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# NUCLEAR POWER IN ASIA: EXPERIENCE AND PLANS

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**Abstract**

Asian countries have developed ambitious energy supply programs to expand their energy supply systems to meet the growing needs of their rapidly expanding economies. Most of their new electrical generation needs will be met by coal, oil and gas. However, the consideration of growing energy demand, energy security, environmental conservation, and technology enhancement is inducing more Asian countries toward the pursuit of nuclear power development. At present, nuclear power provides about 30 % of electricity in Japan, and about 40 % of electricity in Korea. These and other Asian countries are presumed to significantly increase their nuclear power generation capacities in coming years. Korea's nuclear power generation facilities are projected to grow from 12 gigawatt in 1998 to 16.7 gigawatt by 2004. On the other hand, China and India have now installed nuclear capacities of about 2 gigawatt, respectively, which will increase by a factor of two or more by 2004. The installed nuclear capacity in the Asian region totalled 67 gigawatt as of the end of 1997, representing about sixteen percent of the world capacity of 369 gigawatt. Looking to the year 2010, it is anticipated that most of the world's increase in nuclear capacity will come from Asia. It is further forecasted that Asian nations will continue to expand their nuclear capacity as they move into the 21st century. For example, China plans to develop additional 18 gigawatt of nuclear power plants by the year 2010. Nuclear power is also of particular interest to a number of emerging Asian countries in view of environmental conservation and mitigation of greenhouse gas emissions in particular. Nuclear power appeals to some countries because of its high technology content. The strength in an advanced technology, such as the technological capability related to nuclear power, contributes to the overall development of the corresponding country's engineering base, enhancement of industrial infrastructure and expansion of well-trained technical manpower pool. However, the rapid development of nuclear power in Asia will be faced with challenges both in the respective countries and the rest of the world. This paper discusses the nature of these challenges and presents recommendations as to how such challenges might be overcome. These include reactor safety, economics of nuclear power, handling of nuclear waste including spent fuel, and nuclear non-proliferation regime as well as public acceptance. Japan, China, India, Pakistan, South and North Koreas as well as other rapidly emerging Asia-Pacific countries will continue to stress the important role of nuclear power in their energy plans. To varying degrees, these plans have emphasized the need of increasing the level of "self-sufficiency" in their energy supply systems. "Self-sufficiency" entails such issues as indigenous enrichment capabilities, reprocessing spent fuel at the back-end of the fuel cycle to recycle plutonium and uranium, and in-country capabilities for nuclear power plant design, manufacture, construction and operation.

## 1. INTRODUCTION

Man is born to live, to live better and more elegantly by all means. To this end, it is imperative for us to keep our candles lit, to keep the complex wheels of this contemporary civilization well-greased and in continual motion, and also to augment our standards of living by achieving sustainable development.

On the other hand, however, meeting of such material demands must not be allowed to strain the eco-systems surrounding our nest, our vicinity and this world as a whole. In other words, we must do all we can to keep our skies and seas blue, to keep our mountains and fields green, to maintain our waters clear and potable, and to restore the pollution-stricken air to the status quo ante. In this context, we ought to bear in mind what Mahatma Gandhi once said: "Nature can fulfil all of our needs. However, it does not have the capacity to fulfil our desires." For our desires are limitless in nature, and sky is the only limit.

We are entering an era in human history where the energy problem for maintaining our socio-economic systems may not be solved without the use of nuclear energy, and also where the energy problem may not be solved with nuclear energy alone either. Truth be told, nuclear energy will not provide a panacea, a solve-it-all solution to all of the world's energy and other needs, but it will certainly remain an important and an indispensable part of the overall equation.

The pejorative image of the looming nuclear mushroom, long entertained in the terrified minds of people who have lived through the Cold War, is gradually giving way to a more positive view of nuclear power as a source of clean and competitive energy, as we redirect our recent preoccupation with the nuclear sword towards nuclear plowshares in the form of nuclear fuel in a power reactor. To make a reality of this reorientation, human reason must prevail over human avarice, and human wisdom must reign over our less benign impulses, which often warp our lives and history.

In no case must we devolve a polluted environment to our offspring: For our generation to soil the atmosphere and aquatic realm would be indeed criminal, with tremendous consequences down the generations to come. It would be awfully difficult, extremely expensive and also time-consuming to reverse the far-reaching effects of eco-contamination, and its consequences for mankind down the generations would be dire indeed. In this context, it may be right what was stated by Dr. In Soon Chang of Korea Nuclear Environment Technology Institute regarding the relation between nuclear technology and nature, which reads: Successful implementation of nuclear power projects through technical enhancement is our way of expressing love towards nature.

