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ESTIMATES OF CANADIAN FUEL FABRICATION COSTS FOR ALTERNATE FUEL CYCLES AND SYSTEMS

Nuclear Studies & Safety

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ABSTRACT

Unit fuel fabrication costs are estimated for alternate fuel cycles and systems that may be of interest in Ontario Hydro's strategy analysis. A method is proposed for deriving the unit fuel fabrication price to be paid by a Canadian utility as a function of time (ie. the price that reflects the changing demand/supply situation in the particular scenario considered).

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1. Introduction

The fuel fabrication cost is an important variable in economic assessments of alternate nuclear strategies. This document presents our estimates of fabrication costs for fuels that may be of interest to Ontario Hydro in the long-term.

The present estimates are largely based on US data [1,2,3,4]. Canadian cost information is used whenever possible, however, this information is limited to natural fuel and plutonium recycle fuel.[5,6] Extrapolations of Canadian data have been made to adjust the US estimates.

The numerical values of fabrication costs presented here undoubtedly contain many uncertainties that, when resolved, could move the price levels downward or upward. For example, future developments in remote processing are bound to have a beneficial influence on the costs of advanced fuels. On the other hand, more stringent licencing conditions could substantially increase the capital and operating cost of future plants.

Ranges of fuel fabrication costs are given that are believed to be representative of today's status of technology, as well as present licensing conditions in Canada. The actual prices paid by the utility are likely to be within these ranges. However, the fabrication prices cannot be related to the underlying costs in a simple or easily predictable way (due to commercial considerations, such as constraints of competitive bidding). For the purpose of strategy analysis, estimates of fuel fabrication prices are also presented, based on a qualitative assessment of the future commercial environment in Ontario and Canada. Note that these latter estimates do not constitute a price forecast confirmed and endorsed by Ontario Hydro's Fuels Division.

2. Cost Considerations

The fuel fabrication costs are affected by a variety of factors, viz:

(1) Fuel design and its effect on plant design:

- environmental containment,
- safeguards,
- mode of operation and maintenance (contact, lightly shielded, heavily shielded),
- process complexity,
- criticality considerations,
- accountability requirements,
- quality assurance requirements.

(2) Plant location and its effect on plant design:

- stand-alone facility
- addition to an existing plant
- part of an energy centre (shared facilities)

(3) Demand for a given type of fuel:

- plant size,
- plant versatility (dedicated or campaign operation),
- degree of automation.

(4) Investment financing:

- private or public (capital recovery rate),
- taxes, insurance, etc.

The second consideration cannot be adequately analysed at this time since the concept of energy centers is yet undefined. Therefore, this work limits itself to stand-alone facilities.

The latter two considerations are particularly important for the advanced fuels where the capital charges constitute a significant fraction of the fuel fabrication cost. For example, a difference of several hundred percent may occur between the cost based on a small, privately owned plant and that based on a large plant built with public financing (see the following section).

3. Fabrication Cost Estimates

The estimates (in $ per kg of heavy element) are collected in Table 3.1 for various plant types and sizes. The following are some explanatory notes for this table.

COLUMNS:

Range of fuel fabrication costs reflects the possible arrangements of capital financing for a new fuel fabrication plant. The lower boundary is for public investment, the upper boundary is for "high-risk" private investment (see the following section for details).

Estimated (EST) fabrication prices are the recommended input values for Ontario Hydro's strategy analysis. These estimates assume that all U235-based plants are built with private funds. The prices for UO_2 fuels are expected to remain below the costs based on high-risk private financing, due to a favourable investment climate (i.e., some debt financing available) as well as the moderating influence of existing plant capacity. Any small plants for enriched UO_2 are likely to be attached to the existing facilities, hence, the fabrication cost of enriched fuel from small plants should be lower than that based on a stand-alone facility. All Pu or U233 processing plants are assumed to be built with public investment. The recommended price levels for Pu or U233-bearing fuels are higher than those for a new publicly financed plant (public cost + 1/3 of difference between public and private costs). This arbitrary penalty was applied to recognize the higher degree of uncertainty in the base estimates and to make allowance for some participation of private investment in these ventures.

