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Cost Comparison of PWR and PHWR Nuclear Power Plants in Korea

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Abstract

A statistical approach is used to investigate the relative economic advantages of pressurized water reactor (PWR) and pressurized heavy water reactor (PHWR-CANDU) nuclear power plants for hypothetical 900Mwe systems with the throwaway fuel cycle to be built in the Republic of Korea.

Power cost is decomposed into the cost components related to the plant capital, operation and maintenance, working capital requirements and fuel cycle operation. The calculation of construction cost is performed with the modified version of computer code ORCOST, and the modified POWERCO-50 is used to evaluate the cost components.

Most of economic parameters are treated as statistical variables, each being given with a certain range. Through a random sampling procedures, the probability histograms on unit plant construction costs and power generating costs are obtained.

The power cost probability histograms of the PWR and the PHWR plants overlap considerably, and the power costs of two systems appear to be almost same with the PHWR power cost being 0.4mill/kwh lower compared with 39.4 mills/kwh for the PWR plant (July 1986 US-dollars). When a construction period of PHWR plant is longer by one year than that of PWR plant, there is no difference in the unit power cost of two plants. This comparison leads to no definite conclusion on the cost advantage of the PWR plant versus the PHWR plant. We conclude that the selection issue of nuclear power plants in Korea still remains an open question and that future effort to solve this question should be made toward economic quantification of those factors such as technology transfer and localization.

요 약

국내도입이 예상되는 900MWe급 가압경수로형(PWR) 원자력 발전소와 캐나다형 가압중수로형(PHWR-CANDU) 원자력발전소에 대하여 throwaway 핵연료주기를 가상하여 두 노형의 상대적인 경제성을 비교 검토 하였다.

계산을 목적으로 발전단가를 발전소 투자비, 운전보수비, 운전자본비 및 핵연료비로 구분했으며 건설단가는 보완된 ORCOST 전산코드를 그리고 발전단가는 보완된 POWERCO-50 전산코드를 사용하여 구하였다.

계산에 요구되는 각종의 경제인자에 대하여는 단일의 수치값을 갖는 상수보다는 어떤 범위의 수

치대를 이루는 통계적인 변수로 처리하였으며 ORCOST 및 POWERCO-50을 통한 무작위 추출법을 통하여 발전소 건설비 및 발전단가의 확율돗수 분포도를 얻었다.

계산결과 두노형간의 발전단가 분포도는 서로 겹치고 있으며 발전 단가의 기대치는 1986년도 미화로 PHWR의 발전단가가 PWR의 발전단가, 39.41mills/kwh 보다 약 0.4mill/kwh만큼 적지만 PHWR의 건설기간이 PWR 보다 1년정도 더 걸리게되는 경우 차이가 없음을 알았다. 따라서 두 노형간의 경제성은 거의 우열을 가릴 수 없으며 한국에서 원자력발전소 노형을 선정할 때 기술전수, 국산화 등 경제외적 인자도 경제적 인자로 수량화하여 검토하는 것이 필요하다고 결론을 내렸다.

1. Introduction

PWR and PHWR power plants have shown up to be the most promising candidate plant types in planning our nation's near-term nuclear power development programs. Many estimates[1~4] have been prepared on the power economics of two types of plants. Some estimates indicate that the PWR plant is economically more advantageous than the PHWR plant, while others indicate to the contrary. Though the matter appears to be very confusing, we observe a serious deficiency in the present method of economic study. An economics study requires a set of input data for various cost parameters. However, fluctuations in the current values of these cost parameters and uncertainties in their general escalation rates make it very difficult to assign a single numerical value to some of these cost parameters. Therefore, it is understandable that discrepancies can exist between economic studies, when they are based on any single set of cost parameters.

In our previous paper[5,6] we presented how to get over this shortcoming by employing sampling technique in fuel cycle cost study. Unlike the usual deterministic approach, this method treats all the cost parameters as random variables bounded by an upper and a lower limit and then economic indices in interest are computed by a random sampling of the cost parameters. Since the method allows banded numerical values as raw input data, it can take into account automatically fluctuations or uncertainties inherent in the cost parameters. The purpose of this paper is to evaluate the power economics of the PWR and the PHWR plant by the random sampling method and thereby to respond to the increased interest in the selection of power plant types. For our purpose, two plants are assumed to have the same capacity, 900MWe, and to start the commercial operation on the same date, July 1, 1986.

