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Japan's nuclear prospects: challenges and innovation

Introduction

The nuclear industry worldwide has been seeing recently the nuclear energy revival, along with several emerging factors in the energy market as a whole. The high gas and oil prices, seemingly rising endlessly; emerging new economies with high growth in energy demand and consumption; energy producing countries' nationalistic approaches to their energy resource restricting foreign investments; and increasing CO_2 emission and climate change concerns, have all been contributing factors in making public perception of nuclear dramatically shift from anti-nuclear or ignorance of nuclear to an interest in or better understanding of the advantages of nuclear energy. In fact, we are living in an era in which only advanced technology can promise our sustainable development, as the conventional technology in the energy sector in particular has limits to address these challenges on a global scale, let alone nuclear energy. We see advanced R&D in the oil and gas sector, such as carbon capture storage and bio fuel, and even in the renewable sector constant efforts are ongoing to make existing forms of technology better and more efficient, so the global community can take advantage of them at an affordable price with higher electricity generating capacity.

As nuclear energy is widely perceived as a panacea to those challenges mentioned above, the worldwide demand for nuclear energy is naturally accelerating - from South East Asia, Africa and even oil-producing Middle East countries. While most nuclear countries - the US, Russia, EU and Japan - need to replace their existing nuclear fleets, aggressive new-build plans are announced by countries like China and India. This is a move we did not predict even five years ago, when governments and industry strove hard to create incentives for the market and public to appreciate nuclear energy from the energy security point of view.

Japan is one country which has enjoyed since the very early days the fundamentals of continued sustainable nuclear energy use and development. With the policy for energy security, accelerated since the oil shock in the 1970s, and for climate change since COP3 at Kyoto in 1997, nuclear energy has been promoted with the highest technology R&D in the world. Japan, as the one of the mature nuclear countries and as a fuel cycle developing country, is expected to play a leading role in the global nuclear sector. However, at the same time, Japan has been facing serious challenges, as it continues the effective use of nuclear energy, which are not necessarily unique to Japan, and its lessons can be shared in the global nuclear community to make a common approach in addressing those issues, therefore ensuring sustainable nuclear energy development and usage worldwide.

Japan's nuclear energy - where we are now

COMMERCIAL REACTORS

In Japan, there are 55 operating commercial nuclear reactors with a capacity of 49,467 MWe, three reactors under construction (3,668 MWe), and ten planned (13,562 MWe). They generate nearly 30% of total electricity share on average (currently around 20%). Recently plant capacity factor has been down to around 60%, affected by TEPCO's seven reactors at Kashiwazaki-Kariwa plant being shut down due to the earthquake which hit last year. In the normal operating situation, Japan's nuclear plant capacity factor can be below 80% on average, still lower than the major nuclear countries average, reflecting the stringent safety inspection mandate which regulates the plant operator to shut down the plant every 13 months for inspection.

FUEL CYCLE DEVELOPMENT AND NON-PROLIFERATION

Japan has been pursuing a fuel cycle development policy since the 1950s. As the center of its nuclear policy, fuel cycle technologies - enrichment, reprocessing and fast reactors - have been developed under the close international collaboration. As an initial member of Global Nuclear Energy Partnership (GNEP), and of Generation IV International Forum (GIF), Japan is contributing to those multinational initiatives through

its expertise and accumulated knowledge. Japan signed a trilateral memorandum this year with the French and US governments on accelerating its collaboration in developing the sodium fast reactor as part of GIF efforts, while Japan's PUREX reprocessing technology, used for the Rokkasho plant, is underway and will contribute to the more advanced UREX technology under GNEP. The Rokkasho plant, with 800 t capacity, is in the final stage of testing and expected to start within this year. A second reprocessing plant, to be commercialized by 2040, will be considered after 2010. The prototype fast breeder reactor, Monju, is planned to restart in October this year, after the sodium leakage problem in 1995. The new centrifuge enrichment plant is expected to start commercial operation from 2010 with a maximum capacity of 1,500 tSWU/year.

