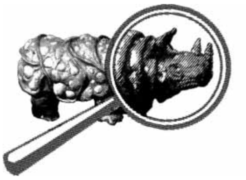

Nikolai Ponomarev-Stepnoi

GLOBAL NUCLEAR ENERGY ARCHITECTURE: A KEY TO ENERGY SECURITY

ANALYSIS

The future of nuclear energy has become a subject of much debate. Will nuclear power plants become the central part of our energy strategies, or will safety concerns spell the end of the *nuclear renaissance*?

Before discussing the problems facing nuclear energy, let us look at what energy security means in this day and age.

First, even if a certain primary energy resource is plentiful, it will not be in great demand if the associated costs are greater than a certain proportion of the GDP. This balance between GDP and energy consumption is key to economic development. The cost of primary energy has immediate repercussions for the rest of the economy. In the early 1980s spending on energy rose to more than 10 percent of GDP. The proportion was the same in 2008. Both periods were a time of economic crisis. Such high energy prices had proved too much for the economy and society to bear.

Second, the gap in energy consumption between the rich countries and the developing world is closing. Rapid economic growth in the developing countries is increasing global energy demand. Their per-capita energy consumption figures have been gradually catching up with the rich world's indicators for the past five decades. In the 1960s the average for the developing world was less than 5 percent of Western figures. It has now grown to about 15 percent. Industrial growth in the developing countries, which is the main engine of higher energy consumption, is now much more rapid than in the developed economies. That trend is being reinforced by the flow of investment and technologies from the rich world to the developing countries, where labor is cheap. There are now fewer barriers to cross-border flows of expertise, technologies, materials, and equipment. The circulation of information, know-how, and products has become much easier. As energy consumption in the developing countries catches up with the rich world, the demand for primary energy resources will see rapid growth. It will triple in as little as 10 years if the developing countries manage to maintain their GDP growth figures at their current level. If growth slows, that tripling might take up to 40 years.

Third, the problem of rapidly growing energy consumption can be resolved by diversifying our energy sources; renewables and nuclear energy will be especially important. Hydroelectric energy and coal will also have a role to play. The easiest way to meet growing demand would be to ramp up oil and gas output—but global oil production may have already peaked. Natural gas still has some room for growth, but gas alone will not be enough to plug the gap between energy supply and demand. There are still plenty of hydrocarbons left underground, but they are becoming increasingly costly to produce; at some point developing the untapped oil and gas fields in difficult geological conditions and harsh climates will simply become uneconomical.

Based on the three considerations outlined above, this article will analyze the role nuclear energy can play in energy security. It will also look into the obstacles on the way to increasing that role, and possible ways of addressing them.

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CURRENT AND POTENTIAL ROLE OF NUCLEAR ENERGY

It is clear that the world economy is facing a serious shortage of fossil fuels, which tend to be concentrated in a few energy-rich countries. One of the obvious solutions is renewable energy sources such as solar, wind, biomass, hydroelectric, and tidal energy. Their role will certainly continue to increase—but they still remain very costly, which slows their adoption.

Nuclear energy is not renewable, but by burning U-235 reactor fuel it is possible to produce new fuel from the U-238 or Th-232 isotopes, which are more plentiful than U-235 by a factor of several hundred. Fuel breeding allows for a far more efficient use of the nuclear materials already produced; it also makes more expensive resources economical to produce. The fuel breeding mechanism essentially makes nuclear energy inexhaustible, for all practical purposes. This unique feature of nuclear fuel makes it very promising in terms of meeting the world's growing energy requirements. The existing nuclear energy industry has already demonstrated that producing electricity from nuclear fuel is entirely economical. The possibility of producing hydrogen with the help of high-temperature nuclear reactors also expands the possible uses of nuclear energy beyond electricity. Hydrogen as an energy storage and as a chemical agent is key to a multitude of new technologies that can be used in industry, utilities and transport.[1]

Other advantages of nuclear energy include the abundance of fuel, many areas of commercial application, availability, technological maturity, and smaller environmental impact compared with organic fuels.

