PROSPECTS AND PROBLEMS OF NUCLEAR POWER DEVELOPMENT IN KOREA

*Woong Bae Rha**

Contents

I. Introduction

There has been a rapid technical progress in nuclear power in the last decade and this technical progress is more or less likely to continue in this field. The consideration of such technical progress in nuclear power suggests to us that the question of having nuclear power in Korea which has only limited resources of conventional fuels is not one of principle but one of suitable timing. Therefore, it is natural to see that the Korean government is strongly interested in constructing one or two nuclear power plants in near future. Although nuclear power plants have shown a decisive market break-through in advanced countries in the last few years, there are a number of difficulties which delay the timing of installing nuclear plants in Korea.

In an analysis of prospects for nuclear power today what is required is not merely to attempt to investigate the economic feasibility of nuclear power, but rather to conduct a searching examination of the technical, social and political factors as well as economic factors which are likely to determine the timing of the introduction of nuclear power. Virtually all aspects of the industrial and political situations of countries are involved in making this decision. Moreover, the construction of a nuclear power plant requires a relatively long

* **Author:** Research Member, The Institute of Management, Research, Seoul National University. Associate Professor, College of Commerce, Seoul National University.

period. Therefore, it would be necessary to have a clear idea of the steps to be taken towards the nuclear power development. This paper is an attempt to analyze some important factors—both economic and extra-economic—related to nuclear power development in Korea.

Ⅱ. Power Supply and Demand Situation in Korea

1. Historical background of electric power system

The hydropower resources of Korea are mostly in the northern part of the country, where installed capacity amounted to 1,300 MW in 1945. Upon liberation in that year, readily available capacity in South Korea was only 50 MW. About 66 percent of the power consumed in South Korea was, therefore, transmitted from North Korea. When supplies were cut off from the north in May 1948, South Korea was faced with a severe crisis in its power supply position. A capacity of about 70 MW was obtained by operating at full capacity of the existing plant with the assistance of power barges. So the power system just managed to meet the essential demand. During the Korean War, most of the existing facilities were damaged. After the cease-fire, in order to meet the essential power demand of both industry and the public, the authorities rehabilitated the war-damaged facilities as far as possible and at the same time commenced the construction of new power plants. The rehabilitation and new construction program was mainly undertaken with financial and technical aid from the United Nation Korean Reconstruction Agency and the United States. However, supply capability has always lagged behind the increasing demand.

A significant milestone for the power system in Korea was passed in 1964 when restrictions on the use of power on its system were removed for the first time. During the first five-year economic development plan (1962—1966), the installed capacity of 402 MW has been newly added to the power system, increasing the total installed capacity of the system to 769 MW in 1966. (See Table 1)

Trend of Installed Power-Generation Capacity in Korea.

<TABLE 1.> (Unit: MW)

Year	Hydropower		Thermal Plants		Power Barges		Total	
	Capacity	%	Capacity	%	Capacity	%	Capacity	%
Aug. 1945	62	31.2	137	69.8	—	0.0	199[a]	100.0
Dec. 1949	62	27.0	141	61.3	27	11.7	230	100.0
Dec. 1951	62	24.4	137	53.9	55	21.7	254	100.0
Dec. 1961	143	39.0	224	61.0	—	0.0	367	100.0
Dec. 1964	143	24.0	424	71.0	30	5.0	597	100.0
Dec. 1965	215	28.0	524	68.1	30	3.9	769	100.0
Dec. 1966	215	28.0	524	68.1	30	3.9	769	100.0
Dec. 1967	215	28.0	524	68.1	30	3.9	769	100.0

Readily available capacity was only 50 MW. The rest of the facilities required major repairs.
Source: Korea Electric Company, *Statistical Yearbook*, Seoul, Korea, 1968

The electric power generation has been increased at an annual ratio of 17 percent between 1961 and 1966. (See Table 2)

In 1967, in spite of 32 percent increase of power generation, the demand has exceeded supply causing the power system to reintroduce the power rationing which had been lifted since 1964.

Since it is expected that such a rapid rate of growth of demand for electric power will continue for at least next decade, the future development of the power supply system is one of the most important tasks to be performed. A regular and dependable power supply system must provided in the future under planned provisions of power capacity additions to meet the anticipated growth of demand at minimum cost. Therefore, all the possible alterinatives have to be carefully investigated.

Trend of Power Generation in Korea

<TABLE 2.> (Unit: GWH)

	Hydro power	Thermal Plants	Power Barges	Power received from North Korea	Total	Per capita generation (KWH)
1946	216	8	—	432	712	—
1949	202	320	133	Cut off on 5—18—48	655	—
1951	59	88	190	—	337	—
1961	652	1121	—	—	1773	69.8
1964	749	1807	139	—	2695	97.7
1965	710	2446	88	—	3244	114.5
1966	985	2787	114	—	3886	134.0

Source: Korea Electric Company, *Statistical Yearbook*, Seoul, Korea, 1968.