ROWS:

CANDU nat. UO_2 plant is perceived as a dedicated plant with a continuous material flow through the manufacturing process (ie the batch identity of incoming material is not vigorously maintained). The starting material is refined natural uranium in solid or liquid form (ie ADU, AU, etc). The fabrication of UO_2 powder as well as all the scrap recycle are done at the plant's premises. Adequate containment of uranium-bearing material is provided. Only minimum provisions are made for security, criticality control or accountability of nuclear material, as called for by the current regulatory standards.

CANDU single enr. UO_2 plant is similar to the above plant with the exception of the head-end process. The starting material in this plant is UF_6. Increased levels of security, criticality control and accountability are provided in this plant but the batch identity of the incoming material is not vigorously followed in the manufacturing process. Consequently, only a single low enrichment can be handled by this plant at any given time. An infrequent change of enrichment is possible but not desirable.

CANDU multi-enr. UO_2 plant is similar to that for LWR fuel. The starting material is UF_6 and several moderate enrichments can be processed more or less at the same time. The batch identity of incoming material is strictly maintained through the whole manufacturing process. Appropriate allowances are made for containment, accountability and criticality control of uranium-bearing materials. All scrap is recycled at the plant's premises. The plant operates in campaigns.

CANDU contact $(Pu,U)O_2$ or $(Pu,Th)O_2$ plant is based on an AECL design concept of contact operation and maintenance.(7) This plant can only process relatively low concentrations of "clean" plutonium. The starting materials are oxide powders supplied by a reprocessing plant. Special security arrangements are made at this plant, based on security standards of early 1970's. The plant operates in campaigns.

CANDU remote $(Pu,U)O_2$ or $(Pu,Th)O_2$ plant provides for remote operation and contact maintenance. Moderate enrichments of plutonium can be processed in this plant but the shielding is not adequate for "spiked" plutonium. The plant operates in campaigns.

CANDU remote $(U3,Th)O_2$ plant is a heavily shielded facility designed for remote operation as well as maintenance. Uranium 233 or "spiked" plutonium can be processed in this plant. The plant operates in campaigns.

LWR enr. UO_2 plant is a standard plant for PWR fuel. Note the similarity between this plant and the "CANDU multi enr." plant.

LWR remote $(Pu,U)O_2$ plant is designed for remote operation and contact maintenance. It is not suitable for processing of "spiked" plutonium.

LMFBR $(Pu,U)O_2$ core plant utilizes remote operation and contact maintenance. It is designed for production of core fuel assemblies. Note that this plant is not suitable for processing of spiked plutonium.

LMFBR UO_2 blanket plant is a contact facility fabricating the radial blanket assemblies.

NOTES:

The present estimates are made for stand-alone facilities. Substantial cost improvements could be made by incorporating the fabrication plant in an energy centre where some costs would be shared by several facilities.

Scrap recycle and waste treatment costs are covered in the present estimates but the costs of final waste disposal are not included.

Different starting materials are used in different fuel fabrication plants, viz:

- Natural UO_2 plant starts from ADU or AU. It costs about $2/kgU to produce these materials from yellowcake (i.e. the cost of mined uranium must be increased by $2/kgHE to derive the cost of feed material to the fabrication plant).

- Enriched UO_2 plant starts from enriched UF_6. The cost of enrichment (in $ per kg of enriched U) depends on the cost of SWU, price of mined uranium, and the tails assay of the enrichment plant. In addition, the cost of conversion of mined U to UF_6 runs at about $4/kgU. This amount must be added to the cost of mined uranium to derive the cost of enrichment plant feed.

- Fabrication of advanced fuels start from oxide powders, presumed to be supplied by the reprocessing plant.

