Государственный научный центр
Научно-исследовательский институт атомных реакторов

НИИАР

STATUS AND BASIC LINES OF DEVELOPMENT OF EXPERIMENTAL AND MATERIAL SCIENCE BASE FOR FAST REACTOR TECHNOLOGIES

"Fast Reactors and Related Fuel Cycles-Challenges and Opportunities"

December, 2009

Alexander Bychkov

SSC RIAR, Dimitrovgrad-10, E-mail: niiar@niiar.ru, Web site: http//www.niiar.ru

40th Anniversary of The BOR-60 Test Reactor

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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

Base for new construction

Place of "fast reactor" in energy production/FC

Complementary to VVER

Light-metal (Na)

Selection of coolant

Heavy-metal (Pb)

Integral economics and ecology of electric energy production and FC

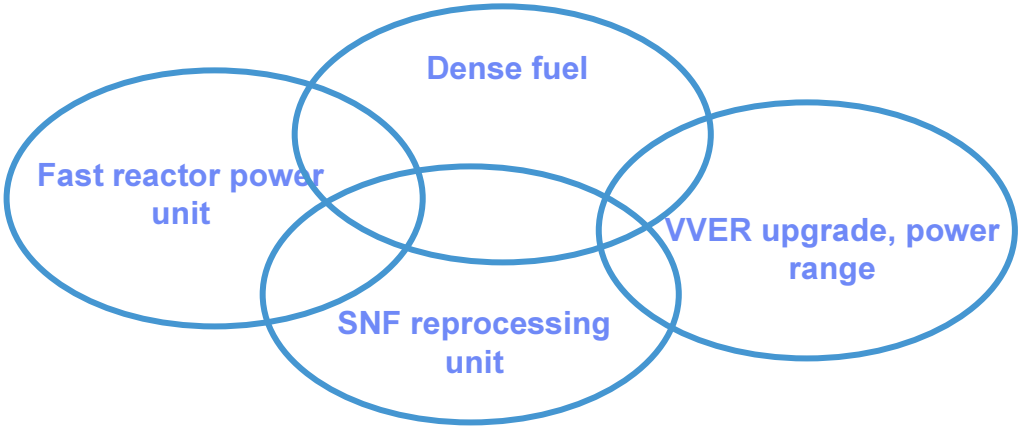
"Aqueous"

Selection of reprocessing technology

"Dry

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

Russian Experimental Facilities for Fast reactors and Closed Fuel Cycle Development

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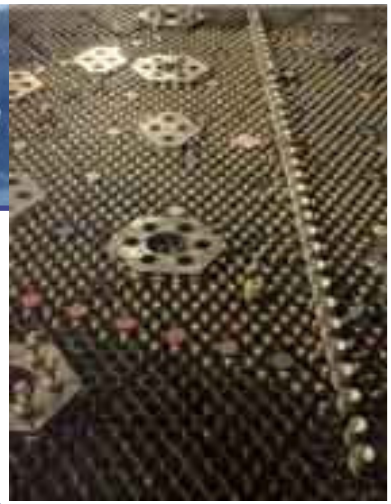
- Test Reactor with Fast Spectrum – the BOR-60 – RIAR (Dimitrovgrad)
- Critical Assemblies (Facility) – BFS – IPPE (Obninsk)
- Material Science laboratories – RIAR, IRM (Zarechny), IPPE
- Radiochemical facilities and labs – RIAR, Radium Inst. (StPetresburg), VNIINM (Moskow), Mayak Plant (Ural), MCC (Krasnoyarsk)
- Fuel development and test facilities – RIAR, VNIINM, Mayak
- “Cold” Stands for reactor systems – IPPE, OKBM (Nyzhny Novgorod)

IPPE – Fast Reactor Scientific Leader



- **BFS-2** – Biggest Critical Assembly (Diameter 5 m, Height of vessel 3 m) for full-scale modeling of fast reactor cores up to 3000 MWt (e) capacity.
- All necessary equipment for automatic maintenance, reloading fuel, relocation of detectors etc.
- Possibility to modeling uranium, U-Pu, Pu cores with heterogeneous and homogeneous composition
- More than 40-years operation. Studies of the models of the IBR-2, BOR-60, BN-350, BN-600 reactors and advanced new BN-800 and BN-1600 reactors core.

IPPE

- testing of core materials and structural elements, as well as of HLMC (heavy liquid metal coolant) technologies for facilities with Pb and Pb-Bi coolants
- in-sodium testing of core materials and structural elements, coolant technologies for promising BN
- development, fabrication and testing of impurities control devices in liquid metal coolants

Complex of Liquid Metal Stands

IPPE

Fuel & Fuel Pins Complex

- Development and investigation in the field of promising fuel compositions and core element structures for promising BN
- Manufacturing of experimental fuel assemblies and their testing at the RIAR reactor base
- Development and investigation in the field of promising materials and designs of fuel pins, absorbing elements and start-up neutron sources for promising cores with HLMC

IPPE

Hot Lab

- Development of Pu-containing compositions, fabrication of prototypes, examinations and testing at RIAR
- Study on the behavior of promising types of irradiated fuel under design-basis and beyond-the-design-basis accident conditions
- Fundamental investigations related to SNF reprocessing