As a non-nuclear weapons country that has permission to develop fuel cycle technologies, Japan has been introducing a vigorous safeguards policy and enjoying close collaboration with the IAEA in developing effective safeguards technology. Japan is the first country with permission from the IAEA to apply the integrated safeguards. Meanwhile, as an active member of GNEP and the nation who puts non-proliferation as the first and foremost principle in its civilian use of nuclear energy, Japan has been engaged in the assured fuel supply dialogue under IAEA, which aims to ensure that non-fuel cycle nations forgo those sensitive technologies in return for sustainable fuel supply.

THE GOVERNMENT OF JAPAN'S ENERGY STRATEGY

The Japanese government set a policy guideline, Framework for Nuclear Energy Policy, in October 2005 to keep the nuclear energy share of total electricity generation at 30-40% even after 2030. The fuel cycle is being promoted under the plan, with an FBR cycle aimed at starting by 2050. In order to fill the gap between the present and that time, mixed oxide fuel (MOX) use, and reprocessing of LWR spent fuel, will stay a mainstream of our fuel cycle. The government of Japan has set the goal of MOX use in 16-18 plants by 2010. Meanwhile, the Ohma plant, with full MOX use, will start operation in 2012. The Nuclear Energy National Plan, adopted in March 2007, not only promotes the fuel cycle, but stresses the reinforcement of the domestic nuclear industry.

The Plan lays out several items as target areas for the medium term for Japan to sustain its nuclear program and to win world-leading nuclear country status, ranging from aggressive uranium acquirement, through the early realization of the FBR cycle, to the acceleration of overseas business deployment. The Plan also promotes government intervention into the workforce shortage, while calling for steady progress in high level waste (HLW) disposal to be operational before 2040 along with an effective public out-reach program to be focused on women and the young generation and countering the safety concerns related to aging plants. For the generation capacity increase, in the very recent Cabinet decision made in July 2008 with regard to the low carbon economy, targeting a 60-80% CO_2 cut by 2050, 9 new builds are required by 2017.

NEXT GENERATION LWR

With the goal of strengthening domestic industry against international competition, the government of Japan has initiated a plan to develop the next generation LWR to be commercialized by 2030. The government, electric utility companies and vendor companies are jointly sharing the cost of up to $600 million over the next 8 years, and will complete the design for one PWR and one BWR of 1700-1800 MWe each. They will meet global standards with a capacity factor of 97%, 80 year plant life, short construction period of 30 months, combining both passive and active safety systems, and a spent fuel volume of 30-40% of the current level. They will have a standardized high seismic resistance, and low radiation exposure at 10% lower than the current level. Under the government's plan, modular-type reactor development will be accelerated to target the global market by 2015.

REGULATORY ISSUES

Japan's nuclear sector is making an effort to improve its low capacity factors and to ensure the seismic resistance of plants anticipating major earthquakes larger than experienced in the past. The aging fleets also require strict safety reviews and inspections as plant life is expected to extend to 60 years, while the higher burn-up of fuel and generation uprates are significant measures to be taken, in order to maximize the current nuclear plants' overall capacity. For the

higher capacity factor, longer period of up to 24 months between inspections is being explored under the Nuclear and Industrial Safety Agency (NISA), the regulatory body, to be executed in five years.

INTERNATIONAL COLLABORATION

As Japan has been collaborating internationally under GNEP and GIF in developing advanced reactor technologies while ensuring the non-proliferation regime, the government of Japan has also been promoting an effective multinational platform in Asia. The Forum for Nuclear Cooperation in Asia originated in 1990 under a government initiative and has been successfully running in 8 fields - radioisotope use for medicine, agriculture, industrial application, research reactor utilization, radioactive waste management, nuclear safety culture, human resource development, and public communication. The collaboration is gradually expanding to the power generation field in such areas as safety regulation, reflecting that more member countries have expressed their interest in having nuclear power reactors for their electricity supply beyond 2015.