It is our conviction that nuclear is new and clear, that nuclear power is, in short, new-clear energy, especially in the Asian region where rapid economic development coupled with very large, energy-hungry populations, will present an impending and critical issue in the arena of global energy market and climate change perspectives.

Asian economics are now at the stage of transforming their industrial infrastructure from the labor-intensive light industries to the energy- and capital-intensive heavy industries. As a result, the average growth rate of GNP for Asian countries in the past decade has consistently surpassed that of the advanced countries, and this increase in GNP has naturally resulted in high energy demand and much faster growth in electric power consumption.

Along with these development characteristics, Asian energy resources are scarce and the cross-border movement of the energy resources is rather limited because of geopolitical barriers. Some countries, therefore, have very high dependence on foreign energy resources. For example, Korea relies on imported energy for more than 97 percent of her energy requirements. The lessons learned from the two oil shocks in the 1970s and the Persian Gulf War have compelled us to adopt national policies to diversify energy resources. Energy and electricity have become pivotal items in government policy especially with respect to long-term planning and technology export drive.

A common characteristic in drawing up electric power development program in the Asian region, excluding Japan, is to meet the immediate demand by fossil energy resources owing to low initial investment, short construction period and lack of technical know-how. To secure stable supply of electric power in the long run, however, nuclear power has long been considered as an optimal choice.

This paper deals with the future aspects of nuclear energy taking into account a number of considerations such as getting rid of oil's grip, contributing to environmental conservation, reducing greenhouse gas emissions, and benefiting from the spin-off effect of high technology. An attempt is also made to address a number of issues associated with the appropriate role of nuclear power in meeting Asian energy needs in the twenty-first century.

## 2. ENERGY DEMAND IN THE ASIAN REGION

Asian demand for energy is forecast to double between 1993 and 2010, raising the region's share of global energy consumption from under one-quarter to over thirty percent (see Table I). Such an increase would be driven by a combination of rising population and skyrocketing economic growth. The growth of energy consumption will be especially pronounced for the electricity sector. Over the next 15 years electricity generation in the Asian region is projected to increase by 130

**Table I. Asian and Global Energy Consumption (M TOE)**

| Region | 1971 | 1993 | 2010 |
|---|---|---|---|
| 1. Asia, of which: | 679 | 1,874 | 3,696 |
| China | 236 | 731 | 1,460 |
| Japan | 270 | 461 | 651 |
| East Asia | 101 | 431 | 927 |
| South Asia | 72 | 251 | 658 |
| 2.Other regions | 4,319 | 6,206 | 8,097 |
| Total (1+2) | 4,998 | 8,080 | 11,793 |

Source: World Energy Outlook, 1996 Edition, OECD/IEA, Paris 1996, and data for Japan are from Atlantic Council's estimates.

percent (see Table II). Even so, electricity use per person will remain very low for most of the Asian population.

It is important to place nuclear power in its context as one of the most important and reliable power-generating wherewithals in this region in consideration of its impending needs. The generation mix varies considerably among countries depending on domestic energy resources. Countries such as Japan and Korea, inherently lacking domestic energy resources, cannot but rely more heavily on nuclear power, which currently accounts for between 33 and 40 % of their electricity supplies.

Asian nuclear power increase from 1997 to 2010 is projected to double. Many countries in Asia are presumed to significantly expand their nuclear power generation capacities in the upcoming years (see Table III). For example, Korea's nuclear power is projected to grow from 12 gigawatt in 1998 to more than 16 gigawatt by 2004. On the other hand, China and India have now installed nuclear capacities of approximately 2 gigawatt each, which will increase by a factor of two or more by 2004.

The installed nuclear capacity in the Asian region totalled 67 gigawatt or 87 units as of the end of 1997, representing about sixteen percent of world capacity. Looking to the year 2010, it is anticipated that the Asian countries will take up a lion's share of new nuclear power generation capacity in the world. For example, China plans to develop additional 18 gigawatt of nuclear power plants by the year 2010.

