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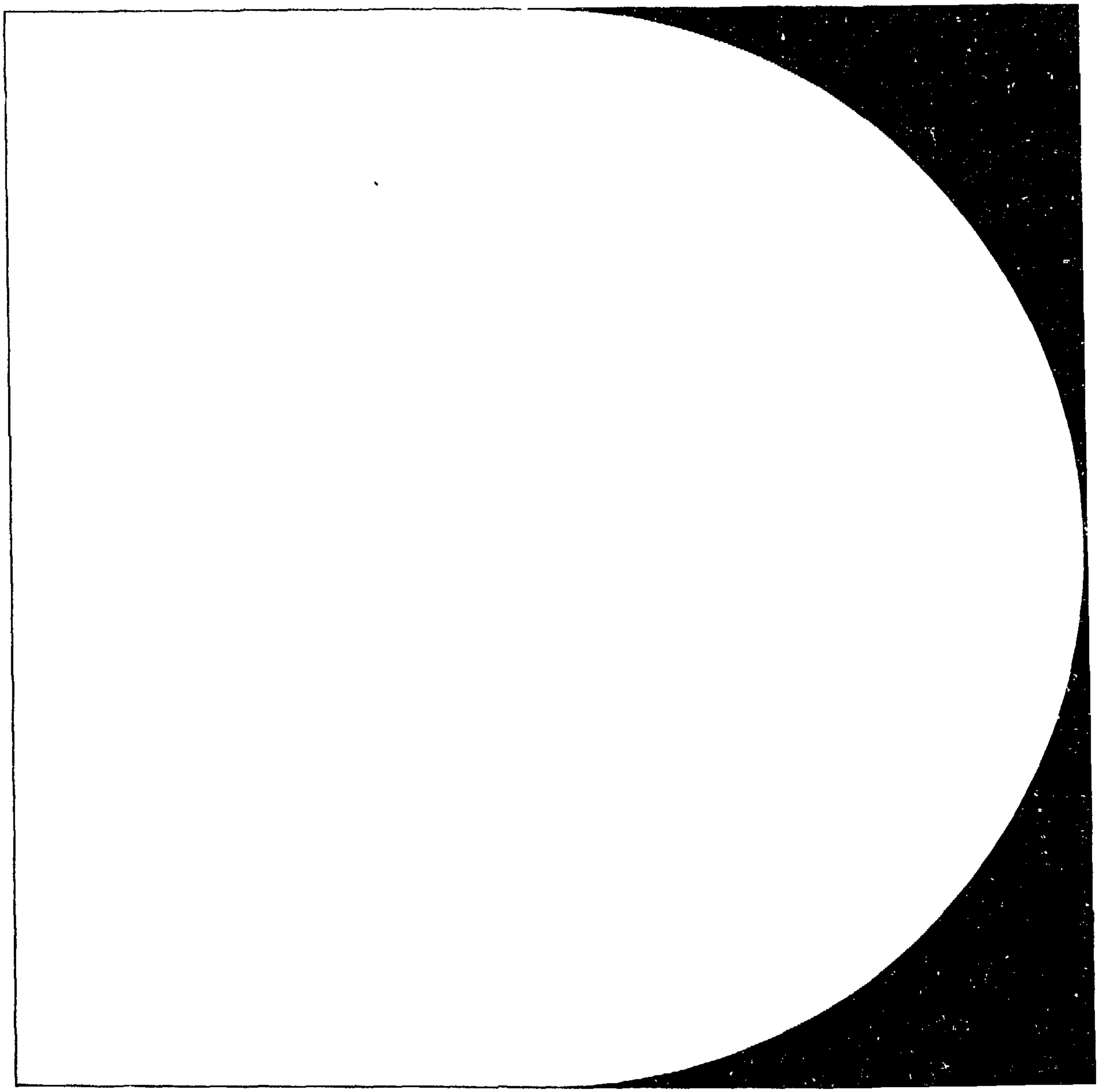

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NUCLEAR GENERATING STATION AND HEAVY WATER PLANT COST ESTIMATES FOR STRATEGY STUDIES

Nuclear Studies and Safety Department

Report No. 79117 July, 1979

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Abstract

Nuclear generating station capital and operating and maintenance costs are basic input data for strategy analyses of alternate nuclear fuel cycles. This report presents estimates of these costs for natural uranium CANDU stations, CANDU stations operating on advanced fuel cycles, and liquid metal fast breeder reactors (LMFBR's). Cost estimates for heavy water plants are also presented.

Cost estimates for natural uranium stations and heavy water plants are based on operating and planned stations. Estimates for advanced stations were derived by evaluating the cost implications of additional technical concerns for each fuel cycle. The results show that station capital costs for advanced fuel cycles are not expected to be significantly greater than those for natural uranium stations. Estimates for LMFBR's are based primarily on U.S. estimates. LMFBR capital costs are expected to be 25-30% greater than for CANDU's.

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NUCLEAR GENERATING STATION AND HEAVY WATER PLANT COST ESTIMATES FOR STRATEGY STUDIES

1.0 INTRODUCTION

The capital cost of new generating stations is the largest single cost component in the nuclear fuel cycle, and is, therefore, an important parameter when comparing fuel-cycle strategies. This document presents estimates of capital, and operating and maintenance (O&M) costs for generating stations operating on fuel cycles which may be of interest to Ontario Hydro in the long-term. Also presented are cost estimates for heavy water plants.

Costs for CANDU stations operating on the natural uranium (Nat. U) cycle are fairly well established, and are the basis for cost estimates of CANDU stations operating on advanced cycles. Estimates for LMFBR's were obtained from the literature.

