Nuclear Power in the 21st Century and its Role in Developing Countries

Yury A. Sokolov, Vladimir S. Kagramanyan and Alan McDonald
Department of Nuclear Energy, International Atomic Energy Agency, Vienna, Austria

21st CENTURY VISION V/s. 20th CENTURY INERTIA

We assemble ambitions faster than solutions. At the outset of the 21st century, high on the lists of global ambitions compiled, for example, in the Millennium Development Goals and the Johannesburg Plan of Implementation, are the eradication of poverty and hunger, universal access to plentiful fresh water and energy, and environmental sustainability.

The world is not on target to meet any of these objectives. We have not yet committed the time, effort and money they require. And while it has proved relatively easy to marginally adjust our business-as-usual plans towards these ambitions and call that progress, it is much harder to identify a clear long-term vision that meets these ambitions, calculate what is required to get there from here, and then follow through. We do not propose to do all that in one article. We will, however, examine two routes to success that have been identified and explore how nuclear power could contribute.

The first of these might be called a ‘technological break-through’ route, while the second relies more on activist, perhaps even revolutionary, government intervention. They both reach roughly the same outcome, but by different means. The technological breakthrough route is reflected in the ‘A1T Scenario’ of the Special Report on Emissions Scenarios (SRES) published in 2000 by the Intergovernmental Panel on Climate Change.1 The A1T Scenario is consistent with stabilising the atmospheric carbon concentration at about 560 ppmv, it sharply reduces sulphur emissions (a proxy for traditional pollution), and it is the richest and most equitable of the SRES scenarios with per capita income worldwide rising to $77,500 in 2100 and the ratio of per capita income between developing and developed regions rising from 0.06 to 0.64. However, it is essentially the happy result of positive assumptions about international cooperation, rapid technical progress and a low global population trajectory. It is plausible, but hardly guaranteed.

The second scenario is the ‘SD Vision Scenario’ published in the fall of 2003 by the OECD International Energy Agency (IEA) in Paris.2 ‘SD’ stands for sustainable development. The SD Vision Scenario lays out a route very similar to the A1T Scenario. However, it is less optimistic in that it assumes that activist policies will be needed to push the world beyond business-as-usual trends. It starts by quantifying three specific non-business-as-usual ambitions. First is the goal of stabilising the atmospheric concentration of greenhouse gases (GHGs) at a ‘safe’ level,3 which it translates into a quantitative target of 60% of the world’s primary energy coming from ‘zero-carbon’ sources by 2050. Second is the objective of energy security and diversification, which translates into a target for reducing oil’s share of the total transport energy demand from 95% in 2003 to less than 40% by 2050. The third ambition is ‘access to energy’, and the quantitative target is access to electricity by at least 95% of the world’s population in 2050.

The result is that, in order to reach these targets, biomass production expands in the scenario between 2000 and 2050 by a factor of three, other renewables expand by a factor of thirteen and nuclear energy expands by a factor of fourteen. For nuclear energy that means average growth of 3.5% per year through 2050 – higher than its recent slow growth (2.5% per year from 1990-2000) but well below its 11.5% average from 1971 to 2000. Most growth takes place in developing countries. In non-OECD Asia, Africa, Latin America and the Middle East nuclear energy expands by approximately a factor of ninety, although from a small base.

In contrast to the substantial nuclear expansion of the SD Vision Scenario, medium-term business-as-usual projections for nuclear energy are much lower. The IAEA prepares two projections each year, shown in Table-1.4 The low projection assumes no new nuclear power plants (NPPs) beyond what is already being built or firmly planned, plus the retirement of old NPPs. The high projection takes into account additional reasonable new proposals.

The projections vary significantly across regions of the world. Current expansion and growth are centered in Asia. Of 30 NPPs currently under construction, 17 are in this region. Twenty-one of the last 30 reactors to

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3. “Safe” level is defined by the International Panel on Climate Change (IPCC) as a concentration of 450 ppmv of CO2.
be connected to the grid are in the Far East and South Asia.