RIAR – Main experimental site

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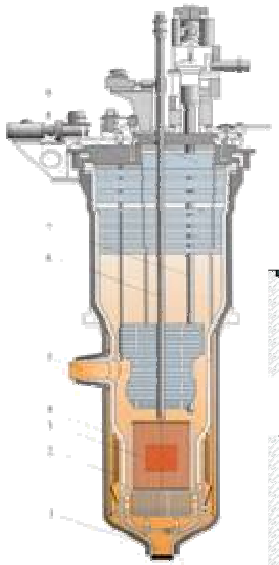
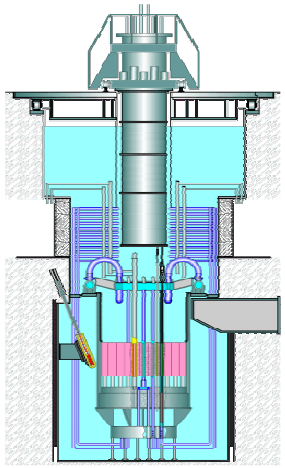
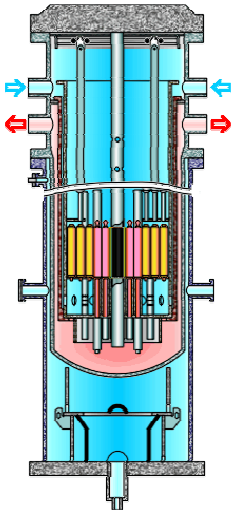
Reactor complex



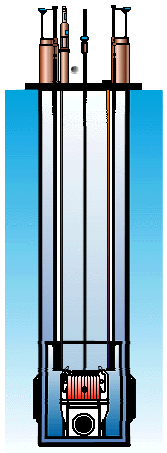
Experimental Fast Reactor BOR-60



Multi-loop Research Reactor MIR



High-Flux Reactor SM



Complex of Pool-type Reactors RBT

Material Science Complex

Chemical Technological Complex

VK-50 Reactor

Research Institute of Atomic Reactors (RIAR)

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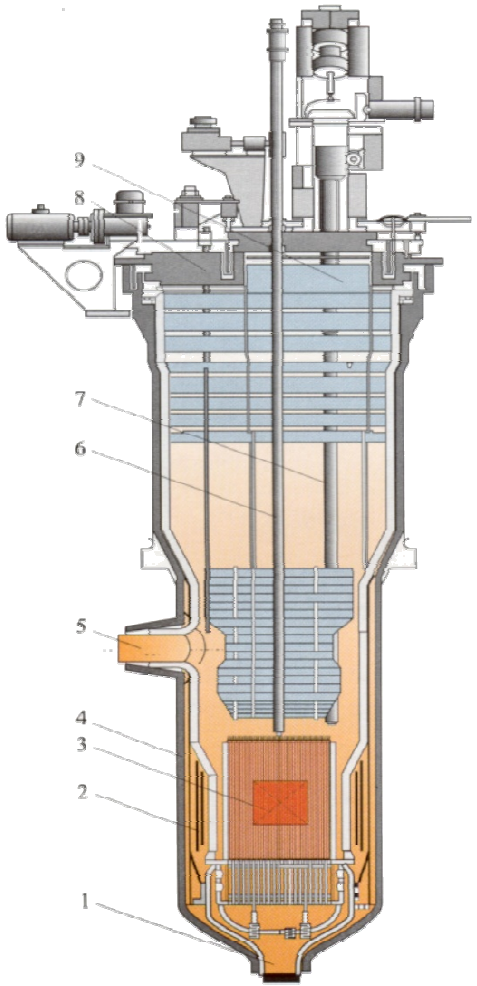
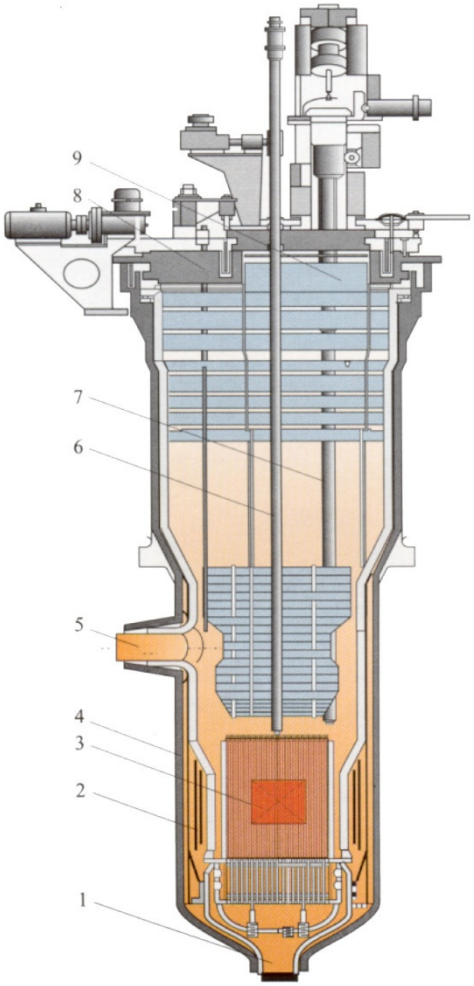
- 6 operated test reactors, included
  - ✓ Sodium cooling fast reactor BOR-60
  - ✓ High flux reactor SM-3
  - ✓ BWR industrial test reactor VK-50
  - ✓ Loop type material science reactor MIR
  - ✓ Pool type reactors RBT-6, RBT-10/2
  - ✓ (two reactors are under decommissioning)
- The biggest in Europe Material Science Complex for full cycle of PIE for all type of Russian industrial NPP's FAs
- Radiochemical Complex for production of different type of isotopes including market scale batch of Am, Cm, Cf
- Radiochemical Complex for advanced fuel cycle development based of pyrochemical technology of fuel production and reprocessing and vibro-pack technology of fuel pins production
- Technology Complex of Radioactive Wastes Treatment included the unique underground polygon of wastes dipper storage (Deep Weel Injection Technology)