The information presented here, especially that regarding the advanced fuel cycles, will be reviewed and updated as new information becomes available.

2.0 SUMMARY

Table 1 contains a summary of station costs for the fuel cycles under consideration. For the CANDU stations in Table 1, the cost of heavy water is included. The estimates for advanced CANDU stations include potential penalties associated with increased power peaking, and the potential benefits of reduced refuelling demand. All stations, except the LMFBR's, which consist of one unit, are assumed to consist of four reactor units. All costs quoted in this report are in January, 1978 dollars.

Table 1: Summary of Station Costs

Summary of Station Capital Costs

Fuel Cycle	Enrichment	Reactor Size (MWe)	Station Capital Cost		O&M Cost* ($/kW-yr)
			(M$)	($/kWe)	
Nat. U	-	600	2509	1046	14.3
Nat. U	-	850	3143	924	10.1
Nat. U	-	1250	3940	788	7.3
Nat. U	-	2000	5396	675	4.7
LEU	1.0%	850	3178	935	10.1
LEU	1.0%	1250	3985	797	7.3
LEU	1.2%	850	3158	929	10.1
LEU	1.2%	1250	3955	791	7.3
Mixed Oxide	3 g/kg	850	3168	932	10.6
Mixed Oxide	3 g/kg	1250	4060	812	7.6
Th(Pu)	24.4 g/kg	850	3168	932	10.6
Th(Pu)	24.4 g/kg	1250	3940	788	7.6
Th(U)	24.2 g/kg	850	3168	932	10.6
Th(U)	24.2 g/kg	1250	3940	788	7.6
LMFBR		1250	1265	1012	8.0

*Excluding fuelling cost but including D_2O upkeep.

3.0 NATURAL UO_2 CANDU COSTS

3.1 Introduction

Cost estimates for Nat. U reactors are based on a combination of past experience, present trends, and short-term projections. The Pickering and Bruce generating stations provide accurate cost data for reactor sizes of 850 MWe and less. The 4x1250 MWe stations are expected to be uprated versions of the 4x850 MWe stations. Thus, most of the equipment will be standard, and reliable cost projections can be obtained. The design of 4x2000 MWe stations is still at a very preliminary stage, and so cost estimates for these stations are only tentative.

3.2 Cost Estimates

Table 2 contains a breakdown of costs for Nat. U CANDU generating stations. The cost estimates for a given station size should not be directly applied to any particular station. The estimates presented here are average values to be used in strategy studies. Since it is expected that all future stations will consist of four units, each cost component applies to the whole station, and therefore includes a portion of common services.

The data in Table 2 was converted to specific capital costs on a $/kWe basis, and the results are shown in Table 3. The effects of economy of scale are shown in Figure 1, which is a plot of station specific capital cost as a function of reactor size. A dashed line is shown for reactor sizes greater than 1250 MWe, indicating a greater level of uncertainty.

3.3 Assumptions

The data in Table 2 corresponds to generating stations which would have in-service dates in 1987. Thus, each component of cost has been escalated at an appropriate rate to obtain costs in 1987 dollars. All components were then de-escalated at a uniform rate to obtain dollars of 1/1/1978. Thus, the figures in Table 2 are for stations coming in-service in 1987, but are quoted in constant 1978 dollars.

Although Ontario Hydro's planning studies include a decommissioning cost, no allowance is made for such costs in Table 2. This is considered justifiable for long-term strategy analysis because the useful lifetime of generating stations may be greater than their amortization period of 30 years. This, combined with the salvage value of heavy water, should more than cover dismantling costs, which are estimated to be $30M for a 600 MWe reactor.(1)

3.4 Discussion

The data presented here is intended for use in a dynamic simulation of nuclear fuel-cycle scenarios. In general, there will be a mix of station sizes and different fuel cycles operating at any given time. A presentation here of unit energy costs for a given station size would, therefore, not be a realistic basis for comparison. In the simulation study, unit energy costs are calculated as a function of time, and data is required only in the form of specific costs, in \$/kWe.

TABLE 2

Natural U CANDU Generating Station Data

Technical Data				
Station Size (MWe)	4x600	4x850	4x1250	4x2000
Burnup (MWth.d/kg U)	6.8	7.1	6.9	7.0
D_2O Inventory (Mg/MWe)	1.0	.9	.8	.75
Cost Data (Jan. 1978 M\$)				
Generating Station Capital				
Equip. Mat. and Labour	1382	1718	2025	2743
Interest at 9.75%/a	417	563	837	1100
Contingency	90	113	143	192
Total	1889	2394	3005	4035
D_2O Inventory	511	651	851	1291
Total	2400	3045	3856	5326
Commissioning Capital				
Labour	71.8	71.8	76.4	90.7
Material and Other Costs	14.4	14.4	15.3	18.2
D_2O Upkeep	8.8	8.8	8.8	8.8
Fuelling	20.9	29.6	43.5	71.3
Interest at 9.75%/a	12.1	10.2	8.3	7.0
O&M and Contingency	9.4	10.1	11.7	15.3
Credit for Energy	(78.1)	(110.6)	(162.8)	(266.6)
D_2O Inventory Interest at 9.75%/a	49.6	63.2	82.6	124.8
Total Commissioning Costs	108.9	97.5	83.8	69.5
Total GS Capital Cost	2509	3143	3940	5396
O&M Costs (Jan. 1978 M\$/a)				
Labour and Purchased Services	19.9	19.9	21.3	22.2
Material and Other Costs	4.4	4.4	4.8	5.0
D_2O Upkeep	9.3	9.3	9.3	9.3
Capital Modifications	.6	.6	.6	.6
Total O&M Annual Cost	34.2	34.2	36.0	37.1