Nonetheless, even in Asia business-as-usual falls short of the expansion needed to realise the ambitions in this article’s opening paragraph and in the SD Vision Scenario. More activist government intervention is needed. In some cases proposals exist, but the challenge will be in implementation and follow through. Consider, for example, India, which has an overall development goal of 5,000 kWh per capita per year of electricity use by 2050. This compares to 460 kWh domestically now, and 16,000 kWh in Sweden, 13,000 kWh in the USA and 6,500 kWh in Germany. The Indian goal translates to approximately 7.5 trillion kWh of electricity per year in 2050, of which at least 25% is intended to be nuclear. Assuming a 90% average capacity factor, that works out to almost 240 GW of installed nuclear capacity in 2050. Relative to today, that is an increase by more than a factor of 90 – much in line with the SD Vision Scenario.

Why are Table-1’s projections so low? While the high projection shows an increase in nuclear generation by 70% in 2030, that is still well below the pace of the SD Vision Scenario. And the low projection shows a decrease in nuclear electricity generation after 2020. Globally, the gap between the ambitions in our opening paragraph and the reality of business-as-usual policies is, quite simply, huge. Why?

One reason is energy market liberalisation. Liberalised, unregulated markets are not good at ensuring forward-looking long-term investments that anticipate needs 30 or 50 years in the future. Such markets have many advantages in terms of rapid dissemination of information through prices, attracting resources to where they are immediately most cost effective, and reducing near-term consumer prices. But so-called ‘market failures’, when it comes to anticipating the future, are long recognised and well analysed. Left to themselves, markets under-invest in products and services for potential customers who are too poor or unconnected to give investors an immediate return. And liberalised markets under-invest in reducing external costs, i.e. social costs suffered by society at large but not explicitly charged to, in this case, electricity producers. Two specific examples are the costs of climate change and the costs of energy supply insecurity. Thus there is no reason to expect any of the three ambitions of the IEA’s SD Vision Scenario – indeed any of the ambitions in this article’s opening paragraph – to be advanced solely by liberalised unregulated markets.

Where markets fail, governments intervene. All legal markets are regulated, and particularly in Europe those regulations are now being extended to GHGs. Governments...
can also intervene through direct investments in research and development to push their energy systems in the directions they want. And in countries where the government is a direct investor in power plants, it can invest directly in new technologies that advance government goals like lower GHG emissions, greater energy supply security and broader energy access, even if a private investor, for whom those benefits have no cash value, would find the investment uneconomic.

Thus closing the gap between the ambitions in the opening paragraph and the business-as-usual trends of Table-1 will require government action – both in terms of policies that redirect market incentives (and by definition cause some pain to beneficiaries of current policies) and in terms of money. Closing the gap will also require international cooperation. The Chernobyl accident in 1986 highlighted the need for improving international safety norms and facilitating the diffusion of expertise and best practices. Today there is increasing awareness that many new challenges related to nuclear energy can only be efficiently addressed through a new level of international cooperation – challenges such as the management of nuclear spent fuel and waste, and the development of new generation nuclear energy systems affordable and acceptable both in developed and developing countries.

Non-proliferation
Fifty years ago the only issues judged to require some internationalisation of national fuel cycles were the proliferation challenges posed by certain nuclear technologies (enrichment and reprocessing) and by fissionable materials (highly enriched uranium and separated plutonium) derived from their use. Negotiations in the late 1960’s led to the 1970 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), with measures to prevent nuclear weapons proliferation and also measures to assure access to nuclear technology for peaceful purposes. Today, however, given the significant political changes since the Cold War, and given the growth and diffusion of nuclear knowledge, and the cases of the DPRK, Iraq, Iran, Libya, and the international black market trade in nuclear technologies, there is a growing feeling that proliferation risks are not adequately addressed. There is a need for international cooperation on its serious enhancement. However, those who call today for measures to strengthen the international non-proliferation regime recognise that different countries have different perspectives and priorities. Some may be most concerned about increased proliferation risks due to insufficient controls over sensitive parts of the nuclear fuel cycle. But for others, the most immediate concern may be their perceived constraints that the non-proliferation regime appears to impose on national efforts to introduce or expand energy supplies from nuclear power. The challenge will be to successfully address both concerns.

