Nuclear Power Development in Taiwan: Operational Performance and Prospects

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Summary

The energy resources in Taiwan are very scarce, more than 95% of the fuel sources are imported from foreign countries. The nuclear power became essential because of its fuel is relatively easy to ship, compact in storage and economic in price. Construction of nuclear power plants started in Taiwan since the early seventies. Commercial operations began at Chinshan, Kuosheng and Maanshan in the years 1978, 1981 and 1984, respectively. The share of nuclear power in electricity production in Taiwan peaked at nearly 50% in 1984, and decreased gradually to about 20% in 2002.

This speech firstly gives an energy resources and power generations structure in Taiwan. It will then describe the current status of nuclear power in Taiwan, followed by the performance of nuclear power plants in recent years. Nuclear electricity production by all units, capacity factors, reportable event reports, scram numbers, and low-level radioactive waste solidification statistics from year 1984 to 2002 will be presented. The trends show that improvements have been made progressively over the years. The current status of nuclear waste disposal programs will also be briefly discussed. Finally, prospects for nuclear power in Taiwan will be presented. Items encompassed are: new policies on nuclear power, laws and regulations for nuclear reactor safety including plant commission, off-commissioning and decommissioning. Efforts to enhance nuclear safety are also included in the discussion.

1. Fuel Sources for Electricity Generation in Taiwan

Prior to the first commercial operation of Chinshan Nuclear Power Plant in 1978, the electricity productions were mainly from coal, oil, and hydropower. Taiwan had a rapid economic growth in the seventies. New energy source for electricity generation must be used to meet the demand. However, the energy resources in Taiwan are very scarce; more than 95% of the fuel sources are imported from foreign countries. The nuclear power becomes essential because of its fuel is relatively easy to ship, compact in storage, and most of all, economic in price. Taiwan has been involved in construction of nuclear power plants since the early seventies. Commercial operations began for Chinshan, Kuosheng and Maanshan in the years 1978, 1981 and 1984, respectively. The share of nuclear power in electricity production in Taiwan peaked at nearly 50% in 1984, and decreased gradually to about 20% in 2002.

To ensure constant and sufficient supply of energy, it is important that energy sources for power generation are well diversified. From the installed capacity, equal amount has been developed for nuclear power, natural gas, hydropower, oil, and private sectors. However, the coal occupies twice the amount. The total installed capacity in Taiwan is 31.91 GWe in 2002. The commercial electricity production in Taiwan totaled 166 terawatt-hours (TWh) for 2002. Figure 1 shows the percentage of each source as follows: coal 33.88%, nuclear 22.91%, independent power producers 13.34%, natural gas 11.97%, oil 8.99%, co-generation 5.07%, and hydro-electric 3.83%. Also shown in Figure 1, the installed capacity for nuclear power has decreased gradually from 32.4% in 1984 to the current of 16.1%. Correspondingly, the nuclear electricity production percentage has been down from 52.4% in 1985 to the current of 22.9%. With the completion of Lungmen project, the structure of power system in Taiwan will be changed again, and nuclear certainly will occupy a bigger share at that time.

2. Current Status of Nuclear Power Plants in Taiwan

The Taiwan Power Company (TPC) is the only electricity utility in Taiwan that owns the nuclear power units. It has six units in operation and two under construction. Basic parameters of each plant (station) are provided in Table 1.

The three nuclear plants at Chinshan, Kuosheng, and Maanshan, with two units at each site, contributed a nuclear share of 22.9% to total domestic electricity production, compared to 21.6% in 2001. Total electricity consumption in Taiwan increased by 5.3% in 2002. The average capacity factor for the three plants was 88% in 2002, compared to 79% in 2001 or 85% in year 2000. The low average in 2001 is due to a long outage of Maanshan Unit 1. The plant suffered from a station blackout due to malfunction of a power distribution system, which caused a loss of off-site power to one of the two units.

Construction continues for two ABWR units at Lungmen, with 45.76% completion by the end of February 2003. Completion of the units is scheduled for 2006 for Unit 1 and 2007 for Unit 2.

3. Operational Performance of Taiwan NPPs in Recent Years

As shown in Table 1, Chinshan Unit 1 began commercial operation in 1978, and Maanshan Unit 1 in 1984. The shares of nuclear power in installed capacity reached the largest portion of the total capacity in that year as can be seen in Figure 2. Since the Maanshan Unit 2 started commercial operation, the electricity production in nuclear power reached the largest portion in 1985 with the share of 52.4% as shown in Figure 3. The nuclear installation was then paused for a long time until the issuance of the construction permit for the Lungmen project in March 1999. As the power plants of non-nuclear were constructed continually during these years, with independent power producers rising at the same time, the shares of nuclear in both installed capacity and electricity production have been decreasing gradually as illustrated in Figures 2 and 3.