But for all these advantages, which attract growing interest in countries around the world, nuclear energy also has clear downsides, especially safety and security concerns. Public perceptions make a steady link between nuclear energy (even peaceful), nuclear weapons, and radioactive contamination. The public is concerned about the risk of civilian nuclear materials and technologies being diverted to nuclear weapons programs. That risk will grow as more countries adopt nuclear energy, especially if their nuclear energy programs involve such proliferation-sensitive nuclear fuel cycle elements as uranium enrichment and spent nuclear fuel (SNF) processing.

The radioactive contamination risks have been highlighted by several high-profile accidents at civilian nuclear energy facilities. The spread of radiation after the accidents at Chernobyl and Fukushima far beyond the national borders concerned has demonstrated the global nature of this threat.

Nevertheless, having weighed all the pros and cons, many countries, including those with no nuclear experience whatsoever, have informed the IAEA of their intention to start developing peaceful nuclear energy.[2] This growing global interest in nuclear power plants raises the need for the international community to develop a global civilian nuclear energy infrastructure that would enable as many people as possible to benefit from nuclear energy without exacerbating the existing safety and security risks.

LEAFING THROUGH THE OLD PAGES

MOHAMED ELBARADEI: We are trying to achieve a broad understanding of the advantages of nuclear energy from the environmental point of view compared to other energy sources. It is important for such comparisons of energy sources to be impartial and balanced. <...> We are determined to make sure that nuclear energy remains a viable source of energy production for countries which choose to use it. Nevertheless, it is also obvious that there are different opinions among the international community and among the IAEA members. It is not part of the agency's remit to foist nuclear energy or any other nuclear technology on countries which don't want these technologies. <...> But we do want a more active dialogue on nuclear issues with government leaders, NGOs and the general public because we believe that by raising awareness of the benefits of nuclear technologies we can make the collective search for solutions to the problems facing our planet more effective.

''The Nuclear Nonproliferation Regime Is Going through Difficult Times'', *Yaderny Kontrol* (Russian Edition), 2004, No. 1, p. 15

Nuclear energy safety and security is a broad definition, which includes accident prevention, nonproliferation, physical protection, accounting, and control of nuclear and radioactive materials. These requirements apply to every component of the nuclear energy infrastructure, including nuclear power plants and all nuclear fuel cycle facilities, and to every stage of their lifecycle, in line with the so-called cradle-to-grave approach.

It is obvious that the objective of such magnitude can be achieved only through joint efforts by the international community. Nuclear energy is a global phenomenon. Nuclear energy safety and security transcends national borders. The problem of developing nuclear technologies while also ensuring their safety and security cannot be resolved by individual nations in isolation. Besides, developing the entire nuclear fuel cycle, from mining the raw materials to nuclear waste disposal, is something only a few nations can do on their own. That is why it is necessary to develop a global nuclear energy architecture.

Efforts to develop that architecture will include two tightly intertwined components. The first is developing and improving the actual nuclear technologies. The second is building the organizational and regulatory framework to define the kind of conduct that is expected of every participant in the global nuclear energy infrastructure.[3] Let us now take a detailed look at these two components, and at the areas where technology and organization are inextricably linked.

TECHNOLOGICAL ASPECTS OF NUCLEAR ENERGY DEVELOPMENT

The Nuclear Fuel Cycle

The international nuclear community continues to debate the relative merits of the partial versus the complete nuclear cycle.

One of the main arguments being made by the proponents of the former is that it does not include the extraction of plutonium from spent nuclear fuel and its re-use in nuclear reactors. They believe that this solves the problem of proliferation. But such an approach also raises new problems: the resources of cheap natural uranium are limited, and the volume of spent nuclear fuel that will have to be stored somewhere will keep growing as enriched uranium production continues to increase. For example, if installed nuclear capacity grows to about 2,000 GW by 2050, annual uranium mining will have to increase to over 300,000 tonnes. More than 10 million tonnes of uranium will be consumed between now and 2050; separation capacity will increase to about 450 million SWU per year, and about 10 nuclear waste storage facilities similar in size to the Yucca Mountain repository will have to be built. The annual capacity of NFC facilities will have to grow in proportion to new generation capacity being installed, and new reactors will have to be supplied with fuel for the entire duration of their lifespan, which can be as long as 60 years.

All of this will put too much strain on the supply of cheap uranium fuel. Nuclear energy will essentially face the same constraint as fossil-fuel energy, i.e. fuel deficit. As for the spent fuel repositories, the Yucca Mountain project in the United States, which was to be able to accommodate about 70,000 tonnes of material, was facing huge difficulties and eventually had to be cancelled.

