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РОСАТОМ

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ГОСУДАРСТВЕННАЯ КОРПОРАЦИЯ ПО АТОМНОЙ ЭНЕРГИИ «РОСАТОМ»

Fast neutron reactors and problem of nuclear nonproliferation

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1. Introduction

2. The role of fast reactors in the sustainable development of civilization

3. Russian achievements in the development of fast reactor technology

4. Start-up and operation of plutonium-fuelled fast reactors

5. Start-up of fast reactors on enriched uranium

6. Possible increase in risk of proliferation in the modern environment

7. Features of fast reactors in the field of nonproliferation

8. The IAEA Safeguards and Recommendation on physical protection

9. Interaction of three S (safety, security, safeguards)

10. The International Nuclear Fuel Cycle Evaluation

11. Concluding remarks

1. Introduction

In the world:

- 450 nuclear power units
- Total installed capacity of ≈ 400 GW(e) (as of December 31, 2016);
- Light-water reactors, open nuclear fuel cycle:

  81% - light water reactors,

  11% - heavy water reactors,

  4% - light water graphite reactors,

  3% - gas cooled reactors,

  BN-600 and BN-800 fast neutron reactors.

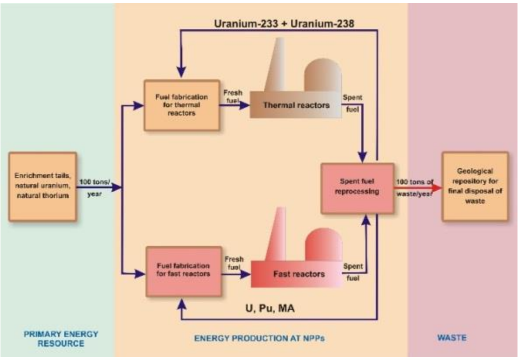
Russia:

- quite successfully operates at world's nuclear power market:
  - actively offering foreign customers nuclear plants with VVER reactors,
  - and services in the nuclear fuel cycle (NFC),
- possibilities to increase the export potential of nuclear power technologies:
  - the export potential of fast reactor technologies,
  - closed nuclear fuel cycle,
  - technology of radiochemical reprocessing and re-fabrication of nuclear fuel,
- the global nuclear non-proliferation regime and physical protection of nuclear materials