2. Projection of Power Demand

According to the projection recently revised by the Korea Electric Company, it is estimated that the demand for electric power would grow at the average rate of 28.1 percent a year during 1967—1971 and 15.2 percent a year during 1972—1976. (See Table 3) These annual growth rates are relatively high even among developing countries which, in general, have quite high growth rates of demand for electric power. The growth rates vary greatly among countries. (See Table 4) For highly industrialized countries such as the U.S.A. and U.K. the rate amounts to about 7 percent. According to the recent projection made by ECAFE, the demand for electric power of the ECAFE region is expected to expand at a rate of between 9 to 12 percent a year up to 1970 and perhaps a little more slowly thereafter.[1] However, this figure seems to be unrealistically low for countries which are striving for successful economic development. For example, Taiwan experienced 12.9 percent average annual growth rate over the last ten years, and expects an increase of 16.1 percent per

(1) United Nations(ECAFE), "Economic Development and Planning in Asia and Far East, IX Planning for Energy Development," *Economic Bulletin*, Bangkok, Thailand, December p. 57.

<TABLE 3.> Forecast of System Power Requirement and Peak Demand

(1959~1970 : actual, 1971~1981 : forecast)

Classification	Unit	1959	1960	1961	1962	1963	1964	1965	1966
1. Lighting	GWH	226	235	228	264	292	157	422	502
2. Small-Power (under 500 kw)	GWH	466	454	421	498	537	625	757	950
3. Large-Power (above 500 kw)	GWH	359	424	542	718	834	1,035	1,252	1,527
4. Agricultural Power	GWH	21	24	21	25	20	26	32	30
5. Total Sales	GWH	1,121*	1,154*	1,189**	1,470**	1,696*	2,043	2,464	3,008
6. Total T&D Loss	%	30.5	28.4	29.4	22.3	20.5	19.9	19.2	18.1
7. Net Generation	GWH	1,613	1,612	1,684	1,891	2,134	2,552	3,050	3,673
8. Auxiliary-Use Rate	%	4.5	5.2	5.0	4.4	4.6	5.5	6.2	5.5
9. Gross Generation	GWH	1,688	1,699	1,773	1,979	2,236	2,700	3,250	3,886
10. Annual Loab Factor	%	68.0	66.9	66.2	65.8	65.0	62.4	61.6	63.7
11. Peak Demand	MW	283	289	306	343	393	492	602	696

Classification	Unit	1967	1968	1969	1970	1971	1972	1973	1974
1. Lighting	GWH	572	713	849	1,013	1,207	1,452	1,747	2,102
2. Small-Power (under 500kw)	GWH	1,106	1,510	1,889	2,352	2,921	3,452	3,949	4,425
3. Large-Power (above 500kw)	GWH	2,190	2,928	3,893	5,155	6,780	8,390	9,980	11,530
4. Agricultural Power	GWH	35	49	70	80	92	106	124	143
5. Total Sales	GWH	1,903	5,200	6,700	8,600	11,000	13,400	15,800	18,200
6. Total T&D Loss	%	16.5	17.0	15.5	14.5	13.0	12.5	12.0	11.5
7. Net Generation	GWH	4,671	6,265	7,929	10,058	12,044	15,314	17,955	20,565
8. Auxiliary-Use Rate	%	4.9	3.2	5.5	5.5	5.5	5.5	5.5	5.5
9, Gross Generation	GWH	4,913	6,609	8,391	10,643	13,380	16,206	19,000	21,762
10. Annual Load Factor	%	72.0	65.9	66.0	66.0	66.0	66.0	66.0	66.0
11. Peak Demand	MW	778	1,142	1,451	1,841	2,314	2,803	3,286	3,764

Classification	Unit	1975	1976	1977	1978	1979	1980	1981
1. Lighting	GWH	2,529	3,043	3,580	4,200	4,900	5,660	6,450
2. Small-Power (under 500kw)	GWH	4,865	5,284	5,700	6,140	6,560	5,020	7,510
3. Large-Power (above 500kw)	GWH	13,040	14,480	16,000	17,600	19,340	21,170	23,400
4. Agricultural Power	GWH	166	193	200	260	300	350	400
5. Total Sales	GWH	20,600	23,000	25,500	28,200	31,100	34,300	37,800
6. Total T&D Loss	%	11.5	10.5	10.0	10.0	10.0	10.0	10.0
7. Net Generation	GWH	23,146	25,698	28,338	31,333	34,558	38,111	42,000
8. Auxiliary-Use Rate	%	5.5	5.5	5.5	5.5	5.5	5.5	5.5
9. Gross Generation	GWH	24,493	27,194	29,982	33,157	36,567	40,329	44,444
10. Annual Load Factor	%	66.0	66.0	66.0	66.0	66.0	66.0	66.0
11. Peak Demand	MW	4,236	4,703	5,186	5,735	6,324	6,975	7,687

NOTES: * This includes 49, 17 and 13 million kw/hr unaccounted for and adjustment for 1959, 1960 and 1963 respectively. ** This excludes 23 and 35 million kw/hr unaccounted for 1961 and 1962 respectively.

annum between 1968 and 1980.[2] Since Korea has been suffering from insufficient power supply, it may be reasonable to expect a little higher growth rate.

<TABLE 4.> Trend of Power Generation in Several Countries

(unit; GWH)

	1955	1965	Average Annual Growth Rate (%)
U.S.A.	629,010	1,157,391	6.2
U.K.	94,076	196,027	7.5
Japan	65,193	192,138	11.6
China (Taiwan)	1,966	6,627	12.9
Philippines	1,336	4,959	14.0
Turkey	1,583	4,941	12.1
India	10,877	33,129	11.8

Source: United Nations, *Statistical Yearbook*, New York, 1960 and 1966.