**Table II. Asian and Global Electricity Output (Terawatt-hours)**

| Region | 1971 | 1993 | 2010 |
|---|---|---|---|
| 1. Asia, of which: | 677 | 2,727 | 6,393 |
| China | 138 | 839 | 2,210 |
| Japan | 385 | 905 | 1,523 |
| East Asia | 78 | 564 | 1,419 |
| South Asia | 76 | 419 | 1,241 |
| 2.Other regions | 4,604 | 9,771 | 14,514 |
| Total (1+2) | 5,281 | 12,498 | 20,907 |

Source: World Energy Outlook, 1996 Edition, OECD/IEA, Paris 1996, and data for Japan are from Atlantic Council's estimates.

**Table III. An Overview of Nuclear Power in Asia**

| Country | Nuclear share out of the total electricity in 1996 (%) | Installed units and capacity in 1996 (%) | Forthcoming units and capacity (net GWe) | Capacity projected for 2004 (GWe) | Capacity projected for 2010 (GWe) |
|---|---|---|---|---|---|
| Japan | 36.1 | 54 (46.5) | 4 ( 4.0) | 52.3 | 70.5 |
| Korea | 36.1 | 12 ( 9.6) | 8 ( 7.0) | 16.7 | 24.7 |
| China | 1.2 | 3 ( 2.3) | 8 ( 6.57) | 2.0 | 20.0 |
| India | 1.9 | 10 ( 1.8) | 6 ( 1.75) | 4.0 | 7.6 |
| Pakistan | 0.9 | 1 ( 0.1) | 1 ( 0.3) | 0.4 | 1.9 |
| North Korea | 0 | 0 | 2 ( 1.9) | 0.3 | 2.0 |
| Other | 28.8 | 6 ( 5.1 ) | 2 ( 2.6) | 7.1 | 7.8 |
| Total | | 86 (65.4) | 32 (24.1) | 82.8 | 134.5 |

Source: Journal of Nuclear Engineering International (1997). Capacities for 2010 in Japan, China and Korea are from Energy Supply Outlook by MITI of Japan (1996), China's Nuclear Energy Outlook by NEI (1997), and KEPCO's internal energy plan (1998), respectively, and other countries' data are from Journal of Nuclear Engineering International (1997). Forthcoming units and capacity are quoted from American Nuclear Society's Nuclear News, March 1998. Korea Atomic Ind. Forum, "The Development and Management Status of Nuclear Power Plants in the World," December 1997.

Over the longer term, this trend is expected to continue, with Asia accounting for an increasing share of global nuclear generation. It is often remarked that Asia will become the new center of gravity in terms of the nuclear industry, wherein additions to capacity over the next 20 years are projected to account for over three-quarters of the global total.

## 3. THE STATUS OF NUCLEAR POWER IN ASIA

For the time being, the growth of nuclear power in Asia will be largely confined to those economies with currently operating facilities (see Table IV). Nuclear energy has already provided a substantial share of electricity supplies for Japan and Korea. China started to take a leaping step toward massive power generation scheme by opening its domestic market, and is expected to be the central arena for the future nuclear power development program in the world, although the current nuclear power generation share of the total is trivial.

In India, nuclear power provided under two percent of total electricity supplies in 1997; further expansion is planned. Pakistan was one of the first Asian nations to have a nuclear power plant and plans to commission a second plant in 1998. Other countries (Indonesia, Thailand) in the region have indicated that their energy systems will include nuclear power facilities sometime after 2010.

Japan, which produces 18 % of the global GDP, is equipped with the largest nuclear capacity in the region. Currently 54 reactors or the installed capacity of 45.5 gigawatt supply about one-third of Japanese electricity. In 1997, Japanese power reactors achieved a record-breaking average capacity factor (81.3 %) in her nuclear history. Especially, the average annual capacity factor of 23 PWRs (19.36 GW) was recorded at 83.4 % which is much higher than that of the world average. The biggest obstacle to nuclear power construction is siting, which is rendered complicated by local Nimby phenomena regarding public acceptance of nuclear power.

Japan has developed an excellent legal framework for siting and operating a power plant, which is entitled "Three Power Source-Related Acts". The philosophy of these three acts is based on the enforced implementation of reciprocal flow of electricity and corresponding compensations between the terminals. That is to say that the generated power is transmitted to the recipients in relatively affluent areas by means of transmission lines, whereas compensations, in a reverse flow, accrue to the local residents adjacent to the power station through the intermediary arrangement of law.