TABLE 3

Natural U CANDU Generating Station Specific Costs

Station Size (MWe)	4x600	4x850	4x1250	4x2000
Cost Data (1/1/1978 $/kWe)				
Generating Station Capital				
Equip. Mat. and Labour	576	505	405	343
Interest at 9.75%/a	174	166	167	138
Contingency	38	33	29	24
Total	788	704	601	505
D_2O Inventory	213	191	170	161
Total	1001	895	771	666
Commissioning	45	29	17	9
Total GS Capital Cost	1046	924	788	675
O&M Costs (1/1/1978 $/kWe-yr)				
Labour and Purchased Services	8.3	5.9	4.3	2.8
Material and Other Costs	1.8	1.3	1.0	.6
Capital Modifications	.3	.2	.1	.1
Total	10.4	7.4	5.4	3.5
D_2O Upkeep	3.9	2.7	1.9	1.2
Total O&M Annual Cost	14.3	10.1	7.3	4.7

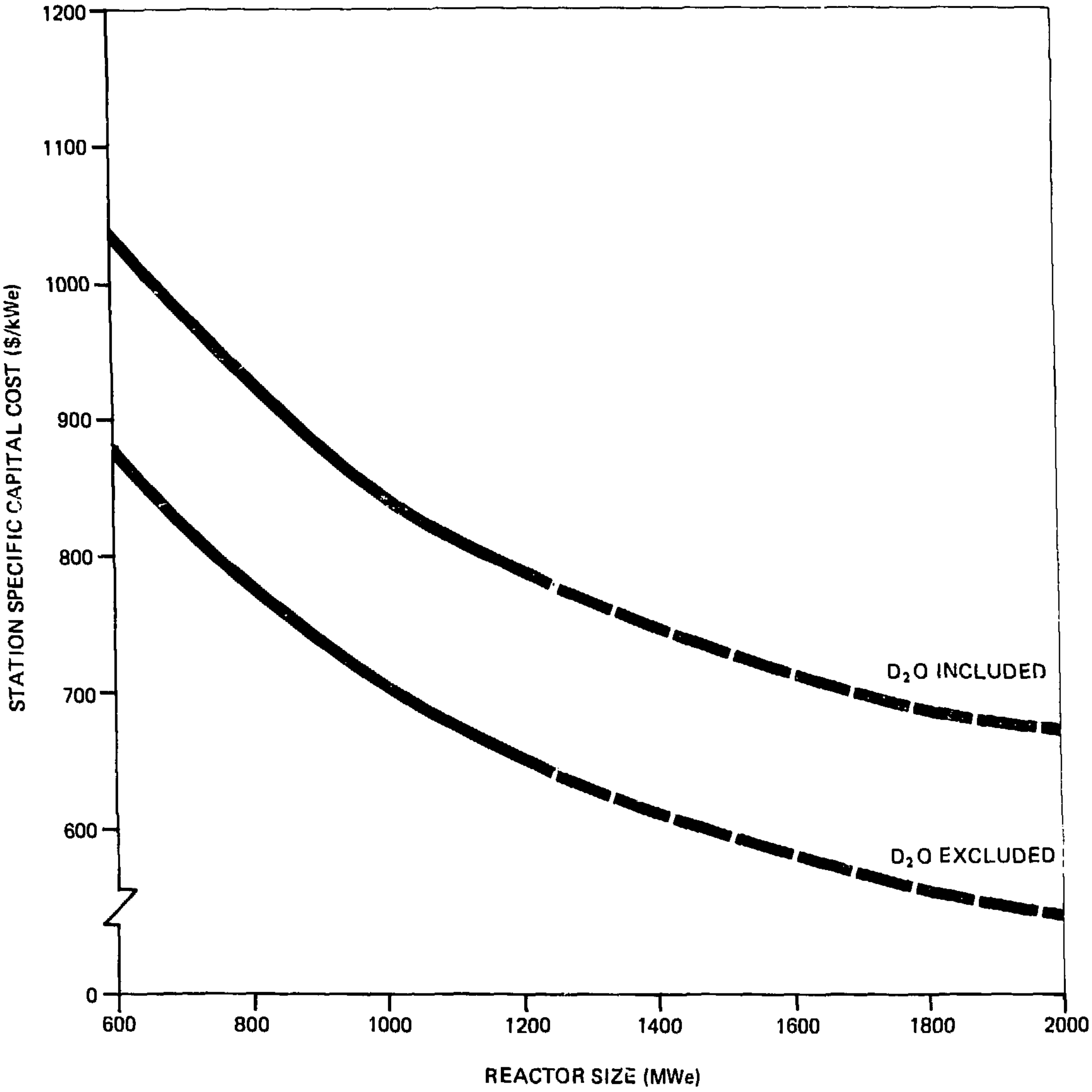

Figure 1:
Natural Uranium Candu Station Capital Costs

4.0 ADVANCED CANDU STATION COSTS

4.1 Introduction

Three types of advanced fuel cycles for CANDU reactors are considered. They are: low-enriched uranium (LEU), mixed oxide (Pu recycle), and intermediate burn-up thorium. It is expected that the LEU cycle will operate at an enrichment level less than or equal to 1.2 w/o U-235. Mixed oxide reactors will probably operate with less than 4 grams of fissle Pu per kg of heavy element. Only intermediate burn-up (27 MWd/kg HE) thorium cycles are considered, with fissile topping being either 93% enriched uranium, or plutonium. At equilibrium, fissile concentration is typically 25 g/kg HE or less. The thorium cycles will hereafter be designated Th(U) or Th(Pu), depending on the topping.