The experimental fast sodium liquid-metal-cooled reactor BOR-60



Research fast reactor BOR-60 is intended for testing of a variety of fuel, absorbing and structural materials that are offered for creation of advanced fast, pressurized water, gas-cooled and fusion reactors and serving for substantiation of the VVER and BN-type reactor service life extension

The experimental fast sodium liquid-metal-cooled reactor BOR-60



Reactor heat power	60 MW
Maximum neutron flux density	$3{,}7\ 10^{15}$ $sm^{-2}s^{-1}$
Maximum specific power	1100 kW/l
Average core neutron energy	0,45 MeV
Fuel	UO_2, UO_2-PuO_2
^{235}U enrichment	45÷90 %
Fuel burn up rate	up to 6% per year
Neutron fluence per year	$5 \cdot 10^{22}$ sm^{-2}
Damage dose rate	up to 25 dpa /year
Inlet temperature of coolant	310÷330°C
Outlet temperature of coolant	up to 530 °C
Microcompaign duration	up to 120 days
Reactor generates energy	~265 days per year
Cells quantity - for S/A - for absorbing rods - instrumented cells	265 156 7 3

Main investigation at the BOR-60 reactor

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- Large number fuel element and fuel assembly test in steady, transient and emergency conditions.
- Testing of different neutron absorbing materials.
- Radiation testing of structural reactor materials.
- Testing of electro insulation, magnetic and hard melting materials for fusion reactors.
- Investigations on radiation material science
- Investigation on radiation material science at temperature from 330 to 1000^{o}C and damage dose up to 200 dpa.
- Investigation on fast reactor safety.
- Investigation and testing of liquid metal technology: impurities and radionuclides trapping for coolant cleaning and personal dose rate decreasing, impurities control.
- Testing of experimental reactor equipment and diagnostic and safety systems
- Investigation on transmutation and incineration of long-lived radionuclides from different reactor spent fuel.
- Radiation alloying of silicon for radio-electronics.
- Generating of high active isotopes for different purposes.

Na Test Loop

Lead test loop

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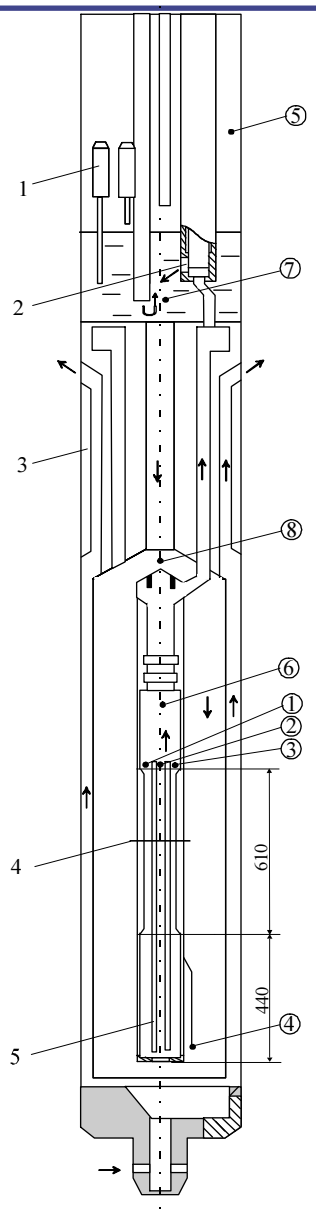
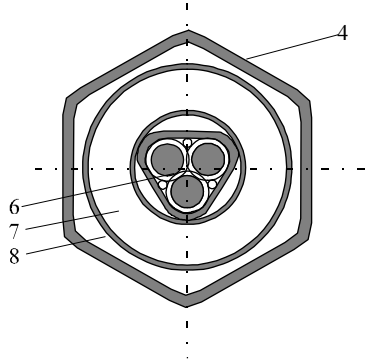
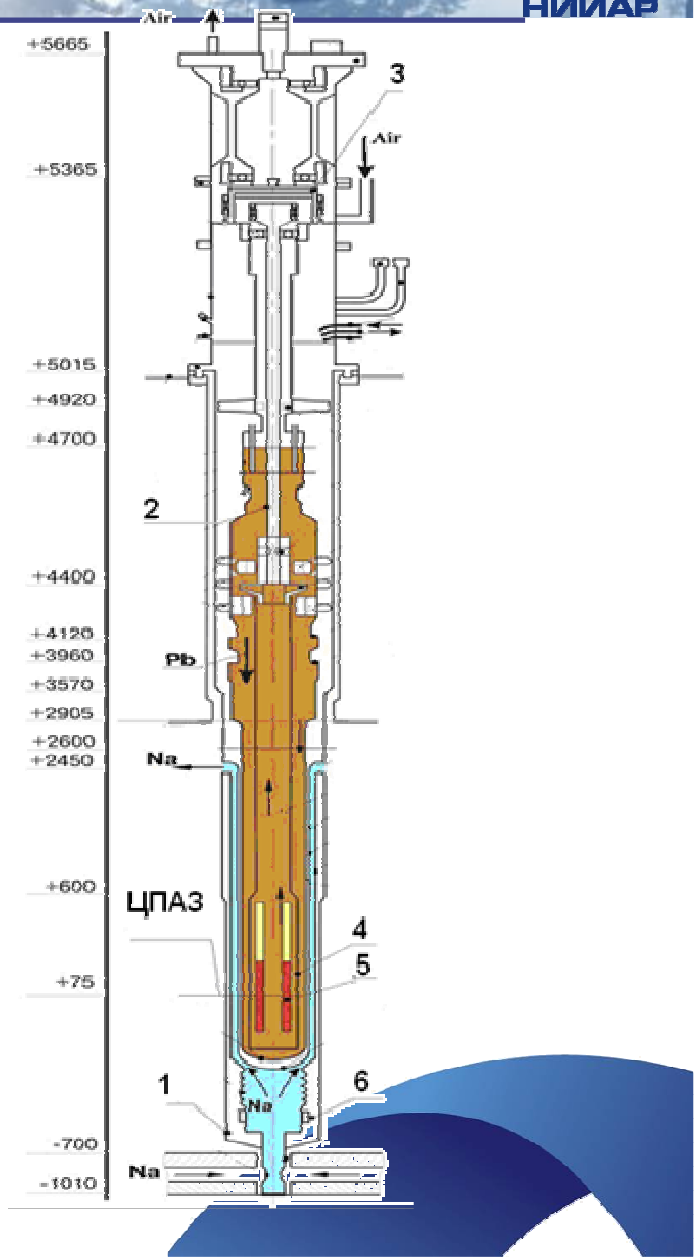
Examples