The government has also been active in bilateral assistance with those countries introducing commercial nuclear power in Asia, such as Vietnam, in the fields of safety regulation and plant operation and management training. The government of Japan, in the Nuclear Energy National Plan, clearly identifies international assistance, especially for those countries developing nuclear power, as an important area for Japanese efforts. This position was repeated in the recent G8 Summit agreement on nuclear, proposed by the Japanese government, noting that as an ever increasing number of countries turn to or consider turning to nuclear power, there is a growing need to establish common ground on the importance of the "3S"s: Safety, Safeguards, Security. The initiative, which will be in cooperation with or complementary to IAEA activities, will amongst other things, encompass actions on sharing good practice, experience and information, identifying infrastructure development areas that could be improved through international cooperation, and implementing bilateral and multilateral projects to support infrastructure.

The Japanese nuclear sector's challenges - is Japan unique?

The Japanese nuclear sector is often foreseeing a shrinking domestic energy market. The overall pressure to reduce CO_2 emissions and declining population, in conjunction with energy efficient appliances and lifestyles, will contribute to low electricity consumption growth in the developed countries. The population in Japan, currently 127 million, will be below 100 million by 2046 with a gradual decline from 2004. With the energy efficient economy to prevail, with government targets requiring a 60-80% CO_2 reduction by 2050, energy demand growth is expected to decline beyond 2020 according to the Japanese government's long term energy demand/supply outlook. This decline interlinks with lowering GDP annual growth, on average 2% before 2020 and around 1% between 2020-30, estimated in the government's Business-as-Usual (BAU) scenario.

Meanwhile, reliance on nuclear energy for electricity supply will increase in a low carbon society, and will create a higher pressure for supply chain security to build and run the plants as planned. Plutonium use as MOX and the FBR cycle will, in the long-run, support fuel security, while reactor hardware may be exposed to unreliable supply due to demand competition. Ensuring non-proliferation and fissile material controls will be continuing requirements, since the nuclear fuel cycle will be of growing interest in some other non-weapons countries, highlighting security in those emerging fuel cycle countries. Fuel cycle development in new countries can be anticipated from both the commercial and assured fuel security perspectives. Meanwhile, as the sustainable use of nuclear energy can become a prerequisite to our economy, finding a solution to the HLW issue will also become a high priority.

These translate into challenges for the Japanese nuclear sector with global implications.

1. Declining workforce and aging society - the nuclear sector already anticipates the shortage of skilled workforce and engineers to sustain the level of knowledge and expertise. In some countries, the challenge is even more severe, depending on the scale of replacement and new-builds to maintain or increase the electricity supply. In the meantime, the skilled engineering and expertise requirements are severe in

countries which are planning to introduce nuclear plants.

2. Declining domestic nuclear market - with the relatively smaller number of new builds expected in the near term, the Japanese nuclear sector needs to look out to overseas markets to continue business and sustain expertise levels. Global competition will be significant for both market acquisition and the supply chain.
3. Increasing reliance on nuclear energy as an electricity source - high capacity factor, high fuel burn-up and generation uprating efforts need to be evaluated. While the utility companies traditionally need to generate electricity under the cost-efficient business model, the mandate to reduce CO_2 emissions will leverage nuclear energy as a viable electricity source even more as the improvement of capacity factor of a 100 MWe reactor by 1% can avoid 3 million tons of CO_2. Meanwhile, safe and efficient operation and maintenance are required as the prerequisite to ensure the reliability of electricity supply.
4. Fuel cycle with assured security - creating advanced technology is one of the targeted goals under GNEP, and technology dissemination and sharing among the countries concerned are significant measures to ensure non-proliferation. Japan, as the sole non-nuclear weapons nation with full fuel cycle capabilities, should leverage its expertise to lead the global industry with cost effective safeguards mechanisms. The damage to the nuclear industry created by going in the opposite direction will be significant in every way.
5. HLW - rational science and engineering are not to accommodate this issue, while the siting process is easily manipulated and blocked by local politics. Deep underground disposal is regarded as a credible solution to HLW in Japan. However, the siting process and the attitudes of the local community have shown that a non-traditional style of safety evaluation of disposal of HLW and a comprehensive public out-reach program are required.
6. Industry transformation - as nations worldwide are showing their interest in the introduction and expansion of nuclear energy capacity in unprecedented magnitude, the nuclear industry cannot approach those issues mentioned above on a single nation basis. The vendor companies - Toshiba, Hitachi and Mitsubishi Heavy Industries - are going through a dramatic shift in their marketing strategies, culminating in mergers with and the acquisitions of major foreign players as recent phenomena. Countries in South East Asia, the Middle East and Africa are providing new markets to those vendors, while their requirements range from effective regulatory systems to the building of a competent skilled workforce to build, operate and maintain reactors. The global opportunities for the nuclear industry worldwide are large and the associated challenges are even larger. Political leadership by mature nuclear countries to accommodate these requirements is important as GNEP may contribute to this end. For the industry side, meanwhile, an unconventional mindset and innovative approach to those issues is required. The uncertainties associated with the growing market are risks both in terms of the financial commitment necessary to enable the creation of markets and in terms of creating a positive public perception of the nuclear industry significant for the industry's successful business operation.

