Nuclear's Second Wind

Innovative "fast" nuclear power plants may be a strategic imperative

by Evgeny Adamov

Nuclear power needed 50 years to gain the same position in global energy production as the one achieved by hydropower over hundreds of years. All those years, proposals for new reactor concepts would come up every now and then alongside mainstream reactor technologies. In the nuclear-friendly 1960s and 1970s, some of those "innovative" concepts even led to demonstration or pilot projects.

Yet for all the diversity of new ideas, nuclear power entered the new century still moving in a rut of older mainstream technologies. Most were devised at the dawn of nuclear engineering, when reactors for production of weapon-grade isotopes and reactors for nuclear submarines propelled development.

Unless we understand the reasons why innovative technologies failed to make any appreciable progress way back then, it is impossible to answer the question of whether there is a need for them now or in the foreseeable future.

Few people, perhaps, may remember that nuclear power was not brought into existence by energy deficiency. Its advent was caused by the Second World War and the associated pressing necessity for increasing the power of weapons. Once the war ended, nuclear plans were fuelled by the intentions of both weapons designers (e.g., Russia's I. Kurchatov who initiated construction of the world's first nuclear power plant in Obninsk and US politicians led by President Dwight Eisenhower's "Atoms for Peace" Initiative in 1953) to counterbalance the military effort by encouraging peaceful nuclear applications.

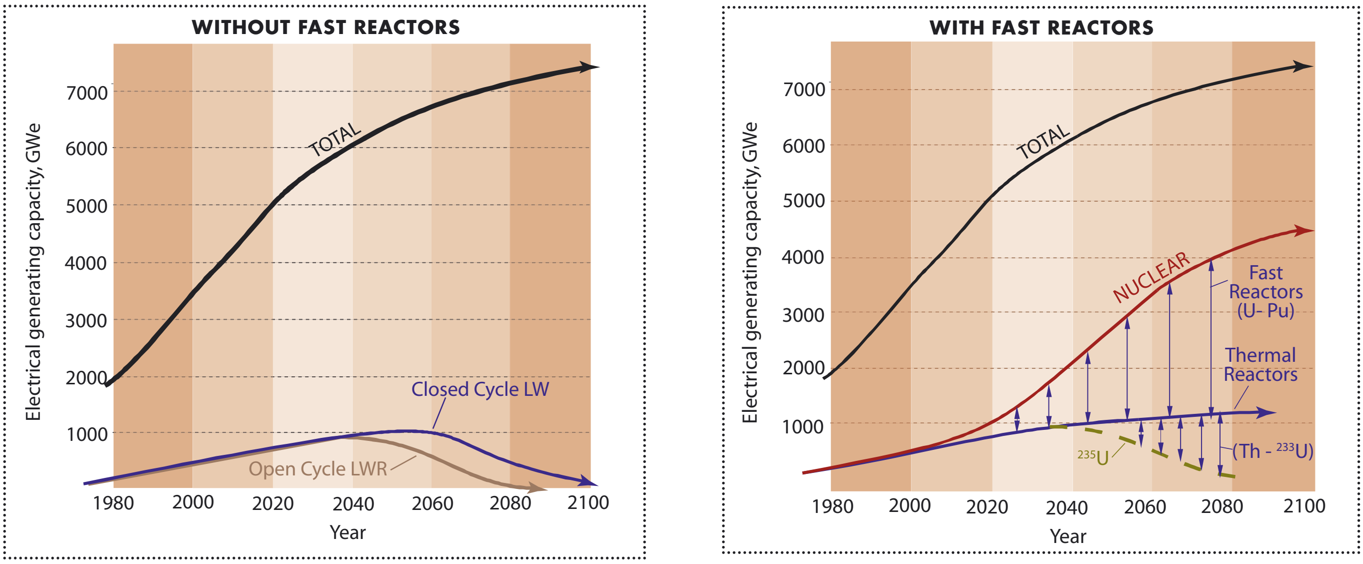
The Changing Context

Today, energy demands still are largely met by fossil fuels, as they were at the outset of nuclear development. In recent decades, zealous supporters of nuclear power have repeatedly referred to the imminent shortages of fossil fuels, though this gloomy prospect will not threaten humanity for another 100 years. That means potential shortages are not the only — or predominant — factor to encourage active search for alternative sources of energy.

