Global Energy Challenges of the XXI Century and Potential Russian Contribution to World and Regional Nuclear Power

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ABSTRACT

The paper considers the world energy demand till the middle of the century, as well as possible forecasting solution for this challenge. On the base of the mathematical model developed in the Kurchatov Institute in 2003-2005, the vision of the global nuclear energy system and its potential contribution in the energy mix was analyzed. The rate of rapprochement between specific energy consumptions in different countries of the world is a key parameter determining the energy market strain. It was shown that a continuation of the current world trends of this rapprochement would result in an energy resource deficit already in the nearest future. Assuming the primary energy sources are growing with a rate close to IAE forecasts, the energy mix picture by the mid-century would contain an "unsatisfied demand" area (i.e., resources, which should be used to meet the projected energy demand). Supposing that the mankind has to meet the "unsatisfied demand" by nuclear energy, installed NPP capacities should make several thousand GW by the mid-century. Thus, the global energy challenges of the XXI century energy do not impose any upper limit on nuclear energy development, the scale of which would be determined by development opportunities. Key nuclear energy requirements – among which we can distinguish the fuel supply, the need of innovative technologies and the extension of application spheres – are determined by the scale of its use. Being one of the founders of the First Nuclear Era, Russia has a unique experience in solving the key problems of nuclear energy of the XX century, and is capable of making a worthy contribution in the challenges faced by the nuclear energy in the XXI century.

1. INTRODUCTION

Thirty-two countries with about two-thirds of the world population operate nuclear power plants. In 2006, in accordance with the IAEA data, 442 nuclear power reactors with total installed capacity of 369.7 GWe (net) were in operation worldwide. Over twenty other countries officially announced their intentions to create nuclear sectors in their national power industries.

Contemporary intentions of nuclear energy development by the mid-century, which the world countries are considering independently, have an internationally acknowledged target of about 1000 GWe.

The idea of consolidating the international efforts aimed at providing an open access to nuclear energy for all countries, while preserving and maintaining the non-proliferation regime, is an incentive for developing the global nuclear energy system concept, as well as for analyzing the outlook of the world nuclear power (i.e., its scope, structure and key requirements), which is obviously determined by the energy demand of the mankind.

2. ENERGY DEMAND

The growth of the global energy consumption in the XXI century is determined by the two principal causes: the growth of population (according to various expert assessments – 1.3-1.9-fold by the mid-century), and the rapprochement of per capita consumption levels in the world countries. Different sources estimate the energy consumption to increase with a factor of 1.6-2.5 by the mid-century.

The specific energy consumption time variance factor for the developed and the developing countries seems to be decisive, so it was specifically analysed by the experts of the leading Russian nuclear centre – Kurchatov Institute [1]. This analysis gave us important results (Fig. 1).

The assessment of the rate of rapprochement between specific energy consumptions in the two groups of countries is a key parameter determining the energy market situation. Assuming the rapprochement trend is maintained in the perspective, it is easy to calculate the required amount of primary energy. It can be shown that a continuation of the current world trends would result in an energy resource deficit already in the nearest future.

The fuel mix picture by the mid-century would contain an "unsatisfied demand" area (i.e., resources, which should be used to meet the projected energy demand).

