Contemplating Nuclear Power Generation Today: Managing Energy Security Risk, Reducing GHG Emissions and Prioritising Public Safety

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Introduction

Nuclear power presently generates approximately 12.3% of global electricity, although only 30 countries have nuclear power generating capacity.[3] Many other countries are now contemplating nuclear power generation for the first time. Countries pursuing nuclear power generation capacity include energy-rich oil exporters, such as the United Arab Emirates (UAE) and Saudi Arabia, as well as developing countries with established programmes, such as China and India.

Following the events at the Fukushima Nuclear Power Plant in March 2011, countries with and without nuclear power plants are reassessing measures to strengthen nuclear safety and international cooperation. Nuclear safety is one of the key concerns and priorities for emerging nuclear countries when developing their nuclear power programmes.

This paper outlines how countries that are interested in introducing nuclear power generation for the first time should be pursuing international best practice, including by following the guidance of the International Atomic Energy Agency (IAEA). Most importantly, it notes that the international nuclear power sector is one that is constantly evolving, through technological innovation aimed at improving safety, versatility and efficiency, implementation of lessons learned in nuclear construction and operation and the strengthening of vital nuclear non-proliferation and nuclear safety regimes.

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[3] International Status and Prospects for Nuclear Power, IAEA 2012, GOV/INF/2012/12-GC(56)/INF/6.

Managing energy security risk

Interest in nuclear power generation is expected to become more widespread because countries, particularly energy-importing countries, continue to be concerned about their future energy security and see a need to diversify their energy supply sources as a risk management strategy.

Those countries with growing populations and expanding economies have a special need to increase their level of power generation investment in order to keep up with demand growth. The region with the highest anticipated growth in nuclear power generation is Asia, largely due to the significant nuclear new-build plans of China (29 under construction and 171 planned/proposed) and India (7 under construction and 57 planned/proposed).[4]

Reduction of GHG emissions

Another reason for widespread interest in nuclear power generation is the increasing recognition by more countries of the need to limit further increases in their greenhouse gas (GHG) emissions or to reduce their present level of emissions.

Nearly all solutions to the GHG problem, even including reduction in energy demand and some energy efficiency measures, involve additional costs.

The objective of generating more power from renewable sources, such as wind and solar, is widely supported but, in current practice and technological reality, is limited by the characteristic of intermittency. For base-load requirements, "clean" coal generation with carbon capture and storage is one low-emissions solution and nuclear generation is another. For peak power requirements, hydroelectric and gas-fired generation are currently utilised. Ultimately, a diversified portfolio is desirable, although each country's optimal generation mix is likely to differ in line with its indigenous resource endowment.

Prioritising nuclear safety and the role of the IAEA

Following the accident at the Chernobyl nuclear power plant in the Ukraine in 1986, the Convention on Nuclear Safety (CNS) was developed. The CNS entered into force in 1996 to establish a number of fundamental principles of nuclear safety, aimed at the protection of individuals, society and the environment from harmful effects of ionising radiation.

[4] World Nuclear Association, Nuclear Power Reactors and Uranium Requirements, January 2013. In the case of China, according to its 2012 White Paper on Energy Policy released on 24 October 2012, its installed capacity of nuclear power is expected to reach 40 million kw by 2015.

One of the primary principles set out in the CNS is that it is the responsibility of each country to establish its own legislative and regulatory regime for the safe use of nuclear power. Each country must design its own safety regime taking account of its constitutional, institutional and legal framework, its social, technical and industrial capacities and conditions, its human resources and, importantly, the need for transparency and community consultation. The regime should implement the fundamental principles of nuclear safety articulated in the CNS.

Although there is no international nuclear regulator, the IAEA plays an essential role. In addition to the IAEA's central contribution to nuclear non-proliferation and the international nuclear safeguards system, the IAEA acts as an advisory and monitoring body for its 158 Member States,[5] its statutory objective being *"to seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world."* [6]

The IAEA is mandated to facilitate exchange of nuclear information and knowledge and help to build the human resource capacity of its Member States, including through its technical cooperation programme and its Integrated Regulatory Review Service missions.

For countries embarking on nuclear power development for the first time, the IAEA publishes a number of very helpful guidance documents including the "IAEA Basic Infrastructure Guide"[7], the "IAEA Milestones" publication[8], the "IAEA Handbook on Nuclear Law" and its companion handbook "Implementing Legislation".[9] The IAEA also publishes advisory international safety standards and guides, which Member States use to benchmark their national nuclear regulatory regimes.