As for operating performance of nuclear plants in Taiwan, it is worthwhile to illustrate the trend of improvements in scram numbers, number of reportable event reports, and the low-level radwaste solidification statistics from year 1984 to 2002. Figure 4 shows scram number statistics for all nuclear units from year 1989 to 2002. Total scram number went from 24 in 1989 and down to 4 in 2002. Note that several external events such as typhoons, big earthquakes, and grid line problems, have caused the plants to scram. Excluding these anomalies, the average annual scram number has decreased from 4 to well below 1 per unit. Figure 5 shows the statistics of the reportable events from year 1990 to 2002. The annual total has come down from the high of 209 in 1991 to only 25 in 2002. Through better management, especially at the plants, strict regulation practices, and experience feedbacks, significant improvements have been achieved successfully. Among all, the most significant improvement in the operation is the reduction of solidified low-level radioactive waste (LLRW). Figure 6 shows that TPC has drastically reduced its annual output of solidified LLRW from a high of over 9900 drums in 1984 to only 818 drums in 2002. The accomplishment could not have been realized without successful implementation of the volume reduction strategy program launched by the Fuel Cycle and Materials Administration (FCMA) in 1990, and the High Efficiency Solidification Technology (HEST) developed by the Institute of Nuclear Energy Research (INER) since 1998, as well as the concerted effort made by TPC and its plant operators.

Table 2 gives the WANO performance indicators for TPC units in 2002. Most of the indicators show performance exceeding the goal, while only few items fell short from the goal with small discrepancies. Overall, it reflects the effectiveness of the efforts made, and also gives clear targets for both the regulator and operator to further the improvement.

4. Current Status of Nuclear Waste Management in Taiwan

The management of radioactive waste is an important task involving both nuclear safety and environmental protection. The Nuclear Materials and Radioactive Waste Management Law was enacted on December 25, 2002, which replaced all administrative orders that had been enforced upon licensees over the past decades. For radioactive waste, the Law sets regulatory requirements for all licensing and enforcement activities on its treatment and storage as well as repository construction, operation, closure, decommissioning and institutional control. The Atomic Energy Council (AEC) with its affiliated FCMA is the regulatory authority.

Low-Level Radioactive Waste

More than 90 percent (by volume) of LLRW generated in Taiwan has been produced by the three nuclear plants, while hospitals, research institutes and industry alike accounted for the remaining amount. The Lanyu storage facility, located in an off-shore islet Lanyu (Orchid Island), provides interim storage for solidified LLRW since 1982. The facility, designed to store 98,000 drums of

LLRW in 23 semi-underground engineered trenches, reached its full capacity in 1996. Modern storage facilities have been constructed at each plant to accommodate for newly generated LLRW.

A new law on site selection for an LLRW repository has been drafted and submitted to the Legislative Yuan for enactment. According to the bill, the Ministry of Economic Affairs (and TPC) is responsible for selecting an LLRW disposal site within five years, which shall be submitted to the Executive Yuan for approval. The enforcement of the law, when passed, is expected to expedite the ongoing siting process.

High-Efficiency Solidification Technology for LLRW

As mentioned earlier, a high-efficiency solidification technology developed for concentrate waste generated from PWR units, or PWRHEST, has been implemented at Maanshan plant since November 1998. As shown in Figure 8, solidified waste produced from the plant has been reduced dramatically from previously 400~500 drums per year down to only 17 drums per year for both units in 2002. This has set the best world record in volume reduction of solidified waste for PWRs. INER has most recently established cooperative agreements with Hitachi Ltd. and Framatome ANP, and continues seeking interested parties to provide technical services in this area.

INER also developed a similar technology for BWR units in Taiwan, which co-solidifies liquid concentrate waste and spent powdery ion-exchange resin generated from BWRs. With co-solidification technology and the uniquely formulated solidification agent, the concept of “solidifying waste with waste” has been implemented in BWRHEST, which provides a maximum waste loading in waste package. Since its formulation in 1998, BWRHEST has been successfully demonstrated at a demonstration plant at INER. With the installation of a full-scale system at Kuosheng, now under construction, it is estimated that the solidified waste will be reduced by three-fold from currently 345 down to 115 (200-liter) drums/year/unit.

In addition, INER is completing an in-house demonstration plant for its newly developed Wet Oxidation Technology (WOT) to treat both powdery and bead-type spent ion exchange resins generated from BWRs. When connected to the existing BWRHEST demo plant, a WOHEST system will be formed to provide a total solution for volume reduction and stabilization of the BWR wet waste including liquid concentrate waste, spent ion-exchange resins and sludge wastes.