Safety
The Chernobyl accident conclusively established that nuclear safety can not be dealt with solely on a national basis. Substantial progress has been made towards internationalisation, and it is well understood that the new generation of reactors should be designed from the beginning with higher reliance on inherent safety features to meet ever-increasing internationally accepted safety standards. It is also understood that internationalisation can reduce obstacles confronting countries seeking to introduce nuclear power, by reducing international concerns that such countries might embark on a development programme without a sufficiently strong safety culture in place and thus risk an accident detrimental to nuclear power development worldwide.

Spent Fuel and Waste
The scientific and technical communities generally agree that high level wastes or spent fuel can be disposed of safely in stable geologic formations and that, in most countries, there is no pressing immediate need for permanent waste disposal facilities.
However, a substantial future expansion of nuclear energy, using an open fuel cycle, could create a serious global challenge. New technological developments might need complementary new institutional arrangements – for example, international repositories on a regional or even broader basis. These may be particularly important for countries with no geologically suitable disposal sites or with nuclear power programs too small to justify the expense of national sites. Moreover, for small countries that do not yet have nuclear power but wish to introduce it, the likelihood of finding themselves in a similar situation, absent international repository options, is a strong deterrent.

Non-electrical Applications

Nuclear energy provides 16% of the world’s electricity (Table-1), but that is only 2% to 6% of the world’s primary energy use (depending on the convention used to convert nuclear electricity to its primary energy equivalent). To make a truly substantial contribution to future global energy supplies and sustainable development, nuclear energy must find applications beyond electricity, particularly in the transport sector where oil now supplies 95% of transport demand. The most promising way that nuclear energy might provide energy for transportation is through the production of hydrogen, either for direct use in fuel-cell vehicles or to produce synfuels. Hydrogen research is currently on the rise. Major automobile manufacturers have set ambitious targets for putting affordable fuel cell cars on the road, and significant governmental initiatives have been launched in the EU, the USA and Japan. Nuclear energy is part of these initiatives, but for nuclear energy to become a major future hydrogen supplier will require significant efforts in both reactor technology development and installing new infrastructures. Both challenges are best addressed through a global approach.

Nuclear energy can also make a substantial contribution to a critical non-energy ambition – universal access to plentiful fresh water. Currently about 2.3 billion people live in water-stressed areas and among them 1.7 billion live in water-scarce areas, where the water availability per person is less than 1000 m³/year. By 2025 the number of people suffering from water stress or scarcity could swell to 3.5 billion, with 2.4 billion expected to live in water-scarce regions.

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The desalination of seawater using nuclear energy (either low temperature heat or electricity) is a demonstrated option. Over 150 reactor-years of operating experience with nuclear desalination have been accumulated worldwide. Several demonstration programs are underway, with technical co-ordination support from the IAEA, to confirm its technical and economical viability under country-specific conditions. Nuclear desalination is most attractive in countries that both lack water and have the ability to use nuclear energy such as China, India and Pakistan. These three countries alone account for about 40% of the world’s population, and thus represent a potential long-term market for nuclear desalination. The market will expand as other regions with high projected water needs, such as the Middle East and North Africa, increase their nuclear expertise and capabilities.

Sustainable Development

Advocates of nuclear energy for sustainable development argue that it is a well-established non-carbon technology, as demonstrated by its 16% share of the world’s electricity supply and even higher share in specific countries – 78% in France for example. Moreover, it has huge growth potential. Its resource base – uranium and thorium – is substantial and has no competing application. Nuclear energy increases the world’s stock of technological and human capital. It is ahead of other energy technologies in internalising external costs. From safety to waste disposal to decommissioning – the costs of all of these are in most countries already included in the price of nuclear electricity. It avoids GHG emissions. The complete nuclear power chain, from resource extraction to waste disposal and including reactor and facility construction, emits only 2-6 grams of carbon per kilowatt-hour, about the same as wind and solar power and two orders of magnitude below coal, oil and even natural gas.