**Table IV. Nuclear Power Program in Asia**
(as of December 31, 1997)

| | In Operation | | Under Construction | | Reasonably Firmly Planned | | Total | |
|---|---|---|---|---|---|---|---|---|
| | GWe | Units | GWe | Units | GWe | Units | GWe | Units |
| Japan | 45.5 | 54 | 0.8 | 1 | 6.0 | 5 | 52.3 | 60 |
| Korea | 12 | 14 | 5.7 | 6 | 11.2 | 10 | 28.9 | 30 |
| China | 2.3 | 3 | 3.3 | 4 | 5.4 | 6 | 11.0 | 13 |
| India | 1.8 | 10 | 0.9 | 4 | 2.9 | 8 | 5.6 | 22 |
| Pakistan | 0.1 | 1 | 0.3 | 1 | 1.5 | 3 | 1.9 | 5 |
| Indonesia | 0 | 0 | 0 | 0 | 1.8 | 2 | 1.8 | 2 |
| N. Korea | 0 | 0 | 2.0 | 2 | 0 | 0 | 2.0 | 2 |
| Other | 5.1 | 6 | 2.7 | 2 | 0 | 0 | 7.8 | 8 |
| Total | 66.8 | 88 | 15.7 | 20 | 28.8 | 34 | 111.3 | 142 |

Source: Korea Atomic Ind. Forum, "The Development and Management Status of Nuclear Power Plants in the World," December 1997. Data for Pakistan are from a local source. Data for North Korea are from the author.

Japan is almost entirely self-sufficient in reactor design, manufacture, construction and maintenance. Japanese and American manufacturers are working together to develop light water reactors, including an advanced pressurized water reactor (APWR) and an advanced boiling water reactor (ABWR). A 1300 MW ABWR design was built by the Tokyo Electric Power Company at its Kashiwazaki-Kariwa site. The first unit of this twin unit plant started commercial operation on November 7, 1996 and the second unit on July 2, 1997.

Japan has a well developed nuclear fuel cycle encompassing fuel enrichment and fabrication facilities at the front-end, and a network of facilities at the back-end of the cycle, including reprocessing and recycling. However, Japan must rely on uranium imports. Longer term plans include recycling plutonium in light water reactors and development of advanced fast breeder reactors, but these plans have been set back by accidents that occurred at the Tokai reprocessing plant and at the Monju fast breeder demonstration plant.

At present, there are three power reactors in operation in China (the domestically designed Qinshan Phase 1 and two French PWRs at Daya Bay). These provide two gigawatt of nuclear power, accounting for one percent of total electricity supplies. However, there are plans to develop a major nuclear power industry with the installation of 20 GW nuclear generation facilities by 2010. The implementation of an ambitious nuclear power development program is underway, which includes two more domestically designed reactors, two imported heavy water reactors, and four more imported PWRs. China National Nuclear Corporation, which operates both its military and civilian nuclear fuel cycle facilities, plans to offer fuel cycle services as well as reactors to the international market. Included in the fuel cycle services would be the output of its gaseous diffusion plant and its new centrifuge plant.

At present, Korea has twelve reactors (of which ten units are pressurized water reactors and two are heavy water reactors) providing 40 percent of the country's electricity supply. Six reactors are under construction and ten more are planned to be operable by 2010 maintaining 40 percent of electricity supply. Virtually all power production is in the hands of the Korean Electric Power Corporation (KEPCO), originally a government-owned utility which is being partially privatized.

A Korean Advanced Standard Reactor has been developed as a model for the next generation reactor which adopts some features of the U.S. and European advanced light water reactor design. Korea has no uranium resources, and has neither enrichment nor reprocessing facilities. Korea relies on Europe, Russia and the United States for its enriched uranium although domestically manufacturing its own PWR and CANDU fuels.

In North Korea, the construction of two 1000 MW-class light water reactors started under the aegis of the Korean Peninsula Energy Development Organization (KEDO), as part of an agreement, under which North Korea suspended the operation of its graphite reactor and halted the construction of two larger units of the same reactor type as well as its chemical reprocessing facilities.

In India, there are currently ten operating nuclear units (two boiling water and eight heavy water reactors). In 1997, nuclear power accounted for about 2 percent of total electricity supplies. All units are in the range of 200 MW capacity. Six more heavy water reactors are in various stage of construction, including two 500 MW plants. Long-term goals include the use of PHWRs to produce plutonium for commercial fast breeder reactors, and developing technologies to use domestic thorium reserves. India has steadily pursued a nuclear self-sufficiency policy.