The share of electric power among various forms of energies has increased in the last few years (See Table 5), as has per capita generation of power. (See Table 2) However, the per capita generation is still much lower than those of advanced countries and some developing countries such as Taiwan and the Philippines. (See Table 6) Hence, in view of the

<TABLE 5.> Trend of The Share of Electric Power to Total Energy Supply in Korea

(Unit: 1,000 tons of Korean-anthracite coal equivalent)

	(A) Power	(B) Total Energy Supply	A/B (%)
1961	1,326	18,832	7.0
1962	1,538	20,171	7.6
1963	1,682	21,379	7.9
1964	2,004	22,284	9.0
1965	2,434	23,695	10.3
1966	2,623	24,790	10.6

Source: Korea Electric Company, *Statistical Yearbook*, Seoul, Korea, 1967.
Korean Reconstruction Bank, *Korean Industries*, Seoul, Korea, 1966, p. 12.

<TABLE 6.> Electric Power Generation per Capita in Several Countries

Country	Per Capita Generation (KWH)	Country	Per Capita Generation (KWH)
U.S.A.	5,948	U.A.R.	185
U.K.	3,590	Turkey	159
France	2,073	Philippines	153
Japan	1,961	Korea	114
Taiwan	533	India	69
		Thailand	46

Note: All figures are based on 1965 statistics except India's figure which is based on 1964 statistics.
Source: United Nations, *Statistical Yearbook*, New York, 1966.

(2) United Nations(E.C.A.F.E.), *Electric Power in Asia and the Far East*, 1964 Bangkok, Thailand, 1966, p. 13.

vital importance of electric power to over-all economic growth, the future development of the power supply system is one of the most important prerequisites for further economic growth.

3. Power Potential and Development Plan

The total installed capacity of the power system amounts to 769 MW at the end of 1967. It includes the installed capacity of 524 MW of the thermal plants, 215 MW of hydropower plants, and 30 MW of power barges. The heavy dependence of the power system on the thermal plants mainly resulted from the following reasons:

a) the initial capital expenditure per KW of the installed capacity of thermal plants is low than that for hydro-plants;

b) the thermal power plants require shorter periods for construction a very important factor in meeting the rapidly increasing demand for electric power;

c) the Korean anthracite coal can be used as fuels for the thermal plants. In fact, anthracite coal is the only locally available resourse of fuel in Korea. The Korean anthracite coal thermal plants can reduce the foreign exchange requirements. In the near future, however, we may be faced with a coal shortage and steeply rising costs. Hence, long-run planning should be based on careful evaluation of potential power resources in Korea.

1) Hydropower potential in Korea

If a country possesses favorable hydro resources, the development of hydropower potential is desirable alternative for power generation. This form of power generation requires no fuel and is therfore free from such consideration as fluctuations in fuel prices. Also it may bring the benefits other than power generation such as irrigation, flood control and water pool for industrial use; and it entails neither pollution of the air as do thermal power stations, nor pollution of the water which is used in the plant.

There are four main rivers in South Korea. The estimated hydropower potential of these four basins could be as much as 1,835 MW and there are 58 possible sites for development.(3) Seven sites have been so far developed, having an aggregate capacity of 215 MW and projects are currently under construction at two sites. It has been indicated that the hydropower sites in Korea have a number of characteristics which limit the economic value of the sites.(4)

They include:

a) The water characteristics of Korea are quite severe. About 70 percent of the annual rainfall occurs between June and September, while annual system peak demand occurs in the winter period.

b) In general, reserve sites will permit only small reserves and there is little opportunity for storage that will adjust the run-off in the water sheds consumed over a year's time.

c) The run-off from rainfall is rapid and large floods occur at frequent intervals. Hence,

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(3) Korea Electric Company; *Statistical Yearbook*, Seoul, Korea, 1967 and Korea Electric Power Industry Survey Team; *op. cit.* Vol. I. pp. 127—8.

(4) Korea Electric Power Industry Survey Team; *op. cit.* vol I. pp. 127—128.

the spillways must have a large discharge capacity, which requires many gates and hoists.

d) The river grades are quite flat and the river beds are wide. Thus long dams are required

c) Average potential at each site is low. Among 58 possible sites, only 9 have potential greater than 50 MW of capacity at each site. The potential sites with a capacity of less than 20 MW number 36, and average less than 10 MW of capacity.

These charactertisics tend to increase capital cost per installed KW and to reduce the availability of the installed capacity. The Survey Team recommended that, from a strictly economic viewpoint, no hydropower plant should be constructed at this time.[5] It is expected that the demand for electric power will reach to approximately 5,000 MW within 10 years. This means that even if all the available hydropower sites will be developed during next 10 years regardless the economic feasibility, it is less than 35 percent of required capacity expansion for next years. Furthermore, since hydropower plants require higher capital investment per KW of installed than do thermal plants, the lack of capital in Korea will further discourage the development of hydropower.

2) **Thermal power development**

As already mentioned, the power system in Korea depends heavily on the conventional thermal plants. Unfortunately, no bituminous coal deposits of any consequence have been found in Korea and geology of the country does not indicate that any substantial amount of bituminous coal or any oil or natural gas will be discoverd. Consequently, anthracite coal is the only locally available fossil fuel in Korea. The recoverable recserves of anthracite coal in the country are estimated to be in the order of 400—500 million tons, with an annual production rate is excess of 12 million tons, but less than 17 million tons.[6]

The anthracite coal-fired thermal plants give two specific advantages; the saving of foreign exchange and the security of power supply. Therefore, up to 1966, the government followed the coal-preference policy. In 1967, in view of the increasing demand for coal and steeply rising production costs, the government drastically increased the use of oil as fuel for the thermal plants. Of course, as the position of foreign exchange improves, the idea of a free choice of energy sources may replace the coal-prefrence policy, and emphasis should be placed on achieving power supply at the cheapest rates. Cheapness of power will be of special importance to the Korean economy when it enters into the group of open economies since it is essential for promoting the international competitiveness of its industries. However, under critical shortage of foreign exchange, it is perhaps advisable to utilize the locally available fuel for power generation.