2. Computational Method

The plant capital investment and the power generating cost are employed as the major figures of merit for the cost comparison of the PWR and the PHWR power plant. The overall computing procedure is based on the random sampling technique assisted by the ORCOST[7] and POWERCO-50[8] codes. In other words, some of the input cost parameters required for the ORCOST and POWERCO-50 computation are treated as random variables which are bounded between a lower and an upper numerical limit. Then the probability histograms on the plant capital investment and/or the power cost are obtained by the ORCOST and POWERCO-50 computation through the random sampling of the input parameters. Since the random sampling method is discussed in detail elsewhere[5,6] only summary information on ORCOST and POWERCO-50 codes is presented here.

ORCOST is used for estimating the capital investment required for the construction of two plants under study. The computational procedures are based on an assumption that the major cost components in any central power station are appoximately the same, regardless of plant size, type, location, or date of initial operation. Therefore, once a base cost model for a reference plant of a given type is established, the capital investment of the plant that differs only in size and location from the reference plant can be computed by taking into account effects of size and location with appropriate scaling exponents and location indices. The time effect on the capital investment can also be estimated in terms of escalation and interest rates, in case the initial operating date of the plant under study is different from that of the reference plant. Accordingly, the typical input data of ORCOST include the base cost model for the reference plant of the given type, size scaling exponents and location indices, and escalation and interest rates.

POWERCO-50, a progeny of POWERCO[9], is used for determining the power cost of nuclear electricity generated by two plants under study. In principle, the code combines the present-worthed cash flow procedure with the fundamental balance requirements that the total revenue received from the sale of electricity should provide for the total expenses spent on generating electricity. The power cost computed by this procedure is either the levelizea unit total power cost held constant over the plant life or its four-subcomponent costs resulting from plant capital investment, non-fuel working capital, fuel-cycle operation, and operation and maintenance expenditures. The required input data include the schedules and amounts of cash expenditures for fuel-cycle operation, operation and maintenance, financial structure, rates of return on investment etc..

3. Input Description and Numerical Results

As mentioned in the Introduction, nuclear power plants under cost comparison are a 900 MWe PWR plant and a PHWR plant of the same size. Two plants are assumed to start their commercial operation on the same date, July 1, 1986. Presented herein are the data basis for the cost comparison, and the specific numerical results for plant capital investments and power generation costs, of two plants.

3. 1 Plant Capital Investment

The input data systems provided for the ORCOST computation are shown in Tables 1-4 and Fig. 1. Listed in Tables 1-2 are base cost models of a 1139 MWe PWR plant and a 638 MWe PHWR plant which were chosen as the reference plant of the corresponding type. The data in Table 1 are from a US study[10] and those in Table 2 from a Canadian study[11]. Two-digit accounting system is the one recommended in USAEC Report NUS-531[12]. The scaling exponents in Table 3 are the 76/77 IAEA-estimated scaling model[13]. The parameters not listed in the above are included in Table 4; location cost indices, escalation and interest rates, contingency allowances, spare parts, indirect cost fraction, etc..

Table 1. Base Cost Model for 1139 MWe PWR Reference Plant[10]

	Equipment	Materials	Labour	Total*
Direct Costs				
20 Land and Land Rights				1,000
21 Structures & Site Facilities	5,902	39,777	55,697	101,376
22 Reactor Plant Equipment	96,569	9,143	27,769	133,481
23 Turbine Plant Equipment	82,630	5,315	23,336	111,281
24 Electric Plant Equipment	13,094	8,541	17,793	39,428
25 Miscelaneous Plant Equipment	7,197	647	3,959	11,803
26 Main Cond. Heat Reject System	15,703	1,300	4,585	21,588
Sub-total	221,095	65,723	133,139	419,957
Indirect Costs				
91 Construction Services	21,080	29,500	19,453	70,033
92 Home Office Eng. & Services	49,220			49,220
93 Field Office Eng. & Services	25,621	3,000		28,621
Sub-total	95,921	32,500	19,453	147,874
Total Plant Cost	317,016	98,223	152,952	567,831

*All the costs are given on mid-1976 US dollar base (×1,000 $).