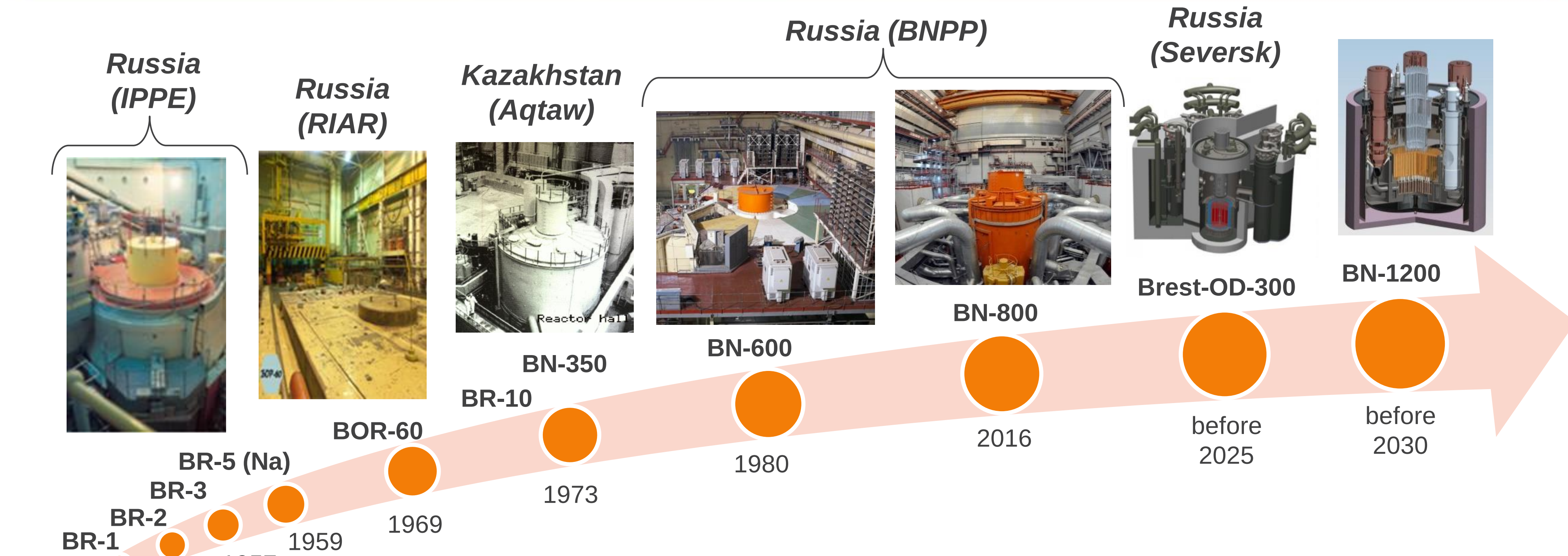
To be continued

2. The role of fast reactors in the sustainable development of civilization

- Sustainable development: "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
- The main objective of sustainable development:
  - to maintain or augment resources : gas, biomass, solar, wind, hydro, coal.
- Energy is essential for sustainable development:
  - population growth,
  - the economy needs of the developing world
- Demand for electricity will grow even more rapidly:
  - more flexible and more convenient for consumers.
- Nuclear energy systems:
  - global energy needs for a historically significant period
  - fast reactors
  - closed nuclear fuel cycle
- The Generation IV International Forum (GIF),
- The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO).



3. Achievements of Russia/SU in the field of development of technologies of fast reactors



- The 1st concrete for MBIR at NIIAR – Sep 2015, commission in 2020;
- Launch the MOX fuel production at an industrial scale at MCC for fast reactors – Sep 2015;
- In 2015, successfully conducted experiments on separation of Am from Cm for its subsequent transmutation in fast reactors;
- Start-up of reprocessing VVER-1000 SNF in 2016 at P.A. "MAYAK";
- Experimental F/As with REMIX fuel loaded for irradiation in MIR reactor and in the 3rd unit of Balakovo NPP (VVER-1000);
- Launch the 2nd phase of Experimental Demonstration Center at MCC for the reprocessing of SNF is planned for 2022;

4. Start-up and operation of plutonium-fuelled fast reactors

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Enrico Fermi and Alexander Leypunsky

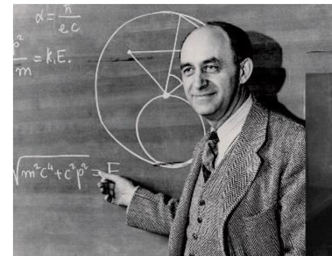

Table1. Composition of plutonium obtained in thermal reactors

Reactor type	Fuel burn-up, GWd/t	Plutonium isotopic composition, %				
		Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
PWR	33	1.6	55.5	23.8	12.8	5.4
PWR	60	3.8	51.8	23.0	14.2	7.2
PWR	100	7.8	47.0	21.7	14.7	8.8
AGR	18	0.6	53.7	30.8	9.9	5.0
MAGNOX	5	~ 0	68.5	25.0	5.3	1.2
CANDU	7.5	~ 0	66.5	26.5	5.5	1.5

Civil plutonium irradiated in fast reactor doesn't change in principal its isotopic composition

Table 2. Evolution of plutonium isotopic composition in a typical fast reactor with recycles.

