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Recommended Citation

Salomon Levy, "SUPPLY OF LIGHT WATER REACTOR(S) TO PYONGYANG: TECHNOLOGICAL ISSUES AND THEIR POSSIBLE RESOLUTION", NAPSNet Special Reports, December 02, 1993, https://nautilus.org/napsnet/napsnet-special-reports/supply-of-light-water-reactors-to-p-ongyang-technological-issues-and-their-possible-resolution-2/

SUPPLY OF LIGHT WATER REACTOR(S) TO PYONGYANG:

TECHNOLOGICAL ISSUES AND THEIR POSSIBLE RESOLUTION

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report to the

December 2/93

INTRODUCTION

The possibility of light water reactor (LWR) technology transfer to North Korea (DPRK) has been raised during high-level talks between North Korea and the United States. The pros and cons of such a transfer were covered by Peter Hayes (1) and the purpose of this paper is to provide details about the technical issues that might be raised by such a transfer and to suggest possible ways to resolve them. It is worth mentioning, at the outset, that my knowledge of the DPRK industrial and electrical capabilities are very limited and that the following comments rely heavily upon information provided in Reference (1). Also, political and legal issues are excluded from this evaluation because they are to be covered in a companion paper. Finally, the treatment in this essay is superficial given the limited time available for this assessment.

This paper first reviews past LWR technology transfer from the USA to other countries and to identify the preferred method of transfer to DPRK. Next, the countries capable of carrying out the transfer are covered and the appropriate choice(s) identified. Finally, key technical problems associated with the transfer of LWR technology are summarized and suggestions provided for their resolution.

HISTORY OF LWR TECHNOLOGY TRANSFER (2)

The light water reactor (LWR) technology was developed in the United States of America (USA) where it was applied successfully first to commercial power production. Two principal concepts of LWR were utilized in the USA: the boiling water reactor (BWR) in which the steam entering the electrical turbine generator is generated in the reactor and the pressurized water reactor (PWR) which employs steam generators to separate the light water coolant in the reactor from the steam flowing to the turbine. The BWR was developed exclusively for power operation and the USA designer of BWRs (General Electric - GE) was the first to commercialize that design. The PWR was designed originally for submarine propulsion and was later adapted to electrical power production. The initial USA designer of PWRs (Westinghouse - W) was the first to commercialize it. These two reactor types have gone on to become the dominant suppliers of nuclear generated electrical power all around the world with about twice as many PWRs operating today than BWRs.

The initial transfer of LWR technology outside the USA was carried out by GE and W and it took three different forms depending upon the country's plans for nuclear power generation, its fiscal resources, and its engineering, manufacturing, and construction capability. The three forms of technology transfer can be formulated in terms of the degree of LWR technology transfer.

Case I - Full Technology Transfer - In this case, the USA vendors of LWR power plants provided the full LWR technology to equivalent companies in other countries (for example, France, Germany, Japan). That transfer of technology included design information about a power station operating in the USA, the engineering, construction and manufacturing methodology employed in the plant as well as training of the licensee personnel. Consulting services were available whenever requested. Improvements in design and developmental results continued to flow to the licensee after they had been applied practically in the USA. There was a backflow requirement of information to the licensor of changes and improvements made by the licensee. Such licenses involved significant initial fees and royalties when the licensor sold its own version of LWR power plants. In many cases the licensor or a licensee-licensor joint venture supplied the first power station and subsequent significant evolutions of that design. With time, most licensees formulated their own design to fit their country's needs and several (i.e., Siemens and Framatome) became capable of competing against the original licensor. Also, with time, other USA vendors [Combustion Engineering - CE (subsequently bought out by ASEA Brown Boveri - ABB) and Babcock & Wilcox -B&W] became capable of supplying LWRs and of licensing their technology.