Pakistan has one PHWR in operation and a PWR nearing completion. Pakistan achieved self-sufficiency in the front-end of the nuclear fuel cycle with its own uranium production, enrichment, fuel fabrication and heavy water production facilities, but has not carried out commercial reprocessing.

## 4. THE REASONS FOR ASIAN NUCLEAR POWER EXPANSION

Asian nuclear capacity expansion endeavors are based on a number of reasons such as meeting the rapidly growing demand for electricity, energy security, reducing greenhouse gas emissions, and benefiting from the spin-off effect of high technology. Many of the reasons are shared by other countries, but, reflecting the diversity of the Asian region, the weight of the different motives varies from country to country.

The rate of dependence on foreign energy resources out of the total energy supply is extremely high in Far Eastern countries compared to other OECD member countries as shown in Table V. That in Japan and Korea is 85 and 97.5% in 1997, while that in UK, USA, France and Germany is 3, 18, 54 and 55%, respectively.

In the Asia-Pacific region, Indonesia, Brunei and Malaysia are the net energy exporters. Indonesia seems to become an oil-importing country from the early years of the 21st century. In fact, Indonesia hit the highest oil production with the annual production of 83 million tons in 1977, but its production rate is decreasing year after year. For instance, her oil production in 1990 was merely 85% of that in 1977. On the contrary, its oil consumption has increased tremendously having recorded 65% increase over the past 15 years.

The world energy market will be largely dependent upon the energy consumption patterns in China which began importing oil as of October 1993 from exporting status. Along with the two-digit growth rate of economy, the increase of China's energy consumption has shown to be skyrocketing. Should the per-capita energy consumption in China reach that of an average (South) Korean, her total

**Table V. The Rate of Dependence on Foreign Energy Resources of the Total Energy Supply**

| Country | % | Remarks |
|---|---|---|
| U.K. | 3 | North Sea oil |
| U.S.A. | 18 | Abundant domestic reserves |
| France | 54 | Nuclear energy |
| Germany | 55 | Domestic coal |
| Japan | 85 | Mostly from the Middle East |
| Korea | 97.5 | Mostly from the Middle East |

energy consumption rate would surpass that of the United States making the global energy picture rather gloomy. And such situation would transform the Far Eastern waters to be a hot conflicting spot.

In addition to the politically unstable situation of oil-producing Middle East, the sea lane between the oil-exporting harbors in the Middle East and the Asian ports is too long and too vulnerable to possible regionable conflicts.

In the year 2010, the Far Eastern region is expected to import 15 million barrels of petroleum from the Middle East a day, which will represent 20% of the total world oil consumption. For this, several tens of oil tanker fleet may have to pass through the vulnerable sea lane every week adjacent to the heavily armed naval and air bases of India, Malaysia, Indonesia and Singapore. In particular, the Malacca Straight, which is 10 km wide and 160 km long and also is shallow territorial sea, is worth receiving special attention in view of strategic considerations. Most of, if not all, the Asia-Pacific countries rely on Middle East oil which has to be transported through this Malacca Straight.

Furthermore, the same oil tankers have to get through another critical zone, that is, South China Sea, wherein many islands and reefs, such as the Paracel Islands, the Spratly Islands and Senkaku Islands are jointly claimed by many neighboring countries. Therefore, this sea lane is another bottleneck in terms of marine transportation security.

The total energy demand in Korea in 2010 will amount to some 250 million TOE (tons oil equivalent). Even if allout efforts be made for the use of nuclear and LNG, at least 125 million TOE of petroleum may have to be imported annually, and this amount will be 50% of Japan's oil import or 200% of those of Hong Kong. In short, therefore, Korea has to be made free from the oil's grip in order not to be a victim of war or conflict in the sensitive area. It is our conviction that nuclear power can be harnessed to play the mitigating role in this regard.

The energy import bill in Korea amounted to 27.1 billion dollars in the year 1997, and this is an unbearable burden to us. In this context, nuclear power can lessen our heavy yoke of balance of trade payments.

### 4.1 Energy Security

Several Asian countries, including Japan, Korea and Singapore, have few domestic energy resources and are obliged to depend on imports for most of their energy needs, at a much higher rate than other OECD countries in North America and Europe. China has become a net importer of oil and gas since October 1993. The Philippines and Thailand are also heavily dependent on imported energy. A large part of this imported energy is shipped from the Middle East through long and potentially vulnerable sea lanes, as mentioned above.