If we were to extend our consideration beyond nuclear fission to nuclear fusion, which is largely outside the scope of this article, some of these arguments would be even stronger. The resource base for nuclear fusion, for example, is huge. However, fusion is still at an experimental stage. It is unlikely to provide a substantial share of electricity to the grid before 2050, although it is a possible contributor to global energy supplies in the second half of the century.

Economics and Innovation

In industrialised countries, where most of the world’s installed nuclear capacity is today, well run existing NPPs can be quite profitable. New NPPs, however, are most attractive in countries where energy demand
survive and flourish in the 21st century, innovate. Indeed for any technology to markets, it will have to reduce costs and rapid returns.

If nuclear energy is to succeed in liberalised markets, it will have to reduce costs and innovate. For any technology to survive and flourish in the 21st century, continual innovation is essential, and nuclear energy is no exception. However, different countries are likely to be looking for different things from nuclear energy in the coming decades, and there is a potential mismatch between centres of nuclear expansion, mostly in developing countries, and centres of established nuclear expertise, mostly still in developed countries.

As many of their current NPPs near the end of their original design lifetimes, countries like France and the UK have begun the debate on whether to replace nuclear with nuclear and, if so, on what schedule and with what technology. They will be evaluating technologies in the context of large electricity grids, where large retiring units can be replaced by large new units and economies of scale can be exploited. It is less clear how desirable large nuclear units will be for expanding electricity supplies. Again, in liberalised markets, the bigger up-front costs of large units, and the bigger financial risk they carry, are disadvantages. Nonetheless, the one new recent NPP planned in Europe, Olkiluoto-3 in Finland, is both very large at 1600 MW, and an important counter-example that long-term thinking does not have to be inconsistent with liberalised energy markets.

With or without highly liberalised markets, developing countries are expected to have a greater interest in small and medium-sized reactors (SMRs). With the exception of large countries like China and India, SMRs may be more suited to the generally smaller national electrical grids of developing countries, and also to their generally smaller financial resources.

Cooperation and coordination across national borders will be required if the world's R&D expertise is to be efficiently brought to bear on these diverse future interests. This is even more true once additional nuclear applications are added to the mix – for seawater desalination or hydrogen production. At the moment there are two principal multinational initiatives promoting such cooperation. Both were begun in 2000. One is the U.S. – initiated Generation IV International Forum (GIF). In 2002 GIF selected six concepts for international collaborative R&D and, in 2003, made progress on establishing the management and oversight structure for subsequent work and specific cooperative R&D agreements. The other initiative is the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). It is open to all IAEA Member States and currently has 19 members. Its initial focus has been on identifying the prospective needs of future NPP buyers and developing 'user requirements' in the areas of economics; sustainability and the environment, including waste management; safety; proliferation resistance; and cross-cutting issues. In a subsequent phase, INPRO expects to facilitate and assist cooperation among Member States developing joint projects on innovative nuclear systems, with a special emphasis on developing countries.

THE WAY FORWARD

Whether nuclear energy can reach its full potential in developing countries where it is already used, and whether it can expand efficiently into new countries, will depend on the existence of trade and security regimes that are open, equitable, and encourage technological diffusion. If proactive measures are not taken to that end, nuclear energy will likely maintain a major role in a limited number of industrialised countries and a few large developing ones. But it will not contribute towards meeting the world’s 21st century ambitions at anywhere near the level estimated in the SD Vision Scenario, for example.

We believe it is wiser to be proactive. A joint, consensus internationalisation strategy tailored to the realities of the new century could prove the critical key to unlocking the full potential of nuclear energy to help meet steadily rising 21st century global energy demands and fuel the economic growth and greater prosperity to which particularly developing countries rightly aspire. Certainly any successful wide-scale deployment of nuclear energy will require broad international cooperation and the consolidation of efforts from many countries.