Case II - Supply of a Prototypic Plant and Stepwise Evolution into a Comprehensive Transfer of Technology. This case applies to countries with an immediate need of power which decided for economic or other reasons (for example, independence of fuel supply) to use nuclear power. However, they did not have the resources or capability to use most of the elements of a full license. Subsequently, as they developed that capability they would acquire the technology stepwise primarily from the original vendor and in a few cases partly from its competitors. There are many reasons for the stepwise approach, including the time required to develop nuclear engineering curricula in local universities; the time needed to put in place the necessary regulations, codes and standards; the time to upgrade quality assurance and manufacturing technology; and the realization that transfer of some elements of LWR technology would not be economical until the number of reactors in a given country and their manufacturing volume was large enough. Several countries have followed this pattern, for example, South Korea and Taiwan.

Case III - Supply of a Prototype and Subsequent Prototype Plants with Very Limited Transfer of Technology. This case applies to countries where the primary interest was in economic nuclear power production. Generally, their demand for nuclear electrical power was small enough to not justify Cases I and II. At the current time, this is true, for example, of the Krsko plant operating in Slovenia or the Koeberg plants in South Africa.

It should be noted that in the USA, over the years, knowledge about the construction and design of some elements of nuclear plants was taken over by Architect Engineers (AEs) (for example, Bechtel, Sargent & Lundy). Such AEs have become responsible for overall project management and design and construction of the non-nuclear systems or so-called balance-of-plant (BOP). Also, it should be realized that some countries (for example, Russia and China) have developed LWR technology on their own; however they have tended to find themselves in a continuous catch-up mode with respect to evolving western LWR technology.

Based upon that brief history, the best strategy for North Korea would be to select Case III and to possibly evolve later into

Case II when it can be justified. Case I is not viable right now; funds, resources, and capability are not available in DPRK and they will not become available for a rather long period of time. It would be premature to go to Case II until the first nuclear plant has been completed satisfactorily in DPRK and until the projected growth in nuclear power in North Korea is established firmly and justified economically.

Also, a premature selection of Case II could have a significant negative economic impact. For example, Brazil acquired significant LWR technology from Germany early and it built large and costly manufacturing facilities which were never utilized. If LWR technology is to be transferred to North Korea, only Case III makes sense at the present time. That was the strategy used in Taiwan and South Korea before being evolved subsequently into Case II. That strategy has been effective in those two countries and it should be in North Korea.

SOURCING OF LWR TECHNOLOGY

In Reference (1), it is reported that North Korea is interested in LWR technology and that its transfer must go directly or indirectly through the USA. France, Germany, and mainland China would not be interested in working through the USA. Japan has the necessary capabilities and may be willing to work through the USA but their acceptance by North Korea is doubtful (1). Also, the Japanese have shown no interest to-date in exporting nuclear power plants anywhere in the world. Russia may be much more acceptable to North Korea but it is not clear why the USA needs to be involved in such a transfer unless it is to provide funding for the project. If the USA is to contribute money, it would make much more sense if it were applied towards an US product. Furthermore, Russia's VVER LWR does not meet all US safety standards in such areas as fire prevention, earthquake protection, and severe accident mitigation, and this would make it even more difficult for the USA to sponsor the transfer of Russian LWR technology.

Since Taiwan is not yet ready for LWR technology transfer, this leaves the US vendors and South Korea as the two possible sources to furnish LWR technology to DPRK through the USA.