Other factors have come more in play. One is the changing environmental context. At the end of the last century, acute environmental awareness demanded a closer look at "green" energy solutions. Nuclear power was assessed and shown to have advantages in terms of environmental protection over the majority of other energy technologies. However, the political enthusiasm of the Kyoto Protocol proponents has recently dropped so low that, with even more convincing evidence of the greenhouse effect hazard, reasons may still be found for taking the problem of greenhouse gas emissions off the priority list. Given the current 6 % share of nuclear in the total energy balance, it is quite reasonable to expect that the overall contribution of the so-called alternative sources (wind, solar, tidal, biomass, geothermal and other forms of energy) may well lead to expulsion of nuclear without noticeable losses to global energy supply.

Another factor is the evolving political framework. In the early period of nuclear power, it was assumed that the commercial industry would develop in the context of bipolar possession of nuclear weapons (NATO with the USA at

Figure 1: **Projected Nuclear Capacity Growth**



Notes: Tentative scenario, assuming potential inexpensive uranium reserves of approximately 10 Mt.

the head *versus* the Warsaw Treaty led by the USSR). As it turned out later, weapons-related technologies would not be confined to the circle of five States declared to belong to the nuclear club. Instead, the problem of non-proliferation acquired a more acute significance compared to developments influencing energy technologies. This was especially so in the context of the energy-saving drive and newly found oil and gas fields — including offshore deposits — which brought down the price of fossil fuels to record-breaking levels.

There is still much room for analysing why nuclear power not only fell far short of reaching generation levels projected in the 1970s, but also why it is very likely to keep losing its share on the energy market during the next 10 to 15 years. Such an analysis has been done in Russia and other countries. With such an approach, the requirements imposed on nuclear power are not subject to normal considerations of the market alone, and nuclear power itself should not be treated as a conventional sphere of commercial activities (as was persistently suggested in the previous decade).

Nuclear's "Second Wind"

The important point is that the necessity for innovative nuclear technologies needs to be assessed in the changing context. It is important to examine the possible conditions that may cause a demand for nuclear power and the circumstances under which the technology may gain its "second wind". For some countries, such as France and Japan, the lack of their own oil or gas resources is in itself a sufficient motive for keeping nuclear in the energy mix. Others may seek diversification of the energy sector or self-sufficiency in energy as a high priority.

Safe nuclear power is also capable of producing hydrogen, for example, and doing it in a profitable way. This use would allow reducing consumption of fossil fuels in electricity generation in the future, thereby saving these resources for other, more expedient applications in transport and energy-intensive industries. Even today, this may be an attractive option for some strong economies.

It is important to examine the possible conditions that may cause a demand for nuclear power and the circumstances under which the technology may gain its "second wind".

Yet paradoxical as it may seem, nuclear's second wind could be fuelled by rising costs and concerns over weapons proliferation and how to manage risks. Until nuclear weapons are totally banned and eliminated, proliferation will remain a risk demanding tight controls to keep nuclear materials and technologies from falling into the wrong hands. Right now, efforts to maintain and develop nuclear technologies, the associated expertise and industrial facilities for the sake of nuclear weapons alone is by far a greater social and economic burden in terms of public spending than if this know-how were channelled and shared for energy production.

In Russia, for instance, activities to remedy the consequences of nuclear-weapons programmes are estimated at tens of billions of dollars, which are yet to be found in the national budget. Meanwhile, reasonable implementation of the strategy for dynamic nuclear power development to the year 2050, already endorsed by the Russian Government, is a way to avoid diverting these weapons-related funds from other sectors of social demand.

In my view, the way forward is to develop advanced nuclear power plants based on technologies that help deter the spread of nuclear weapons. Large-scale nuclear power should be built upon innovative reactor designs and fuel processes that can provide technological support to the nuclear non-proliferation regime, while helping to meet the world's electricity needs.

"Fast" Nuclear Plants

On non-proliferation and other grounds, designs for *fast neutron reactors* offer the most promising option *(See box, Fast Reactors).* They would burn uranium-238 alone and, hence, allow eliminating uranium enrichment and separation of weapons-grade plutonium from the set of fuel-cycle technologies now used for nuclear power operation. Unlike earlier types, these fast reactors will have no fuel blanket where weapons-grade plutonium could be produced.