1 - уровнемеры внутри канала;
2 - регулятор расхода натрия;
3 - МГД насос;
4 - центр активной зоны;
5 - тепловыделяющие элементы;
6 - восходящий поток петлевого натрия;
7 - нисходящий поток петлевого натрия;
8 - поток реакторного натрия
①-⑧- термопары

Сечение по центру активной зоны петлевого канала





The Material Science Complex with hot cells is designed for post-irradiation examinations (PIE) of irradiated FAs, fuel pins and reactor materials.

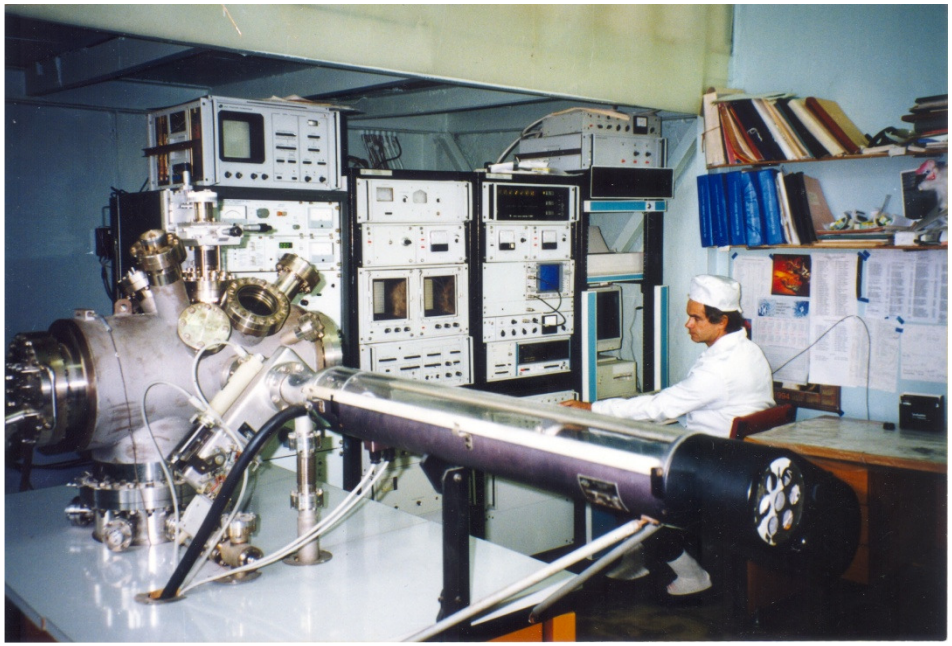
Being the largest complex in Russia, it is located in 3 buildings housing about 50 hot cells and more than 100 heavy boxes. The properties of fuel and materials after irradiation in the reactor cores, as well as delivered standard burnt-out FAs, control rods and other items from power reactors are examined in the Material Science Complex.

In one of the buildings, NDEs of FAs and pins are performed and testing of fuel and absorbing element fragments is conducted under emergency parameters.

In the 2nd building, material science investigations for fuel and absorbing element specimens cut from standard or prototype items are performed based on the NDE results.