Plutonium isotopic composition, % Pu-239/Pu-240/Pu-241/Pu-242		Equilibrium plutonium isotopic composition, % Pu-239/Pu-240/Pu-241/Pu-242
Loading into reactor	Unloading out of reactor	
100/0/0/0	89,2/10,5/0,3/0,02	59,3/31,4/5,7/3,6
60/25/10,9/4,1	58,7/28,4/8,1/4,8	49,1/35,9/7,9/7,1
55/20,8/17,8/5,9	57,5/24,3/11,1/7,1	53,2/33,0/7,3/6,5
43,2/38,8/10,3/7,7	43,8/38,8/9,2/8,2	45,5/37,9/7,9/8,7

The equilibrium composition of plutonium in fast reactor

Fast plutonium-fuelled reactors produce plutonium of quite bad quality, thus preventing its ready use in nuclear weapon. Enrichment technology is not used in this option.

5. Start-up of fast reactors on enriched uranium (Professor V.V. Orlov)

Gradual transition to a mix of U-Pu fuel with the use of its own bred plutonium.
Fast reactors is to be independent of availability of thermal reactor plutonium.

Table 3. Isotopic composition of plutonium in spent uranium fuel of fast reactors.

Reactor type	Fuel campaign	Plutonium in spent fuel, %				
		Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
BN-1200 with UO2	5 years	0.4	91.8	7.7	0.3	0.02
BREST-1200 with UN	5 years	0.1	95.5	4.3	0.1	0.003
Weapon Pu	-	0.012	93.8	5.8	0.35	0.022

The content of Pu-239 and the highest mass isotopes are very close to that for weapon-grade plutonium…

Moreover, such plutonium will be formed in the reactor core with substantial more amounts as compared to blanket.

German scientist Professor H. Kessler:
- obsolete chemical explosives (Baratol, Composition B, TNT)– up to 1.8% of Pu-238 in plutonium pit ,
- modern explosives (PBX 9502, TATB) - up to 3.6% without application of any measures of forced cooling.

<u>At the option both sensitive technologies – uranium enrichment and spent fuel reprocessing - will be used</u>

6. Possible increase in risk of proliferation in the modern environment

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- Two “sensitive” technologies are possessed by a limited number of countries.
- The increase in the number of countries possessing these technologies increases the risk of proliferation of nuclear weapons (NW).
- The number of countries declaring their desire to use nuclear energy remains significant:

  - by the latest forecast about 15-20 of newcomers will have first NPP by 2030 or some time beyond.
- India and Pakistan, the continuing tests in North Korea…
- The apparent inability of the world community to prevent these actions are examples for other totalitarian regimes on how they might come to possess a NW.
- How the NPT can be modified? Enhanced enforcement mechanism? Politics and economics profits?
- Problem of SNF and the plutonium in it, especially for beginners...
- Physical protection and selecting <u>indigenous (local) personal/staff</u>

7. Features of fast reactors in the field of nonproliferation and physical protection

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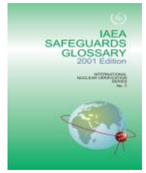
- Cross sections markedly ↓ with neutron spectrum hardening → concentration of fissile isotopes ↑.
- Nonproliferation (safeguards) and physical protection (security) should be given increased attention.
- Open NFC → SNF storage → risk of proliferation ↑ over time because ↓ radiation barrier and → withdrawal by the state-proliferator or theft by a subnational/terrorist groups.
- Closed NFC: discharged SNF → cooling time → go directly for reprocessing.
- The simplest "gun-type" NED needs enriched uranium, the use of civil plutonium is practically impossible.
- For an "implosion-type" both with plutonium or uranium needs quite advanced technology…
- Centralized or on-site NFC, pro and contra:

  - on-site: almost absolute control over NM, no transportation routes outside guarded area, no terrorist attacks, no contamination of population areas in case of accident during transportation,

  - on the other hand, the export potential of such technology is the subject of comprehensive system analysis with taking into account all possible factors.

8. The IAEA safeguards and recommendations on physical protection

- The IAEA safeguards are a set of technical measures for the verification of the political commitment of States in the field of nonproliferation of NW in accordance with the IAEA Statute and NPT.
- The aim of safeguards is to guarantee the timely detection of diversion of significant quantities of NM from peaceful activities to the manufacture of NW or NED.
- The IAEA concludes with the State agreements, which provide the application of safeguards.