3) **Tidal Power Potential**

The tidal power potential of the country is represented to be on the order of 1,600 MW.[7]

(5) Korea Electric Power Industry Survey Team; *op. cit.* Vol. I, p. 3.

(6) Korean Reconstruction bank; *Korean Industries*, Seoul, Korea, 1966.

(7) Korea Electric Company; *Statistical Year book*, Seoul, Korea. 1965.

However, none of this power potential has been developed and econonic possibility is very doubtful since capital cost per installed KW will be greater than for a conventional hydropower plant. There will be no possibility of introducing the tidal power plants in the near future.

This brief observation suggests that a large proportion of power development for next decade should be conventional thermal plants. It can also be concluded that nuclear power is likely to become an attractive alternate as a major source of energy in Korea in the future. According to the fifteen-year power development plan by the Korea Electric Company, the Company is going to increase the installed capacity of the power system from 769 MW to 10,477 MW; an increase of 9,708 MW for next fifteen years. It is planned that only 730 MW of hydropower and 100 MW of nuclear power will be added to the system for the same period. The rest of the capacity addition will be conventional thermal plants.

Ⅲ. Economics of Nuclear Power

1. Economic Characteristics of Nuclear Power

Because of the lack of favorable hydropower sites and fossil fuel supply in Korea, it is likely that nuclear power may become and attractive alternative as a major source of energy in Korea in the future. Before we examine the economic feasibility of nuclear power, it may be better to notice some characteristics of nuclear power.

First of all, the economies of scale in nuclear power are considered to be more important than in conventional thermal power. That is, it is a characteristic of nuclear power that its competitive position improves as the size of plant increases.(8) For reasons of system reliability, however, it is desirable that the proportion of total capacity represented by a single plant should not exceed a relatively small fraction —10 to 15 percent unforeseen— so that the normal system reserve can be counted upon in the event of unforeseen difficulties, because the larger the plant is the more severe are the economic consequences of an unscheduled shutdown. There is evidence that electric utility companies in the United States are experiencing a higher than expected rate of forced shutdown in the operation of their newest, largest and most sophisticated conventional plants.(9)

Nuclear Power is new technology and its dependability is not well evaluated yet. Moreover, the rate of failure might be higher in underdeveloped countries because of the absence of nuclear skills.

Secondly, nuclear power is capital-costly technique for power generation. Therefore, a high

(8) The formula C=KX 0.6 is often used to represent the construction cost of nuclear power where K=Constant, X=Size of plant in terms of MW, 0.6=Economies of scale factor See:
Deutch, M. J.; "Atomic Power in the Energy Programme of Asia and the Far East," *Proceedings of the Regional Seminar on Energy resources and Electric Power Development*, UNECAFE, Bangkok Thailand, 1962, p. 161.

(9) See J. H. Horgeston, "The Arrival of Nuclear Power" *Scientific American*, February 1968, p. 27

utilization factor is essential for the most economic use of it. This fact suggests that there should be big enough base loads which accomodate relatively big nuclear power plants. It should be noted that the condition of power supply and demand in Korea are becoming increasingly favorable for the introduction of nuclear power plants of 300—500 MW unit. It is expected that the demand for power will grow rapidly and exceed 3000 MW within four or five years, and local sources of electric power are very limited as indicated.

2) Cost comparison of nuclear and conventional power

It would be advantageous to analyze conventional thermal and nuclear alternatives in one category and hydropower in another in view of their rather different characteristics. Comparative costs—capital and operational— for the conventional thermal and nuclear alternatives are given in Table 7 as they have emerged from a recent study in Korea. Since one of the main objectives of the study was to examine the prospects of nuclear power, alternatives have been considered with relatively large unit sizes of the order of 500 MW. While this range would appear somewhat too large in relation to the current demand in Korea, the needs of Korea will be consistent with this range in the near future.

It will be seen from Table 7 that, under the conditions obtaining in Korea, the costs of power generation of nuclear power are slightly lower than those of conventional thermal power. However, we should realize that the figures are obtained on the basis of many assump-

<**Table 7.**> **Generation Cost Comparison**

	Conventional plant	Boiling Water Reactor	Pressurized water Reactor
Size of Unit (MW)	500	500	500
Gross Output (MW)	521	544	497
Net Output (MW)	506	525	479
Fuel		Nuclear	Nuclear
Capacity Factor	85%	85%	85%
Net Annual Energy produced(10KWH)[a]	3,765	3,907	3,570
Capital Cost($/KW)	132	220	224
Fuel Cost (cents/10^6BTU)	41.56	15.39	16.39
Annual Operation and maintenance($)	196,000	349,000	349,000
Nuclear Liability Insurance($)	—	203,200	200,000
Generation cost (mills/KWH) Fixed Cost[b]	2.426	3.902	4.198
Fuel Cost	3.842	1.607	1.749
Operation main.	0.052	0.089	0.098
Materials & Supplies	0.200	0.200	0.200
Nuclear Liab. lns.	—	0.052	0.056
Total(mills/KWH)	6.520	5.850	6.301

Footnote (a) Net Annual Energy Produced=Net Output $\times \frac{85}{100} \times 8760$

(b) Fired cost charge rate=13.6%

Source: Burns and Roe, Inc. *Feasibility Study fort he First Nuclear Power Project in the Republic fo Korea*. Oct. 1968, p. Ⅳ—3.

tions and, therefore, it would be useful to examine the assumptions and their implications to the prospects of nuclear power in Korea.