Costs for advanced reactors were estimated by examining modifications to Nat.U CANDU stations which might be required to accommodate the specified fuel cycle.

4.2 Technical Considerations For Advanced CANDU Reactors

Compared to Nat. U reactors, an increase in capital costs for CANDU reactors operating on an advanced fuel cycle may occur as a result of one or more of the following:

(a) Increased power peaking.

(b) Increased instrumentation.

(c) Larger worth of reactivity controllers and/or more numerous controllers.

(d) Shielded and/or criticality controlled fuel storage.

(e) Remote handling of new fuel.

(f) Additional shielding to fuelling machines.

(g) Safeguards to reduce proliferation concerns.

Considerations other than item (a), increased channel power peaking, are not expected to contribute significantly to increased capital costs. It is difficult to estimate cost increments for increased instrumentation and reactivity control without the completion of detailed designs. Similarly, costs for remote handling and safe storage are difficult to assess, except to say that LEU reactors will have less stringent requirements than either mixed oxide or thorium reactors.

Increased channel power peaking is expected to be the major problem to be overcome prior to the implementation of an advanced cycle. Methods of reducing power variations on refuelling include:(2)

(1) Reduction of reactor specific power.

(2) Reduction in number of bundles shifted per channel visit.

(3) Use of burnable poisons.

(4) Radial shuffling of fuel.

(5) Fuel design changes (graded enrichment, graded element size, more elements per bundle).

(6) More sophisticated control of macroscopic power distributions.

Detailed studies are required to determine which combination of the above items would be adequate and economically optimum. A combination of actions (1) and (2) represents a preferred approach, since these items require the least research and development. Furthermore, a reduction in reactor specific power would probably result in the greatest increase in capital cost for advanced reactors. Thus, capital costs estimates based on action (1) as a solution will tend to be conservative.

4.3 Cost Implications

4.3.1 General

A change in the capital cost of a CANDU station can be estimated by evaluating each of the terms in the following equation for the fuel cycle under consideration.

Change in capital cost = Change due to power peaking

\+ Change due to reduced refuelling demand

\+ Other changes (1)

where 'Other changes' includes additional costs for items (b)-(g) in Section 4.2.

As mentioned in Section 4.2, it is difficult to quantify cost penalties for items (b)-(g). Penalties of $15M per station for the LEU cycle, and $25M per station for the mixed oxide and thorium cycles, will be assumed for these factors. Without detailed designs, these penalties are highly uncertain. The effects of these uncertainties are discussed in Section 4.3.5.

The following two sections describe an analysis of potential cost changes for advanced CANDU stations due to increased power peaking and reduced refuelling requirements.

The results of this analysis are then combined according to Equation 1 to produce overall estimates of capital cost penalties (benefits) for advanced CANDU stations.

4.3.2 Channel Power Peaking

A reduction of reactor specific power implies that, to achieve the same rated output, reactor size must be increased. This results in the increase in capital cost. Capital cost penalties imposed by reducing average channel power have already been investigated for LEU reactors for up to 1.2% enrichment.(3) As shown in Figure 2, the ratio of capital cost of an LEU reactor to that for a Nat. U reactor was found to be linearly related to the ratio of critical power ratios (CPR).

In another study (2), refuelling ripple was estimated for a number of advanced fuel cycles. Results of AECL studies using the supercell 'MIX' code were normalized to a detailed fuel management simulation of the Bruce GS A Nat. U core, using the Ontario Hydro 'SORO' code. Figure 3 shows a comparison of refuelling ripple for some advanced cycles.

The estimates described above of refuelling ripple for the advanced cycles were used here to calculate the CPR for each type of reactor. Capital cost penalties for advanced reactors were then estimated by using the relation in Figure 2 between capital cost ratio and CPR ratio.

Due to a lack of data for advanced fuel cycles, a number of simplifying assumptions were made in the above analysis. The study of capital cost penalties for LEU reactors was performed for Darlington A, and it was assumed that the same capital cost - CPR relationship also applied to Bruce A, for which the refuelling ripple calculations were done. It was further assumed that the same percentage capital cost penalties calculated for Bruce A also applied to future 850 MWe and 1250 MWe reactors. This is probably a conservative assumption, since economy of scale effects might tend to reduce capital cost increases.

Possible capital cost penalties due to power peaking are listed in Table 4. Both 2 and 4 bundle shift schemes were considered.

Table 4 indicates that a 2 bundle shift scheme would result in no capital cost penalty. However, it is not clear that the refuelling rates required by a 2 bundle shift scheme could be achieved with present refuelling configurations. A calculation of fuelling machine demand and supply for each fuel cycle for various combinations of bundle shift schemes and number of fuelling machine trolleys, is described in the following section.