IAEA SAFEGUARDS ADDITIONAL PROTOCOL

- The Generation IV International Forum (GIF): Safeguards-by-Design (SBD) is a new approach to the design and construction of nuclear facilities in which nuclear safeguards provisions and features are designed into the facility from the very beginning of the design process.
- The overall goal of the state's physical security system is the protection of persons, property, society (people) and the environment from malicious acts involving NM and other radioactive materials. Recommendations on Physical Protection of NM and NF are set out in the relevant IAEA document.
- State's physical protection regime should regularly review and update, in order to reflect changes in the threats and advances in approaches to physical protection in the field of systems and technologies, and the use of new types of NM and NF.

9. Interaction of three S (safety, security, safeguards)

Safety

There are the well developed requirements at national and international level on providing nuclear safety, which are at the base of technical requirements designing and substantiating of nuclear safety

IAEA Safeguards

Today there are no consolidated requirements especially at national level, which would be converted into a task for facility designing, as one may say “make the facility safeguards friendly”. Today's practice consists of that the IAEA begins to develop approach on safeguards implementation, on the basis of information provide by the State to the IAEA about a design, when facility, as a rule, begins building.

Basics for designing NPPs and facilities of NFC

Security

Today also there are sufficiently well developed national requirements for implementation of its providing, which are also included in requirement specifications on designing. The analogues of initial events in this case there are scenarios of actions of external and internal adversaries (terrorists, criminal elements etc.) from which nuclear material and nuclear installations must be protected (and these actions can be initial events for nuclear safety as well)

10. The International Nuclear Fuel Cycle Evaluation (Remembers of the Future)

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- INFCE was established almost 40 years ago. The main conclusions and recommendations have not lost their relevance today, especially on nonproliferation in the analysis of fast reactors and NFC.
- Nuclear reactors → plutonium production. How to safely deal with this material. Danger of diversion of NM at the early stages of the NFC of fast reactors was considered. The experts concluded that this risk does not exceed the danger in the case of uranium-plutonium cycle of LWRs.
- Measures → to reduce to a minimum the danger of NM diversion without prejudice to the development of nuclear power. Such measures are technical tools, enhanced safeguards system and organizational measures.
- The technical measures → to reduce the amount of NM in NFC, which is suitable for NW, protection of NM by radiation barrier, and physical security barriers. Deployment of NFC facilities on the same site eliminates transportation of NM outside of the protected area, ensuring the safety of the population, reliable control of NM materials and their physical protection.
- Nuclear power is playing and will play an increasing role in meeting the energy needs of humanity. And fast reactors can play a major role in terms of sustainability.
- Proliferation risk, is inherent in all of the NFC, comparison cannot be carried out separately but depends on many other factors.
- There is no NFC completely free from this risk, as well as there is no NFC that are not compatible with the objectives of nonproliferation of NW.
- Proposal: to renew

  It is necessary to continue the research of this kind on the basis of the experience of development of nuclear energy gained over the past 40 years.

11. Concluding remarks

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1. Deployment of fast reactors and closure of NFC → export potential of these technologies and the impact of such exports to the global nuclear nonproliferation regime.

2. About 15-20 new countries will have their first NPP by 2030 → force discussion about increasing probability of proliferation risk. To create its own infrastructure, or use the services of the exporting countries. The underestimation of the problem with SNF will lead to increase risk of theft and terrorist acts.

3. To start-up fast reactor with plutonium fuel → enrichment technology is not required, pure quality plutonium.

4. To start-up with uranium fuel → both sensitive technologies have to be used, good quality plutonium.

5. The IAEA safeguards system is an important part of the global regime of nonproliferation of NW, physical protection of NM and NF is an important element of global security.

6. Recommendations of the INFCE have not lost their relevance today with regard to fast reactors and closed NFC. New study is desirable.

7. Export potential of Russian nuclear power technologies, including in the country's nuclear power system fast reactors for energy utilization of SNF from VVER reactors.

8. From human point of view any NM carries a certain risk in case if it is handled inadequately.

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Thank you for your attention!