Table 2. Base Cost Model for 638 MWe PHWR Reference Plant[11]

	Equipment	Materials	Labour	Total*
Direct Costs				
20 Land and Land Rights				1,000
21 Structures & Site Facilities	2,526	22,958	32,980	58,464
22 Reactor/Boiler Plant Equipment	77,349	499	18,135	95,983
23 Turbine Plant Equipment	53,784	1,454	11,701	66,939
24 Electric Plant Equipment	6,988	5,938	9,066	21,992
25 Miscellaneous Plant Equipment	6,964	770	6,328	14,062
Sub-total (physical plant)	147,611	31,619	78,210	257,440
(Indirect Costs)				
91 Construction Facilities, Equipment and Services				42,810
92 Engineering and Construction Management Services				69,660
93 Other Undistributed Costs				2,630
Sub-total (Indirect Costs)				115,100
Single Unit-Total Plant Cost				373,450

*All the costs are given on mid-1976 US dollar base (×1,000 $).

The data in Table 4 are derived mainly from the references cited. In Table 4 those parameters for which a fixed numerical value is hardly justified are treated as random variables and two figures connected by dash denote a lower and an upper bound of random variables. Finally, the curve in Fig. 1 represents the capital

Table 3. Scaling Exponents for Nuclear Power Costs

No. Account	Cost model (1976-1977)
21 Structures	0.20
22 Reactor Plant	0.356
Nuclear Steam Supply System	0.30
Balance of Reactor Plant	0.41
23 Turbine Plant	0.75(0.83)*
24 Electric Plant	0.37
25 Miscellaneous	0.20
Base Cost	0.45

*Figure in the bracket is applied to PHWR Nuclear Power Plant

Table 4. Economic Parameters

1. Plant size: 900MWe
2. Construction period[15,21]: 6-9 years
3. Beginning of commerical operation: July 1986
4. Interest rate[1,22]: 8-15%
5. Indirect cost fraction of physical plant[13]: 30-45%
6. Miscellaneous[1,12,22,23]:

	Equipment	Materials	Labour
Location Cost Index	0.9-1.1	0.8-1.1	0.3-0.7
Escalation Rate (%/yr)	3-7	3-7	5-10
Contingency Allowance (%/yr)	0-10	0-10	0-10
Spare Parts (%)	0-10	0-10	

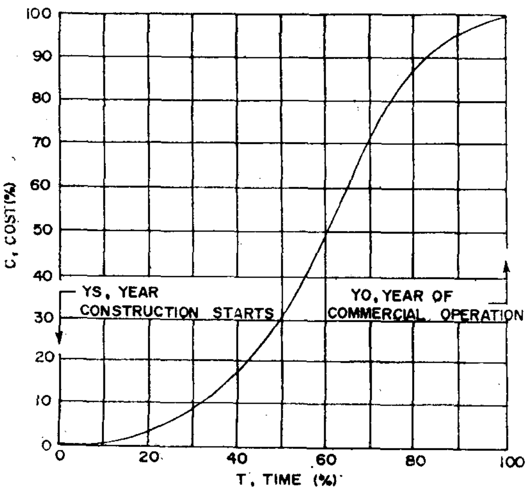

Fig. 1. Plant Capital Investment Expenditures vs. Time (from Ref. 14)

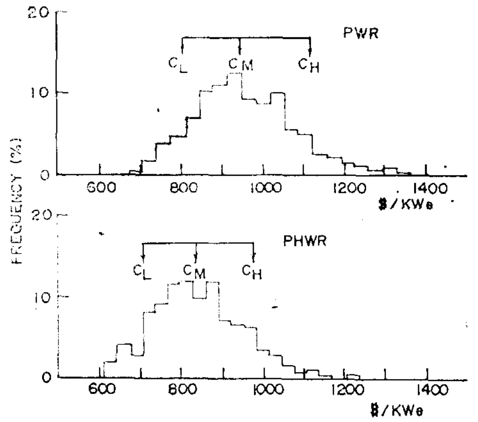

Fig. 2. Unit Construction Cost Comparison (1986 u.s. $)

Table 5. Unit Construction Cost of 900 MWe Nuclear Power Plants.