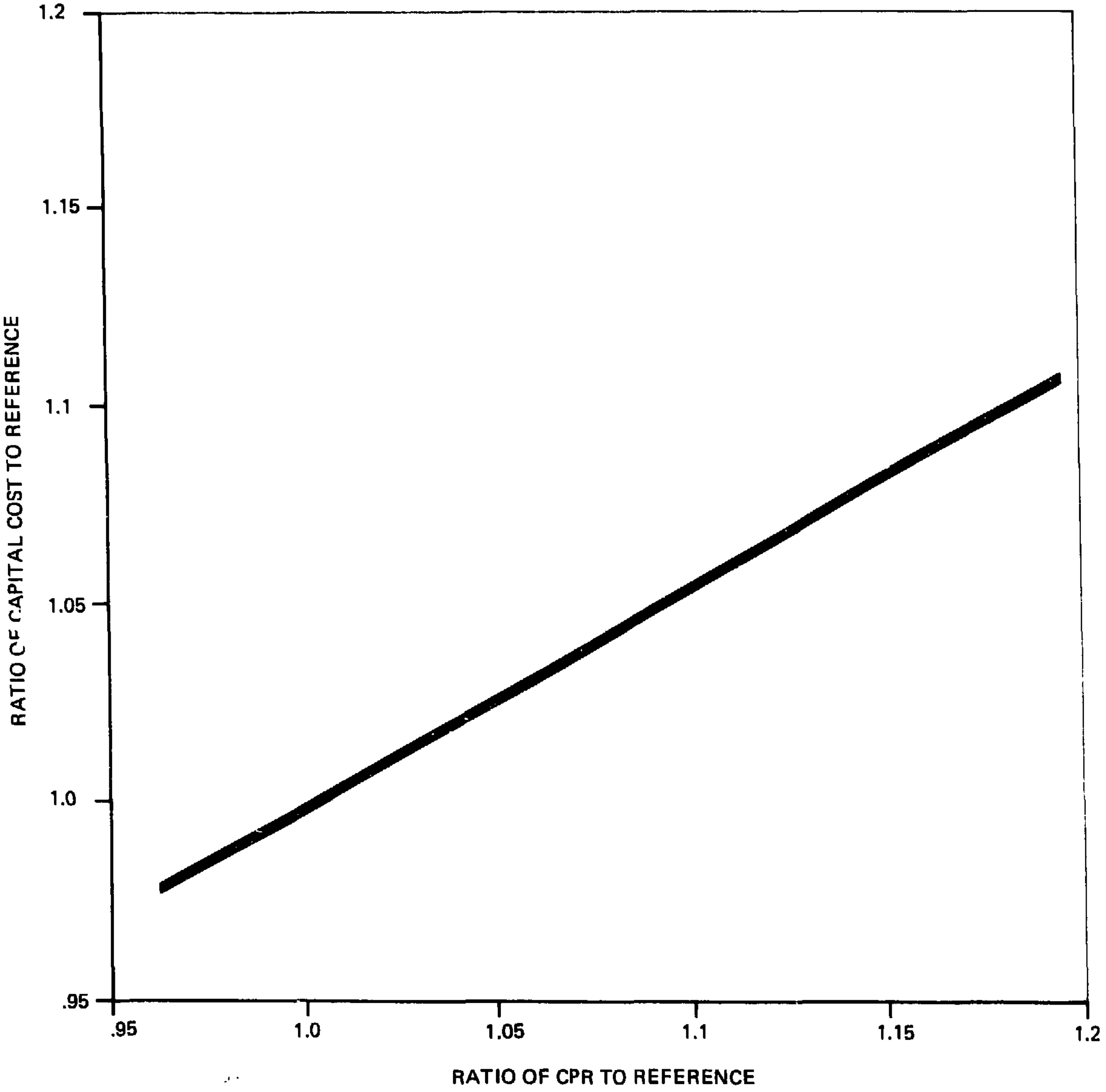

Figure 2:
Capital Cost Ratio vs. CPR Ratio

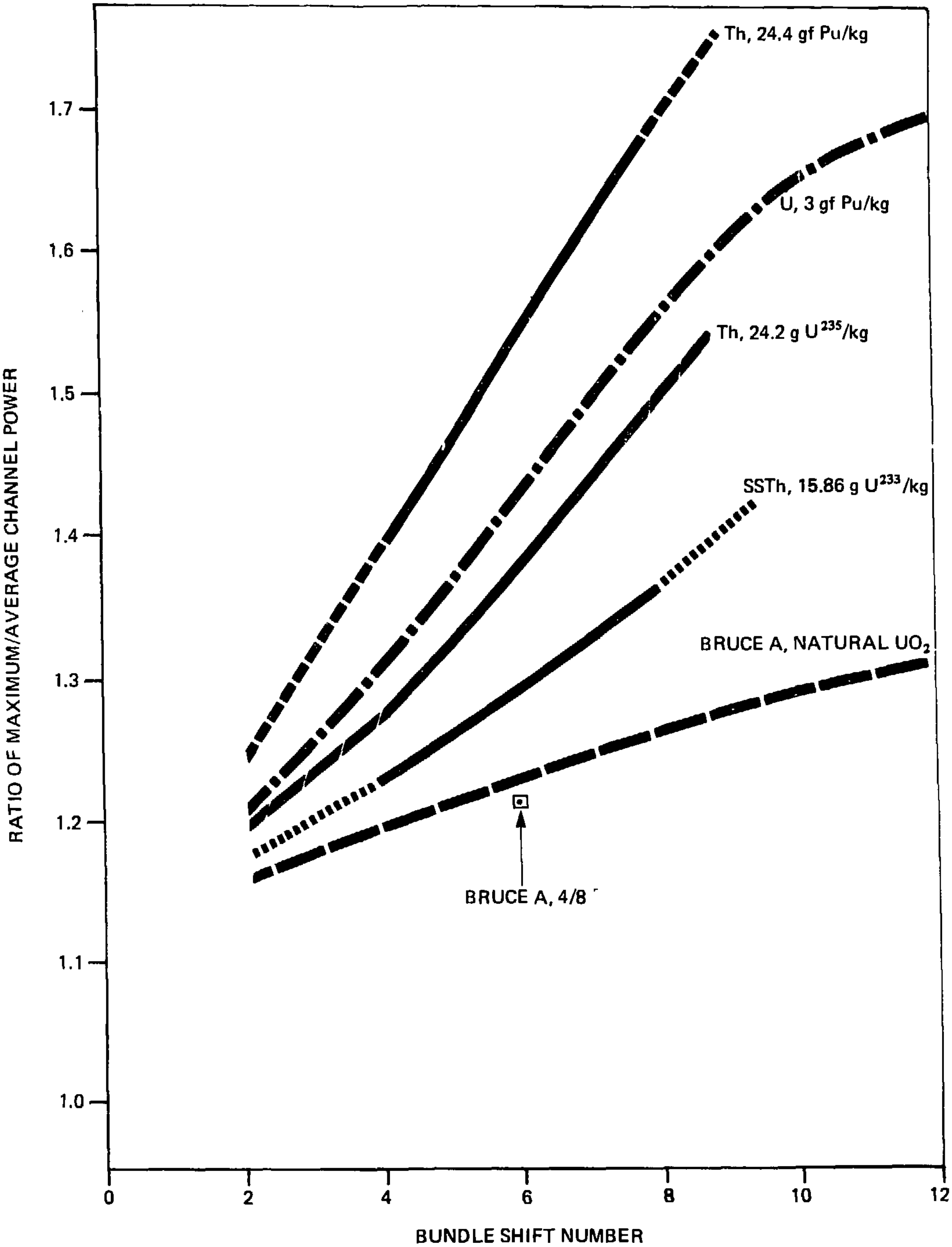

Figure 3:
Refuelling Ripple: A Comparison of Alternative Cycles

TABLE 4

Capital Cost Penalties Due to Power Peaking*

Fuel Cycle	LEU		LEU		Pu Recycle		Th(Pu)		Th(U)	
Enrichment	1%		1.2%		3g Pu/kg HE		24.4g Pu/kg		24.2g U/kg	
Bundle Shift	2	4	2	4	2	4	2	4	2	4
Capital Cost Penalties										
4 x 850 MWe Station										
Penalty (M$/Station)	0	50	0	180	0	100	0	140	0	30
Penalty ($/kWe)	0	15	0	53	0	29	0	41	0	9
4x1250 MWe Station										
Penalty (M$/Station)	0	60	0	230	0	125	0	175	0	40
Penalty ($/kWe)	0	12	0	46	0	25	0	35	0	8

*Assuming Nat. UO_2 fuelling configuration

4.3.3 Refuelling

The increased burnups for the advanced fuel cycles may enable refuelling of reactors in two or four bundle shifts. This would aid greatly in reducing problems associated with channel power peaking. Presented here are results of calculations of required and achievable refuelling rates, and associated capital cost penalties or benefits, for advanced CANDU stations.

Table 5 shows the required fuelling rates for advanced CANDU stations as a function of the number of bundles shifted per channel visit, assuming standard 50 cm length fuel and expected average discharge burnups. Fuelling rates are expressed as maximum allowable values of average refuelling time per channel.

Allowable refuelling configurations can be determined by comparing required fuelling rates with the calculated fuelling capability for 2 or 4 bundle shifts. Post-Darlington stations will likely use fuelling machines with 16-bundle magazines. Only the 16/0 magazine loading scheme, and bundle shift schemes of 4x4 or 8x2, will be considered when calculating fuelling capability. More efficient fuelling strategies might improve fuelling capability, so the estimates derived here may be on the conservative side.

The refuelling time per channel can be calculated according to

$$T = \frac{tm + y \times ty + td + tt}{y}$$

where tm = magazine loading time