The 3rd building houses hot cells and boxes provided with the process equipment required for manufacturing of experimental and test fuel pins with various fuel compositions.

Complex for PIE



Chemical-Technological Complex

- Upgraded facilities designed for fuel production, fabrication of fuel pins and FAs with granulated vi-packed fuel from fast neutron reactors

Radiochemical Complex

- Boxes for investigations of high temperature non-aqueous methods of producing and reprocessing of fuel from different reactor types (a possibility of handling 1 kg of fuel with MAs and FP simulators within one process cycle)
- Universal stand designed for obtaining of experimental data on process parameters of developed non-aqueous methods of nuclear fuel treatment and on the operation of test equipment (a possibility of handling 6 kg of irradiated fuel simulators within one process cycle)
- Boxes designed for examinations of high temperature non-aqueous methods of burnt-out SNF reprocessing using gas-fluoride and pyroelectrochemical techniques

Investigations in justification of performance of fuel pins and FAs, core elements, structural, absorbing and fuel materials of fast neutron reactors, investigations of nuclear fuel under emergency conditions

Investigations in justification of fast neutron reactor CFC:

- Development of innovative fast neutron reactor fuel compositions
- Involvement of power- and weapon-grade plutonium in fast neutron reactor NFC
- Development of management technologies for accumulated and future fast reactor SNF, including reprocessing, recycling, fractioning and transmutation to establish balanced systems of innovative fuel cycles and SNF management

RIAR-based Centers

Experimental center for development of CFC elements based on innovative technologies:

Taking into account RIAR's large reactor base, material science and radiochemical labs, as well as RW management system and highly developed system for performance of experimental work, the Institute shall suggest its site as a base for establishment of the Experimental center for development of CFC elements using innovative technologies. The Center can be established in cooperation with other institutes.

Key objects:

- BOR-60 reactor
- testing and research complex for MOX fuel production
- radiochemical complex
- material science complex

Center for Monitoring and Testing of Materials and Fuel for NPPs

- Current demand for reactor testing of new materials and fuel, conducting experiments in justification of safety and emergency experiments results in the demand for a single system for calculated and experimental justification of core elements. This task is important for companies utilizing Russian fuel and WWER reactors in foreign countries. The concept of the RIAR-based Center was proposed earlier by VNIINM and KI.
- The Center can be established using the following objects:
- MIR, SM, RBT-6, BOR-60 reactors
- Material science complex (including examinations of full-size WWER-1000 FAs)
- Facilities for preparation of irradiation devices
- radiochemical complex

Hot cell facility for MOX fuel production and reprocessing and dry technology tests

Fuel manufacturing and test

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- Production of different type of fuel pins for irradiation in the BOR-60 and other test reactors
- production of “hot” fuel (Fuel after pyroreprocessing, Fuel with MA – Am, Cm)
- Production of assemblies with hot fuel

Equipment for the pyrochemical process and vibropacking for the BN-600 and BN-800

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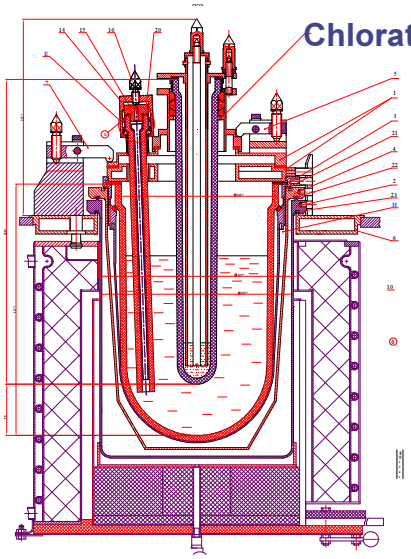
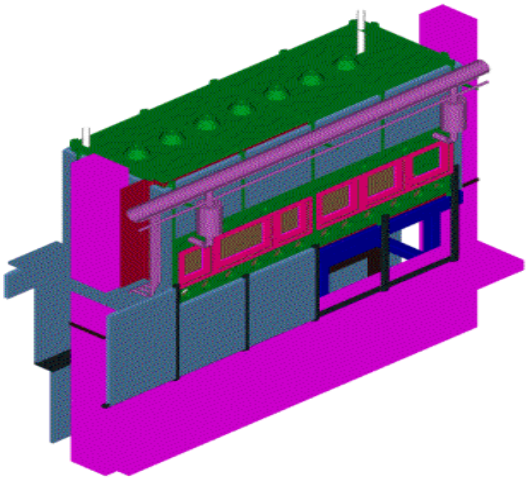
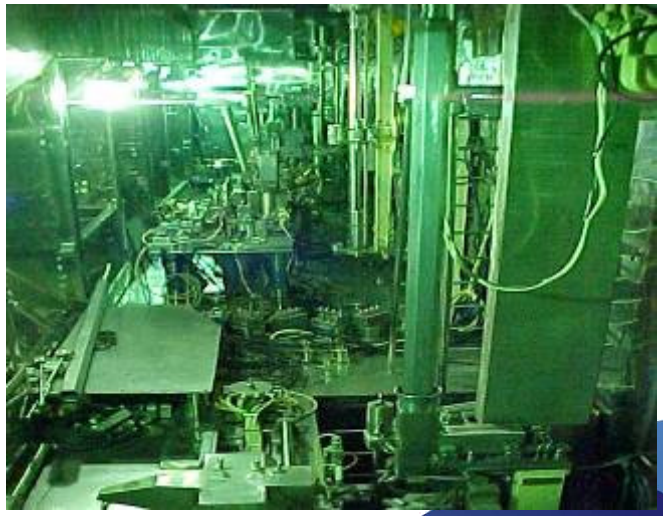
Chlorator-electrolyzer