This option enables nuclear power development to become more technologically detached from the production of materials useable for weapons. It further would support other elements of the non-proliferation regime, including political and legal arrangements, such as inspections. These could be considerably facilitated, for example, by using satellite systems to watch the configuration of fuel-cycle buildings.

With such an approach, States now shouldering the cost burdens of nuclear proliferation could channel efforts differently. They could define the optimal conditions for sharing the advantages of innovative nuclear energy technologies with countries that have no nuclear weapons and, at the same time, feel a pressing need to develop their own energy production systems.

So, for example, while providing maximum access to nuclear technologies, nuclear States could address the non-proliferation problem, at first, by arranging — all on their own — energy production in needy regions of Asia and Africa. The use of nuclear energy, subsidised in its early development period in these regions, would be essentially non-commercial, and based on international assistance. The initiative thus might become a crucial factor in stabilising the political situation in areas of international conflicts — both known today and likely to appear in the future. At the same time, this initiative would fit excellently into the currently practised "design-build-operate" approaches and may well turn into major business for State-owned or international corporations as energy markets develop.

In my view, the way forward is to develop advanced nuclear power plants based on technologies that help deter the spread of nuclear weapons.

Can Nuclear Meet the Needs?

If nuclear power is to be considered as a strategic imperative for global economic and security, it is necessary to have a clear idea of its potential. Based on today's reactors and using an open fuel cycle (without reprocessing), nuclear power would use up the available reserves of reasonably priced uranium towards the end of this century. The total capacity of nuclear power plants would not rise much higher than the current level of about 350 GWe. By reprocessing and reusing fuel in thermal reactors, as practiced in some countries, a 15 to 20% increase in total power output could be attained. If thorium were used as fuel in addition to natural uranium, nuclear's potential contribution could be doubled at the most.