Unit: $ /kwe

	PWR*	PHWR (CANDU)*		PHWR (CANDU)**	
		Dry	Wet	Dry	Wet
C_L	806.0	709.7	1110.9	716.3	1117.5
C_M	924.9	832.6	1233.8	851.6	1252.8
C_H	1114.2	983.7	1385.0	1024.9	1426.2
Expected	956.0	842.3	1244.5	864.0	1266.2

*Construction period of 6-9 years is assumed.
**Construction period of 7-10 years is assumed.

cash flow percentage of the total capital investment. Though the curve is intended originally for the US plant[14], it is observed that the case of Canadian PHWR plants fits in approximately with this curve[11]

The probability histograms in Fig. 2 show the numerical results of the sampling computation for the unit construction costs of the 900 MWe PWR and PHWR plants on the 1986 US dollar basis. Here C_m stands for the medium value meaning that the probability the unit construction cost will be either higher or lower than C_m is 50%. Also C_H and C_L dente 10% confidence values in that the probability the unit

Table 6. Fuel Cycle Schedule for 3 Loop 2774 MWt (No Recycle)

Batch No.	Inserted at start of cycle	Discharged at end of cycle	Number of fuel assemblies	Uranium Loading(MTU)		U-235 Enrichment (w/o)		Discharge Expose (MWD/MTU)
				Initial	Discharged	Initial	Discharged	
1	1	1	53	24.456	23.980	1.60	0.70	13050
2A	1	1	1	0.461	0.452	2.40	1.23	14350
2B	1	2	51	23.534	22.721	2.40	0.71	25150
3A	1	2	3	1.384	1.343	3.10	1.35	21650
3B	1	3	49	22.611	21.626	3.10	0.84	32700
4A	2	3	5	2.307	2.228	3.16	1.22	34750
4B	2	4	49	22.610	21.610	3.16	0.85	33250
5A	3	4	5	2.307	2.228	3.16	1.21	25000
5B	3	5	49	22.610	21.605	3.16	0.84	33450
6A	4	5	5	2.307	2.228	3.16	1.21	24900
6B	4	6	49	22.610	21.606	3.16	0.85	33400
7A	5	6	5	2.307	2.228	3.16	1.21	24950
7B	5	7	49	22.610	21.606	3.16	0.85	33400
8A	6	7	5	2.307	2.228	3.16	1.21	24950
8B	6	8	49	22.610	21.606	3.16	0.85	33400

construction cost will be higher than C_H or lower than C_L is 10%. Based on these histograms, the 1986 construction cost of the 900 MWe PWR plant will range from 800 $ to 1100 $ per kwe. As for the PHWR plant of the same size, the dry plant will cost 700 to 980 $ exclusive of the initial heavy water cost, while the wet plant 1100 to 1380 $ inclusive of the heavy cost. Listed in Table 5 are the summary of these cost estimates. It is worthy to note that the above histograms are obtained on an assumption that the construction period of two types of plants is in the same range of 6-9 years, whereas the general trends for the construction period indicate that the PHWR plant takes longer construction period, roughly by 6-12 months, than the corresponding PWR plant[15]. The lengthening of the construction duration can have effect upon the total construction cost due to escalation as well as inflation in plant material, equipment and labor expenses. The last column of Table 5 shows the effect of one year delay in construction period upon the unit construction cost of PHWR plant. In terms of expected values which are probability-weighted average values, this effect amounts to about 20 $/kwe, equivalent to additional construction expense of 18 million dollars for the 900 MWe PHWR plant.

3. 2 Power Generating Cost

Power generating cost consists of four major cost components; plant capital cost, fuel cycle cost, operation and maintenance cost, and non-fuel working capital cost. Listed in Tables 6-10 are the input parameters used to enumerate these cost components by POWERCO-50. Given in Tables 6 and 7 are the reactor fuel mass balance and energy generation data of the 900 MWe PWR and PHW plants. These data can, in principle, be obtained by a