Finally, the increase in uranium enrichment capacity required by the partial nuclear cycle model runs counter to the main argument being made by its proponents regarding the need to take proliferation concerns into account. The United States is well aware of this problem; it is working to develop the modified partial cycle model, which includes spent fuel reprocessing and partial separation of the resulting products so as to use the uranium fuel more efficiently.

In contrast, a complete nuclear fuel cycle can accommodate the fuel supply requirements of a nuclear energy sector of any size without running out of cheap natural uranium. It also addresses the problem of radioactive waste disposal. The ability of fast breeder reactors to generate nuclear fuel in large quantities enables them to produce enough fuel to keep themselves in operation and even leaves a surplus that can be used to load the initial fuel batch into new reactors, and to supply the existing thermal reactors. This feature of breeder reactors can be used to establish the complete nuclear fuel cycle, which includes SNF processing and using the extracted newly generated fuel material and minor actinides to produce fresh fuel. The nuclear waste that results from SNF reprocessing is much more compact than the original spent fuel itself; after a series of additional operations it can be moved to final storage. The initial fuel batch loaded into fast reactors will use plutonium produced by thermal reactors. There is already enough of it to load the fast reactors; some of it can also be added to the fuel mix used in thermal reactors.[4] For that reason we need to make a start on developing and introducing technologies for processing spent nuclear fuel—first from thermal, and then from fast reactors—and using the extracted plutonium in mixed fuel for improved thermal reactors and fast breeder reactors. In addition to centralized SNF reprocessing and fuel recycling facilities, research is also under way into the on-site nuclear fuel cycle at the nuclear power plants themselves. One important requirement of a complete nuclear fuel cycle, which defines how quickly the reactor plutonium can be returned to produce fresh fuel, is the duration of one complete cycle; it should take no longer than three years, if at all possible. The capacity of SNF reprocessing facilities could reach about 50,000 tonnes a year by 2050, and the amount of plutonium being re-circulated about 1,500 tonnes a year.

Nuclear Reactors

The nuclear energy sector is currently dominated by thermal (slow) light water reactors used for centralized production of electricity. In future thermal reactors can be used not only to produce electricity but also to supply energy to industrial facilities and utility services, to desalinate water, and to produce hydrogen. There will be a market for a broad range of reactor sizes: small and medium ones for autonomous and regional consumers, and big ones for centralized grids. It will be necessary for these reactors to be able to work in load-following mode. Thermal reactors will also need to become more efficient at burning their fuel (to get the reproduction ratio to about 0.9) and to be able to use different types of fuel (U, Pu, Th). These requirements can be met by improving the existing light-water technology, as well as developing new reactor types, including high-temperature gas reactors. Technological innovation in reactor design and nuclear fuel composition should also aim to improve safety, with a special emphasis on minimizing the risk of serious accidents.

The global nuclear energy architecture which relies on a complete nuclear fuel cycle should include fast reactors designed for both electricity generation and nuclear fuel breeding (Pu, U-233) with a complete nuclear fuel cycle for uranium, plutonium, and minor actinides. Due to the duel purpose of fast reactors, the optimum power output level for one such reactor is about 1 GWe, and it is better to keep them in the baseload operational mode.[5] The fuel breeding ratio for fast reactors can be as high as 2.0.[6] The choice of the exact type of fast reactor—i.e. the core coolant and the fuel type—and of the resulting breeding ratio is determined by the pace of nuclear energy development, the availability of natural uranium, the ratio of fast and thermal reactors in the nuclear energy sector, safety and security considerations, and various economic variables. Based on current projections for global nuclear energy development and its future structure, the breeding ratio of fast reactors should be at the level of 1.2–1.5. Fuel breeding by fast reactors, in combination with the local nuclear fuel cycle at the NPPs, imposes restrictions on exports of this technology. On the other hand, using fast reactors without fuel breeding, and with an enriched-uranium initial fuel load, will slow the pace of nuclear energy development due to the limited resources of natural uranium; it will also require additional uranium enrichment capacity.[7]