USA Supply of LWR Technology

In spite of no new domestic nuclear plant orders for over 15 years, all US vendors, B&W, CE, GE and W, are still capable of transferring LWR technology to North Korea, In fact, CE, GE and W have submitted proposals and are still in contention for the supply of two nuclear power plants to Taiwan. It is true that some equipment suppliers in the US have withdrawn from the nuclear business but all the US operating nuclear plants have been kept supplied with adequate and equivalent products. Also, in many cases, readily available commercial grade hardware has been used after it has been upgraded to meet the nuclear requirements. In my opinion, US vendors could still deliver an entire nuclear supply safety system from the USA. However, they may have to pay a premium for some components sourced domestically (for example, pressure vessels, pumps, valves) and they may choose to procure such components from Europe, Japan, and even South Korea to reduce their costs. Finally, CE, GE and W are all involved in the formulation of Advance Light Water Reactors (ALWRs). These advanced designs include both evolutionary versions of operating large (1200 - 1300 megawatt electrical) light water reactors and small (600 megawatt electrical) reactors with new passive or "natural" safety features (3). Both types of plants include all of the lessons learned from today's operating LWRs and are being prepared for introduction in the USA in the late 1990's. Currently, there are four ALWR designs: CE is pursuing an evolutionary PWR, CE-80+, which is under construction in South Korea (Ulchin Units 3 and 4 expected to go operational in mid-1998); GE is going ahead with an evolutionary ABWR which is under construction in Japan (Koshiwazaki 6 and 7 expected to startup in early 1997); both GE and W are pursuing passive plants called the SBWR and AP- 600, respectively. The passive plants are under development and their designs are still being evaluated by the Nuclear Regulatory Commission (NRC). The evolutionary plants CE-80+ and ABWR are very close to receiving NRC approval.

If US vendors are to supply the first nuclear power plant to North Korea, they would show strong preference for providing their latest LWR version. This means that GE would propose an ABWR, CE the PWR 80+, and W their latest PWR version constructed in England (Sizewell B PWR, expected to go operational in 1994). All of these plants presently have an output of 1000 to 1200 MWe. In the past, US vendors have offered plants with two or three different outputs ranging from 800 to 1200 MWe. They may be willing to consider offering a plant in the range of 600-800 MWe if there is a market and a volume for that size, but that possibility does not appear to be very likely right now. Three to four years from now they may be ready to offer the 600 MWe SBWR and AP-600.

The anticipated capital, operating and generating costs associated with such plants are provided in Reference (3). The capital costs in the USA of one 1200 megawatt electrical (MWe) evolutionary plant were estimated to be about $1360 dollars per kilowatt electrical ($/kWe) in 1992 dollars excluding any financial costs incurred during the project and assuming a construction time of 72 months. The corresponding generating costs were established at 3.8 cents per kilowatt hour (›/kWh) and were found to be competitive with two 600-MWe pulverized coal plants, four 250 MWe integrated-gasification-combined cycle or combined-cycle combustion turbine. If financial costs are included, the capital cost of the 1200 MWe unit would rise to about 1570 $/kWe (which corresponds to about 2.65›/kWhe). The corresponding number for a 600 MWe nuclear plant would be 1860$/kWe. The numbers provided in Reference (3) could be achievable in North Korea because the reduced labor costs in that country should compensate for its inadequate industrial and project culture. However, a contingency factor of at least 20 percent may be appropriate to take into account the fact that this will be the first LWR project in DPRK and that the relations will be complex and difficult between DPRK and the foreign project team. Similarly, a construction schedule of 60 months may be attainable in North Korea if the project is not subjected to political or other interferences. An additional two years are needed from signing a letter of intent to select the site and to prepare an adequate Safety Analysis Report for approval by the regulatory bodies. An additional schedule contingency of one to two years could be justified in this case for anticipated complications.

The US vendors may have a commercial advantage over other suppliers of LWR technology.

Many US supplied plants were canceled prior to their completion and some of the hardware could be obtained from incompleted plants where the equipment is installed or from warehouses where it is stored. For example, W might be very interested in transferring the completed 620 MWe PWR installed in the Philippines. However, no proposal of that type has been successful to-date for several reasons: The canceled plants have been cannibalized to get spare parts for operating plants; also, the regulations and code requirements have evolved over time and have tended to become more stringent; finally, problems have arisen during the course of operating the earlier plant versions. For instance, steam generators in PWRs have developed a variety of problems which have led to tube plugging, reduced power output, and, in many cases, their eventual replacement. Therefore, improved steam generators and changes in the balance-of-plant would have to be made to the older plants. In other words, while a few components could be obtained from canceled US projects, their impact upon plant costs would be minimal and, in my opinion, it would be preferable to employ the latest safety or design features to assure increased safety and improved plant performance.