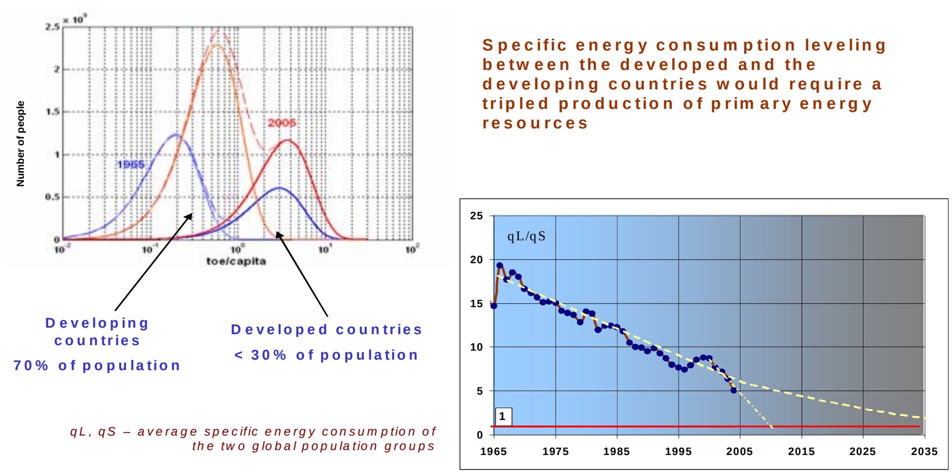


Fig. 1: Rapprochement by Specific Energy Consumption

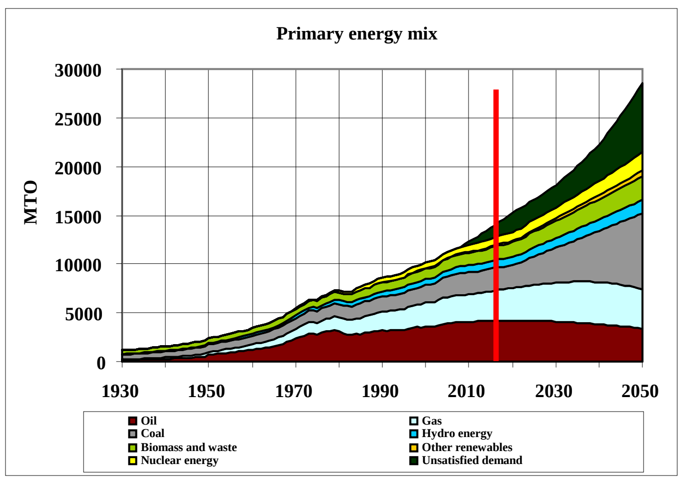


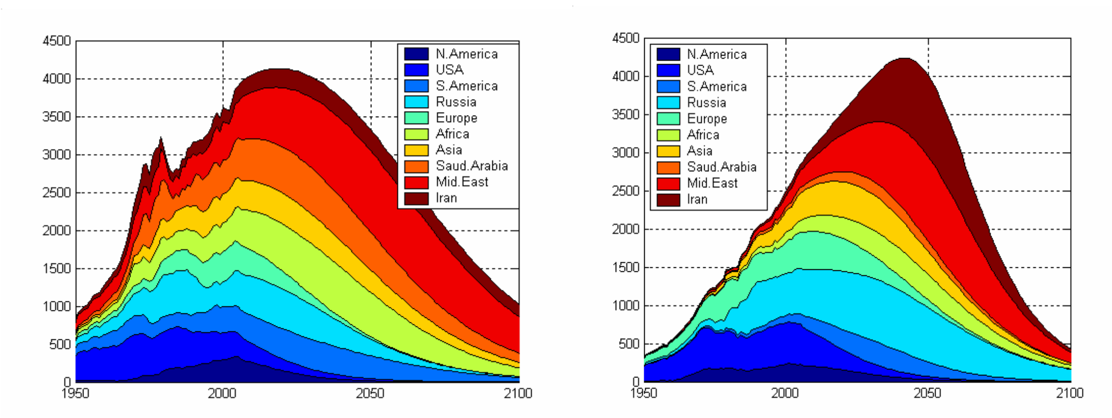
Fig. 2. Primary Energy Supply

Fig. 2 shows primary energy production forecasts together with the demand growth curve (by 2030 – IEA forecasts [2]. The scale of nuclear power development was assessed on the basis of contemporary ideas of its growth prospects (about 1000 GW of installed capacity by 2050 compared with the present level of 360 GW). Between 2030 and 2050, the assessment was extrapolated assuming the same growth rates of all energy technologies, except oil and gas.

These primary energy production growth assessments assume that coal production in 2050 would increase four times compared to the present-day level, hydro energy would increase twice, biomass uses for energy purposes – three times, renewables (mainly wind energy) – 9 times, and nuclear energy – three times. It is assumed that by 2050 the level of oil production, with account of its peaking production factor to be reached around 2020, would reduce by 10%, and the level of gas production would increase with a factor of 1.5. Forecasted (based on the Kurchatov Institute's assessments) dynamics of the global oil and natural gas production is shown in Fig. 3.

But, even assuming the maximal growth of primary energy production, the energy ratio between demand and supply cannot be balanced. Black color in Fig. 2 marks the area of unsatisfied demand, which makes about 10 000 Mtoe of total energy to be consumed by 2050.