AN UNCONVENTIONAL APPROACH - INNOVATION IN THE NUCLEAR INDUSTRY

How can we utilize nuclear energy to its maximum value and extend its use to more nations and the people living there, and to the next generations? How can we share and pass on these valuable assets and knowledge of the global nuclear community to the following generation? How can we do this in a sustainable manner, within the limited resources available?

The advanced utilization of information technology can create a new environment for the nuclear industry to address these questions. The industry is utilizing IT already in such areas as plant design, operation and maintenance, and contents and documents management. However, the wider and more extensive use of IT for advanced system requirements could facilitate the issue to a better degree. For example, a super computer can simulate a variety of challenging issues, such as extending the lifetime of the existing fleets, material degradation analysis, providing better designs for fuel and safety margins for the complex next generation reactor designs, and simulating the fuel cycle. It can also enable operational analysis to determine best practice. With effective advanced simulation, IBM's multiple levels of super computer capabilities have been ensuring reactor safety against seismic impact, and the modification of aging fleets, while simulating the design of new power plants and new fuel cycles which require a massive amount of

simulation for strict safety, security and environmental requirements. A super computer is also key to the appropriate understanding of nuclear power plants' operating environments through large multi-physics, multiscale, 3D analysis, including material science and thermal hydraulics.

Also, the integration of maintenance, repair and operation system by utilizing IT is possible in order to improve the safety and efficiency of building and operating nuclear plants. With the effective use of IT, it is possible to streamline the construction process, and the licensing risk involved in the combined construction and operating license (COL) process will be significantly reduced by the consistent maintenance of plant information. With the application of IT, the life cycle management of plants can be improved, by incorporating not only the plant design and decommissioning, but also fleet strategy and management, plant data management, supply chain and strategic sourcing, and project management and control. As one of the crucial areas for sustainable nuclear energy development and to counter the anticipated shortage of engineers and engineering skills, knowledge management can be also addressed through the re-use of maintenance and operational management strategies for plant equipment and maintenance, by leveraging effective IT tools and methodologies across multiple applications.

With the effective and advanced use of technology, nuclear researchers and the industry can maximize the resource available at low cost with higher accuracy and safety. As the industry pursues advanced types of reactor while operating existing plants for longer lifetimes with high expectations of reactor and fuel performance, the technical challenges can be offset if we use the IT tools effectively. They can also pave a way to address public concerns about those traditional issues such as non-proliferation, safety of plants and HLW disposal. The public, otherwise, will be likely to be more concerned as they are learning about those challenges that the nuclear industry is facing.

The conventional approach can only bring a conventional result, but time and resources will be running out before the conventional means and thought processes can produce effective solutions, if ever. Global collaboration is one way to meet the unconventional scale of the challenges ahead, and the innovative use of technology another. They are complementary in the effort that will be vital to the future of our industry.