TECHNOLOGY PLUS INTERNATIONAL REGIME

Nuclear Nonproliferation

Measures and actions aimed at reducing the risk of nuclear proliferation must not be ad hoc or reactive. This requires continuous research into the existing and potential threats to the nonproliferation regime resulting from widespread adoption and development of nuclear energy. Such research should be based on a systemic analysis of nuclear energy development in order to identify and assess the proliferation risk factors. These factors include:

- ❑ growing number of countries which use nuclear energy;
- ❑ growing number of nuclear power plants;

- ❑ development of the complete nuclear fuel cycle, including SNF processing and recycling of nuclear materials;
- ❑ growing number of nuclear fuel cycle facilities, including enrichment plants;
- ❑ growing circulation and transport of nuclear materials;
- ❑ use of fast breeder reactors;
- ❑ growing volume of radioactive waste.

Systemic analysis should lead to recommendations regarding specific steps to strengthen the nonproliferation regime. Such recommendations will obviously have to be the product of a compromise, taking into account the economic and energy security benefits of installing additional nuclear capacity versus the potential damage that can be done unless the nuclear energy architecture is made more proliferation-resistant. To make these recommendations more reliable there needs to be an instrument that would enable comparative quantitative analysis of proliferation risks resulting from the adoption of various solutions.

At present, solutions to the proliferation problem are being sought using qualitative criteria first developed some 40 years ago. Nuclear technologies have come a long way since then, becoming cheaper and more widely available in the process. The international climate in which these old criteria were formulated has also seen substantial changes. Technological progress, greater availability of nuclear technologies, their falling costs, and less stringent secrecy associated with all things nuclear have changed the situation very dramatically. For example, the emergence of new technologies such as enrichment centrifuges has radically shifted the balance of proliferation risks associated with nuclear energy.

One recent proposal is to perform quantitative assessment of risks based on statistical processing of expert assessments.[8] The method has been applied to compare the risks of various types of materials being diverted to secret nuclear weapons programs, and thereby to spot the vulnerabilities in the existing nonproliferation mechanisms. Table 1 gives an example of such a quantitative approach being used for comparative assessment of proliferation risks depending on the type of nuclear materials being used.

This instrument of qualitative analysis of the risks can and should be used to develop institutional solutions aimed at addressing nuclear nonproliferation problems in the new era nuclear energy is now entering. It can also be used to compare the risks associated with various innovative reactor designs and nuclear fuel cycle technologies.

A great deal of research relying on quantitative analysis will be needed to assess and optimize various institutional solutions designed to facilitate widespread adoption and development of nuclear energy. Priorities in this area are as follows:

- ❑ To develop a concept of International Nuclear Fuel Cycle Centers in order to reduce proliferation risks by internationalizing the most proliferation-sensitive components of the nuclear fuel cycle. This includes uranium enrichment; an LEU bank; nuclear fuel manufacturing and supply; SNF storage; SNF processing; and fuel recycling.
- ❑ To introduce the practice of international regulation and control of global remote monitoring of nuclear materials at every stage of the declared nuclear activities. This must become a compulsory instrument of monitoring the stockpiles and any movements of fissile and radioactive materials so as to prevent secret stockpiling and diversion of nuclear materials, including detection of any possible theft during transportation or at any other stage.
- ❑ To introduce a compulsory requirement for all nuclear facilities (NPPs, NFC facilities, etc.) to be equipped with computerized anti-proliferation systems (accounting and control, physical protection, etc.).
- ❑ To regulate the spread of sensitive nuclear know-how.

Identical or similar approaches should be used for innovative reactor and fuel technology projects in order to develop recommendations regarding the criteria for assessing proliferation risks posed by such projects and technologies.

Table 1. ***Proliferation Risks Posed by Various Types of Nuclear Materials***

Material	**Time** **T_H-T_B** **To**	**Cost** **F_H-F_B** **Fo**	**Secrecy** **S_H-S_B** **So**	**Safety** **D_H-D_B** **Do**	**Availability** **A_H-A_B** **Ao**	**Proliferation risk** **Ro5-R95** **Ro**
LEU	1.5–3 2.1	3–15 6.1	10–50 24	0.5–1 0.7	10–100 39	8.16–185 **53.3**
HEU	1	1	1	1	1	**1**
Reactor grade plutonium (Rpu)	3–10 5.2	8–60 19	0.2–0.9 0.46	0.2–0.9 0.46	0.1–5 1.25	0.00014–0.0139 **0.0028**
Weapons grade plutonium (WPu)	1.5–4 2.4	2–20 5.1	0.2–0.9 0.46	0.5–0.9 0.68	0.1–0.5 0.24	0.00095–0.0217 **0.0062**