It is seen that the deficit of energy resources could not be covered by nuclear energy only, even assuming its maximal – but still reasonable – growth rates (by 2000 GWe by 2050). Certainly, the potential of nuclear energy is considerably higher, but it would be a great problem to increase the level of its use so much in so short a period.



By 2050 - Data Base Statistic BP(2005); after 2050 – forecast depending on resource amount

Fig. 3. Oil and gas production in the world

Unsatisfied demand would present a permanent source of international tension, and no ways to eliminate it can be seen by the moment. Most probably, the demand of all energy resources would only grow. In this context, the intensions of nuclear energy development announced by many countries would probably revised towards further growth already in nearest future.

3. NUCLEAR ENERGY DEVELOPMENT SCENARIOS

Thus, the projected XXI century's world energy demand does not impose any upper limit on nuclear energy development, the scale of which would be determined by development opportunities meeting the list of requirements, which should be analysed right now.

The bottom level of nuclear energy development by the mid-century could be represented by the above-mentioned current plans of its development in the world countries, or by the 1000 GWe level, which has been considered as a "ceiling" recently enough.

It is important that the scale of nuclear energy development determines the key nuclear energy requirements – among which we emphasize the fuel supply, the need of innovative technologies and the possibility of application area extension.

In scenarios conditionally considered as "low" (below 1000 GW by 2050), fuel supply requirements are met relatively easily, and there is practically no need of innovations or possibilities of extending the nuclear energy application sphere. In fact, such scenarios leave nuclear energy on the level of a "technological experiment" (or a result of the countries' wish to possess nuclear technology in their national security interests), which has no significant impact on the energy supply of the mankind.

"High" nuclear energy development scenarios are (also conditionally) considered starting from the "medium" scenarios proposed by IPCC international expert group [3] as far as 2000, i.e. 2000 GW by the mid-century.

It is easy to predict that light water reactors (PWR, BWR, VVER), which currently make 80% of the world reactor park, will become the basis of nuclear energy development of many countries, which iintroduce nuclear power in their national energy mix (Fig. 4).

However, the restrictions imposed by the available uranium resources begin to manifest themselves already during the period considered here. Not only realistic 15 million tons (Red Book [4]), but also quite speculative 30 million tons would not be enough for high development scenarios based on light water reactors in the second half of the century.

Besides, the required amount of spent nuclear fuel repositories (dozens of facilities similar to Yucca Mountain) make this optional development unrealistic.

Innovations in form of a closed fuel cycle and fast neutron reactors, even those with moderate breeding (BR 1.25) would allow us to preserve integral (for 100 years) demand of natural uranium range up to realistic 10 million tons, and the maximum annual separation work up to 200 thousand tons of SWU (stabilized by the mid-century). Breeding systems would allow us to reduce the amount of spent nuclear fuel several times (Fig. 5).

Without going into much detail, it should be nevertheless noted that the calculations have practically considered the whole "range of interest" of the global nuclear energy system development scenarios: from the very moderate approach with about 1000 GW of projected NPP capacity by the mid-century, to the so-called "aggressive" nuclear energy increasing its market attractiveness by replacing a fraction of other energy sources in the electricity generation and in other applications – such as hydrogen, heat or potable water production, with the global nuclear energy system capacity reaching up to 10 000 GWe by 2100.