ty = on-channel operation for y bundle shift
td = discharge time
tt = traversing time

Fuelling machine capability is given by:

$$FC = FT + LOSS$$

where FT = mean fuelling time (hr/chan)
$LOSS$ = loss of fuelling time due to maintenance, personnel unavailability, forced idle, etc. (assumed to be constant).

Based on a reference 8/4 fuelling scheme at Bruce, LOSS = 2.92 hr. Therefore, using the above equations, and as-achieved refuelling data, the refuelling capability was calculated to be 4.1 hr/chan for a 2 bundle shift scheme, and 4.5 hr/chan for a 4 bundle shift scheme. Based on these figures, and the data in Table 5, the minimum allowable refuelling schemes are shown for each fuel cycle in Table 6.

TABLE 5

Required Refuelling Rates for Advanced CANDU Stations

	LEU (1%)		LEU (1.2%)		Th	
Unit Size (MWe)	850	1250	850	1250	850	1250
Fission Power (MWth)	2798	4136	2798	4136	2798	4136
Fuel Burnup (MWth.d/kg HE)	16.0	16.0	21.0	21.0	27.0	27.0
HE/Bundle (kg)	18.7	18.7	18.7	18.7	16.9	16.9
Refuelling Rate (BDL/d/Reactor)	9.4	13.8	7.1	10.5	6.1	9.1
Refuelling Rate (Average hr/chan)						
Two Trolleys						
n=2	2.6	1.7	3.4	2.3	3.9	2.6
n=4	5.1	3.5	6.8	4.6	7.9	5.3
Three Trolleys						
n=2	3.8	2.6	5.1	3.4	5.9	4.0
n=4	7.7	5.2	10.1	6.9	11.8	7.9
Four Trolleys						
n=2	5.1	3.5	6.8	4.6	7.9	5.2
n=4	10.2	7.0	13.5	9.1	15.7	10.4

n = number of bundles shifted per channel visit

TABLE 6

Minimum Allowable Refuelling Configurations

LEU(1%)		LEU(1.2%)		Th	
850 MWe	1250 MWe	850 MWe	1250 MWe	850 MWe	1250 MWe
2T-4B	3T-4B	2T-4B	2T-4B	2T-4B	2T-4B
4T-2B	No 2B	3T-2B	4T-2B	3T-2B	3T-2B

T = Number of trolleys
B = Bundle shift

The capital cost estimates shown in Table 2 for future 4x850 MWe stations are based on Darlington, whose present design assumes three fuelling machine trolleys, each with 16-bundle magazines. The 4x1250 MWe station costs include the cost of four trolleys. The cost of a fuelling machine trolley is estimated to be $30M.(4) Based on this data, and the results in Table 6, a summary of capital cost benefits due to new fuelling schemes is contained in Table 7.