The IAEA Milestones publication provides guidance for Member States on preparing for a nuclear power programme through a sequential development process. It also sets out a detailed description for a policy, legislative and technical audience of a range of infrastructure issues that need to be addressed in each phase and the desired level of achievement at each milestone, prior to progression to the next phase. This publication can be used by Member States to develop roadmaps for the introduction of nuclear power, assess the status of development of their programme, to enable prioritisation of activities that need to be carried out in preparing to embark on the procurement of a nuclear power plant, its licensing and construction and, then, to safely operate a nuclear power plant.

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[5] As of November 2012.
[6] The Statute of the IAEA, Article II.
[7] IAEA, 'Basic Infrastructure for a Nuclear Power Project', IAEA-TECDOC-1513, 2006.
[8] IAEA, 'Milestones in the Development of a National Infrastructure for Nuclear Power', IAEA Nuclear Energy Series No NG-G-3.1, 2007.
[9] Carlton Stoiber et al, 'Handbook on Nuclear Law', IAEA, 2003; 'Handbook on Nuclear Law: Implementing Legislation', IAEA, 2010.

Focusing on the legislative and regulatory infrastructure, the guiding approach of the IAEA Handbook and Implementing Legislation is the '3S' concept, which emphasises the interrelations between the three key areas of nuclear safety, security and safeguards and the need for legislation to reflect these interrelations in a comprehensive and synergistic manner. The Handbook and the Implementing Legislation make the point that measures taken to address one key area can reinforce the others as well. An example is the adoption of measures for the physical protection of nuclear material, which are designed to protect against the misuse of nuclear materials including by unauthorised persons and, at the same time, contribute to nuclear safety.

Overall, the IAEA documents provide invaluable guidance to countries embarking upon a nuclear power programme for the first time. They promote the establishment of a comprehensive nuclear infrastructure, including solid and internationally compliant frameworks for nuclear legislation and regulation for the peaceful, safe and secure use of nuclear energy.

National legislation

Any country considering embarking on a programme to develop nuclear power should put in place a national legislative infrastructure covering safety, security and safeguards and providing for effective control and regulation of all phases of the lifecycle of a nuclear power plant and associated activities. This legislative infrastructure should be in compliance with international standards and best practice.

National legislation should implement in an effective manner all obligations contained in international nuclear instruments to which the country is a party. Table 1 lists the key international nuclear instruments, to which the IAEA recommends countries developing a nuclear power programme should become a party.

TABLE 1: INTERNATIONAL NUCLEAR INSTRUMENTS

- Comprehensive Safeguards Agreement
- The Additional Protocol to a Comprehensive Safeguards Agreement
- Convention on Early Notification of a Nuclear Accident
- Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency
- Convention on Nuclear Safety
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management

- Convention on the Physical Protection of Nuclear Material and Amendment
- Vienna Convention on Civil Liability for Nuclear Damage ('Vienna Convention')
- Joint Protocol Relating to the Application of the Vienna Convention and the Paris Convention
- Protocol to Amend the 1963 Vienna Convention on Civil Liability for Nuclear Damage
- Convention on Supplementary Compensation for Nuclear Damage
- Revised Supplementary Agreement concerning the provision of Technical Assistance by the IAEA

NOTE: The Vienna Convention regime is developed under the auspices of the IAEA and is open to all countries. The Paris Convention on Nuclear Third Party Liability ('Paris Convention'), developed under the auspices of the OECD, also covers third party nuclear liability and is open to OECD countries and other countries (upon the consent of parties to the Paris Convention).

One of the most important aspects of developing a nuclear power programme is to establish and mandate a national nuclear regulatory authority. The IAEA advocates the institutional separation of the regulatory authority from agencies concerned with the promotion and utilisation of nuclear energy. This is also one of the fundamental safety principles embodied in the CNS. Therefore, national legislation should provide for an effective separation between the functions of the regulatory body, and those of any other body or organization concerned with the promotion or utilisation of nuclear energy. An effective regulatory authority also requires sufficient human and financial resources, which should also be important precepts of the enabling legislation for the nuclear regulator.

While events at the Fukushima Nuclear Power Plant touch on many areas that are the subject of international nuclear conventions, nuclear safety has, understandably, been a primary focus of both national and international responses to Fukushima. In April 2011, the Contracting Parties to the CNS met in Vienna for the 5th Review Meeting. At the Meeting, the Contracting Parties committed to drawing upon the lessons learnt from events at the Fukushima Nuclear Power Plant and resolved to hold an Extraordinary Meeting in 2012 dedicated to the Fukushima accident. The Extraordinary Meeting was held in August 2012 and the Contracting Parties held discussions on plant design issues, severe accident management and emergency preparedness and responses. The Contracting Parties also considered the effectiveness of the CNS and ways it may be strengthened in the future.