3) Capital Costs

The fixed capital costs of the oil-fired thermal plant with 500 MW of unit sizes is estimated to be per KW of installed capacity and the extent to which they task into account the latest technological trends can be seen from the facts that the average capital outlay on thermal plants in Japan during 1959—62 was $167 per KW for oil fired units.(10)

Steady technical progress is being made in the conventional thermal plants. Technical progress, in general, is mixture of several factors such as economics of scale, pure technological change, and improvements in the quality of the inputs. Year by year, higher temperatures and steam pressure are obtained leading to higher efficiency and smaller fuel consumption per KWH of output. The cost reduction has been accelerated by an increase in the average size of conventional thermal plants. There is a tendency to install increasingly large generating units to derive maximum benefit from economics of scale. Since coal-fired thermal plants need coal and ash handling facilities, the construction costs of those plants are in general higher than that of oil-fired thermal plants.

There are some conservative views as to technical progress in conventional thermal plants. J. Ullmann indicates that.

Many of the economics found effective in the past have now been exhausted or yield

Fossil Plant Capital Cost Estimates Two-500-MW Nominal Units

<TABLE 8.> (All costs Based on Late 1968 Price Levels)

Acct. No.	Description	UNIT No. 1	UNIT No. 2
310	Land and Land Rights	500,000	—
311	Structures and Improvements	3,812,000	3,196,000
312	Boiler Plant Equipment	19,230,000	18,641,000
314	Turbogenerator Units	15,336,000	14,532,000
315	Accessory Electric Equipment	4,238,000	3,917,000
316	Miscellaneous Power Plant Equipment	253,000	79,000
353	Station Equipment	708,000	708,000
	Freight, Insurance and Local Transportation	1,583,000	1,474,000
		45,660,000	42,547,000
	Other Expenses	600,000	500,000
		46,260,000	43,047,000
	contingency	4,626,000	4,305,000
		50,886,000	47,352,000
	Engineering, Design and con struction Supervision	4,400,000	2,000,000
		55,286,000	49,352,000
	Interest during construction	11,886,000	9,870,000
	TOTAL ESTIMATED COST	$67,172,000	$59,222,000

Source: Burns and Roe, Inc., *Feasibility Study for the First Nuclear Power project in the Republic of Korea*, Ordell, New Jersey U.S.A., p. IV—6.

(10) UNECAFE, *Economic Bulletin*, Bangkok, Thailand, December 1965, p. 33.

little changes. For example, pressure of 6,000 psi are now feasible and relatively little is to be from going even higher into the supercritical range. Temperatures now used are close to the metallurgical limits of conventional construction materials. Labor is now at a mininum and the automation systems now being offered for electric power systems now being offered for electric power systems must be justified on the basis of fuel economics and avoidance of major breakdowns rather than labor saving. The capitalized value of more saved labor would be insuffiuist under present conditions to pay for any significant new control system.[11]

By contrast, there are many identifiable potential savings to be made in nuclear power. However, it does not nessessarily mean that the capital cost of nuclear power will drastically be reduced in near future. Since nuclear technology is a new field, the construction cost of nuclear power plants is still uncertain. A considerable reduction in construction cost was realized in the first half of the 1960. In the early 1960 the construction cost of nuclear power plants in the United State was in the range of $200—$250 per KW of installed capacity with the unit sizes of 200 MW—500 MW. During 1964—1966, the breakthrough of nuclear power into the commercial maket was realized.

<TABLE 9.> **Construction Cots of Nuclear Power Plants Completed or Under Construction in the United States**

Plants	Size(MW)	$/KW	Remarks
Yankee	158	$248	Completed in 1960
Dresden	205	250	Completed in 1960
Conn. Yankee	463	183	Completed in 1967
San Onofre	428	214	Completed in 1967
Post-Oyster Creek	605	139	Ordered in 1964
Post-Dresden	800	123	Ordered in 1965
Browns Ferry 1, 2	1100	115	Ordered in 1966
Browns Ferry 3	1100	132	Ordered in 1967
Bridgman	1100	139.50	Ordered in 1967
Surry	815.5	152.55	Ordered in 1967

Source: International Atomic Energy Agency; *Bulletin*, Vienna, Austria, October 1963 and American Nuclear Society; *Nuclear News*, April 1968, p. 8.

As shown in Table 9, however, despite a number of technological advances, substantially no progress has been made to lower costs since 1964. As the breakthrough of nuclear power into the commercial market was realized, the turnkey philosophy by which the manufacturers had borne the major risks in pricing was abandoned, and the construction cost has risen to around $150 per KW for units in the range of 800 MW—1,100 MW. It becomes apparent that the construction cost of nuclear power plants will remain uncertain until experience is gained with the big plants now under construction or on order.

(11) J. E. Ullmann; *Economics of Nuclear Power*, Advances in Nuclear Science and Technology," edited by E. J. Henly and H. Kouts, 1962, pp. 234—235.