Automatic fuel pins line



Hot shielded box



Assembling line

Beloyarskaya NPP site (Zarechny)

BN-600 with hot cell for Fuel Assemblies inspection

Institute of Reactor Materials
(IRM) is located near Beloyarskay NPP
It has hot cells PIE line and skilful staff.
Some pins of the BN-600 reactor are inspected after irradiation

BN-800 is under construction

VNIINM (Bochvar Inst.)

VNIINM is the leading ROSATOM institute for material science and NFC technologies, as well as for technologies of handling fissile and nuclear materials used for defense purposes.

Its research base incorporates several material science-technology and radiochemical complexes with a unique experimental and technological base allowing the performance of a whole set of R&Ds, from research to development of technologies and fabrication of experimental and pilot batches of fuel

VNIINM

VNIINM is the leading ROSATOM institute for material science and NFC technologies.

- Development of MOX pellet fuel
- Development of nitride mixed fuel (pelletaized)
- Development plutonium fuel for GT-MGR (VTGR reactor)
- Development of new cladding materials for fast reactors
- Development of fuel pins
- Development of technologies for spent fuel reprocessing
- Development technologies for HLW treatment

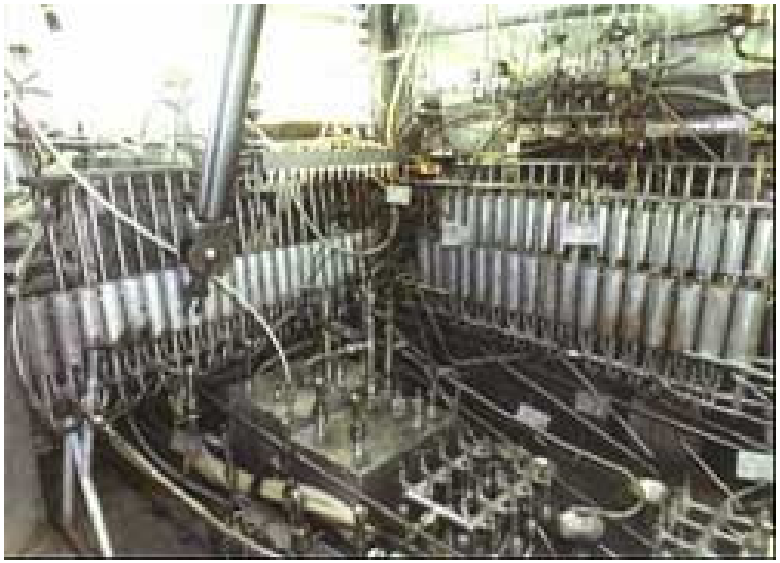
Radium Institute

- Its branch, Scientific and Experimental Complex in the city of Gatchina in Leningrad Region, has been a site for testing innovative SNF and RW reprocessing technologies since the date of its foundation
- The scientific and experimental complex (SEC) is equipped with hot cells and heavy boxes, systems for RW management, gas purification, radiation monitoring, physical protection and other systems required for Class 1 operations.
- The SEC has experience in testing various options of the SNF extraction reprocessing, including PT-2 plant technology, aqueous portion of the combined technology, simplified alternative of the PUREX process. More than 100 kg of different SNF types has been reprocessed.
- The Institute has a complete set of State licenses for performing scientific and technological activities in the sphere of nuclear power engineering
- At present, the complex is undergoing the refurbishment, which includes upgrading of the main systems and the vessel process equipment to verify the Testing and Demonstration Center (TDC) technologies, as well as to develop promising SNF and RW management technologies

Radium Institute

The SEC hot cells are provided with the equipment to perform basic SNF reprocessing operations:

- Chopping and laser cutting of fuel pin fragments
- Weighing of SNF specimens
- Voloxidation of fuel pin fragments
- SNF dissolving and clarification of produced solutions
- Extraction and separation of target components (U, Pu and Np)
- Fractioning of isotopes of Cs, Sr, REE and transplutonium elements



Scientific and Experimental Complex in Gatchina

Radium Institute

The following facilities were designed for LRW disposal:

- Unit for LRW collection and temporary storage
- Facility for LRW concentration by evaporation
- Sorption facility for Cs and Pu isotopes extraction
- Unit for cementation of cubic solution

With the extension of research fields the following facilities for high-level waste (HLW) immobilization operations were developed and tested :

- Facility for HLW vitrification
- Plasma-chemical facility to produce mixed oxide powders
- Facility for gasostatic pressing of mineral-like matrices

Scientific and Experimental Complex in Gatchina

Now the equipment for verification of main SNF reprocessing operations of the TDC is being installed in the SEC hot cells

Recent activity for closed fuel cycle facilities on industrial sites

- **Mining-Chemical Combine (Krasnoyarsk)**
- Facility for Pu (military) conversion to MOX fuel granulate for BN-800 in the frame of cooperation with RIAR
- Experimental-Demonstration Center for advanced aqueous reprocessing studies
- Future place for LWR Spent fuel reprocessing Plant