APPLICATION OF ESTIMATES:

In strategy analyses, plant types and sizes must be selected empirically to fit the particular scenario. The following principles are recommended in selecting the plant sizes:

- The sum of plant capacities should closely match the total demand for fuel. The unit costs given in Table 3.1 are based on full loading of the plant. Any excess capacity (i.e. underloading) will increase the unit cost of fuel.

- Maximum size of plant for U235-based fuel should not exceed 6 MgHE per day.

- Maximum size of all other plants should not exceed 4 MgHE per day.

- Plants with contact operation operate 260 days per year.

- Plants with remote operation operate 240 days per year.

- A single fuel fabrication plant is permitted only in the introductory period of a new fuel cycle. At least two independent plants are required for the commercial deployment of a fuel cycle, to ensure the security of fuel supply.

The average unit fuel fabrication cost can be derived using the empirically fitted supply scenario (discussed above) and the estimates from Table 3.1. In the case of uranium-based fuels (natural or enriched UO_2), the fuel fabrication technology is "established" in Canada or can be readily obtained from abroad. Hence, the average cost can be derived directly from the estimates in Table 3.1 as follows:

$$\text{Average unit cost} = \frac{\sum P_i C_i}{\sum C_i}$$

where P_i = estimated unit price from plant i
C_i = capacity (or throughput) of plant i

In the case of advanced fuels that require "glove-box" or "remote" fabrication technology, a principle of the "first-of-a-kind" cost must be recognized in the introductory period of a new fuel cycle. This remote technology is not readily available and a substantial effort will be required to develop it as well as to secure the equipment supply sources. In Canada, much of the development cost can be expected to be borne by the federal and/or provincial governments and only a small portion of it will be reflected in the cost to the customer. Based on the experience with CANDU reactors, the first plant may bear a unit cost surcharge of 10%, as compared to an identical plant built within the framework of the "established" industry. If additional plants are built within 10 years of the in-service date of the first plant, a smaller surcharge will apply, decreasing gradually with the delay between the in-service dates. The average fabrication cost for the advanced fuel cycles can be calculated as follows:

$$\text{Average unit cost} = \frac{1.1\, P_1C_1 + xP_2C_2 + yP_3C_3 + \ldots + \sum P_iC_i}{C_1 + C_2 + C_3 + \ldots + \sum C_i}$$

where P_1, P_2, P_3, P_i = estimated unit prices for "established" plants
C_1, C_2, C_3, C_i = plant capacities
x, y = surcharges applicable to the plants built within 10 years of the in-service date of the first plant = (10-delay) x 0.01

The application of the preceeding principles is illustrated in Figure 3.1 for a hypothetical scenario involving the remote fabrication of $(Th,U)O_2$ fuel.

For the purpose of strategy analysis, the stepped price changes with time should be "smoothed-out" as illustrated in Figure 3.1. This "smoothing-out" will allow for building up the inventories needed to get over any short term demand/supply discrepancies.

TABLE 3.1

FUEL FABRICATION COST ESTIMATES (IN $ PER kg OF HEAVY ELEMENT, 1 January 1978 dollars)