No increase in O&M costs due to increased fuelling machine usage is expected. In fact, for the 4x1250 MWe stations, a decrease in O&M costs can be expected because one less fuelling trolley is required. However, to avoid optimistic estimates, it will be assumed that any O&M benefits will be offset by expenditures on items such as safeguards and security.

TABLE 7

Capital Cost Benefits Due to Refuelling

Fuel Cycle	LEU	LEU	LEU	LEU	Th(Pu)	Th(Pu)	Th(U)	Th(U)
Reactor Size (MWe) Enrichment	850 1%	1250 1%	850 1.2%	1250 1.2%	850 24.4g/kg	1250 24.4g/kg	850 24.2g/kg	1250 24.2g/kg
Capital Cost Benefit For Fuelling Strategy (M$/Station)								
2T-4B	30	N.A.	30	60	30	60	30	60
3T-2B	N.A.	N.A.	0	N.A.	0	30	0	30
3T-4B	0	30	0	30	0	30	0	30
4T-2B	-30	N.A.	-30	0	-30	0	-30	0

N.A. - Not Allowed

4.3.4 Summary

Capital cost penalties for advanced CANDU stations are summarized in Table 8.

A small increment in O&M costs for all advanced cycles, except the LEU, might be expected. Factors contributing to the increase are increased maintenance for new and irradiated fuel handling, and increased security. An annual penalty of $2M per station, for 4x850 MWe and 4x1250 MWe stations, is assumed for these factors.

The reduced rates of bundle throughput associated with the higher burnups of the advanced cycles offer the potential for reducing the size of irradiated fuel storage bays. Hence, the station capital cost may be reduced. However, the higher activity and heat generation of the irradiated advanced fuels may require deeper bays and larger cooling capacities. Criticality concerns associated with a full core discharge may require extra space in the bays. Possible longer storage times for the once through LEU cycle may also require extra space. These factors may eliminate any station capital cost benefits associated with irradiated fuel management for the advanced cycles. Hence, no benefits, or penalties, are assumed here.

Net capital cost penalties, and the resulting station costs, are shown for the advanced fuel cycles in Table 9. The 4x1250 MWe stations operating on thorium cycles are shown to have the same capital costs as Nat. U stations. The possible $5M benefit due to the reduced fuelling machine requirement has been ignored.

The overall result of the foregoing analysis is that advanced fuelled CANDU stations are not expected to have significantly higher capital costs than Nat. U stations. Problems with power peaking, the major concern, will likely be minimized through smaller bundle shift schemes.

No credit has been taken for modifications to station design, which could conceivably reduce capital costs. Thicker and/or longer pressure tubes (which would lead to greater thermal efficiency), smaller radial reflectors, and reducing the moderator/coolant D_2O purity are areas where capital cost improvements seem possible. The cost of the burnup penalty associated with a given modification must, of course, be less than or equal to the reduction in capital cost afforded by the modification. The potential for reducing capital cost through the use of advanced cycles is under investigation.

4.3.5 Areas and Effects of Uncertainty

The design of LEU reactors is a relatively small step from the design of the present natural uranium CANDU reactors. It is likely that the present methods of assessing lattice physics and control and safety aspects are appropriate for LEU assessments. This, coupled with the inherently conservative assumptions used, gives us considerable confidence that the capital cost penalties associated with LEU will not exceed those quoted in this report.

The largest calculated capital cost penalty associated with the LEU cycle is 45 M$ per station. This is about 1% of the total capital cost, and adds 0.06 m$/kWh to the TUEC of the station. This, of course, must be deducted from the savings in fuelling cost attributable to the LEU cycle, and increases the U_3O_8 "break-even" cost of the LEU and natural cycles by about 6 $/lb (based on preliminary static analysis reported in Reference 5). The 1250 MWe, 1.2% LEU station has a capital cost penalty of 15 M$, equivalent to only 0.02 m$/kWh, or an increase in break-even price of 2 $/lb U_3O_8. (The above range of penalties are not expected to eliminate the commercial competitiveness of the LEU cycle at prevailing world uranium prices.)

The calculational methods for assessing the fuel management for the thorium cycles have generally not been verified by experiments. In addition, there are more changes required to the fuel handling equipment at the station. Hence, there is much less confidence in the capital cost penalties associated with the thorium cycles, and less assurance that the actual penalties will not exceed those calculated.

Nevertheless, Reference 5 has shown that the break-even cost of thorium cycles is significantly less sensitive to the capital cost penalty than was the LEU cycle. The largest calculated capital cost penalty for the thorium cycles was 25 M$ for the 4x850 MWe station. This is equivalent to 0.05 m$/kWh, but changes the break-even price between thorium and LEU cycles by less than 3 $/lb U_3O_8. Increasing the penalty for the 4x1250 MWe thorium stations from 0 to 100 M$ would change the break-even price by about 6 $/lb U_3O_8.