Nuclear power, especially if the technology and civil works can be provided domestically, is seen to upgrade the degree of energy security through diversifying energy supplies and lessening the import dependence share. Even though most Asian countries are obliged rely on imported uranium and overseas enrichment services, nuclear fuel can be more easily stored than fossil fuel and can thus contribute to overall diversification of energy supplies.

Even for the economics in the region that are better endowed with energy resources, long-term plans to develop or expand nuclear generation have been drawn up to support their industrialization progress. For example, China and India which have abundant energy resources, particularly coal and hydro, fall under this category. In the case of China in particular, these are located far from load centers along the industrialized sea coast. Nuclear power, which is not dependent on the constant flow of fuel supply over a long distance eases these logistical problems.

Despite being endowed with energy resources, India's oil imports account for one-quarter of total export earnings, thus making the balance of payments to be in a bad shape. Even Indonesia, one of the most richly blessed in energy resources of the Asian economies, has expressed an interest in nuclear power so as to allow its oil and gas for export.

### 4.2 Environmental Conservation

Nuclear power is also of interest to a number of countries owing to its environmental conservation aspects. Urban air pollution is very high in many Asian cities, being much higher than that in most cities of North America and Europe, and typically exceeds the World Health Organization (WHO) guidelines by a large margin.

Heavy dependence on coal in India and China, has led to particularly acute urban air quality problems. The continued and accelerated use of coal in rapidly growing metropolitan areas in Asia would cause further serious deterioration of urban air quality, and expand the area of already extensive acid rain deposition.

With regard to greenhouse gas emissions, most of carbon dioxide discharge into the atmosphere results from the combustion of fossil fuels. As a viable non-carbon emission alternative, nuclear power is expected to be discussed in the context of global measures to limit the emission of greenhouse gases into the environment.

### 4.3 Nuclear Technology Enhancement

Nuclear power appeals to some countries in view of its high technology content. Such countries would like not to be left behind in technology that could propel modernization and economic development. These countries also argue that strength in an advanced technology, such as the technical caliber in managing nuclear power, contributes to the overall development of that country's technological base, industrial infrastructure and reservoir expansion of trained manpower.

By the end of 1997 over 8500 reactor-years of operation plant experience had been accumulated by the current nuclear reactor systems of the world. On the basis of this experience, the development of advanced reactor designs is taking place nowadays, which comprise three basic types:

- Water-cooled reactors, using water or heavy water as coolant/moderator,
- Fast reactors, using liquid metal, e.g. sodium, as coolant; and
- Gas-cooled reactors, using gas, c.g. helium, as coolant and graphite as moderator.

About 90 % of the nuclear power reactors now in operation are water reactors such as pressurized water reactor (PWR), boiling water reactors (BWR) and heavy water reactors (HWR). While the designs of advanced LWRs (ALWRs) resemble those of their predecessors, they incorporate new passive safety systems as well as plant simplification. The first and second BWRs of advanced design were successfully connected to the Japanese grid in 1996 and 97, respectively.

## 5. ISSUES INVOLVED IN NUCLEAR POWER EXPANSION

Rapid development of nuclear power in Asia raises a number of issues which are important to the power development of the countries concerned and which also have a global impact. These include; reactor safety, handling of radioactive waste including spent fuel, economic aspects, and nuclear non-proliferation. Naturally the shared interest over a wide range of issues makes world-wide co-operation indispensable.

### 5.1 Reactor Safety and Safety Culture

Safety issues are of universal importance. The future of nuclear power everywhere depends on the safe operation of all nuclear power plants, as evidenced, for example, by the impact of Chernobyl. Hans Blix, former director general of the IAEA, said once: "A nuclear accident anywhere is a nuclear accident everywhere". This suggests the possibilities of mutual co-operation on safety questions both within and outside the region. Several international institutions and programs are designed to promote nuclear safety.

Concern for safety pervades the entire nuclear power sector, in the design, manufacture and construction stages as well as operation. In design and engineering, this includes adopting sound basic designs, providing adequate margins and fail-safe arrangements and provision of proper measures for operation and maintenance. Standardization of reactor design also promotes safety and reliable operation. Advanced maintenance technologies reduce the risks of workers' exposure to radiation.