National regulation

The nuclear regulator undertakes the day-to-day oversight of a country's nuclear sector and plays a vital role in overseeing and enforcing a country's nuclear safety regime.

The IAEA Milestones publication states that the fundamental elements of national nuclear regulation should include those set out in Table 2:

TABLE 2: FUNDAMENTAL ELEMENTS OF NATIONAL NUCLEAR REGULATION

- Designation of an effectively independent regulatory body, with clear authority and adequate human and financial resources
- Assignment of core regulatory functions for the development of regulations, for licensing, review and assessment, inspection, enforcement and public information
- Authority to obtain technical support as needed
- Clear definition of the relationship of the regulatory body to other organizations
- Establishment of the rights and responsibilities of licensees
- Authority to engage in international cooperation
- Provisions to protect proprietary, confidential and security information
- Provisions for stakeholder and public information and interactions
- Compatibility with the existing regulatory framework for radiation, waste and transport safety.

The regulatory infrastructure may be developed in phases, ensuring at all times that regulations, codes and standards are in place to facilitate a transparent and effective licensing process for the design, construction and operation of the nuclear power plant.

Transparency and cooperation are essential

Transparency and open communications amongst the government, the utility/developer, the reactor vendor/vendor consortium, the owner/operator and the public should be maintained. In addition, effective international cooperation and communications that span all different levels and involve all participants are particularly important for countries with emerging nuclear programmes. This includes active government participation in international organisations such as the IAEA, as well as other multinational initiatives. Also important are bilateral relations between countries that set out fundamental principles of peaceful nuclear cooperation and, for some bilateral agreements, the conditions of international nuclear trade that implement export control regimes.

An area of future growth is regulatory cooperation, both among established nuclear regulators, such as the Multinational Design Evaluation Programme, and between established nuclear regulators and new regulatory authorities that promote the sharing of information, harmonisation of international safety standards and tap into particular experience with certain technologies or facilities. Regional initiatives are also becoming more important as a way to share experiences and lessons learned, such the Forum of Regulatory Bodies in Africa and the Asia-Pacific Safeguards Network.

Finally, industry cooperation within organisations, such as the World Association of Nuclear Operators, pool nuclear reactor operational experience, with the objective of supporting global nuclear safety.

Case study: the recent UAE experience[10]

In 2009, a South Korean consortium, led by Korean Electric Power Corporation (KEPCO), won the international bidding process to build four nuclear power plants in the UAE for the Emirates Nuclear Energy Corporation (ENEC).

The plants are to be located in Barakah, 270 kilometres west from Abu Dhabi. They are scheduled to commence supplying electricity to the grid, one per year, from 2017 to 2020. The KEPCO-led consortium is responsible for designing and constructing the plants, supplying the first load of nuclear fuel and providing technical support, training and education for operations personnel.

Promoting transparency

The UAE's program has been developed pursuant to the 2008 Policy on the Evaluation and Potential Development of Peaceful Nuclear Energy.[11] This policy prioritises six principles:

- Complete operational transparency
- The highest standards of non-proliferation
- The highest standards of safety and security
- Working directly with the IAEA and conforming to its standards
- Partnerships with responsible nations and appropriate experts and
- Long-term sustainability.

As part of its commitment to transparency, in 2009, the UAE established a nine-member International Advisory Board (IAB) to independently assess its nuclear

[10] The information contained in this case study draws on publically available information from several public websites.

[11] The Policy on the Evaluation and Potential Development of Peaceful Nuclear Energy is available from: http://enec.gov.ae/nuclear-energy-in-the-uae/uae-nuclear-energy-policy/

program, headed by Hans Blix of Sweden and former IAEA Director General. The role of the IAB is to review the overall nuclear programme of the UAE, in particular assisting the UAE to achieve its goals.

The IAB's reports are made available to the public so that both domestic and international stakeholders can monitor performance against international standards.

The IAB's first annual report, issued in February 2010, endorsed the UAE's effort to make nuclear safety its highest priority, as well as the UAE's commitment to international nuclear security and non-proliferation. The IAB also endorsed the UAE's commitment to operational transparency throughout the development of the nuclear program.

Nuclear regulation

In 2009, the UAE passed the Federal Law Regarding the Peaceful Uses of Nuclear Energy, which established and mandated an independent regulator, the Federal Authority of Nuclear Regulation (FANR), to be responsible for the regulation and licensing of all nuclear energy activities. FANR's primary objective is to ensure public safety.[12]

ENEC has chosen KEPCO's APR1400, a Generation III, 1400 megawatt nuclear power plant. The reference plant is Shin Kori 3, which is under construction in South Korea. In 2010, ENEC submitted a 9000 page Construction License Application ("CLA") to FANR.