Notes: **Time T**: Time required to build an arsenal of explosive nuclear devices; greater time translates into lower risk. **Cost F**: The cost of building a nuclear arsenal, including investment in every component of the program to build explosive nuclear devices from source material, plus the cost of the source material itself; greater cost translates into lower risk. **Secrecy S**: The feasibility of keeping secret the nuclear weapons program based on a given material. Greater feasibility translates into greater risks. **Safety D**: Technological safety of the program to build an arsenal from a given material; greater safety translates into greater risks. **Availability A**: The availability of the source material; the more available the material, the greater the risks. **Proliferation risk R**: a function calculated as: $\mathbf{R = (1/T) * (1/F) * S * D * A}$

Research aimed at developing new approaches to preventing nuclear weapons, materials and technologies proliferation is just as important for greater adoption of nuclear energy as measures to strengthen nuclear and radiation safety.

Nuclear and Radiation Safety

The serious accident at the Fukushima nuclear power plant has once again highlighted the crucial importance of safety for the broader adoption of nuclear energy. The catastrophic chain of events—an earthquake, the resulting tsunami, the failure of residual heat removal systems, overheating and disintegration of fuel, the release and several explosions of hydrogen, and the failure of protective barriers—caused a very serious accident which led to radioactive contamination of large territories far away from the NPP.

The Fukushima crisis has triggered a serious debate about the need for innovation not just in nonproliferation but in nuclear and radiation safety as well. Officials and the expert community are discussing proposals to set up new agencies, develop innovative control and management methods, and introduce compulsory international standards.

There is a clear need for detailed and comprehensive analysis of the Fukushima accident in order to develop new measures, including new technology and better regulation, so as to prevent a repeat of the crisis at the existing and new facilities. This requires openness concerning the process of assessing and stress-testing safety measures at the nuclear power plants. Nuclear energy is a global phenomenon, so safety requirements must be global as well. All assessments of the reliability and safety of NPPs must involve experts from foreign countries and international organizations. Such cooperation is also required during the approval of NPP safety requirements and inspection procedures.

The international nuclear safety regime, which is based on the Convention on Nuclear Safety and other agreements, depends on nations' willingness to follow its recommendations voluntarily. Even minor instances of these internationally accepted norms being ignored pose major risks for everyone. We must work to improve the regime and make it more stringent. There needs to be a single set of standards, and enforcement measures for those who ignore nuclear safety principles.

First and foremost, we need to make sure that the existing nuclear energy sector is safe. To that end stress tests are being conducted at existing nuclear power plants to ascertain their resilience to extreme conditions, including loss of external power supply, loss of coolant, etc. But stress tests are not a one-off exercise. Safety of nuclear power plants must be tested and ascertained on a continuous basis. This work should be conducted in an international format; joint efforts are required to improve the methods and criteria of stress-testing, and to exchange best practice. There must be total transparency in order to establish trust. That purpose can also be served by establishing international centers of expertise, which would participate in analyzing safety measures and provide support and assistance to nuclear operators if need be.

Another important area is providing assistance to newcomer countries that are only just beginning to adopt nuclear energy. There needs to be a set of clear requirements for countries that intend to develop nuclear energy. As a precondition for joining nuclear energy programs the newcomer countries must build the requisite infrastructure, introduce a licensing and safety supervision system, and build a comprehensive regulatory framework. Another important task these countries face is to train nuclear energy specialists.[9] Russia is now setting up an international center to train foreign specialists, including nuclear power plant operators. Efforts to improve NPP safety through technological innovation must be made on a continuous basis.

Hydrogen release is a common vulnerability of energy reactors that use water as coolant and contain zircon in fuel cladding. A release of hydrogen took place not only at Fukushima but also during the Three Mile Island and Chernobyl accidents. Hydrogen is a real and grave threat. Developing measures to prevent its release, or at least to ameliorate its consequences, is a problem the industry has faced for decades—but the recent disaster at Fukushima has served as another reminder that this problem requires an urgent solution. Other challenges that need to be addressed as a matter of priority are to improve the reliability of cooling systems and to prevent hydrogen detonation or combustion. In the medium time frame, the existing and future light water reactors will require new types of fuel with better resilience to water vapor in emergency situations.