The countries of the region should continue to recognize the great importance of nuclear safety, strengthen the "safety culture", and adopt strict international standards of safety in plant performance including design, engineering and construction, operation and maintenance, and staff training at all levels. As safety is a universal issue, the Asian countries could benefit from regional exchange of information and data, and from adherence to many international programs and protocols governing reactor safety.

### 5.2 Economics of Nuclear Power

A basic question is whether nuclear power is cost-competitive with other forms of power generation. However, estimating comparative costs of nuclear and other base load power plants is a complex issue, and is subject to changes with time and also subject to considerable uncertainty. The cost of individual plants can vary widely according to location, design, siting requirements, and scale of plant. Many things can happen over the lifetime of a power plant that can impact the economics.

Operation and maintenance (O&M) costs in nuclear plants tend to rise as plants become older and regulatory requirements more strict. Some of these cost factors are also shared by fossil fuel plants, further complicating the comparisons. Fuel prices can change in unanticipated ways. Current low price of coal improves the competitiveness of coal-fired power generation. Lower price of uranium, which constitutes a very small part of nuclear power generation cost, does not have a big impact on total costs.

The sharp fall in the price of gas, its increased availability, and highly efficient technologies (the combined cycle gas turbine) have recently introduced a new competitive element into power generation choices.Advances in other non-nuclear technologies for power generation (renewable, advanced coal-burning technologies) can also have a major impact on the competitive economics of power generation.

Other changes with major implications for nuclear power in the past have been regulatory requirements involving expensive redesign and retrofitting, and licensing processes that have added years to construction and commissioning time. Such delays add nuclear power cost drastically as the capital cost of nuclear power plants represents an exceptionally high share of total costs. Moreover, the capital-intensive nuclear power plant is highly sensitive to the discount rates used to calculate their levelised cost.

Asian countries should work jointly with international organizations to develop acceptable models for determining the cost and economics of nuclear power, relative to their own circumstances. These models should provide consistent means of estimating the uncertainty range for each major cost component.

### 5.3 Management of Radioactive Waste and Spent Fuel

The safe storage of radioactive waste has proved to be one of the most intractable global problems of nuclear power generation, and one that could potentially inhibit further development of nuclear power in the future if not satisfactorily addressed. Discharge of spent fuel from world nuclear power plants was estimated at about 32,000 metric tons in 1997, and is expected to be reduced to about 10,000 tons per annum in the near future.

The current storage procedures for "once-through" fuel cycle concept are to temporarily store spent fuel assemblies at the reactor site in specially designed water-filled pools. Those pools were originally envisioned for short-term storage, but in the absence of reprocessing alternatives, and considering the difficulties in selecting permanent disposal sites, these are now providing longer-term storage.

As in other regions, waste management poses major problems in Asian countries. In Japan, each utility is responsible for storing the waste it produces, under government supervision. A permanent disposal facility for low-level waste is already in operation at Rokkasho-Mura. Longer-term solutions such as constructing a facility for vitrified waste or deep underground disposal are being investigated.

In Korea, waste management is the responsibility of the utility, KEPCO. Low-level waste is stored on site, as is spent fuel. At present, there are no tangible activities for storage of radwaste. High level waste, i.e., spent fuel, is stored on site, and no site has yet been selected for the deep underground disposal of high level waste. According to the mutual agreement, Taipower attempted to ship radwaste to North Korea, but this transaction has been hampered due to regional politico-diplomatic argument.

In India, each nuclear station stores its own waste. India follows a closed fuel cycle approach and has established fuel reprocessing plant and associated facilities for vitrifying and immobilizing high level waste. India operates an interim-storage facility with surveillance for high level waste, while ultimate deep underground disposal is being investigated. In Pakistan, intermediate- and high-level waste is currently stored at the associated nuclear facilities.

At present, none of the Asian countries is equipped with a permanent central facility for the disposal of high level waste. As many Asian governments are planning the expansion of nuclear power, the issue of nuclear waste management must receive continued priority attention. Given concerns in some countries, the possibility of regional storage facilities could be examined.

### 5.4 Nuclear Non-Proliferation

One of major issues in making use of civilian nuclear energy is the probability of its risk related to the diversion of nuclear materials and proliferation of nuclear weapons.

