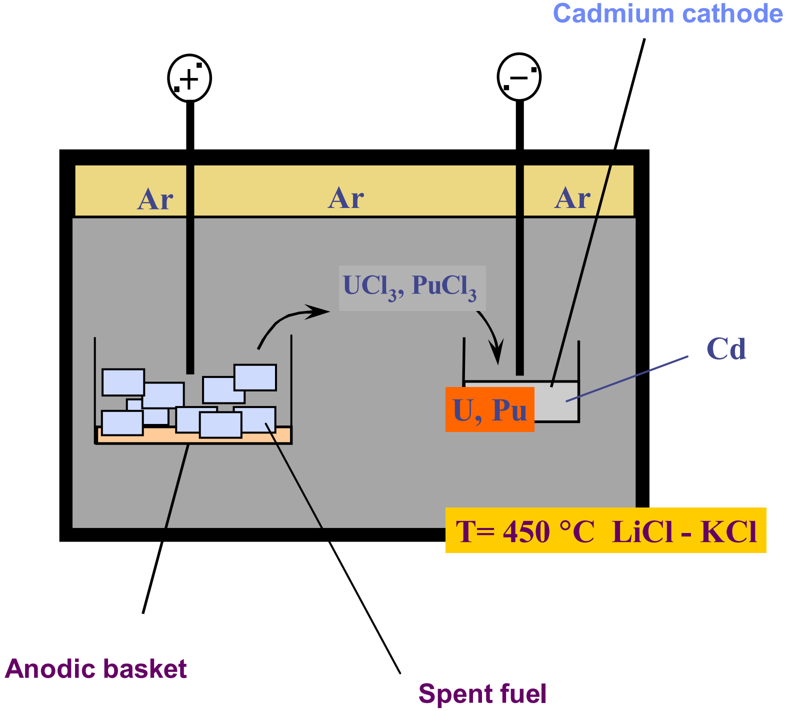
Production of mononitride fuel from the BREST spent fuel at the stage of pyrochemical reprocessing