Spent Nuclear Fuel

As for the spent fuel management, on-site dry storage was recognized as a favorable option before implementing final disposal. Commissioning of the storage facilities at Chinshan and Kuosheng plants is anticipated in 2008 and 2009, respectively. A long-term investigation plan is being undertaken by TPC to select a suitable site with geological formations of preferred characteristics for a final repository of spent nuclear fuel. Preliminary results submitted by TPC show that some potential host rocks in certain regions of Taiwan are worth further investigation. In considering the geological and engineering complexity of implementing spent fuel final disposal, it is worthwhile to pursue regional or international cooperation along with the domestic siting program.

5. New Development of Nuclear Power in Taiwan

The society in Taiwan has changed greatly since 1990. The power industry is no longer monopolized by the government. Private sectors gradually took shares from the pot as demonstrated in Figure 1. Contrary to the conventional concept that nuclear power generation is confined to be the base load electricity supply, the situation in Taiwan is becoming open for the load regulation to meet the public demand by the private sectors. As a result, a rule for nuclear power plants to be available for keeping a unit on/off at its necessity becomes urgent. An "off-commissioning" rule has thus been established for a nuclear power plant, even under the circumstance of nothing impair to safety, to perform a scheduled shutdown of a plant for a certain period of time. In this case, a nuclear unit in off-commissioning status is still holding a valid operating license while extra review may be needed for its startup.

Plant Off-Commissioning

In the process of setting the nuclear energy policy, the Executive Yuan has paid special attention to its social, economic and environmental impacts. To reduce impacts to the least, and from my observations on all factors, I raised the concept of "plant off-commissioning". The idea is to create a buffer stage to the plant life cycle of construction, operation, and decommissioning. Plant off-commissioning is under thorough planning, plant maintenance programs are still in effect, and the pre-decommissioning program is underway at the same time.

There are advantages to the implementation of plant off-commissioning:

1. It provides strategic energy storage.
   The fundamental difference between plant off-commissioning and plant de-commissioning is that the plant still maintains its availability to generate power. The reactor cooling water system has to be operable, the electrical system and the air-conditioning must be in good condition as well. Once the country deems the need to add more power supply in the future, the unit can be restarted at once. This measure meets the current situation in Taiwan very well.
2. It reduces radiation doses and radioactive waste
   The prolonged outage of the plant, i.e. off-commissioning, will reduce the strength of the radioactivity in the plant. As such, even if the stand-by plant goes directly to the de-commissioning, workers in tearing down the plant will receive far less radiation dose because longer time has passed. Take Co-60 as an example, it has a half-life of 5.3 years. If plant off-commissioning has lasted for five years and then decided for de-commissioning, the strength of the gamma ray has already reduced to half. Not only does it reduce radiation doses, but also effectively reduce the volume of waste.
3. It gives an opportunity to augment decommissioning technology.
   The prolonged length of time in plant off-commissioning gives an opportunity to augment the

decommissioning technology. The planning and implementation of the decommissioning plan do take time to reach its final goal. The extra time provided by the adoption of off-commissioning will add many advantageous aspects to the final plant decommissioning.

As mentioned earlier, Taiwan is indeed scarce in energy resources. More than 95% of the resources are imported from foreign countries. How to avoid energy shortage is the prime consideration of, and great challenge to, the government. The plant off-commissioning concept provides a strategic energy storage means, and it can also be initiated when an over power supply encounters. Furthermore, when the economic cycle changes and power demand increases, the off-commissioned plant can be restarted to generate power again.

Even though the plant off-commissioning is a relatively new concept in Taiwan, there has been some practical experiments elsewhere in the world. Four units of Pickering A and three units of Bruce A in Canada were laid up by the Canadian Authority for poor performance. These units could be restarted depending upon the economic and market situation in the future. These lay-up measures are quite similar to what I have proposed in the plant off-commissioning concept.

Plant Decommissioning

A complete plan to build a nuclear power plant encompasses a plan for the future plant decommissioning. The back-end management fund for the plant decommissioning starts to collect once the plant is in commercial operation. However, when the power company, i.e., TPC in Taiwan, decides to close its nuclear power plant permanently, the facility must be decommissioned by safely removing it from service and reducing residual radioactivity to a level that permits release of the property and termination of the operating license. Items involved in the decommissioning of a nuclear power plant are mainly cleanup of radioactively contaminated plant systems and structures and removal of the spent nuclear fuel.