The CLA included:

- a preliminary safety analysis, with a description of the plant design and a summary of the associated safety analyses
- a probabilistic risk assessment report, which demonstrated the low profitability of a severe accident and provided assurance of public health and safety
- an independent safety verification report
- a preliminary safeguards plan, with information on how nuclear fuel and nuclear-related components would be kept secure in line with UAE safeguards commitments
- a quality assurance manual for design and construction and
- a physical protection plan, laying out how ENEC would secure the facilities during construction.

[12] For the UAE's official report on its policy on nuclear safety and the status of its nuclear program, see the UAE National Report to the Second CNS Extraordinary Meeting, August 2012 www.fanr.gov.ae (last accessed on 14 October 2012).

At the end of 2011, ENEC submitted to FANR its evaluation of the lessons learned from Fukushima. ENEC proposed a number of design changes to further improve plant safety margins, which FANR approved.

FANR has entered into a number of cooperation agreements with other national regulatory authorities, including with the Korea Institute for Nuclear Safety, the South Korean regulatory authority that licensed the APR1400 for deployment in South Korea.

Construction, financing and fuel

The construction licence for the Barakah Units 1 and 2 was issued by FANR in July 2012, following approval a "No Objection Certificate" from the Environment Agency – Abu Dhabi. Days later, the safety concrete was poured for Barakah Unit 1.

In July 2012, ENEC also awarded fuel contracts to six companies for services covering the purchase of natural uranium, conversion and enrichment.

Another key milestone in the project's development was the US ExIm authorisation of a $2billion direct loan to Barakah One Company of the UAE, the joint venture company acting as the borrower in the UAE deal.

A model for other emerging nuclear power states

The UAE's approach to the development of a civil nuclear energy program has received strong support from the international community. Many commentators have stated that its nuclear energy program has become 'a model program'.

Small modular reactors – the future?

All feasible technological solutions to the public safety issue are being closely examined, including smaller-scale, less complex nuclear power plants. These include small modular reactors (SMRs) that hold the promise of reducing not only safety risks but investment costs and risks as well:

> *"In increasingly liberalized electricity markets, investors who must bear the bulk of the construction and other performance risks will favor less capital-intensive and shorter construction lead-time investments. There are also some early signs of a potential paradigm shift in electricity markets, away from the large, centralized power stations and towards more decentralized, distributive generation systems that reduce the need for expensive regional or national electricity grids."*[13]

[13] Ioannis Kessides and Vladimir Kuznetsov, 'Small Modular Reactors for Enhancing Energy Security in Developing Countries,' *Sustainability 2012, 4, pp 1806-1832.*

SMRs with outputs in the range of 25 – 300 megawatts are expected to be particularly attractive as a reliable power source for small grid systems or for remote locations, particularly where transport of fossil fuel for conventional generating plant is expensive. The advanced SMR technologies are currently at various stages of conceptual and engineering design and many are seeking to move to commercialisation and first licensing to facilitate deployment.

The latest SMR designs have high levels of inherent safety and no external electrical supplies or pumps are required to cool the reactor, thereby enabling it to remain safe under certain severe accident conditions. Some of the designs are to be installed underground, which may enhance the level of physical security against external hazards and unauthorised interference. The complete reactor assembly may be factory-produced, with the intention of minimising on-site construction time and, also, possibly minimising project delays.

Although the economics of SMRs are currently difficult to predict, one intended benefit is to avoid the high initial capital investment normally associated with large nuclear power plants. For most designs, modules may be added in an incremental fashion, as extra capacity is required. Anticipated to be simple to operate and maintain, SMRs could bring advanced safety features and offer a competitive option for future low-emissions electricity generation.

Conclusion

As countries weigh up their future energy options for moving towards a low carbon society, the nuclear power option is increasingly in the mix. Protection of public safety remains paramount and must be the top priority in all countries, together with continued strengthening of the international nuclear non-proliferation regime and nuclear security.

International best practice is a constantly evolving concept and all countries with active nuclear power programmes and programmes under development must take account of all prevailing international and domestic experience, incorporate lessons learned and continue to rigorously review their legal and regulatory infrastructure.

For emerging nuclear power programmes, a transparent approach is essential. Transparency should be promoted as an important goal of all new programmes, entrenched in national policy and law and implemented by all stakeholders.

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