We also believe there is an important role for the IAEA in promoting such international cooperation and that we also have an obligation to be proactive. Let us therefore close by listing the principal, current and prospective areas of IAEA assistance to Member States, including INPRO and new ideas on the internationalisation of the fuel cycle. IAEA assistance focuses on:

- developing a vision for a possible global nuclear energy role,
- assessing and clarifying affordability and acceptability requirements for large-scale nuclear energy use in the 21st century, taking into account both developed and developing countries,
- facilitating international cooperation in the development of different types of
new generation nuclear energy systems which meet these requirements,

• defining how to enhance existing international institutional systems related to nuclear energy, and

• facilitating (political) discussion aimed at establishing enhanced institutional systems acceptable to both developed and developing countries.

References


Yury Sokolov, a graduate of Moscow University, began his scientific career in 1971 at the Kurchatov Institute in Moscow, where he became a Candidate of Science and Doctor of Science in 1980 and 1996 respectively. He has worked in the fields of plasma physics and fusion, engineering design of fusion facilities and thermonuclear reactors. Since 1988 he has been active in the International Thermonuclear Experimental Reactor (ITER), firstly, as a member of the ITER Managing Committee, leading the Russian team of physicists and engineers, and, later, as the Russian representative on many ITER-related inter-governmental boards, which supervised and promoted the work of ITER.

In 1996, he was appointed Head of the Department of Science and Technology at the Ministry of the Russian Federation for Atomic Energy. In this post, as well as fundamental nuclear science, he was also responsible for nuclear power strategy development in the Russian Federation and for innovation across the full spectrum of fuel cycle and waste management technologies. He has initiated several nuclear knowledge preservation activities in the Russian Federation, some of which are linked to Agency activities in this area.

Mr. Sokolov has served as a member of the Scientific and Technical Council of Minatom in the Russian Federation and on various national and international committees for science and technology, on the editorial boards of scientific journals, on bilateral committees for scientific cooperation etc.

In October 2003, Mr. Sokolov joined the International Atomic Energy Agency in Vienna as Deputy Director General, Head of the Department of Nuclear Energy.

Dr. Vladimir Kagramanyan has been with the Planning and Economic Studies Section (PESS) of the International Atomic Energy Agency’s (IAEA’s) Nuclear Energy Department. He co-authored Global Energy Perspectives, the final report of the recent joint study on long-term energy prospects by the World Energy Council (WEC) and the International Institute for Applied Systems Analysis (IIASA). He was a contributing author to the IPCC’s 2000 Special Report on Emissions Scenarios (SRES), and has published on the future of nuclear power, innovation, technological learning, gas infrastructures in Eurasia, international scientific cooperation, and interactions between climate change and acid rain policies. He began his career at the General Electric Company’s former Fast Breeder Reactor Department, and worked at the California Energy Resources Conservation and Development Commission, the American Academy of Arts and Sciences, and IIASA before joining the IAEA. He holds graduate degrees in Aeronautical and Astronautical Sciences from Stanford University and in Public Policy from Harvard University.

Alan McDonald is with the Planning and Economic Studies Section (PESS) of the International Atomic Energy Agency’s (IAEA’s) Nuclear Energy Department. He co-authored Global Energy Perspectives, the final report of the recent joint study on long-term energy prospects by the World Energy Council (WEC) and the International Institute for Applied Systems Analysis (IIASA). He was a contributing author to the IPCC’s 2000 Special Report on Emissions Scenarios (SRES), and has published on the future of nuclear power, innovation, technological learning, gas infrastructures in Eurasia, international scientific cooperation, and interactions between climate change and acid rain policies. He began his career at the General Electric Company’s former Fast Breeder Reactor Department, and worked at the California Energy Resources Conservation and Development Commission, the American Academy of Arts and Sciences, and IIASA before joining the IAEA. He holds graduate degrees in Aeronautical and Astronautical Sciences from Stanford University and in Public Policy from Harvard University.