REGIONAL NUCLEAR ENERGY SYSTEMS

Access to cheap and reliable sources of energy, such as nuclear energy, is a critically important precondition of growth in the developing countries. More countries are expected to announce plans to launch nuclear energy programs or to add to their existing nuclear generation capacity. This raises the question of the role individual countries and whole regions can play in the global nuclear energy architecture.

Every country makes independent decisions regarding the structure of its nuclear energy sector. Some of the developing nations, such as China and India, have already made the decision; their nuclear programs include both the reactors and a more or less complete nuclear fuel cycle. But many other countries that have only just announced plans to adopt nuclear energy must decide which part of the nuclear technology complex they want to develop on a national level, and where to procure the rest of the services required by their nuclear energy industry. Developing and operating a complete nuclear fuel cycle on their own may prove too much of a burden for many individual countries. At present the trend towards international integration can be discerned, to greater or lesser extent, at every individual stage of the nuclear fuel cycle, starting from uranium mining. Only a relatively small number of countries have already mastered the complex technologies of enriching uranium, fabricating nuclear fuel, processing spent fuel, or producing mixed uranium–plutonium fuel. But new members continue to join the nuclear club. All of this, as well as concerns over the proliferation of fissile materials, calls for new solutions to the problem.

One of the most promising solutions is to set up large international NFC centers to help the developing countries in their quest for peaceful nuclear energy by addressing the problems of cost, safety, and proliferation risks. These centers could serve as nuclear fuel banks and production facilities; they could also store, process, and recycle spent nuclear fuel, offer actinides burnout services, lease out nuclear power plants, and even operate nuclear-powered hydrogen plants to supply hydrogen to various external customers.

As for the global NFC services system, it must be taken into account that various commercial and national interests are involved. The system in its current form consists of two separate industries, which correspond to two separate stages of the nuclear fuel cycle. The international market for the front end of the NFC is fairly mature; it includes uranium mining, conversion, and enrichment, as well as fabrication of nuclear fuel for various types of energy reactors. This industry has some spare production capacity at this time.

The tail end of the NFC is an entirely different matter. There is no proper market for services such as SNF processing and disposal, including radioactive waste disposal. The existing technologies in this segment date back to the 1950s and 1960s. The key problem is that the countries which have these technologies have no intention of leaving on their own territory the nuclear waste resulting from the processing of spent nuclear fuel received from other countries. The idea is that all nuclear waste should be returned to the country of origin of spent nuclear fuel. The economics of processing SNF and MOX fuel remain uncertain. It is clear, however, that global nuclear energy has no future without clear arrangements for the tail end of the NFC based on new technologies.

One team of researchers has assessed the prospects for regional nuclear energy systems.[10] It proceeded from the notion that by adding nuclear generation capacity the developing countries can close the gap with the rich world in terms of per capita electricity consumption. It analyzed a scenario whereby these countries achieve the per capita consumption figure of about 4,000 KWh per year, which the UN deems as a sufficient global average, only by building nuclear power plants. Under that scenario, new NFC facilities (enrichment, fuel fabrication, and SNF processing) are built only in those countries and regions that already operate such facilities (the United States, Western Europe, Russia, Japan, India, and China). Of course, various economic and political motives can lead to other scenarios. But the team's numerical assessment of the required new generation and NFC capacity, as well as of the flows of nuclear and radioactive materials, provides a preliminary basis for laying the organizational foundations and developing concepts of international NFC centers. Figure 1 shows one example of the assessment of key elements of an international nuclear fuel cycle.