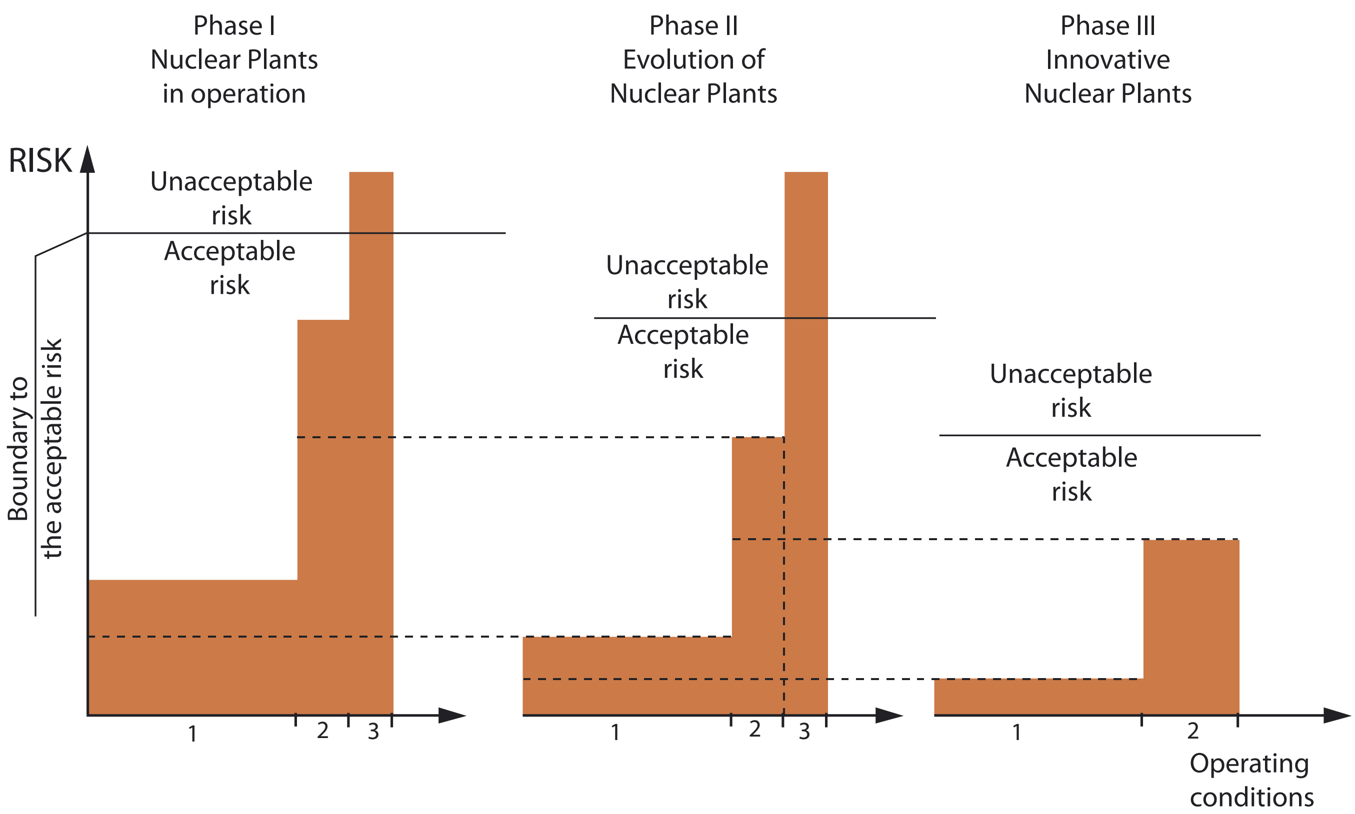
Fast Reactors

Fast reactors are not new, but their development is breaking new ground. Initially they were designed and configured to both consume and produce fuel. Such "breeder" reactors burn uranium fuels and breed plutonium that can be reprocessed and recycled to fuel reactors anew. France, Russia, Japan and other countries developed fast breeder reactors, though only a few generate electricity commercially today. Russia's BN-600, for example, has been supplying electricity to the grid since 1981.

Today's commercial nuclear plants mainly are "thermal" reactors that may or may not include fuel reprocessing. In basic terms, "fast" and "thermal" refer to what's happening inside the reactor core. In all types of reactors, the fission, or chain reaction, that generates heat is kept going by the energetic collision of neutrons with the fuel. In a thermal reactor, the neutrons are slowed down to what physicists call "low energy" by a moderator, such as graphite or water. In a fast reactor, the neutrons from the chain reaction are not slowed down and stay at "high energy".

For more technical information about fast reactors and what countries are doing, visit the IAEA's nuclear energy web pages at www.iaea.org.

Figure 2: **Nuclear Safety in Terms of Risk Categories**



1- Normal Operation; 2- Design-basis accidents; 3 - Beyond-design-basis accidents (including severe accidents)

The projected picture changes significantly if fast reactors are deployed and a closed fuel cycle is followed so that spent nuclear fuel is reprocessed and recycled for energy use. Nuclear then could provide all of the required increase to electric power production foreseen during the next few decades by the World Energy Congress (WEC). At a later point, nuclear would even be able to do away with constraints on fuel resources. The requirements of the Kyoto Protocol would be met automatically in this case and the greenhouse gas emissions of the power industry could be fixed at any predetermined level.

If large-scale nuclear power is to be considered as a realistic option, there is no escape from the conclusion that the foundation of the industry should be formed by fast reactors.

In recent years, the pessimism of the 1990s has given way to some tendencies towards reinstating nuclear power among the priorities of energy strategies in a number of large countries, such as China, India, Iran, and Russia. The National Energy Policy of the USA also is quite symptomatic in this respect. Nevertheless, whatever the motives for nuclear power revival may be, the primacy of non-proliferation will remain an invariable priority of international politics. If large-scale nuclear power is to be considered as a realistic option, there is no escape from the conclusion that the foundation of the industry should be formed by fast reactors. Down the line, successful solution of the problem of controlled thermonuclear fusion may only add to nuclear's capabilities to meet ever-increasing global energy demands.

Safety & Waste

Beyond energy and proliferation concerns, the issues of nuclear plant safety and radioactive waste disposal are important to consider.