PLANT SIZE:	0.5 MgHE/day		1.0 MgHE/day		2.0 MgHE/day		3.0 MgHE/day		4.0 MgHE/day		6.0 MgHE/day	
	Range	Est.	Range	Est.	Range	Est.	Range	Est.	Range	Est.	Range	Est.
CANDU												
nat UO_2	53-80	N/A	46-67	N/A	41-57	50	38-52	48	36-49	46	34-45	42
single enr UO_2	66-96	85	58-81	73	51-69	65	47-63	59	45-59	56	42-55	52
multi enr UO_2	77-112	100	67-94	82	58-80	75	54-73	68	51-68	64	48-63	59
cont. $(Pu,U)O_2$	124-197	148	105-162	124	90-135	105	83-122	96	78-113	90	-	N/A
rem. $(Pu,U)O_2$	237-381	285	205-328	246	178-284	213	165-261	197	156-246	186	-	N/A
rem. $(U3,Th)O_2$	348-594	430	300-511	370	260-441	320	240-405	295	226-381	277	-	N/A
LWR												
enr UO_2	126-167	160	112-145	135	101-127	121	96-118	113	92-112	107	88-105	101
rem. $(Pu,U)O_2$	396-649	480	343-556	414	299-479	359	277-439	331	263-414	313	-	N/A
LMFBR												
$(Pu,U)O_2$ core	602-959	721	535-838	636	480-736	565	451-684	528	433-651	506	-	N/A
UO_2 blanket	139-171	150	129-157	138	119-141	126	114-133	120	111-128	117	-	N/A