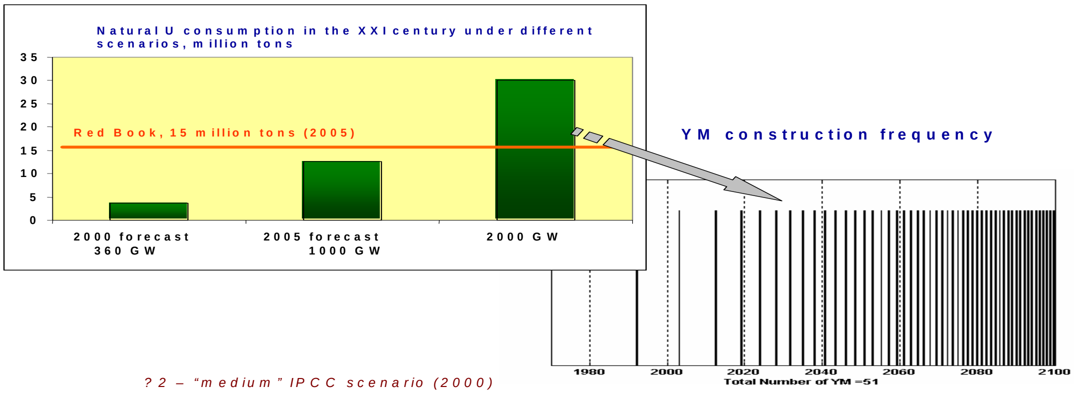


Fig. 4. Once-Through Nuclear Fuel Cycle

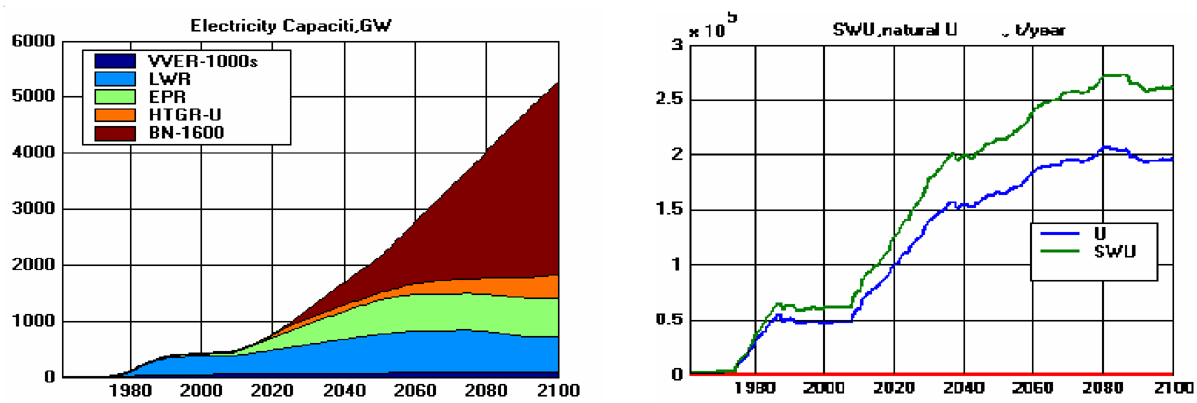


Fig. 5. Closed Fuel Cycle: "Moderate" Breeders (BR=1.25)

Thus, assuming the uranium resource constraints based on the existing data, realization of "high" nuclear energy development scenarios leaves a two-component nuclear energy system with plutonium breeding for further consideration.

The extension of NPP capacity ranges should be included on the list of innovative technologies needed by the world. Today the leading companies offer on the nuclear power market the nuclear power units with capacities starting from 1000 MW, while in conditions existing in many countries determine their interest in medium and small capacities.

It is also necessary to mention high-temperature reactors intended for extending the sphere of nuclear energy uses towards industrial technology – such as nuclear hydrogen, for instance.

It is not a coincidence, that many "fast nuclear deployment" countries (China, India, South Korea and others) are developing innovative nuclear energy technologies in practice.

As we see, the wish to develop nuclear energy with the given rate dictates so rapid innovations that – at least, for a considerable part of the world – its implementation would require a consolidated international effort to make nuclear energy accessible for all the countries concerned. It is several years that the analysis of the global nuclear energy system's outlook, as well as of innovative reactor and fuel cycle requirements, is underway (with considerable contribution of Russian specialists) in the framework of the IAEA INPRO Project [5], which today unites 27 countries.

4. RUSSIA'S CONTRIBUTION TO NUCLEAR ENERGY CHALLENGES

Being one of the founders of the First Nuclear Era, Russia possesses vast experience of solving the key nuclear energy problems of the XX century, and is capable to make a significant contribution in the challenges faced by the nuclear energy in the XXI century.

Today 10 Russian NPPs have an installed capacity of 23.2 GWe and generate about 16% of the country's electricity. In accordance with the government's Federal Program adopted in 2006, by 2020 the total installed capacity of Russian NPPs should reach 41 GWe, with annual energy production of about 300 TWh. The government intends to invest over 25 billion USD from the federal budget in the construction of NPPs between 2007 and 2015.

Russia's nuclear industry is capable of supplying competitive high-technology products to the world market. This is especially true for nuclear fuel cycle products and services. Our nuclear industry includes areas, where our country's authority is internationally recognized, such as: uranium enrichment (isotope separation services) and SNF management (long-term storage, transportation and radiochemical reprocessing services). Russia's world market share in uranium enrichment makes 42%, in NPP construction – 15%, in nuclear fuel fabrication – 14%, and in uranium production and nuclear fuel reprocessing – 8%.