The feasibility study for the first nuclear power project in Korea estimates the capital costs of two—500 MW units in the range of $220—224 per KW of installed capacity. The Taiwan power company took the capital cost of $200 per KW for a 324 MW size of nuclear power plant in the feasibility study made in 1964. (12)

Capital Cost Estimate of Two-500-MW Nuclear Power Plant

<TABLE. 10.> (all costs based on late 1968 price level)

Description	Pressurized Water Reactor		Boiling Waterr Reactor	
	UNIT #1	UNIT #2	UNIT #1	UNIT #2
Land and Land	514,000		514,000	—
Structures and Improvements	10,035,000	7,166,000	11,666,000	8,216,000
Reactor Plant Equipment	35,460,000	35,392,000	34,450,000	34,382,000
Turbogenerator Units	22,130,000	21,173,000	22,794,000	21,849,000
Accessory Electric Equipment	4,723,000	4,342,000	4,687,000	4,628,000
Miscellaneous Power Plant Equip.	435,000	253,000	435,000	253,000
Station Equipment	633,000	633,000	672,000	672,000
Freight Insurance and Local Transportation	1,557,000	1,150,000	1,458,000	1,257,000
	75,487,000	70,109,000	76,926,000	71,257,000
Other Expenses	600,000	500,000	600,000	500,000
	76,087,000	70,609,000	77,526,000	71,757,000
Contingency	7,609,000	7,061,000	7,753,000	7,106,000
	83,696,000	77,670,000	85,279,000	78,933,000
Engineering, Design and Construction Supervision	7,000,000	4,000,000	7,000,000	4,000,000
	90,696,000	81,670,000	92,279,000	82,933,000
Interest During Construction	19,500,000	16,334,000	19,840,000	16,587,000
TOTAL ESTIMATED COST	$110,196,000	$98,004,000	$112,119,000	$99,520,000

Source: P. IV—14. and P. IV—20

However, the construction cost of nuclear power plants operating or under construction in ECAFE countries is considerably higher than that range. (See Table 11) Even we take

Construction Costs of Nuclear Power Plants Operating or under Construction in ECAFE Region

<TABLE 11.>

Plants	Reactor Type	Capacity (MW)	Cost/KW	Remarks
Tokai (Japan)	GCR	160	$750.00	In operation
Tsuruga (Japan)	BWR	320	281.25	To be completed in 1970
Fukushima (Japan)	BWR	400	262.50	To be completed in 1970
Mihama (Japan)	PWR	340	252.94	To be completed in 1970
Tarapore (India)	BWR	380	266.70	In operation

Footnote: BWR=Boiling Water Reactor
PWR=Pressurized Water Reactor
GCR =Gas Cooled Reactor

Sources: For plants in Japan, V. Gilinsky and P. Lange, *op. cit.*, p. 15. For the plant at Tarapore, India, IAEA, *Bulletin* Vienna Austria, October 1963.

(12) Taiwan power company, "A Report on the Prospect of nuclear power in Taiwan", Sep. 1964, Taipei, Taiwan.

into account the recent technological progress in nuclear power, it may be safe to expect that the actual construction cost of nuclear power will be slightly higher than the estimated figures in the nuclear power feasibility study.

In addition to the capital costs per KW of installed capacity, it is essential to look into the capacity factor of plants and fixed charge rate before we can determine the fixed cost per KWH of power generation. A capacity factor of 85 percent has been assumed for both nuclear and conventional plants. This is rather high, considering that allowance has to be made for all scheduled and enforced idleness of plants. But it may be adopted here to show the altrnatives operating at the highest possible energy potential and hence at best economic performance. It may be safe to assume a lower capacity factor for nuclear power. A lower capacity factor would certainly weaken the competitive position of capital-costly nuclear power. For instance, let us assume a 65 percent of capacity factor. This alone is sufficient enough to make conventional plants less costly for power generation without changes of any other assumptions. The generation costs in Table 7 were based on a fixed-change rate of 13.6 per cent of investment cost per year. This fixed-change rate was made up of the following:

Interest rate	7.54%	
Depreciation	3.33%	(based on 30—year life)
Insurance	2.27%	
Income tax	0.46%	
	13.60	

Here we have a few problems to be examined. First of all, a 2.46 percent of income tax is included in the fixed rate. It is certainly necessary to consider income tax when the comparison is based on the viewpoint of the Korea Electric Company. However, it is not relevant to include income tax for cost comparison for the choice of alternatives on the basis of national interest.

Another problem rests on the choice of an appropriate interest rate. In the feasibility study a 7.54% is assumed for the cost of money. A higher interest rate would weaken the competitive position of capital costly nuclear power. For example, the use of a 10 percent interest rate would reverse the conclusion shown in Table 7. Some people think that the rates of interest in many underdeveloped countries are relatively high-sometimes as high as 10, 12 and 15 percent. However, even if this were true, it does not necessarily mean that such a high interest rate should be taken as the socially appropriate rate in evaluating alternative techniques in public utilities such as electric power and transportation. I think this is not the place to delve deeply into this problem. However, it may be better to repeat the comparison by using different interest rates within a certain range.

4. Conventional Fuel Costs

Obviously, in any comparison of various possible power costs, what delivered fuel costs would be is a very important factor and largely determines the type of power plants selected.