See Text For Boundary Conditions and Rules for Application of These Estimates

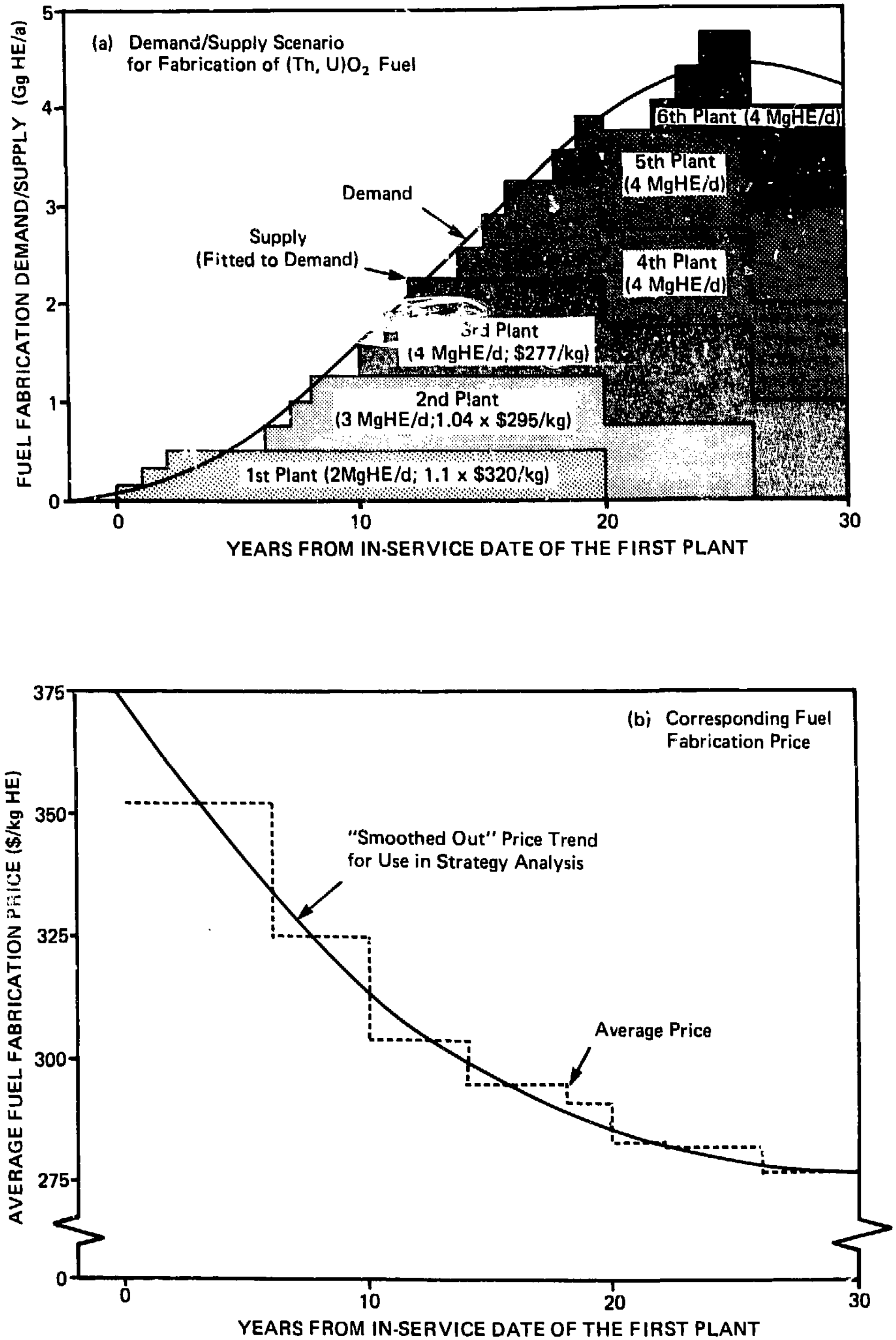

Figure 3.1
EXAMPLE OF ESTIMATING THE UNIT FUEL FABRICATION PRICE IN A DYNAMIC DEMAND/SUPPLY SITUATION

4. Base Cost Estimates

Base estimates of facility, equipment, hardware and operational costs are collected in Table 4.1. These estimates apply for a reference plant size of 2Mg HE/day.

Unit fabrication costs given in the preceeding section were computed from these base cost estimates as follows:

$$\$/\text{kgHE} = \frac{C_F R_F + C_E R_E + C_P R_P + C_H + C_O + C_D}{T}$$

$$C_F = B_F S_F$$

$$C_E = B_E S_E$$

$C_P = 0.33\ (C_F + C_E)$ for contact operation plants,

$\quad = 0.45\ (C_F + C_E)$ for other plants

$$C_H = B_H S_H$$

$$C_O = B_O S_O$$

C_D = not applicable for contact operation plants,

$\quad = 0.05 C_O$ for other plants

where:

B_F = base cost estimate for facility (M$)

B_E = base cost estimate for equipment (M$)

B_H = base cost estimate for hardware (M$/a)

B_O = base estimate for operation cost (M$/a)

*S_i = plant-size scaling factor for cost category i (fraction)

CF = capital cost of scaled facility (M$)

C_E = capital cost of scaled equipment (M$)

*C_P = capitalized preoperational cost (M$)

C_H = annual hardware cost (M$/a)

C_O = annual operating cost (M$/a)

*C_D = annual payment to decommissioning fund (M$/a)

*T = average annual throughput of scaled facility (GgHE/a)

*R_i = annual fixed charge rate on capital i (fraction/a)

*see the following section for details.

The FACILITY cost category includes buildings, plant services and any facility-related equipment (i.e. maintenance, out-process handling, security, etc.). Also included are shipping flasks for incoming materials and finished fuel (if required).

The EQUIPMENT cost includes only the process-related equipment (machinery, in-process handling, etc.).

The HARDWARE cost category includes all components other than fuel materials that consititute the fuel assembly (i.e. zircaloy, tubes, end caps, etc.).

The OPERATING cost includes labour, expendable materials, inventory cost, etc.

Derived PREOPERATIONAL cost should cover the owner's cost during construction (planning, commissioning, working capital) and capital interest charges during construction.

The DECOMMISSIONING fund payment is applied to all the remotely operated plants. It is intended to cover the high costs of dismantling and decontaminating the facility at the end of its useful life. In contact-operation plants, the decommissioning component of unit fabrication cost (in $/kgHE) is very small, compared to other cost components, and it need not be considered separately from the annual operating cost.

The interim replacement of equipment is not treated as a separate cost component. It is covered in the annual fixed charge rate on equipment investment (R_E, see the following section).