- **Mayak Plant**
- PAKET facility operation for MOX and experimental pellet fuel manufacturing
- Studies for advanced aqueous reprocessing

- **VNIITF (Snezhinsk)**
- Laboratory facility for fluoride volatility process investigation

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

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New experimental facilities

- 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

➢ Renovation of BFS and prolongation the BOR-60 up to 2015

➢ Open for International Programs

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

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Characteristic	Value
Maximum flux Φmax, n/cm2·sec	> $5.0 \cdot 10^{15}$
Thermal power, MWth	~ 150
Electric power, MWe	~ 40
Number of independent experimental loops (~1 MWth, sodium, heavy metal and gas coolant + salt coolants)	4
Driven Fuel	Vi-pack MOX, (PuN+UN)
Core height, mm	550
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	~ $1 \cdot 10^{23}$ (up to 45 dpa)
Design lifetime	50 year
RR creation time (no more than, years)	2018

Main goals of RIAR Multi-Purpose Pyrocomplex (MPC) for 2020

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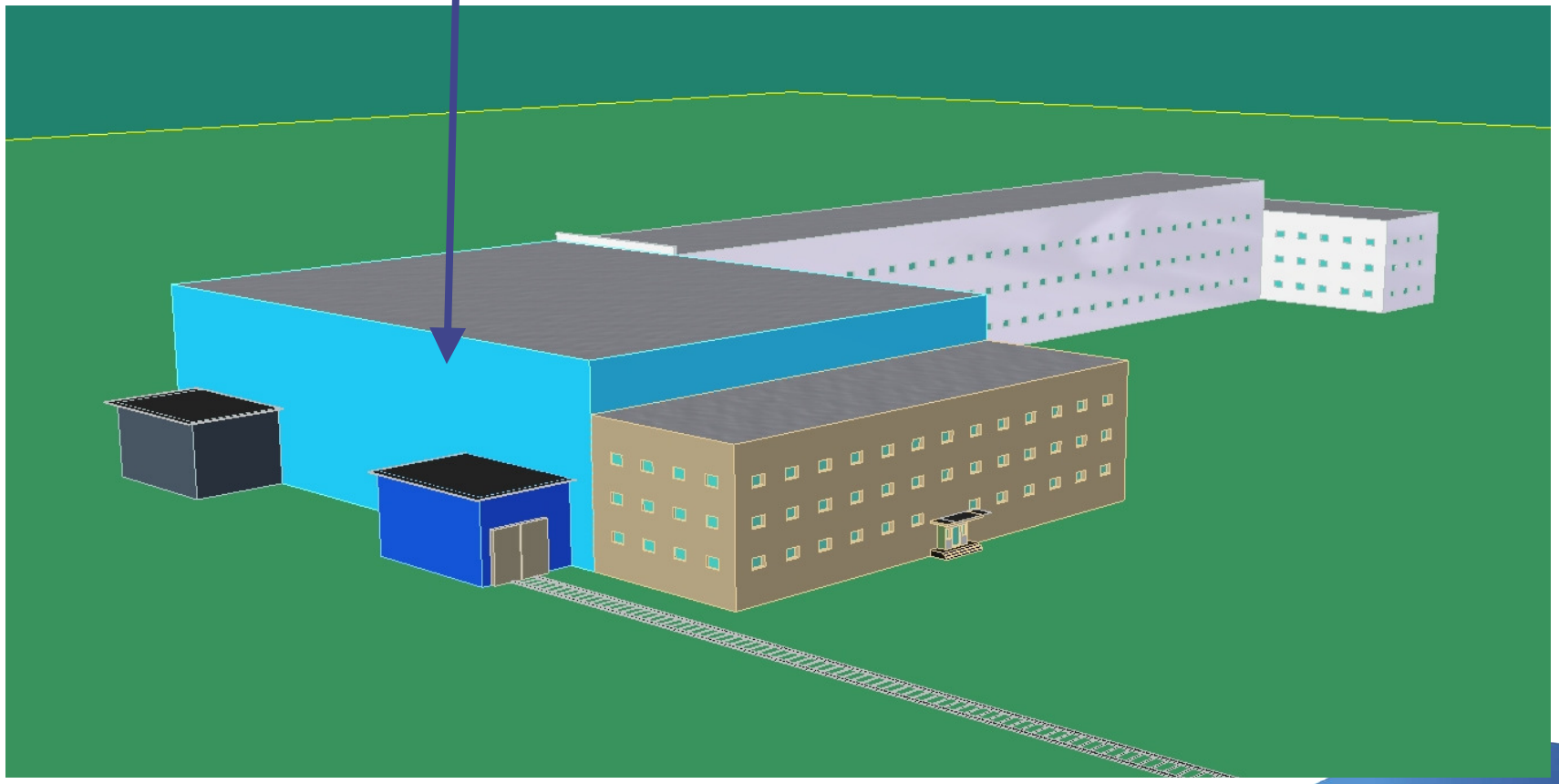
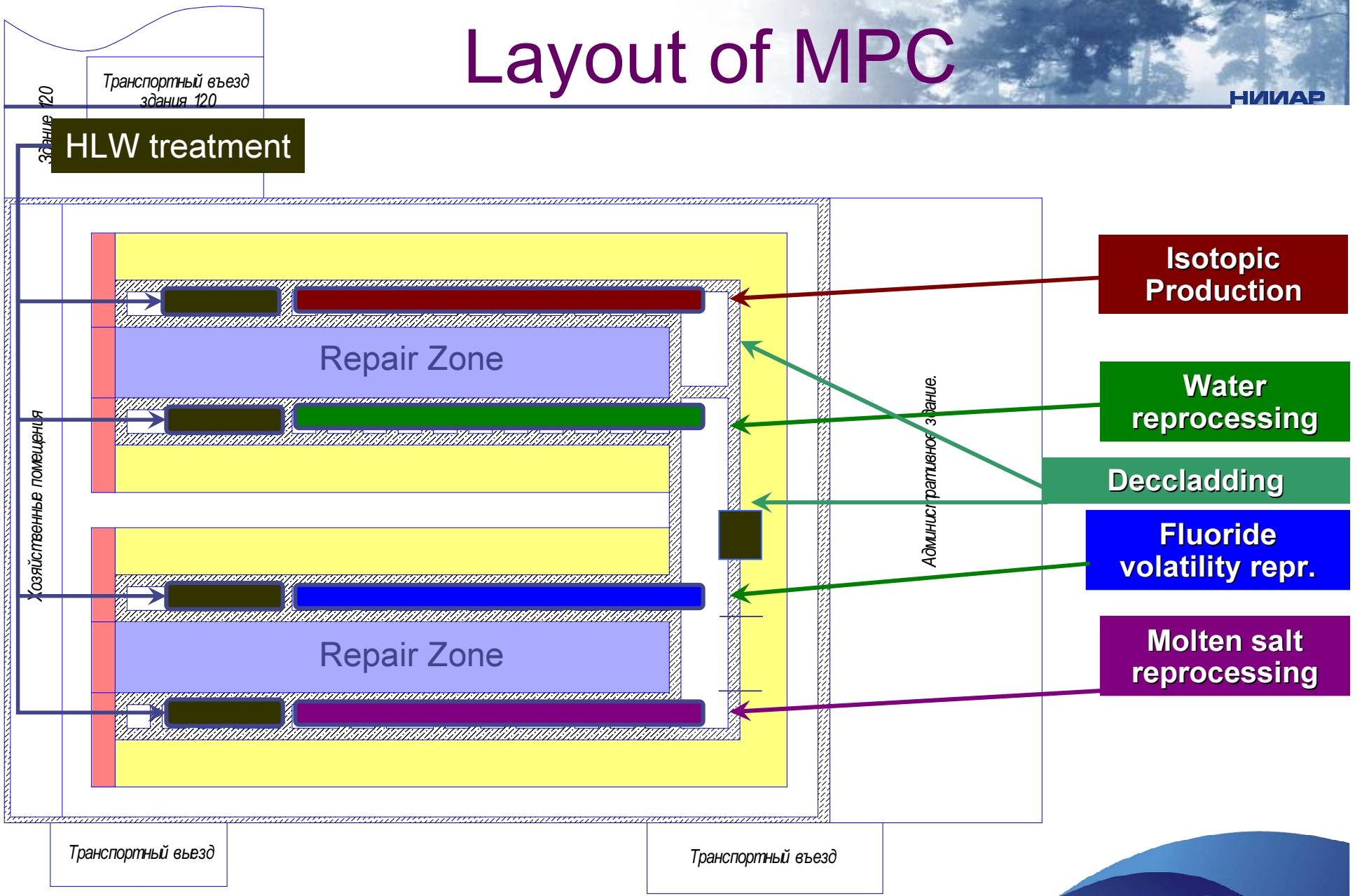
- Development of Pyro reprocessing technologies on a semi-industrial level:
  - FR SNF – molten salt technologies
    - MOX