On the waste front, the nuclear engineering expertise built up throughout the years has helped find very efficient ways of radioactive waste disposal. These include various methods of sealing it off from the environment and burying it in carefully chosen geological formations. It is always a problem, however, to demonstrate safety of any storage facility — let alone a spent fuel repository — for a geologically meaningful span of time. This points to the need to develop a fuel cycle that does not add to waste problems, but minimizes them.

A nuclear electricity system based on fast reactors and a closed fuel cycle would make it possible to achieve what has been called "radiation-equivalent management" of nuclear materials. This management involves a process known as "transmutation" of minor actinides and fission products that is being developed as an alternative strategy for reducing and managing long-lived radioactive waste. With a closed fuel cycle for fast reactors, for example, the total activity of nuclear waste would approximate that of mined ore in no more than 150 to 200 years. This is certain to influence public perceptions of waste management.

Regarding plant safety, I cannot but acknowledge impressive achievements in the safety improvement of existing nuclear plants, through the use of probabilistic safety assessments and other measures. However, if we pursue the right innovative nuclear technologies, reactors can be developed that present no chance of severe accidents by virtue of their design, physics and materials. The advantages of such facilities may prove decisive in the public choice.

Such reactors have been referred to recently as "natural safety facilities". They would rely for their safety on laws of nature, rather than on additional engineered safety barriers and extra personnel. For instance, fast reactors can be designed so that their physics would exclude the possibility of serious accidents such as occurred at Chernobyl in 1986 or at Three Mile Island in 1979. *(The differences are illustrated in Figure 2.)*

Global Cooperation & Support

On various grounds then, fast reactors could open up new opportunities for assuring nuclear power's competitiveness. To serve strategic interests for energy and non-proliferation goals, national and international support will be needed for this new chapter in nuclear power development.

Many studies have analysed and defined the basic safety, economic and associated requirements for innovative reactor technologies. These are fundamentally different requirements from those of the 1960s and 1970s. The new requirements were translated into the key principles laid down in the Strategy of Nuclear Power Development in Russia in the first half of the 21st Century and were cited by the Russian President in his Initiative for International Cooperation announced at the UN Millennium Summit in New York in September 2000.

The IAEA General Conference in 2000 additionally gave rise to the so-called INPRO programme (International Project on Innovative Nuclear Reactors and Fuel Cycles), through which many countries are collaborating *(see "Fuelling Innovation" in this Bulletin edition)*. Recent statements of IAEA Director General ElBaradei are largely in accord with President Putin's global initiative.

In parallel, changes in the political attitudes towards nuclear energy, reflected in the US National Energy Policy, drove some countries to join forces through the Generation IV International Forum (GIF) for developing advanced nuclear reactors. Six reactor concepts, including fast reactors, have been selected for more detailed review before a final decision is made.

To serve strategic interests for energy and non-proliferation goals, national and international support will be needed for this new chapter in nuclear power development.

Incidentally, such work was carried out in Russia in the last decade and led to the choice of a lead-cooled fast reactor whose engineering design is in detailed development. The project is in a very advanced stage, and a site has been chosen in the Urals for possible construction of a demonstration plant. During the same period, R&D efforts were completed to support the approach of radiation-equivalent management of nuclear materials. The findings of the studies could serve as a basis for comparison with other reactor concepts and approaches to fulfilment of fuel cycle objectives.

The review of progress through INPRO and GIF has shown that the two could be coordinated, provided that the final goal is harmonised and defined as development of economically competitive large-scale nuclear power based on a closed fuel cycle and proliferation-resistant technologies. In light of rising interest in new approaches for nuclear power, it may be expedient to join INPRO and GIF activities to reach their common objectives through international cooperation. Successful implementation of the International Thermonuclear Experimental Reactor (ITER) fusion project, even though it comes ahead of the actual need for such facilities, is an excellent example of efficient cooperation in tackling the most challenging engineering tasks.

Cheap electricity produced by innovative nuclear power plants is an attractive basis for future economic development. It can help efforts to eliminate the oppressive disparity in regional standards of living and, ultimately, help resolve the basic reasons underlying political tensions and international conflicts.

Evgeny Adamov served as Minister of the Russian Federation for Atomic Energy from 1998-2001, and has been an Adviser to the Chairman of the Russian Government since 2002. Full references and further technical details may be obtained from the author. E-mail: avde@nikiet.ru