TABLE 4.1

COST ESTIMATES FOR REFERENCE PLANT SIZE OF 2MgHE/day

		Facility (M$)	Equipment (M$)	Hardw. (M$/a)	Oper. (M$/a)	Preop. (M$)	Decom. (M$/a)
CANDU:	nat U	17	26	7	5	14	N/A
	single enr U	19	29	8	8	16	N/A
	multi enr U	22	35	8	10	19	N/A
	contact Pu,U	60	55	12*	12	38	N/A
	remote Pu,U	170	70	8	28	108	0.7
	remote Th,U3	310	100	9	35	185	1.0
LWR:	enr U	32	34	23	15	22	N/A
	remote Pu,U	208	209	28	26	188	2.1
LMFBR:	(Pu,U)O_2 core	358	232	77	29	266	2.3
	UO_2 blanket	24	34	33	15	19	N/A

* Note: This facility(7) uses prefabricated bundle components supplied by an outside contractor (all other facilities have on-site component fabrication facilities).

5. Assumptions

The following plant design assumptions apply for base cost estimates:

- Reference plant capacity 2MgHE/day
- Plant life: building and facilities .... 20 years
  process equipment .... 10 years
- Effective production: contact operation ...... 260 days/year
  non-contact operation ...... 240 days/year
- Plant operating factors: 1st year 33%
  2nd year 67%
  3rd-20th years 100%
  lifetime average 95%

The following economic assumptions are used to calculate the unit fabrication costs:

- constant (uninflated) dollars .... 1st January 1978
- pre-operational cost[(a)]: contact operation ..... 33% orig. capital
  non-contact operation .... 45% orig. capital
- return on investment after taxes[(b)]: private ... 15%
  public 9.75%
- property tax on original capital: private 2.5%
  public .... N/A
- insurance on original capital: private 0.5%
  public .... N/A
- income tax: private 50%
  public .... N/A
- interim equipment replacement charge .... 1% equip. capital
- decommissioning fund payment:
  contact operation .... N/A
  non-contact operation .... 5% oper. cost

Note (a): The construction of the "non-contact operation" plant will take approximately 6 years. Based on typical cash flow scenarios, the interest charges and the owner's cost during construction may range from 37% to 48%, depending on the cost of money (interest rate) and other economic assumptions. For simplicity, a conservative value of 45% has been adopted for this study. In the case of "contact operation" plants, the construction period will be about 25% shorter and the preoperational costs will be lower by a corresponding amount.

Note (b): "Private" financing implies "high-risk" industrial investment (100% equity) with adequate return on investment after taxes. "Public" financing corresponds to "utility" investment (80% debt, 20% equity). These two conditions can be viewed as boundary conditions for possible investment arrangements in Canada.

The capital charges are derived from the above assumptions for private and public financing of the plant:

			Private	Public
o Facility:	capital recovery		.160	.115
	income tax		.110	-
	property tax		.025	-
	insurance		.005	-
		R_F =	0.300	0.115
o Equipment:	capital recovery		.199	.161
	income tax		.099	-
	property tax		.025	-
	insurance		.005	-
	interim replacement		.010	.010
		R_E =	0.338	0.171
o Pre-operational:	capital recovery		.160	.115
		R_P =	0.160	0.115

The plant-size effect on individual cost categories is estimated as follows[3]:

$$C_i = B_i S_i = B_i (X/R)^{Y_i}$$

where: C_i = scaled cost in category i

B_i = base cost estimate for category i

S_i = plant-size scaling factor for category i

X = scaled plant capacity

R = 2MgHE/day = reference plant capacity

Y_i = cost category scaling factor

The numerical values of Y_i are as follows:

Y_F = 0.6 for contact facility

Y_F = 0.8 for non-contact facility

Y_E = 0.7 for equipment

Y_H = 1.0 for hardware

Y_O = 0.8 for operating costs

The plant-size scaling factors S_i are enumerated below:

Plant capacity:	0.5	1.0	2.0	3.0	4.0	6.0
S_F (contact)	.435	.660	1.000	1.275	1.516	1.993
S_F (other)	.330	.574	1.000	1.383	1.741	2.408
S_E	.379	.616	1.000	1.328	1.625	2.158
S_H	.250	.500	1.000	1.500	2.000	3.000
S_O	.330	.574	1.000	1.383	1.741	2.408

6. Discussion and Conclusions

The cost estimates presented in this document contain a number of uncertainties, as outlined below.