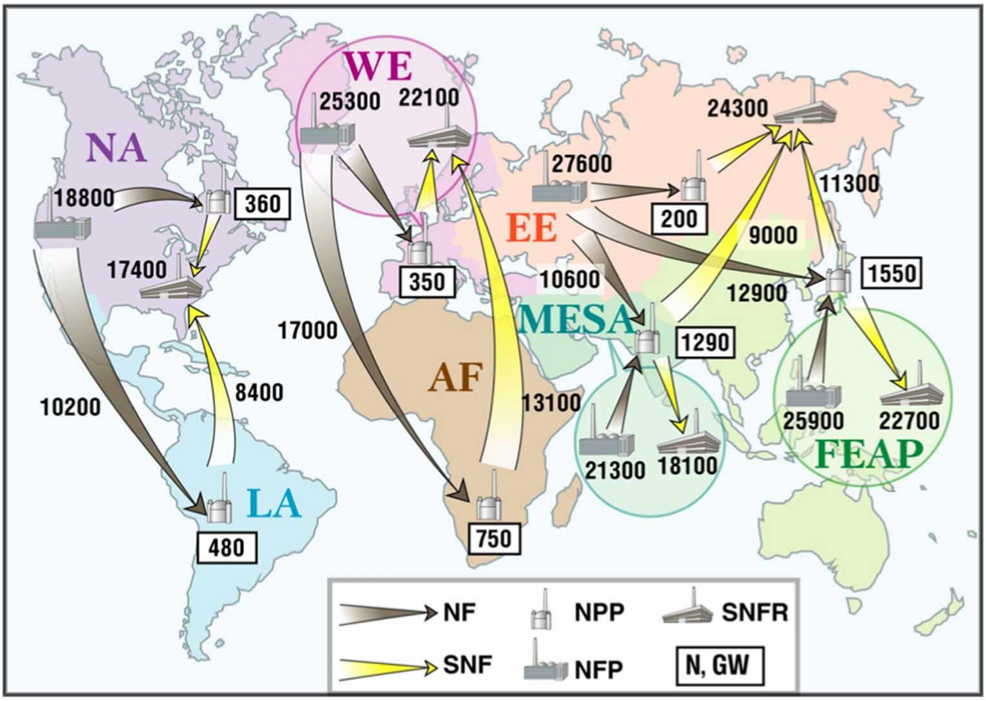

Figure 1. **Production and Trans-Regional Flows of Fresh and Irradiated Nuclear Fuel in 2100 (based on the ''*closing gap*'' model)**

Assessments summarized in Figure 1 suggest that the required scale of NFC operations (up to 100,000 tonnes a year) and transport flows (up to 50,000 tonnes a year) are at a technologically feasible level (for nuclear generation capacity of about 5,000 GWe).

It goes without saying that serious structural changes in the global nuclear energy sector can have an adverse impact on the level of nuclear and radiation safety, increase the availability of nuclear materials, and therefore exacerbate the risks of proliferation of nuclear technologies and materials.[11] New approaches and measures will have to be introduced to reduce those risks or, at the very least, keep them at their current level. Obviously, those measures must be applied in every area—political, institutional, and technological—of the nuclear safety, security, and nonproliferation regime.

MAINTAINING THE REGIME

Solutions to ensure safe and secure development of nuclear energy must involve governments, the state-owned sector, and the private sector. These solutions will need to take into account the often diverging interests of all parties, including governments, the general public, non-governmental organizations, and the private sector. Ways must be found to reconcile all these interests in order to remove the current and future obstacles to nuclear energy development.

The problems facing nuclear energy are being addressed by the international community at the level of international organizations and bilaterally. Russia is well aware of the importance of these objectives, and it is taking specific steps to achieve them. Based on the notion that uranium enrichment is one of the most proliferation-sensitive elements of the nuclear fuel cycle, Russia has launched the International Uranium Enrichment Center in Angarsk. The new approach is essentially a commercial offer based on the build–own–operate principle for NPPs in newcomer countries. That approach is the basis of the agreement between Russia and Turkey on the construction of a nuclear power plant in Akkuyu. In an effort to identify new solutions for sustainable global development of nuclear energy Russia is also participating in bilateral projects. As part of a joint project with the United States it is developing proposals for a new architecture in the civilian nuclear energy sector and analyzing mutually complementary concepts of setting up international NFC centers and offering cradle-to-grave nuclear fuel services. This research will be coordinated with the IAEA and other international organizations to build upon these concepts and prepare them for a broader discussion.