TABLE 8

Capital Cost Penalties - Summary

Fuel Cycle	LEU	LEU	LEU	LEU	Th(Pu)	Th(Pu)	Th(U)	Th(U)
Reactor Size (MWe) Enrichment	850 1%	1250 1%	850 1.2%	1250 1.2%	850 24.4g/kg	1250 24.4g/kg	850 24.2g/kg	1250 24.2g/kg
Capital Cost Penalty Due to Power Peaking (M$/Station)	50 (2T-4B)	60 (3T-4B)	0 (3T-2B)	0 (4T-2B)	0 (3T-2B)	0 (3T-2B)	0 (3T-2B)	0 (3T-2B)
Capital Cost Penalty For Fuelling Strategy (M$/Station)	-30 (2T-4B)	-30 (3T-4B)	0 (3T-2B)	0 (4T-2B)	0 (3T-2B)	-30 (3T-2B)	0 (3T-2B)	-30 (3T-2B)
Capital Cost Penalty Other Considerations (M$/Station)	15	15	15	15	25	25	25	25
Total Capital Cost Penalty (M$/Station) ($/kWe)	35 10	45 9	15 4	15 3	25 7	0 0	25 7	0 0

TABLE 9

Station Costs for Advanced Fuel Cycles

Fuel Cycle	LEU	LEU	LEU	LEU	Mixed Oxide	Mixed Oxide	Th(Pu)	Th(Pu)	Th(U)	Th(U)
Enrichment	1%	1%	1.2%	1.2%	3g/kg	3g/kg	24.4g/kg	24.4g/kg	24.2g/kg	24.2g/kg
Reactor Size (MWe)	850	1250	850	1250	850	1250	850	1250	850	1250
Capital Cost Penalty (M$/Station) ($/kWe)	 35 10	 45 9	 15 4	 15 3	 25 7	 35 7	 25 7	 0 0	 25 7	 0 0
Station Capital Cost (M$) ($/kWe)	 3178 935	 3985 797	 3158 929	 395[illegible] 791	 3168 932	 4060 812	 3168 932	 3940 788	 3168 932	 3940 788
Station O&M Cost (M$/yr) ($/kWe-yr)	 34.2 10.1	 36.0 7.3	 34.2 10.1	 36.0 7.3	 36.2 10.6	 38.0 7.6	 36.2 10.6	 38.0 7.6	 36.2 10.6	 38.0 7.6

5.0 LIQUID METAL FAST BREEDER REACTOR COSTS

To date, estimates of LMFBR costs for Canadian conditions have not been performed. However, studies at ORNL for the U.S. NASAP evaluation have compared costs of heavy water reactors and LMFBR's for American conditions. Preliminary results of those studies indicate that capital costs for a mature system of LMFBR's are 25% greater than for heavy water reactors (heavy water excluded), for reactor sizes of 600 MWe to 1300 MWe. Operation and maintenance costs are estimated to be equivalent to those for advanced heavy water reactors.

It seems likely that, if LMFBR's are included in Ontario's generation program, the technology will be purchased from abroad. Therefore, it will be asumed that the NASAP data, with a 10% penalty due to exchange rates and other considerations, will apply to breeder costs in Ontario.

The ORNL data applies to a fully developed mature system of LMFBR's. Costs for demonstration plants, and initial commercial plants will probably be significantly greater. ORNL estimates that LMFBR capital costs will initially be about 60% greater than those for mature plants. To be on the conservative side, it will be assumed here that LMFBR capital costs will decrease, at a rate inversely proportional to installed breeder capacity, from 160% to 100% of mature costs during the first 10 years of breeder commercialization.

It is possible that decommissioning of LMFBR's will be more difficult than that of CANDU reactors. The need to handle and decontaminate very large components may result in higher costs. Hence, an annual surcharge of 5% will be applied to O&M costs to allow for the possible extra costs of decommissioning.

A summary of LMFBR cost estimates is contained in Table 10.

TABLE 10

LMFBR Cost Data

Unit Size (MWe)	850	1250
Capital Cost (Initial Plant)		
(M$/Reactor)	1781	2024
($/kWe)	2094	1619
Capital Cost (Mature)		
(M$/Reactor)	1113	1265
($/kWe)	1309	1012
Operating and Maintenance Cost		
(M$/Reactor - yr)	9.5	10.0
($/kWe-yr)	11.2	8.0

6.0 HEAVY WATER PLANT COSTS

A total of three heavy water plants, owned and operated by Ontario Hydro, are scheduled for the Bruce Nuclear Power Development site. These are the only three heavy water plants currently planned for Ontario. Bruce Heavy Water Plant A (BHWP A) has been operating since 1973. BHWP B is scheduled to be placed in-service in 1981. Construction of the second half of BHWP D has recently been suspended, and the first half of BHWP D is to be mothballed pending an increase in the need for heavy water.

The heavy water plant cost estimates outlined below are based on incurred and expected costs for the Bruce Heavy Water Plant D. These estimates were made prior to the decision to suspend construction. BHWP D was to be the final plant built at Bruce, and a certain level of maturity in costs was expected.

Table 11 outlines plant capital costs and the unit mass cost for heavy water. The unit capital cost is based on a 100% capacity production rate of 925 Mg/a. The unit mass cost for heavy water is projected to decrease, in constant dollars, over the next 15 years. A value of $213/kg represents the expected cost in 1985, de-escalated to constant dollars of January, 1978. The heavy water inventory costs shown in Table 2 for CANDU reactors are based on this price.

TABLE 11

Heavy Water Cost

Plant Capital Costs (M$)	
Enriching Units	181.9
Finishing Units	8.5
Water Supply and Treatment	11.3
Site Development and Buildings	3.4
Yard and Utilities	10.2
Instrumentation and Control	0.1
Auxiliary Systems Reinforcement	0.3
Indirect Costs	63.7
Engineering and Other Costs	55.2
Interest During Construction	128.0
Commissioning	65.0
Total Capital Cost	527.6
Unit Capital Cost ($/kg/yr)	570
Unit Mass Cost ($/kg)	213

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