The uncertainties in cost estimates for natural or enriched UO_2 fuels are relatively small. This is because the manufacturing technology and the regulatory criteria are reasonably well defined, supported by the experience from existing fuel fabrication plants.

For a new UO_2 facility, the uncertainty in base cost estimates (ie. estimtates for a reference plant size of 2 MgHE/day, see Table 4.1) is ±10%. For scaled facilities, the uncertainty in estimated capital and operating costs increases to about ±15%. Additional uncertainties exist in the economic assumptions used to calculate the unit product cost. The uncertainty range of unit cost estimates thus becomes approximately ±20%.

In the case of advanced fuels (that require "glove-box" or "remote" fabrication technology), the uncertainty in the cost estimates is somewhat larger. Industrial experience with the advanced fuels is very limited, the regulatory criteria are uncertain and cost quotations are not available for some equipment components since there are no established supply sources.

For a new advanced fuel fabrication facility, the uncertainty in base cost estimates is approximately ±30%. For scaled facilities, the uncertainty in capital and operating costs increases to approximately ±35%. The uncertainty in the unit costs is estimated at ±40%.

The recommended price levels for strategy analysis (see Table 3.1) include a contingency that, to some extent, reduces the error range of the present unit cost estimates. Under the assumption that all advanced fuel fabrication plants in Canada will be crown corporation, the uncertainty in unit prices is estimated at +20% to -40%.

Should the fuel fabrication price become a governing variable in the strategy analysis of alternate fuel cycles, sensitivity analysis should be performed within the following ranges:

±20% for UO_2 fuels
+20% to -40% for all other fuels

References

1. A.R. Olsen, "Fuel Fabrication Processes and Cost Estimation" presented at the University of Tennessee, September 12, 1977.

2. A.R. Olsen, R.R. Judkins "Fuel Fabrication Cost Discussions" data package of ORNL/OH meeting held at ORNL March 19, 1978.

3. A.R. Olsen et al, "Fuel Cycle Cost Studies - Fabrication, Reprocessing, and Refabrication of LWR, SSCR, HWR, LMFBR and HTGR Fuels", ORNL/TM-6522, draft R1, September 27, 1978.

4. "Draft NASAP Provisional Data Base", September 18, 1978.

5. A.T. Jeffs, "Fabrication Costs from Large $(U,Pu)O_2$ Fuel Plants", internal AECL report

6. A.T. Jeffs, "Mixed Oxide Fuel Fabrication for CANDU Reactors: Cost Estimates as a Function of Plant Size", internal AECL report.

7. "Report of the First $(U,Pu)O_2$ Fuel Fabrication Plant Committee", internal AECL report

Appendix

MIXED OXIDE FABRICATION FOR CANDU REACTORS

Updated cost estimates for a 400 Mg/a plant with contact operation and maintenance.

The cost estimates of CRNL-1393 are escalated to 1978 dollars in Table 1. Unit fabrication costs are computed for different financial assumptions in Tables 2 and 3. These unit costs apply for 1.7 MgHE/day plant size.

Our reference plant size is 2 MgHE/a. To derive the cost components for the reference plant, the original cost estimates are increased proportionally to the throughput. This should be acceptable because of the small difference between the two plant sizes. Additional facilities and equipment have been included that are considered essential in today's regulatory environment. Also, shipping flasks have been added to the reference costs. The reference estimates are collected in Table 4.

The unit cost estimates for the reference plant range from $90/kg (public investment) to $135/kg (private investment). This compares favourably with the escalated AECL estimate of $108/kg (see Table 2).

