Scientific and Technical Problems of Closed Nuclear Fuel Cycle in Two-Component Nuclear Energetics
Dr. Alexander Orlov, IPPE, Russia

Berta Oates
Doing today's introduction is Dr. Patricia Paviet. Patricia is the Technical Group Manager of the Radiological Materials Group in the Nuclear Sciences Division of the Pacific Northwest National Laboratory. She is also the Chair of the Gen IV International Forum Education and Training Taskforce. Patricia?

Patricia Paviet
Thank you so much Berta. Thank you. Good morning everybody. We are very pleased to have Dr. Alexander Orlov with us today. He earned his Ph.D. at the National Research Nuclear University, MePhi University in Moscow in 2009. He is currently the advisor to the Scientific Director of R&D of Proryv Project.

Since 2012, he has been a member of a team in charge of developing the new technological platform for Nuclear Energetics consisting of Fast Reactors with lead and sodium coolants, new type of reactor fuel; mixed Uranium-Plutonium nitride and technologies to reprocess the spent nuclear fuel in order to return it into the fuel cycle. These technologies combined are known as the Proryv. Without further delay, let me give the floor to Alexander. Let me thank him for volunteering to present this GIF webinar. Thank you so much Alexander.

Alexander Orlov
Thank you Patricia. Hello everyone. Before I begin, I just want to make two comments. On the first slide, it showed that I work in IPP in Russia. I am working in the Proryv Project as it was said on the second slide. Second, I am making this presentation on behalf of Dr. Valerie Rajikov [ph] who was supposed to be initially the presenter.

Now we can go to slide 4 to see the base expectations. Slide 5 please. Here you can see that rapid development of Nuclear Energetics starting from the first Nuclear Power Plant in Obninsk in 1954. It was just 5 megawatts power. And up to 200 gigawatt power in 1980, gave birth to optimistic forecasts for Nuclear Energy development, including those that planned 30% energy production share for Nuclear Energy by 2020. However, these forecasts were not destined to happen.

Slide 7. On slide 7 you can see that today Nuclear Energy share is just 5% compared to other means of energy production.

Slide 8, current forecasts are also quite pessimistic not only for Russia. Here you can see that three scenarios. Here you can see the Nuclear Energy share, which is marked in green, and it's probable scenario, preferable scenario, and critical scenario. They are all not very optimistic. Three scenarios have been developed for Russia that carry on the logic of world scenarios. Probable scenario includes all the ground lines of world scenario combining them with preservation of current economy and energy sector performance of Russia. Russian economy in this scenario will reach after 2020 moderate growth rates of 2.2%-2.4%. Energy balance structure by means of generation will be kept intact in Russia. Thermal Power Plants will remain the foundation of electrical power generation, providing in all scenarios approximately 62% of generation by 2040.

Slide 9 please. Nuclear Energy development scenarios are also quite pessimistic for the world in general, excluding of course China. Here you can see Russia, marked in green.

Slide 10 please. Naturally there arises a question, why so? Let's try to answer it.

Slide 11, the basis of modern world Nuclear Energy are Thermal Reactors with uranium fuel in an Open Nuclear Fuel Cycle. Here you can see annual flows of nuclear materials in Open Nuclear Fuel Cycle of 1 gigawatt electrical production.

On slide 12, it should be noted that the current technological base of Thermal Reactors with Open Nuclear Fuel Cycle is sufficient for the projected up to 2050 scale of Nuclear Energy development. But its potential in solving long-term energy problems is limited due to lack of compliance of its technical safety with the basic requirement for large-scale nuclear energy excluding of accidents requiring evacuation of the population.

Slide 13, but besides this obvious limitation there are other systemic problems of the old technological basement of Nuclear Energetics. They are low utilization efficiency of the extracted natural uranium, a lack of environmentally-acceptable treatment of the Long-Lived High-Level radioactive waste, minor actinides and so on, and proliferation concern.

Slide 14, barriers for Nuclear Energy development. The maximum share of nuclear power plants in global electricity generation of 18% was reached in the early 90s. For today, it has dropped to 10.7%. Forecasts show further decrease of the share. The main obstacle to the development of modern nuclear power is the problem of competitiveness which rests on the safety problem. Attempts to solve the safety problem by creating additional active protection means led to decrease in competitiveness of nuclear power in comparison to organic energy sources which you can see on the picture here.

Slide 16 please. Today, the need to move to a new technological platform of Fast Reactors with Closed Nuclear Fuel Cycle of Nuclear Energetics is evident. Here you can see the approximate annual flows of nuclear materials in Closed Nuclear Fuel Cycle. And if we compare them to the previous one for the Open Nuclear Fuel Cycle, you will see they are much less.