The Legislative Yuan passed the “Law on Nuclear Reactor Facilities Regulation” in December 2002, which was promulgated by the presidential decree on January 15, 2003. The Law requires that the decommissioning of the nuclear facilities use the dismantling technique, and the plant removal project be completed within 25 years. The licensee shall submit the decommissioning plan and the environmental impact report to the authority three years prior to the permanent termination of the plant operation. The Nuclear Back-end Management Fund shall be used for all expenditures of the decommissioning.

Article 22 of the Law states that the dose at the site after the removal of the nuclear facilities must be less than the standard amount. The standard amount has been set by AEC referencing the practice in the U.S.A. Relevant limits in the Law are as follows:

1. The whole body dose of the general public must be less than 0.25 mSv/yr when the site is under

unrestricted usage.

2. The whole body dose of the general public must be less than 1.00 mSv/yr when the site is again under restricted usage.

Articles 21-28 of the Law stipulate specific rules for regulating off-commissioning and decommissioning of a nuclear power plant.

6. Nuclear Safety Enhancement

National Nuclear Emergency Response Center

Aside from the various safety measures and rule making efforts being implemented, AEC has completed a brand new "National Nuclear Emergency Response Center" which was just put to service last September. The Center is located in the same building as AEC's newly relocated headquarters. It is devised to help ensure more effective and efficient responses and decision-making in the event of a nuclear emergency, and has proved its functions to be satisfactory and acceptable after being put to the test as part of a recent annual drill.

A 24-hour nuclear safety duty office has also been launched at the Center to serve as a single reporting channel for any abnormal event including a nuclear emergency, and as an inter-ministerial communication gateway within the framework of national disaster prevention, with telephone hotlines to the control rooms of all three nuclear plants and emergency planners.

Advisory Committees

While providing its staff with systematic training to maintain their professional capability up-to-date for meeting ever-increasing regulatory challenges, AEC also invite experts outside the Council in relevant fields of expertise to serve as advisors in various in-house committees. Four advisory committees were created within AEC to help ensure the quality of its regulatory practices on issues related to: nuclear facility safety, ionizing radiation safety, nuclear accident investigation and evaluation, and nuclear legislation. Members of these advisory committees meet frequently to help AEC resolve issues in related areas. For example, members of the Advisory Committee on Nuclear Legislation have been meeting almost every week in the past two years to review proposed nuclear legislations before they were submitted to the Executive Yuan or the Legislative Yuan for approval. In addition, the Supervisory Committee on Environmental Protection of Lungmen Station was formed in 1992 to help supervise and audit TPC's implementation of environmental protection measures and monitoring actions during construction of the plant. The Committee has so far held more than 40 meetings including 13 site visits. Advisory committees of similar nature also exist in other nuclear entities such as TPC and FCMA to enhance safety culture, boost operating performance and strengthen radwaste management.

International Cooperation

It has been recognized by many nations that nuclear programs are becoming more and more international. There is growing international cooperation in nuclear infrastructure, safety regulation and R&D to enhance the safety of nuclear activities. Declining national budgets in recent years for nuclear programs also increase the value of international cooperation. The nuclear community in Taiwan has long had sound cooperative relationship with nuclear advanced countries such as Canada, France, Japan, Sweden, Switzerland, UK, USA, in various aspects of nuclear programs. For example, we have benefited greatly from the visiting team of JAPEIC to investigate our welding and NDT programs at Lungmen Project quarterly, and now are seeking the feedback experience of ABWR construction and operation. We also take part in some of the cooperative activities and training seminars sponsored by the OECD's Nuclear Energy Agency and the International Atomic Energy Agency (IAEA), and will continue to seek opportunities for such participations.

7. Conclusions

1. Of the operational performance of our nuclear power plants, the trend shows that significant improvements have been made on important indices over the past decade.

2. The construction of the 4th nuclear plant continues, with 45.76% completion by the end of February 2003. Commercial operations are targeted for 2006 for Unit 1 and 2007 for Unit 2.

3. The high efficiency solidification technology for both types of waste, i.e. PWRHEST and BWRHEST, developed by INER, has been demonstrated as effective in significantly reducing the volume of solidified nuclear waste. These technologies are readily available for commercial application.

4. To balance the nuclear share and the challenge from independent power producers, the idea of plant off-commissioning has been set forth for practice in Taiwan.

5. As Taiwan has begun the planning phase for future decommissioning of nuclear plants, exchange of technology and information with countries with decommissioning experiences will become a new focus in our international cooperation activities. As for final disposal of spent nuclear fuel, it is worthwhile to pursue regional or international cooperation along with the domestic siting program.