Table 1

Capital and Operating Costs for 400 MgHE/a
Mixed Oxide Fabrication Plant Per CRNL-1393

	Component	1974 Cost (M$)	Escalation Factor (2)	1978 Cost (M$)
1.	General Projects	5.22	1.37	7.15
2.	Site and Improvements	1.10	1.45	1.60
3.	Building and Structures	7.65	1.45	11.09
4.	Process	22.86	1.33	30.40
5.	Process Services	2.77	1.33	3.68
6.	Plant Services	12.99	1.33	17.28
7.	Spares	1.72	1.33	2.29
8.	Commissioning	5.86	1.39	8.15
9.	Interest During Project[a]	21.56		37.65
10.	Escalation During Project[b]	13.42		23.44
	TOTAL CAPITAL (excluding 10)	81.73		142.47
11.	Plant Staff (501 people)	6.81	1.38	9.40
12.	Operating and Maintenance	1.90	1.38	2.62
13.	Zircaloy Components	8.00	1.40[c]	11.20
	TOTAL OPERATING	16.71		23.22

Notes:
(a) 10% interest, based on escalated project cost
(b) 8% per annum
(c) approximate value only; wide fluctuations in material prices experienced between 1974 and 1977 but the fabricated components rose only about 40%.

Table 2

Cost Estimates for 1.7 MgHE Plant Based on Original Economic Assumptions of CRNL-1393

Capital Cost (per Table 1)	142.5	M$
Inventory[a]	3.7	
Working Capital[b]	4.5	
TOTAL	150.7	M$
Capital Recovery[c]	19.82	M$/a
Annual Operating	23.22	
ANNUAL PRODUCT VALUE	43.04	M$/a

$$\text{UNIT COST} = \frac{43.04}{400} = \$108/\text{kgHE}$$

Notes:

(a) 4 months supply of Zr components

(b) 10 weeks operating cost

(c) 10% p.a. for 15 years = capital recovery factor 0.1315.

Table 3

Cost Estimates for 1.7 *MgHE/day* Plant
Based on Present Economic Assumptions

General Projects 7.15 Site and Developments 1.60 Building and Structures 11.09 Plant Services 17.28 Spares 1.29		FACILITY	38.41 M$
Process 30.40 Process Services 3.68 Spares 1.00		EQUIPMENT	35.08 M$
0.33 x (38.41 + 35.08)		PREOPERATIONAL	24.25 M$
Zircaloy components 11.20		HARDWARE	11.20 M$
Plant Staff 9.40 Operating and Maint. 2.62		OPERATING	12.02 M$

Unit Costs in $/kgHE

Component	Private	Public
Facility	30	12
Equipment	31	16
Preoperational	10	7
Hardware	29	29
Operating	32	32
	$132/kgHE	$96/kgHE

Table 4

Cost Estimates for Reference Plant

	AECL Plant 1.7 MgHE/d	Reference Plant 2.0 HgHE/d
Capital Costs (M$)		
AECL Facility	38.41	45
Shipping Flasks	-	10
Additional Security and Safeguards	-	5
		60 M$
AECL Equipment	35.08	41
Additional Waste Treatment	-	5
Additional Handling and Process Equipment	-	5
Additional Security and Safeguards	-	4
		55 M$
Preoperational Cost	45.8*	38 M$
Annual Costs (M$/a)		
Hardware	11.2	12 M$/a
Operating	12.0**	12 M$/a

* From AECL estimate = interest during construction + commissioning

**No change expected by increasing the capacity from 1.7 MgHE/d to 2.0 MgHE/d.

References for Appendix

1. A.T. Jeffs, "Mixed Oxide Fuel Fabrication for CANDU Reactors: Cost Estimates as a Function of Plant Size", internal AECL report.

2. Ontario Hydro Economic Division, "Economic Outlook and Economic Forecasting Series", October 1977.