Slide 17, advantages of Closed Nuclear Fuel Cycle to an Open Nuclear Fuel Cycle. These advantages are in minimization of fuel and radioactive waste flows in lowering stored Spent Nuclear Fuel quantities, and in lowering the stored plutonium quantities.

Slide 18, formalization of approaches to new technological platform of Nuclear Energetics.

Slide 19, the requirements aimed at overcoming the problems of modern Nuclear Power in the field of safety, raw materials, nuclear waste, nonproliferation, and economy were first worked out in Russia at the end of the 20th century and presented in the strategy for the development of Nuclear Energy in Russia in the first half of the 21st century approved by the government. It's called Strategy-2000.

Slide 20, these requirements follow the world trend. Within the framework of the largest international forum, GENERATION-IV, organized at the beginning of the 21st century, nuclear technology developers elaborated requirements for the new generation of reactors. Among the six technologies chosen for joint development, four are different technologies of Fast Reactors and Closed Nuclear Fuel Cycle.

In the framework of another major INPRO, international project, user requirements for innovative nuclear power systems that meet the principles of sustainable development have been formulated. INPRO research also confirmed the importance of the development of Fast Reactors and Closed Nuclear Fuel Cycle technologies, especially for countries with large Nuclear Power Plants park or for those planning to have a large-scale development for nuclear power.

Slide 21, these are the major milestones for the development of the concept of Closed Nuclear Fuel cycle with Fast Reactors in Russia: Year 2000, strategy for the development of Nuclear Energy in Russia, 2010 Federal Target Program, nuclear energy technologies of new generation for the period of 2010-2015 and for the future up to 2020; and 2012, the beginning of Proryv project.

Slide 23, requirements for new technological platform. Now, what are exactly the requirements for the new technological platform? They are, of course, technical safety of nuclear energy, elimination of accidents that require evacuation of the population. Also, environmental safety of the nuclear fuel cycle, solving problems of long-living high-level waste, handling and Spent Nuclear Fuel accumulation. Sustainable fuel supply for Nuclear Energy, Closed Nuclear Fuel Cycle can become the basis for long-term provision of nuclear fuel for thousands of years with fuel raw materials. And competitiveness of Nuclear Energy.

Slide 25, technical safety. Let's elaborate the first requirement for the new technological platform, technical safety. The goal is clear. It's elimination of accidents at nuclear power plants and other nuclear fuel cycle facilities that require evacuation of the population. Ways to reach this goal are clear as well. We need to eliminate reactivity accidents which may lead to the need for evacuation of the population. Eliminate accidents with loss of heat removal which can lead to the need for evacuation, and exclude fires and explosions at nuclear power plants, which may lead to the need for evacuation.

Slide 26, the following means to reach the goal are suggested. They are dense fuel in the reactor core with zero reactivity margin for burnup, lead coolant, air heat exchanger, natural circulation of coolant with heat removal through the air heat exchanger. Fires and explosions at the reactor unit with the release of radioactivity should be excluded by physical and chemical properties of the coolant and structural materials that do not enter into an explosion or fire hazard interaction with the environment (water and air) with evolution of hydrogen.

Slide 28, environmental safety. The goal is clear here. Publicly acceptable treatment of the Long-Lived High-Level Waste and avoidance of Spent Nuclear Fuel accumulation. Ways to reach these goals are prohibition of disposal of radioactive waste containing ecologically significant demands of Long-Lived High-Level waste, reduction of the quantity of Thermal Reactors Spent Nuclear Fuel stored, and exclusion of Fast Reactor Spent Nuclear Fuel accumulation, and isolation of radioactive waste.

Slide 29, the means to reach these goals are processing Spent Nuclear Fuel of Thermal Reactors and Fast Reactors, minor actinides transmutation, and disposal of radioactive waste.

Slide 31, stable fuel supply. The goal is long-term provision of nuclear fuel for thousands of years with raw materials. The ways to reach the goal are full reproduction of fissile nuclides in the core, transition to a closed Nuclear Fuel Cycle.

Slide 32, means to reach the goal are in development. They are Fast Reactor with Breeding Ratio equal to 1, Spent Nuclear Fuel reprocessing, fabrication of nuclear fuel from Spent Nuclear Fuel reprocessing products, and natural or depleted uranium.

Slide 34, competiveness. The following ways and means to reach the competiveness goal are suggested. Elimination and simplification of a number of Nuclear Power Plant safety systems, reduction of construction material consumption by simplifying the design of the reactor, reduction of the fuel component, reduction of transportation costs, the on-site Nuclear Fuel Cycle.

Slide 35, now let’s move to the main results of research and development of new technological platform components in the Proryv project framework.