The adoption of nuclear energy by countries that are not yet prepared to handle nuclear technologies in a way that ensures nuclear safety and minimizes proliferation risks can be facilitated by countries which already have the necessary experience. It will be necessary to develop the terms for supplying the required technologies that would ensure nuclear and radiation safety as well as minimize proliferation risks associated with nuclear facilities. These terms might be as follows:

- ❑ Exporters of nuclear power plants should also provide the full range of nuclear services (international nuclear fuel cycle centers, cradle-to-grave principle), including deliveries of fresh fuel, return of irradiated fuel, removal of radioactive waste from the NPP sites, and decommissioning.
- ❑ Nuclear technologies must be supplied only on the condition that they will be subject to international controls. This includes controls of all NPP and NFC facilities, including nuclear materials and radioactive waste in the exporter and recipient countries.
- ❑ Another compulsory condition of supplying nuclear technologies must be physical protection and continuous monitoring systems.
- ❑ Yet another condition must be the use of standardized, computerized accounting and control systems for nuclear and radioactive materials and radioactive waste, in combination with continuous remote monitoring and detection of all such materials.

All these issues must be addressed as part of an international effort. International cooperation is not limited to technology; it also includes developing a regulatory and organizational framework to define the conduct expected of all participants in the sustainable development of global civilian nuclear energy. It also includes monitoring compliance and ensuring that all participants have an adequate level of nuclear expertise and capability. Efforts must be made to develop various aspects of public–private partnership to achieve safe, secure, and sustainable development of nuclear energy in terms of the global NFC services and other components of the nuclear energy sector.

Much is already being done, and much has yet to be done to put in place the framework for the sustainable development of civilian nuclear energy, with adequate levels of nuclear and radiation safety, minimal environmental impact, and strong resilience to proliferation.

In order to make sure that nuclear energy can contribute to meeting the growing global energy demand, the following strategic objectives will have to be met.

First, uranium is a limited resource, so even a moderate, let alone an aggressive scenario for nuclear energy expansion will require a multi-component architecture of the nuclear energy system that relies on fuel breeding, a complete nuclear fuel cycle, thermal reactors, and fast reactors of various types. A key component of the global nuclear architecture with a complete nuclear fuel cycle is fast breeder reactors, which produce energy as well as fuel (Pu, U-233) and complete the nuclear fuel cycle for U, Pu, and minor actinides.

Second, in order to improve the reliability of recommendations on nuclear nonproliferation there needs to be an instrument that allows comparative numerical assessment of proliferation risks posed by various solutions. Based on numerical and qualitative analysis, the following anti-proliferation measures need to be developed:

- ❑ produce a concept of international NFC centers aimed at reducing the proliferation risks by internationalizing the most sensitive elements of the nuclear fuel cycle;
- ❑ introduce global remote monitoring of nuclear materials at every stage of declared nuclear activities;
- ❑ introduce a compulsory requirement for nuclear facilities supplied to customers to include computerized anti-proliferation systems (accounting and control, physical protection, etc.);
- ❑ regulate the spread of proliferation-sensitive nuclear know-how.

Third, massive structural changes in the global nuclear energy sector can have an adverse impact on nuclear and radiation safety, increase the availability of nuclear materials, and exacerbate the risk of proliferation of nuclear materials and technologies. We need to develop and discuss new approaches within the framework of the international nuclear safety regime formed on the basis of the Convention on Nuclear Safety and other agreements. Further efforts are required to strengthen the regime, using political, institutional, and technological measures. Continuous multilateral efforts need to be made to improve the safety of nuclear power plants by means of innovative technological solutions.

Fourth, there needs to be a clearer organizational and regulatory framework for relations between the supplier and the customer in the global nuclear energy infrastructure. We need to establish the requirements of energy consumers and the ability of energy suppliers to satisfy those requirements. Current projections envisage a sharp growth in demand for nuclear generation capacity in many countries around the world. There is also growing demand for small and medium-sized reactors in addition to the traditional large ones; for autonomous energy sources; and for various types of nuclear energy (i.e. other than electricity) for various applications. Every buyer of nuclear energy generation capacity will also require fuel supplies, SNF and radioactive waste management services, decommissioning services, and the training of specialists in areas such as nuclear engineering, management, control, and regulation. The suppliers must provide the entire range of services required by the customers; they must also bear the responsibility for and provide adequate guarantees of both quality and timeliness of these services.

NOTES

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