Table 7. Reference Fuel Cycle Scheduld for 900 MWe PHWR

Unit:MT

Year of operation	Initial weight	Final weight
1st year	89.63	88.25
2nd year	128.01	126.70
3rd year	119.58	118.16
Equilibrium	120.96	119.52

a) Thermal efficiency: 29.0%
b) Capacity factor: 0.80
c) First refueling is made since plant startup: 119 effective full power days
d) Initial loading: 128.7 MT of natural uranium
e) Average burnup: 7500 MWD/MT

Table 8. Miscellaneous Economic Data

1. Project life: 30 years	
2. Depreciable life: 30 years	
3. Intrim replacements factor fraction (k_a) of original plant investment per year 0.0025	
4. Property insurance fraction (k_b) of original plant investment per year 0.0033-0.0048	
5. Fraction of investment in bonds	0.7
6. Interest rate on bonds (%/yr)	8-15
7. Earning rate on equity (%/yr)	10-20
8. Effective tax rate (%/yr)	8.1
9. Capacity factor	
PWR	0.60-0.85
PHWR	0.65-0.90

Table 9. Designation of Cost Parameter and Numerical Values

Random Variables	Statistical Lower limit	Variables Upper limit
General escalation rate (%yr)	0	10
Escalation rate for conversion (%yr)	0	8
Escalation rate for enrichment (%yr)	2	10
Escalation rate for fabrication (%yr)	0	8
Escalation rate for heavy water (%yr)	6	10
Enrichment cost ($/kg-SWU)	70.0	80.0
Long-term storage of discharged fuel ($/kg)		
PWR	80.0	280.0
PHWR	10.0	40.0
Heavy water cost ($/kg)	210.0	300.0

Constants	
U_3O_8 cost ($/lb)	44.0
Conversion cost* ($/kg)	5
Fabrication cost** ($/kg)	
PWR	140.0
PHWR	50.0
Fresh fuel shipping cost ($/kg)	6.0

*Conversion cost for U_3O_8/UF_6 4 $/kg
**1.2 times for initial loading

long-term fuel management study. For this work, however, the PWR data are obtained from the Korea Electric Company[16] while the PHWR data from an interpolation of the IAEA study[17], and the mass and energy data of 600 MWe Wolsung Unit 1[13] from its PSAR.

In Table 8 the major economic parameters are shown including the capital structure, tax rate, and property insurance rate. The weighted average bond fraction is the assumed value in which capital fund raised in the form of loan is treated like the bond investment. Taxes to be imposed on nuclear power plants are two kinds; residence tax and defence tax. The effective tax rate of the annual 8.1% is based on the current tax rates of the two types of tax[19]. The property insurance rate depends on the risk involvement of the plant and is estimated using the insurance policy applied to the Ko-Ri plant[6].

Fuel cycle cost computation requires the projection of the price behaviour of indiv-

Table 10. Operation and Maintenance Expenses* for Nuclear Power Plants[19]

(mid-1986 US dollars)

Items	(× 1,000 $)
1. Staff payroll	1,625.2
2. Consumable supplies and equipment**	1,369.7
3. Outside support services	501.5
4. Miscellaneous	286.4
5. General and administrative (15% total of four items above)	571.5
6. Liability insurance	30.0
Total	4,411.3

*Input variance: 70-130%
**Variable portion which is assumed linearly dependent upon capacity factor is 50%

Table 11. Summary of Power Generating Cost (Unit: mills/kwh)

Items		PWR Plant				PHWR(CANDU) Plant			
		C_L	C_M	C_H	Expected	C_L	C_M	C_H	Expected
Plant Capital	Plant Investment	15.84	20.49	26.07	20.71	13.02 (13.25)*	16.92 (17,30)	21.29 (21.93)	17.12 (17.53)
	Initial Heavy Water	—	—	—	—	6.37	8.42	10.52	8.44
	Sub-Total	15.84	20.49	26.07	20.71	19.84 (20.14)	25.50 (25.93)	31.23 (31.82)	25.57 (26.00)
Fuelcycle cost	Yellow Cake	6.65	7.77	8.84	7.80	5.05	5.88	6.69	5.90
	Enrichment	4.52	5.12	5.86	5.17	—	—	—	—
	Fabrication	1.48	1.68	1.90	1.68	2.07	2.34	2.65	2.36
	Long term disposal	0.56	1.34	2.20	1.38	0.39	0.89	1.41	0.90
	Converesion&Shipping	0.31	0.34	0.38	0.34	0.53	0.58	0.64	0.58
	Heavy Water Up-keep	—	—	—	—	1.20	1.44	1.72	1.45
	Sub-Total	14.64	16.26	18.17	16.37	9.98	11.14	12.48	11.19
Non-fuel working capital		0.12	0.20	0.30	0.21	0.15	0.26	0.40	0.27
O & M cost		1.49	2.07	2.77	2.11	1.43	2.00	2.64	2.03
Total		34.39	39.29	44.62	39.41	33.43 (33.73)	39.02 (39.44)	44.46 (45.18)	39.04 (39.47)