There are significant obstacles to the US transfer of LWR technology:

þ The supply of US LWR technology and nuclear plant to DPRK is bound to lead to other suppliers wanting to compete for the project. This will be particularly true of France, Germany and possibly Great Britain. The transfer of LWR technology will then become dominated by commercial arguments at the expense of the primary objectives of non-proliferation and nuclear facility inspections.

þ The US vendors will insist on nuclear risk liability coverage. It is not clear how, where, and when DPRK could obtain the necessary nuclear insurance.

þ The selected nuclear vendor and AE would want to be paid in US dollars. In the USA, the nuclear power plant owner raises the necessary money through stock or debt. DPRK cannot follow that pattern and they would expect a substantial loan arrangement with the USA. Some other countries may be much more willing to accept such an arrangement (for example, France, ROK) because some of the technology suppliers are owned by the government.

þ US supply of LWR technology would raise considerable public and congressional debate. One should remember that GE had a letter of intent for the two Koeberg nuclear units now operating in South Africa and that the public and congressional furor about the project led to the order going to Framatome.

þ In the past, the US vendors have not shown a great interest in transferring their technology to countries with a small or doubtful nuclear power future. Commercially, this is a sound strategy.

ROK Supply of LWR Technology

ROK has achieved LWR technology transfer with the purchase of the two PWRs from CE. These units have an electrical output of 950 MWe and are expected to go in operation in 1998- 99. ROK has developed a South Korean LWR standard based upon that technology. It is patterned after the CE-80+ ALWR version being approved by the NRC in the USA. ROK would undoubtedly be interested in LWR transfer of technology to DPRK particularly if it does improve and normalize the relations between the two Koreas. There are many advantages to ROK involvement:

þ They speak the same language and understand the culture prevalent in that part of the world.

þ They may be willing to finance a significant portion of the project, particularly with a guarantee from the USA in the case of a default by DPRK. One way toreduce the costs of the project is to initially transmit a good portion of the power produced by the plant back to ROK. The ROK also may be much more willing to accept repayment in kind from DPRK, i.e. raw materials and food. The US suppliers have shown little interest in such an approach.

þ ROK would be a source of spare parts and other support during plant construction and operations at DPRK. For example, if the plant installed in DPRK is identical to plants existing in ROK, operator and maintenance training could be obtained in ROK for the first project without having to build a plant simulator and a training center within DPRK. Such a strategy not only would reduce costs but also it would encourage continued cooperation between the two Koreas.

þ ROK capability in project management of large projects is well established. Most South Korean nuclear projects have been completed relatively on schedule and close to the original costs. ROK has manufacturing facilities capable of producing most of the components and of satisfying the required nuclear quality level. Their universities have strong nuclear engineering schools which North Koreans could attend until similar capability is developed in DPRK.

On the other hand, there are several obstacles to ROK having a dominant or partial involvement in LWR technology transfer to DPRK:

þ The project will not be successful unless ROK and DPRK can work together. The project will require flow of information and of personnel back and forth over the territorial boundaries. The mistrust between the two countries is very great right now and it will take many years to overcome past years of dislike and conflict. Also, the mistrust is bound to resurface several times during the project and some US participation may be desirable if not absolutely necessary to start and bring the project to its conclusion. A US project, technical, and safety strong mission or group could be useful in meeting that objective.

þ ROK does not have the capability to supply all the components and services for an LWR. For example, key safety-related valves and pumps are not yet being fabricated in ROK. The same is true of instruments and particularly of digital control systems and their software. Independent quality assurance (QA) coverage is still being obtained from US architect engineers. ROK simulators for training operators are most likely behind comparable versions in the USA. However, the missing components, services, and software could be obtained from the USA.

þ ROK will demand some nuclear risk liability protection but possibly to a lesser extent than the US vendors. Also, it is not clear whether ROK would have to get approval from CE before they can proceed with an LWR technology transfer to DPRK.