Slide 37, technical safety, as for technical safety, seven main technical solutions for a reactor unit are suggested. Equilibrium core of the Fast Reactor which allows to minimize the reactivity margin of nuclear fuel and practically exclude the acceleration on instantaneous neutrons. Also, dense mononitride fuel which makes it possible to implement an equilibrium core with uranium blanket. Third, wide grid of the core, allowing to have such level of natural circulation that is sufficient to remove residual heat. Four, integral layout of the reactor unit which allows localizing coolant leaks in the bulk of the reactor body and ensuring conditions for efficient natural circulation.

Five, heavy liquid metal coolant which allows to implement wide rating [ph] and to exclude positive halo [ph] effect of reactivity. The system for maintaining quality of coolant, lead coolant, which allows the use of heavy coolant in fast reactors of high power and the use of atmospheric air as the final cooler in a naturally circulating removal of residual heat in a high power plant.

Slide 38, as for lead coolant technology, the technological regulations for the operation of lead coolant technology system for BREST reactor installation have been developed. Designs of the equipment of the Lead Coolant Technology System also have been developed. The means of quality control of the coolant, oxygen sensor passed the acceptance tests. Here you can see the pictures of some of that equipment.

Slide 39, here is a list of software codes developed and used for BREST reactor verification.

Slide 40, now about the results of research and development of dense nitride fuel. Its advantages are relatively well known and I think do not require a detailed comment. This slide gives you an idea of the scale of the development works in Russia.

Slide 41, the specifics and details of experimental verification of dense nitride fuel rods and bundles are shown here. For BN-600 reactor, 19 experimental fuel bundles placed for testing. And then, fuel bundles completed irradiation. All bundles remain sealed. In BOR-60 reactor, 9 disassembly experimental fuel bundles placed for irradiation and five finished irradiation. In MIR reactor, instrumental assembly of 7 fuel rods with sensors for in-reactor temperature control of the fuel center, gas pressure under the shell, and fuel column extension have completed irradiation.

Slide 43, environmental safety. This slide represents a known concept of radiation equivalent burial of radioactive waste that suggests burying radioactive waste only after its activity decreases to the level of natural uranium. The reprocessing of Spent Nuclear Fuel from Fast Reactors opens the possibility for solving the problem of radioactive waste for Nuclear Energetics by choosing the proper approaches to treatment of various Long-Lived High-Active waste components and minor actinids transmutation. The use of combined Spent Nuclear Fuel reprocessing technology allows to reprocess Spent Nuclear Fuel with low holding time and high burnout, provides support for nonproliferation regime, ensures losses of fissile materials of less or equal than 0.1%, and provides low volumes of high level waste.

Slide 45, robustness of new technological platform. Three major technical solutions for Closed Nuclear Fuel Cycle. They are pyro-chemical reprocessing of Fast Reactor Spent Nuclear Fuel to reduce the duration of Spent Nuclear Fuel retention before its reprocessing, and to exclude the separation of pure plutonium during its processing.

No blanket design of Fast Reactors to exclude the production of weapon-grade plutonium.

Slide 47, raw material stability. As for raw material stability of New Technological Platform, it’s enough to note that all types of Fast Reactors with Closed Nuclear Fuel Cycle allow changing raw materials base of Nuclear Energy from limited Uranium-235 to practically unlimited uranium 238.

Slide 49, competitiveness. In recent times, there have been presented justified calculations showing that Nuclear Energetics with Fast Reactors has a high potential to increase competitiveness and that reaching equal competitiveness with organic energetics is really possible.

Slide 51, external problems of New Technological Platform, analysis of approaches in Russia and other countries to the future of nuclear energy shows the presence of two main trends. First, development of nuclear power on the basis of thermal reactors with Open Nuclear Fuel Cycle. Second, development of Closed Nuclear Fuel Cycle with the introduction of reactors that provides simple or extended nuclear fuel reproductions, Breeding Ratio were equal or more than 1. Large-scale nuclear power is only possible under the second approach.

Slide 53, preliminary results. Preliminary results in development of technological elements of New Technological Platform in the Proryv framework. What is being developed? It's first the Pilot Demonstrational Energy Complex, PDEC for short, which consists of lead cooled BREST Power Unit, fabrication/refabrication unit for dense nuclear fuel, and reprocessing unit for Spent Nuclear Fuel. Second is BN-1200 power unit with sodium coolant. Third, design project of Industrial Energy Complex with Fast Reactor of 1200 megawatt capacity and Closed Nuclear Fuel Cycle.

Slide 54, now about the preliminary result in choosing the base scenario for Nuclear Energy development in Russia. This slide shows possible development dynamics of Nuclear Energy structure in Russia. On this slide you can see marked in different colors are various types of Russian reactor designs, water cooled, and Fast Reactors with sodium or lead coolants. Results of systemic study showed that Russian Nuclear Energetics can reach up to 120 gigawatt by the end of the century.