In the feasibility study, nuclear power is compared to oil-fired thermal plant. But it might be better to look in to the possibility of using the Korean-anthracite coal for conventional thermal plants here since the coal is the only locally available fuel resources in Korea. The price of the Korean-anthracite coal at power plant sites is currently ₩ 2,190 or $7.74 per ton. With a heating value of 9,200 BTU, the wet per million BTU becomes 42.0 cents. On the other hand, the Burns and Roe study shows that the use of oil gives cents per million BTU. Therefore, from a strictly economic point of view, no coal-fired thermal plants should be constructed at this time since both capital and fuel costs are higher than those of oil-fired thermal plants.

However, the use of coal is considered to be more favorable than the use of oil mainly because it will reduce import requirements for oil. Hence, long-run planning should carefully evaluate the competitive position of coal compared to oil for conventional thermal plants. This evaluation, of course, involves some difficult problems such as the rate of foreign exchange and the future price movement of coal and oil. Furthermore, the coal industry has the important advantage that it provides the maximum direct employment among all energy sectors. In labor surplus economies such as the Korean economy, the employment effects should be given a credit on the basis of social policy as well as economic policy. However, it is obvious that the idea of a free choice of energy sources will eventually dominate energy policy in near future. Cheapness of power will be of special importance to the Korean economy when it enters into the group of open economies since it is essential for promoting the international competitiveness of its industries. It is understandable to see a increasing tendency to use fuel oil for power generation in conventional power plants in Korea. Recently, Korea has constructed two refinary factories with the financial support of some petrolium companies. [13]

The construction of petrolium refinary factories in Korea affected to a considerable degree to which petrolium is used for the purpose of power generation. The price of the fuel oil at power plant sites is approximated to be $2.50 per barrel including handling and local transportation. At 6.1 million BTU per barrel, the cost per million BTU becomes 41.6 cents. It is expected that the prices of potrolium products will remain stable or fall slightly in the future. It is often suggested that oil price may be lowered to permit oil-fired thermal plants to continually undercut nuclear plants. To assess how far this is possible would be difficult. But it is certainly conceivable that the oil supplier would try to reduce his supply price in the case of the widespread availability of cheap nuclear power. [14]

(13) There has been a great increase, particularly in developing countries, in refinary counstruction. This was brought about partly as a result of the technological developments which now make it possible for a small refinary to match the performance of a big one in efficiency, and partly as a result of the willingness of some petrolium companies to finance the construction of refinaries in petrolium-importing countries, provided the companies are allowed to supply the crude petrolium for a certain number of years.

(14) One good example in the United States is that in situations where utilities are known to be

5. Nuclear fuel costs

The cost structure of the nuclear fuel cycle is very different from that of conventional fuels and varies from one reactor system to another. Whereas the conventional fuelling cost is essentially the cost fuel consumed, the cost of uranium consumed is but one of the components of the nuclear fuelling cost and is in most cases smaller than the cost of preparing and fabricating the fuel. Also, the credit for the plutonium contained in the irradiated fuel elements is an important determinant of total fuel costs.

In the feasibility study, nuclear fuel cost vary from 15.39 cents per million BTU for boiling water reactor to cents per million BTU for pressurized water reactor.(15) In evaluating the economic feasibility of nuclear power plants in the Philippines by the International Atomic Energy Agency, the fuel cost is estimated to be in the range of 19 to 21.9 cents per million BTU for light water reactors.(16)

Taiwan Power Company estimated nuclear fuel cost as 20 cents per million BTU for the purpose of its feasibility study.(17) Here we see some evidence of technological progress in nuclear power for last few years. However, we still do not have enough reliable data on the performance of nuclear power plants with respect to core capability and burn up at present. Hence, the estimated cost figures are uncertain. It is conceivable that nuclear fuel cost will decrease in the future due to the progress in nuclear technology. But it seems to be reasonable to rely on somewhat conservative figures in evaluating economic feasibility of nuclear power, particularly in developing countries such as Korea.

Ⅳ. Other problems related to nuclear power development in Korea.

The cost comparison in previous section has shown that nuclear power is already economically competitive to conventional thermal power in Korea. There are also some other

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seriously considering a nuclear project, substantial cuts were made in coal prices. (See J.H. Horgerton, *op. cit.*, p. 27)

(15) It is based on 30 years levelized costs as follows:

Reactor Type	BWR	PWR
Norminal size of Unit(MW)	500	500
Reactor Rating(MW)	1593	1495
Net generation(MW)	524	479
Plant capacity factor(%)	85	85
U_3O_8($116)	8.00	8.00
Fabrication cost($1/KgU)	66.15	77.50
Separation Work($1/KgU)	26.00	26.00

Source: Burns and Roe Inc., *op cit.* p. IV—5.

(16) See United Nations Development Programme and International Atomic Energy Agency. *Pre-investment study on Power including Nuclear Power in Luzon, Republic of the Philippines*, Vienna, Austria, pp. 103—108.

(17) Taiwan Power Company, *A Report on the Prospect of Nuclear Power in Taiwan*, Taipei, Taiwan, 1964.

factors which encourage an earlier construction of nuclear power in Korea.

First of all, the construction of nuclear power will diversify the sources of energy in Korea. Since the domestic energy resources are very limited, it is natural to expect that the increasing demand for energy has to be met by imported oil. Import of oil has been rapidly increased in the last few years and such a tendency is likely to continue so that the Korean economy will depend heavily on imported oil as, for example, the Japanese economy does today. However, considerations of security of energy supplies suggest that the heavy dependence of energy requirements on imported oil may not be desirable. The introduction of nuclear power would serve the diversification of energy sources and may contribute toward bringing better bargaining position in purchasing oil in the future.