*Figures in bracket refer to the construction period of 7-10 years.

idual fuel cycle element. Base prices and escalation rates are given in Table 9 for projecting the unit price of individual fuel cycle element using the sampling method presented in elsewhere[5]. Given in Table 10 are the roughly-estimated operation and maintenance expenses for the first year operation of the 900 MWe nuclear plants[19]. Due to the roughness of the estimation, the actual operation and maintenance expenses are assumed to be in the range from 70 to 130% of the estimated total. In addition, a half of the expenses of consumable supplies and equipment is assumed

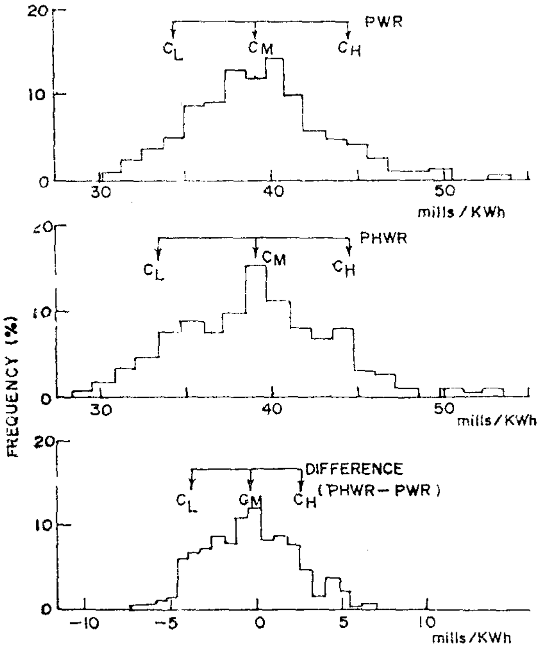

Fig. 3. Power Generating Cost Comparison (1986 u.s. $)

to be linearly dependent on the capacity factor while the other half is assumed to be fixed. As for the non-fuel working capital requirements, NUS-Guide[12] is adopted.

The various cost parameters obtained thus far are then used to determine the levelized unit cost of electricity from the plants under study. In Table 11 the summary is given for the sampling computation results of the power cost, while in Fig. 3 the probability histograms are depicted. There is yet no general concensus upon which component of the power cost the D_2O contribution suould be categorized into. For the comparison purpose, however, the contribution of the initial heavy water inventory to the power cost is classified into the plant capital cost, whereas the annual makeup D_2O contribution into the fuel cycle cost in this work.

Upon inspection of the probability histograms and numerical results tabulated in, the following features are noted: The levelized unit power cost of the 900MWe PWR plant ranges from 34.4 to 44.6 mills/kwh with the expected value of 39.4 mills/kwh. Here the expected values is obtained by weighting levelized unit power cost values with the probability histogram. On the other hand, the levelized unit power cost of the corresponding PHWR plant ranges from 33.4 to 44.5mills/kwh with the expected value of 39.0 mills/kwh; The power cost probability histograms of the PWR and the PHWR plants overlap considerably with each other within the cost range just mentioned; The power cost of the PHWR appears to be lower in expected value by 0.4 mill/kwh than that of the PWR plant. When a slightly longer construction period is assumed for the PHWR plant-7 to 10 years instead of 6 to 9 years; however, no cost advantage can be indentified. In Summary, what these features indicate is that there is no significant difference in the unit power costs of two plants.