    - Mixed Nitrides
    - Metallic
  - LWR SNF – combination of fluoride volatility and molten salt technologies
    - UOX
    - MOX
  - Others
    - So called hard-to-reprocessing SNF (test and transportation reactors)
    - Innovation types of fuel (IMF, MSR +++)
- Demonstration of Closing of BN-800 Fuel Cycle - on a semi-industrial level
    - up to 30 % annual loading, i.e. up to 3,5 – 4 t of MOX SNF per Year
- Testing and Demonstration of Closing FR Fuel Cycle for MA
- Develop the Initial Data for full scale Design of Industrial Pyro Module for FR SNF Reprocessing

3D View on MPC



Layout of MPC



Conclusions

- Russia has enough experimental basis for development of Fast Reactors and Closed Fuel Cycle systems
- Part of key facility (BFS and BOR-60) demands renovation and re-equipment. Key problem is limited operation time of the BOR-60 test reactor (till 2015)
- Main Decision in the frame of Federal Program is design and create new facilities for testing of Fast reactor and Closed Cycle innovative technologies :
  - New multifunctional test fast reactor – MBIR
  - New Multi-purpose PyroComplex
  - Completion of facilities for MOX fuel production
- All new subject must by multi-functional
- All subjects must be open for international cooperation

Thank you for your attention!

Alexander Bychkov
State Scientific Centre Research Institute of Atomic Reactors