There is no question that ROK involvement in the transfer of LWR technology would be desirable but DPRK would have to agree to it and would have to realize that the decision cannot be reversed subsequently. A strong US presence in the program could help to stay that course.

POTENTIAL TRANSFER PROBLEMS AND POSSIBLE SOLUTIONS

1. The characteristics of the first DPRK power plant need to be established early.

The type of LWR, its size and location have to be defined early before agreement is reached on the transfer of technology. There are different types of LWRs and different versions among the available PWRs and BWRs. If ROK involvement and component supply are to be pursued, the LWR will have to be a PWR. If the latest LWR design in ROK is to be adopted, the LWR will be the CE type and preferably the CE-80+ standard being adopted in ROK. In my opinion, this will be the least costly approach and it has the greatest chance of helping normalize relations between ROK and DPRK.

The location of the plant and its features are important. There would be an advantage to a site not far from ROK to allow power transmission from the plant to ROK and from ROK to the plant. As noted previously, initial power supply to ROK would reduce the funds required for the plant. Also, nuclear power plants need a strong electrical grid to provide power for decay heat removal during nuclear plant shutdowns. The present DPRK grid would not satisfy this important safety requirement.

The size of the plant is usually determined by economic considerations and the overall capacity and stability of the grid system. Nuclear power plant costs decrease with plant size and the largest possible size is usually selected. Current North Korea available electrical capacity was estimated between 10,000 and 12,000 MWe (1), which suggests a nuclear plant size of at most 600-800 MWe allowing for the grid weakness and future growth. Most LWRs built in recent years have been at or above 1000 MWe and there is a significant cost advantage to using a plant already designed and under construction. Furthermore, the ROK standard plant is at 1000 MWe and that size plant could be introduced in DPRK only with a tieback to the ROK electrical grid. With no tieback to ROK, a 1000 MWe plant may still be the best choice if it can be operated in a derated mode in the first few years of operation until the DPRK electrical grid grows and becomes more stable.

The site characteristics need to be studied in terms of population, seismic, flooding and geological conditions. Access to the site and transportation of large components to it as well as availability of construction materials are other important features. It will take at least one year to 18 months to verify that a site is suitable for nuclear construction.

2. Development of a Strong Compliance Group and a Safety Culture are essential to success.

In a nuclear power plant, safety has to always be the dominant objective because the risks associated with release of fission products from such plants can be enormous. While the power plant owner has many inherent reasons to operate the plant safely, a regulatory or compliance group has been found necessary to assure that the plant is kept on safe grounds at all stages of design, construction, and operation. DPRK will have to develop and put in place such a group. It needs to define the applicable DPRK regulations and how to implement them. An exchange agreement with the NRC would be appropriate and training of DPRK regulators through assignments in the USA would be desirable. Because this program takes several years to implement, most countries have required that the first nuclear plant they acquire be a duplicate of a plant being constructed or operated in the supplying country and that the plant satisfy all the safety regulations prevailing there. This is a good approach, but still the DPRK will need regulators able to pass judgment on the safety of their plant once it starts to operate and to undergo changes. These regulators should be placed in a different and independent agency from the one responsible for operation of the plant. Finally, the regulators must have the authority to stop work and shut down the nuclear plant if necessary.

A safety culture also needs to be instilled in all personnel associated with the DPRK nuclear plant. It requires understanding and analysis of plant performance and intensive training of plant operators and maintenance personnel. The magnitude of this job should not be underestimated. Between 500 to 700 people are needed to operate and support a 1000 MWe plant. DPRK can acquire a core of that capability by assigning a limited number of their personnel at the suppliers, architect engineers facilities and at similar operating plants. With time, that capability needs to be developed within DPRK. Also, DPRK should eventually consider joining the World Association of Nuclear Operators (WANO). This will allow participation of DPRK personnel in peer review of other LWRs and of foreign LWR personnel visiting the DPRK plant. These visits are only advisory in nature but they still provide a chance to keep up with how operational excellence is achieved at other plants world-wide.