Secondly, the construction of nuclear power will facilitate the development of technical skill in the related fields. The operation of a nuclear power plant requires a highly trained technical staff of nuclear engineers, reactor operators, electronic engineers and skilled technicians. Hence an earlier introduction of nuclear power plants may facilitate the development of such technical skills. The development will generally contribute to scientific and technical progress in Korea. Of course, as a developing country, Korea will not be able to promote the development and utilization of nuclear power independently in the foreseeable future. Nevertheless, the importance of impacts from the construction of nuclear power plants on the technical skill may not simply be ignored.

Thirdly, it is conceivable that political leader might feel that an earlier introduction of nuclear power may raise the prestige of the country. This sort of political desire favors development of nuclear power regardless of economic efficiency.

However, we should also notice a number of difficult problems which discourage an earlier introduction of a large-scale nuclear power plant in Korea.

First of all, nuclear power is capital-costly alternative for power generation. For the construction of a 500 MW size plant, the capital cost amounts to 11 million dollars and at least additional 2 million dollars will be required for initial nuclear fuel inventory. Since Korea suffers from a severe shortage of capital for economic development, we may have to choose less capital-expensive techniques in order to meet rapidly increasing demand with the limited capital available. That is, the lack of capital will certainly delay the introduction of nuclear power regardless its economic efficiency.

Secondly, in Korea the growth of demand has always been ahead of the growth of supply. Hence, in order to meet rapidly increasing demand, the gestation period becomes an important factor in choosing the type of plants. Conventional power plants, in general, involve shorter gestation periods than nuclear power plants and, for this reason alone, installations of conventional plants can often be justified. Since no sufficient reserve capacity is maintained in Korea, an unexpected increase of demand forces decision-makers to choose the alternatives which have shorter gestation periods such as gas turbine and conventional thermal plants regardless of their costs.[18] It is thought that more than 4 years will be required for the construction of a nuclear power plant. This is certainly an unfavorable factor for nuclear power development in Korea at present.

The third problem is related to the unexpected failure and plant capacity factor. Since nuclear power is capital intensive, the plant capacity factor is very important. In the early stage of nuclear introduction, it is conceivable that the plant capacity factor may be low because of the lack of technical skills and experience. The dependability of nuclear power has to be evaluated carefully in the future. So for, none of the large pressurized or boiling water reactors have begun routine operation. In the United States, the plant at San Onefre, a 430 MW pressurized reactor, has experience some start up trouble with its turbine. Unexpected failure may be more frequent and the costs of required readjustment may be higher in underdeveloped countries than in developed countries. Also, the economic consequences of an unexpected failure will be more several in the case of nuclear power because plants will typically be bigger than conventional plants. The fourth problem is safety. It has been indicated the safety and control provisions incorporated in various type of commercial nuclear plants have performed satisfactorily and reliably. However, it is conceivable that safety consideration may require an additional costs. For example, if a nuclear plants is located away from the ocean, it would probably be necessary to use substantial quantities of fresh water consumptively for cooling purposes. The use of river water may lead to an unacceptable rise in water temperatures or unacceptable radiation hazard. Since Korea is a peninsula country, it would not be difficult to find sites near ocean. But this consideration may increase transmission costs by restricting possible sites of nuclear power. The considerations of safety make the adoption of nuclear power legislation one of the important prerequisites for undertaking a nuclear power plant. Such legislation is necessary to establish regulatory control over nuclear power facilities and materials with a view to protecting public health.

Finally, suitable short or long-term contracts for the supply of nuclear fuel should be arranged before a considerable expansion in nuclear power. The fuel supply arrangements for nuclear power pose certain special problems not encountered with fossil-fuel plant. While fuel-oil supplies can be negotiated directly from private suppliers, there is greater governmental involvement in the procurement and use of nuclear fuels, their sale by one country to another is usually carried out under bilateral or international agreements. While the price of natural uranium is determined largely by producers according to the laws of supply and demand, the price of enriched uranium is at present fixed by government agencies in the producing countries. Hence, it will be essential to make nuclear fuel supply arrangements before a sizale expansion of nuclear power.

(18) This is what has happened in Korea in 1967. An unexpected increase of demand has resulted in construction of 150 MW of gas turbine.

V. Conclusions

1) There has been a rapid technical progress in nuclear power in the last decade and nuclear power plants have shown a decisive market breakthrough in advanced countries in the last few years.

The feasibility study of nuclear power in Korea has shown that nuclear power is already economically competitive to conventional thermal power in Korea

2) Further reduction of nuclear costs may be expected to result from a variety of reactor improvements. Breeding reactors are likely to come increasingly to the forefront.

3) The high rate of growth of power consumption in Korea is likely to continue for, at least, the next 20 years. This growth will assure a favorable environment for the construction of large-scale nuclear power.

4) However, there are many difficult problems which may discourage an earlier introduction of nuclear power in Korea. The crucial difficulties rest on the lack of capital and a long gestation period required for the construction of nuclear power. Unexpected failure may be frequent and capacity factor may be low because of the lack of technical skills and experience.

5) Hence, the timing of the construction of nuclear power must be based on a careful analysis of existing domestic energy resources as well as technological progress in nuclear power.

6) Since the construction of nuclear power requires a large amount of capital and a relatively long period, it would be necessary to have a clear idea of the steps to be taken towards the actual construction of nuclear power.

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