The largest contributor to the power cost is the plant capital cost. Next to this comes the fuel cycle cost. Base on Table 11 the plant capital cost of the PWR plant represents about 50%, while that of the PHWR plant up to 60%, of the power cost. The fuel cycle costs of the PWR and the PHWR plant occupy 40% and 25% of the power cost, respectively. Aside from the construction cost of the dry plant, factors influencing the power cost are uranium ore, enrichment services and heavy water. It is worthy to note that the annual makeup heavy water accounts for roughly 3.7% of the PHWR power cost. As for the non-fuel working capital

Table 12. Cost Comparison between CANDU-PHWR and PWR

Items \ Reference \ Reactor Types		CANDU-PHWR					PWR				
		MIT[2]	EP-DC[24]	Wol-Sung[25] Unit 1	Korea-900[4]	This Study	MIT[2]	EP-DC[24]	Ko-Ri[25] Unit 1	Korea -900[4]	This Study
Capacity of Power Plant (MWe)		1,000	600	680	900	900	1,000	600	650	900	900
Construction Cost($/kwe)		1,460	1,423	1,302	1,109	1,244	1,177	1,166	996	873	956
O & M Cost ($ 10^6/yr)		12.5	20	7.6	3.5	4.4	12.5	20	6.0	2.5	4.4
Capacity Factor(%)		80	75	75	75	65-90	65	65	70	70	60-85
Fixed Charge Rate ($/yr)		11	8	12.87	12.87	—	11	8	12.87	12.87	—
Operating Start Year		1985	1987	1982	1985	July 1986	1985	1987	1982	1985	July 1986
Power Generating Cost (mills/kwh)	Capital Investments	22.90	17.3	25.48	22.08	25.57	22.72	16.4	22.46	19.40	20.71
	Fuel Cost	6.67	6.3	5.92	3.46 }	11.19	8.23	7.7	9.11	4.70	16.37
	Heavy Water Cost	0.5	1.1	0.5 }	0.53 }		—	—	—	—	—
	O & M Cost	1.78	5.1	1.71 }		2.03 (0.27)*	2.20	5.9	1.40	0.46	2.11 (0.21)*
Total (mills/kwh)		31.85	29.8	33.61	26.07	39.04	33.15	30.0	32.97	24.56	39.41

* Non-fuel working capital cost

cost and the plant operation & mainte nance cost, their contribution to the power cost is found similar in two plants.

4. Conclusion

Selection of appropriate nuclear power plants is one of the pressing issues in planning the long-term nuclear power development programs. As is known public, our nation's nuclear energy program calls for introducing more than 40 nuclear plants with a combined total capacity of 50,000 MWe by the year of 2,000[20]. Under this program, Ko-Ri Unit 1, the nation's first PWR plant, has been in commercial service since April 1978. Additional five PWR plants are under construction. Also construction of the Wolsung Unit 1, the first PHWR plant, is currently in progress. In the light of this development, some people insist that nation's nuclear energy program hereafter should be directed toward the PWR system only, yet others argue that addition of PHWR system will be beneficial due to its potential advantages.

This argument about the superiority between two systems can be seen in parts from the comparison given in Table 12. While the works of Refs. 2 and 24 indicate the advantage of the PHWR system, those of Refs. 4 and 25 contradict the former. The results of our work are also included in this table. Another outstanding feature of this comparison is the wide discrepancy in estimation of capacity factors for two systems. The results in factor of PHWR are based on 10-15% larger capacity fact ors, whereas those in favor of PWR and our study estimate only 5% larger capacity factors for PHWR systems.

The issue is in reality a very complicated matter to settle, simply because many factors such as power economics, safety, fuel utilization, potential for the localization of the plant material and equipment, etc. are interrelated. As an important first step toward the ultimate settlement of the selection issue, we have made here the power plant cost comparison of two plants accounting for the existing uncertainties in cost parameters using the random sampling technique. All we could observe in this comparison is that a definite conclusion on the cost advantage of the PWR plant versus the PHWR plant cannot be made. As a matter of truth, the PHWR plant seems to have potential advantages with respect to the fuel utilization, possibility of renting heavy water, and localization of the plant equipment and materials, as some people argue. To our best knowledge, however, these advantages have not yet been assessed on the quantitative basis with due regard to the current technological status of the nation. Therefore, we conclude that the selection issue still remains an open question and that future effort to solve this question should be made toward economic quantification of those factors such as technology transfer and localization.

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