3. A strong Project Management and Scheduling Team are necessary.

A significant portion of the costs associated with a nuclear power plant are dependent upon its construction schedule. A construction schedule of 60 to 72 months can be attained only with a strong project management and scheduling team. This will require an organization with clearly established responsibilities and accountabilities. The scope of supply of the various participants needs to be defined before the start of the project. This means that a visit to DPRK will be necessary to establish and to agree upon its capability of supply. For example, most concrete materials of construction and some balance-of-plant components could be obtained from DPRK. Also, it would be desirable to use a majority of the field workers from DPRK and to even train them into performing such more difficult tasks as nuclear related welding. However, the project and scheduling team should be controlled by the supplier of LWR technology. Parallel positions could be assigned to DPRK personnel to assure the transfer of project and scheduling techniques to DPRK. The same strategy should be used for startup of the plant.

The schedule and budget will be satisfied only if changes and interferences are kept to a minimum during the project. In particular, politics can have no role in the process or the costs will rise sharply and the schedule extended by several years.

4. Previous pitfalls should be avoided.

Included in this category are:

þ utilizing more than one type of LWR. This only increases training of personnel and increases technology and manufacturing knowledge to be absorbed.

þ premature use of local components. Inferior components will impact and reduce plant power generation.

þ weak compliance group. The power plant personnel will emphasize power production at the expense of safety and good maintenance.

þ insufficient fuel cycle planning. In some cases, there was a failure to recognize the generation of low to medium activated wastes and the need to provide for their storage. In others, there was a premature rush to install fuel fabrication and other fuel treatment facilities. All such facilities are strongly volume dependent and should not be considered until the volume justifies them (for example, 6 nuclear power plants). For those concerned about cutoff of supplies, limited inventory buildup of nuclear fuel can provide protection. Long-term planning for disposal of spent fuel needs to be considered because the suppliers of LWR technology will not agree to the disposal of fuel they have fabricated or to the storage of high activity wastes it may generate.

The best lesson learned from previous transfer of nuclear technology is that it is best to proceed slowly and carefully because it will be much less costly. In my opinion, the following is a deliberate and appropriate model for DPRK:

Step One (1994-2000): Allow ROK to build an LWR next to DPRK. In exchange for that agreement, DPRK gets assurance of supply of up to 50 percent of the power generated by that unit; also, be allowed to have DPRK personnel participate as observers and workers in that project. This will provide DPRK with an initial knowledge about LWRs. Also, ask the US to help with energy conservation in DPRK in the short term.

Step Two (1998-2004): Have ROK build an LWR in DPRK and obtain increased knowledge about that design, its construction and operation. Let ROK run the project with seconded personnel from DPRK. Terminate power supply from ROK when this unit is available.

Step Three (2000-2006): Have DPRK build its own LWR with large components and fuel obtained from ROK and consider full technology transfer beyond that point. While the volume of fuel supply beyond this point is still too small for DPRK to built its own fuel cycle infrastructure, they may decide to do so for other than economical reasons and assuming that they have the financial resources to do so.

It should be noted that the proposed model is more ambitious schedule-wise than the ROK program. ROK ordered its first LWR in the early seventies and it will achieve full LWR technology transfer only by mid-1998 when Ulchin Unit 3 is operational. The approach should be patterned after ROK. DPRK would have to designate an AE, a constructor, and a reactor supplier which would assume increased responsibilities from Step one to Step three of the plan. In South Korea, they are KOPEC, KHIC and Hyundai or Dong Ah.

This plan has a chance of succeeding only if North and South Korea realize that it is beneficial to both countries. The USA could be asked to participate and to act as a moderator through its execution and particularly during periods of disagreement. The plan should help to lead to harmonious relations between North and South Korea. Without such a harmony, it is difficult to see the possibility or the merit of any LWR technology transfer to DPRK.

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