Slide 56, this slide shows our view of the Tree of Problems in Proryv framework. I will highlight only four of them. It's the lead coolant for BREST reactor. It's mixed nitride fuel for BREST and BN-1200 reactors, and pyro-chemistry.

Slide 57, on this slide you can see further Research & Development tasks of Proryv projects. The major ones are research and development of PDEC objects until its commissioning. Then it's going to be a Research & Development program on PDEC after its commissioning. It's Research & Development of Industrial Energy Complex Objects and General Systemic Research & Development.

Slide 58, in conclusion, Proryv project provides the State Corporation Rosatom with leadership in the following areas: Construction of Fast Reactors with inherent safety, creation of dense mixed nitride fuel optimal for Fast Reactors, final solution of the problem of Spent Nuclear Fuel accumulation, and radiation equivalent treatment of radioactive waste, creation of world's first pilot energy complex with Fast Reactor and Closed Nuclear Fuel Cycle. The crisis of world nuclear power can be overcome by the creation in the time period between 2018 and 2035 of the first industrial energy complex. It's going to be with BN-1200 reactor, if competitiveness with Water Cooled Reactors will be confirmed by design project. It can be with BR-1200 reactor which is competitive with CCGT and RES.

Reduction of natural uranium consumption by six times and the growth rate of Spent Nuclear Fuel stocks with the introduction of Fast Reactors. Phased introduction of Spent Nuclear Fuel reprocessing technologies when economic feasibility is achieved. Thank you. That's all I wanted to say.

Berta Oates
Thank you for your presentation. There are some questions coming in. While people have questions typing into their Q&A pod, we'll take a look at the upcoming webinar presentations. In February, a presentation is planned on the Safety of Gen IV Reactors. In March, The Allegro Experimental Gas Cooled Fast Reactor Project, and in April a presentation on the European Sodium Fast Reactor: An Introduction.

There is a question on Slide 5 on the graph. It's indicated by 2080 thorium will replace uranium, but thorium based reactors cannot operate just by using thorium. Could you clarify it? You want to go back to the graph?

Alexander Orlov
Could you go? Yes, please.

Berta Oates
Let's see if I can quickly do this.

Alexander Orlov
Here it doesn't replace completely. It goes in combination, thorium and uranium as you can see.

Berta Oates
Is there a reduced demand for plutonium and dense fuel or is it the same as in the oxide fuel?

Alexander Orlov
Sorry could you repeat that?

Berta Oates
Is there a reduced demand for plutonium and the dense fuel or is it the same in the oxide fuel?

Alexander Orlov
You mean in the quantity of plutonium used for the same amount of? I see. They are coming with a delay. Well, I can take this question for

note and clarify it for later. But for what I know is that there are various scenarios that have been researched for the dense nitride fuel. But I am going to have to come back with this question later.

Berta Oates
Okay, thank you. The next one is…

Alexander Orlov
Yeah I can see. This is short for Fast Reactor in Russia, BR, Bystry Reactor, which is short for Fast Reactor 1200. For the moment it is projected to be a lead coolant reactor.

Berta Oates
There is a question.

Alexander Orlov
I can see. I just need time to read it.

Berta Oates
If it's okay I don't think the attendees can see the questions. You just mentioned the competitiveness of Closed Fuel Cycle but haven't mentioned the main challenges that prevent adopting this approach. Besides technological challenges, the current prices of uranium caused many countries to see Closed Fuel Cycle as non-economical. What should happen that this approach would become the main one? Do you think that it should be a governmental decision to adopt this worldwide approach?

Alexander Orlov
Well, it's a good question. Of course, there are technological barriers and problems, but there are no technological barriers that couldn't be solved by research and development process. As for the economics, I'm not quite a specialist in economics, but in my opinion if we are developing a technology that could be creating new fundamental technology for the use up to 100 years up to 2100, we should not be taking into consideration only the uranium prices that are now.

Berta Oates
Excellent. Thank you. Those are the questions that I see. If you have additional questions for Dr. Orlov, please go ahead and type those in and we'll hang on just a little bit longer to make sure that we get all of your questions answered. I want to be sure and thank you again for your participation and a very interesting webinar presentation. I apologize that we were just a little late getting started today.

Alexander Orlov
It was my pleasure, thank you.

Patricia Paviet
Thank you Alex. Again, thank you for the audience. Sometimes, if you are like me, we had kind of a small delay between the time Alexander talked and the audience could see the slides. We apologize. We hope to fix this little issue for our next presentation on the 19th of February. Thank you Alexander. Thank you so much Berta.

Alexander Orlov
Thank you.

Berta Oates
Thank you Patricia.

Patricia Paviet
Bye.

Berta Oates
Bye.

Alexander Orlov
Bye.

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