Production of mononitride fuel pellets

Fabrication of fuel rods with sublayer on the basis of pelletized fuel

Manufacturing of the BREST fuel assemblies

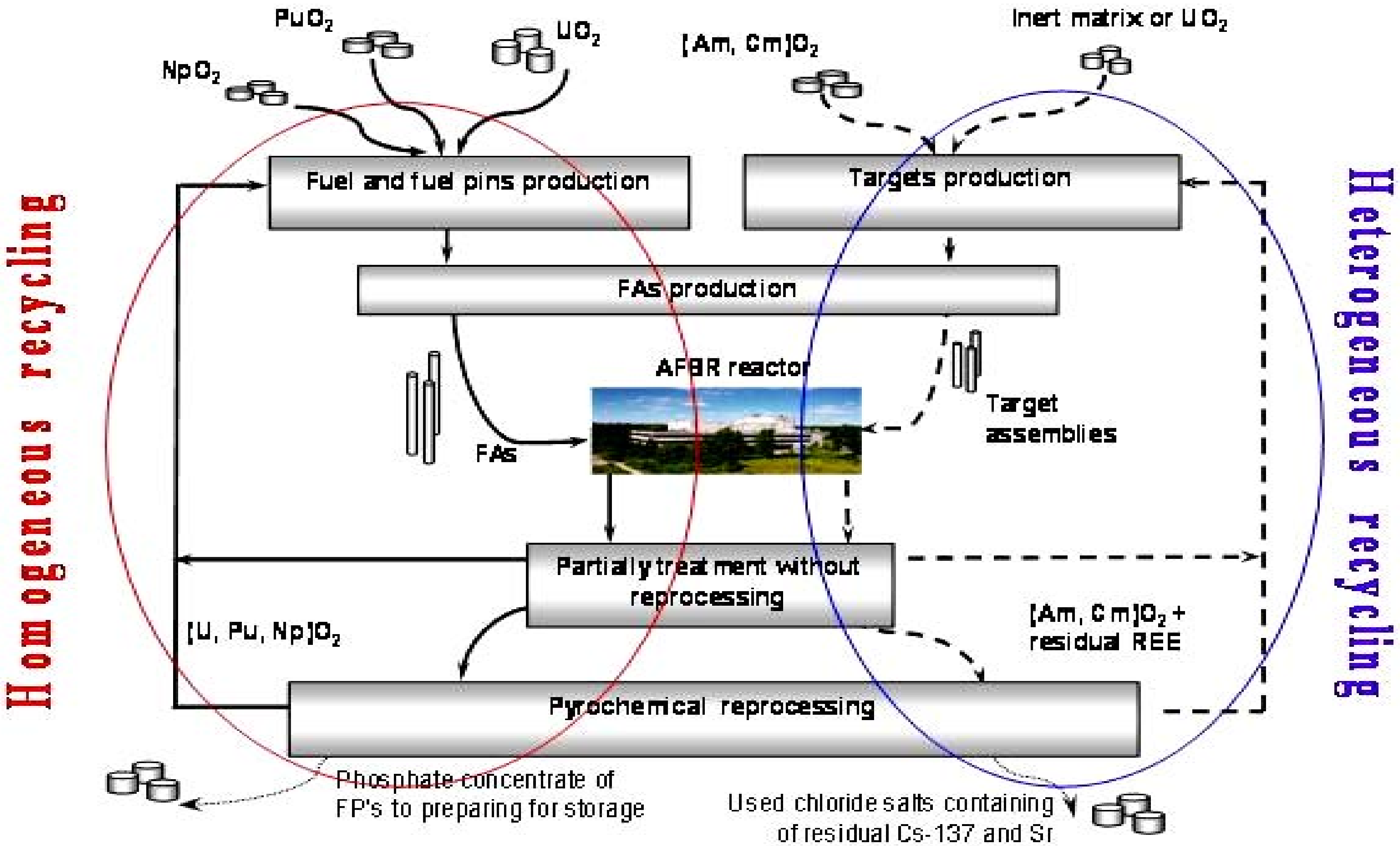
Hot cell design and infrastructure are similar as MOX recycling Plant



Since 1992 RIAR has been performing own R&D DOVITA Program

- Dry technologies for MA fuel reprocessing and preparation
- Oxide fuel application as the most widely studied one
- Vibropacking automated technology of the fuel pin production
- Integrated disposition of fuel reprocessing and fuel element refabrication facilities on the same site with the reactor
- TA The whole complex of approaches will permit a creation of the compact plant for Transmutation of Actinides

DOVITA fuel cycle



Recent RIAR activities in frame of DOVITA-2 Program

- R&D for production of vi-pack oxide Fuel with MA
  - Under continuation
- R&D for production of vi-pack nitride Fuel with MA
  - Under development
- R&D for production oxide pellet fuel with MA
  - Under development
- R&D for production metallic fuel with MA
  - Feasibility Stage
- Molten Salt chemistry of Am and Cm for fluorides
  - Under preparation
- Partitioning of MA/REE in molten chlorides/fluorides
  - liquid cathodes
  - reductive extraction
  - Oxide precipitation

Conclusions

- Basic studies on pyrochemical processes in molten chlorides are mainly completed
- Different technological methods developed and tested for oxide and nitride fuel reprocessing and refabrication
- Pyroelectrochemical technology for production of MOX vibropacked fuel for the BN-800 fast reactor is under implementation in Russia. Both type of plutonium – military and power grade civil - will be used for MOX fuel production.
- Dry technologies were choose as basic advanced processes for the closed fuel cycle with the fast reactors
- New facilities are under design and construction for investigation and demonstration of industrial closed fuel cycle with the fast reactors in Russia

Thank you for your attention!

Alexander Bychkov
State Scientific Centre Research Institute of Atomic Reactors