Asian nations committed to the use of nuclear power should take steps to the enhancement of regional co-operation in developing advanced reactors and in operating nuclear fuel cycle facilities; and all such endeavors should be implemented with crystal-clear transparency in sensitive nuclear materials management in strict compliance with the nuclear non-proliferation regime.

North Korea and its nuclear facilities present a special concern to the global village from the viewpoint of nuclear non-proliferation regime. North Korea became a party to the Treaty (NPT) in 1985 but delayed more than six years before agreeing, in April 1992, to permit IAEA inspection of its nuclear activities.During that interval, it is known to have produced a quantity of plutonium that may be sufficient for one-to-three nuclear weapons. As of March 1998, it has not satisfactorily accounted for this material and is not in compliance with the IAEA safeguards obligations under the Treaty because of its refusal to allow the IAEA to permit an IAEA "special inspection" of two nuclear waste sites believed to contain information regarding the production of plutonium in the past. Under an "Agreed Framework" signed with the United States in October 1994, North Korea has agreed to resolve these issues at a future date. In the meantime, it has accepted restrictions on its nuclear activities that go beyond its obligations under the NPT, including a freeze on the operation and construction of a number of sensitive facilities.

At about 40 km northwest of the Yonghyun nuclear complex, there has been the construction of a huge underground facility, and this suspicious facility is believed to be the site for North Korea's clandestine nuclear weapons production.

India and Pakistan have nuclear power plants and are seeking to expand their programs. But they are neither parties to the NPT nor have ratified the CTBT (Comprehensive Test Ban Treaty), and are refusing to accept the full-scope safeguards required by most supplier states. Under such circumstances, India detonated five nuclear devices at two days apart in May 11-13, 1998 at Rajastan desert where her first nuclear bomb test had taken place in 1974. Pakistan claimed to have detonated 5 bombs on 28th of May, two weeks after the India's tests. On May 30th, she conducted another test at the same site. The Indo-Pakistan's tests may become conducive to igniting chain reactions among the threshold countries that will see them as an open invitation to acquiring this dreadful technology. This cannot but be a worrisome concern to the global and Asian nuclear communities.

The Asian nuclear power industry and authorities should work with other nations to reaffirm their commitment to the non-proliferation regime. Areas for co-operation could include physical protection of nuclear materials, its control and accounting, regional co-operation in nuclear fuel cycle activities, and advanced reactor development. Asian governments should increase their efforts for transparency and undertake systematic confidence-building measures in order to contribute to minimizing proliferation concerns in and outside the region.

## 6. CONCLUSIONS AND RECOMMENDATIONS

The Asian region is likely to account for a large part of the total increase in nuclear capacity over the next few decades. These countries are motivated by the desire to expand the power for upgrading the standard of living and for expediting national modernization as well as enhancing energy security, conserving environment and benefiting from the technology spin-offs.

Although most of the emphasis in this report has been placed on the inter-co-operation within the region, there is also room for enhanced co-operation between the Asian countries and others outside the area. The benefit should be mutual and reciprocal. Some of the countries outside Asia may be able to pass on the benefits of their past experience to the Asian partners, but they will also be able to learn from the experience of rapid nuclear development in Asia, including evolutionary improvements to technology, at a time when there is virtually no new activity in their own countries.

In terms of reactor and fuel cycle technology development, the advanced western nuclear community resembles a fast-running rabbit, whereas the Asian partner is similar to a turtle. Now this Asian nuclear turtle is moving slowly but steadily towards the self-reliance of its technology and also towards the continued development of evolutionary water-cooled reactors and related fuel technology at a time when there is virtually no new nuclear projects in the western hemisphere and while the rabbit is taking a nap under a tree.

From the historical perspectives, it may be the Asian nuclear turtles who are assigned to keep this nuclear flame continuously burning and to fuel this nuclear candle for the future of mankind and for the world to be less pollutive.

Several decades ago, Rabindranath Tagore, the first Asian Nobel laureate from India, wrote a poem for Korea as follows ;

> In the golden age of Asia ,
> Korea was one of the lamp-bearers.
> And that lamp is waiting to be lighted once again
> For the illumination in the East.

I think I know what he meant by light and the lamp. This is nothing but light from the nuclear lamp. The light to be lit by the nuclear lamp which is another name of the evolutionary water-cooled reactor which has been developed by the Korean nuclear community under the direction of Korea Electric Power Corporation in the nomenclature of KNGR or Korea Next Generation Reactor. Thank you.

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