There are also some nuclear power technologies, where the available experience and prospects could give Russia a stable position in nuclear exports – comparable, according to Russian experts' assessments, with their internal consumption.

4.1 VVER reactors

Construction of Loviisa NPP with VVER-440 reactors in Finland in 1977 has been the first case of VVER technology implementation in the West. The total of 65 VVER units has been built, including 48 VVER units constructed abroad. It can be said with confidence that VVER technology will play a considerable role in the nuclear energy of the XXI century.

As concerns the new nuclear construction in the short term, the technology meeting international standards and ready for large-scale implementation is the technology of VVER-1000. Existing VVER-1000 designs have many references, and are currently being built in China, India, Iran and Bulgaria. The nearest prospects of VVER line are connected with the implementation of the unified NPP-2006 design with a VVER of 1200 MWe capacity.

4.2 Small and medium reactors for regional energy

The task of deployment of regional nuclear power plants adds to the development of large nuclear power units.

Russia possesses a unique experience of serial industrial fabrication of nuclear power facilities for nuclear submarines, cruisers, icebreakers and other vessels, totaling to over 6000 reactor-years, as well as a developed scientific, design and industrial infrastructure of nuclear shipbuilding.

This experience in the field of sea technologies could be used efficiently for creating medium power units of industrial fabrication, the best adapted to grid and capacity conditions existing in regional energy supply. This reactor type could become the most attractive one for the world market.

By the moment, the design of a small NPP with floating KLT-40S power unit (improved serial facility of nuclear icebreakers) having two light-water reactors of 35 MW capacity each is the closest to practical implementation. Floating NPP construction began in the town of Severodvinsk in 2006. Its commissioning is expected in 2010; and it is planned to create a series of seven similar plants by 2016. Between 2013 and 2019, it is also supposed to build a large series (about fifteen) of floating nuclear electricity and heat co-generation plants of smaller capacity (17 MWe). Over twenty countries have already expressed their interest in such small plants, with account of their desalination capabilities.

Nuclear power facilities, as well as floating and onland NPPs on their base ranging from 6 to 600 MWe, are currently proposed on the basis of nuclear shipbuilding technologies.

4.3 High-temperature gas-cooled reactors

Our country's research stock in the field of high-temperature as-cooled reactors (HTGRs) makes over 50 years of R&D, which reached the stage of detailed design (ABTU-50, VG-400 with outlet temperature of 950^{o}C), as well as the operating prototype space propulsion facility with unique outlet temperature of 3000 K.

HTGRs could serve as an efficient energy source for electricity generation and hydrogen production from water, thus creating the basis for environment-friendly nuclear hydrogen energy.

4.4 Closed nuclear fuel cycle and fast neutron reactors

As shown above, the key development directions of innovative nuclear energy development are: the closing of nuclear fuel cycle and the development of fast breeder reactors.

Here Russia also has over 50 years of R&D, several prototype reactors and 20-year experience of operating BN-350 reactor coupled with a desalination facility. Our country is the only country in the world, which continues to operate a commercial fast neutron reactor with sodium coolant – BN-600. Future construction of a nuclear power unit with BN-800 reactor would be an important step towards the preservation of fast reactor technology and its further successful development.

The next stage of works on implementing the concept of fuel breeding and the closed fuel cycle in the short term would consist of developing an innovative NPP design with the lead serial reactor BN, as well as developing and constructing industrial facilities for fuel production and recycling.

This would allow us to reach a considerable progress in the practical implementation of fast sodium-cooled reactors without waiting for cheap uranium resources' exhaustion, and to preserve our high-technology industry infrastructure needed for sustainable nuclear energy development. Moreover, the escalation of global fossil fuel prices in the recent years may draw nearer the starting time of intensive deployment of NPPs with fast neutron reactors.

5. CONCLUSION

- The world is entering a system energy crisis, Nuclear energy development can considerably mitigate the situation at the energy market to the mid-century;
- Many countries are interested in developing nuclear energy to assure their energy security and to preserve and efficiently use their resources, as well as to export them;
- Russia is capable of making an important contribution in the challenges faced by the nuclear energy in the XXI century.

6. REFERENCES

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