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REPORT

COMPARATIVE COSTS OF OXIDE FUEL ELEMENTS

VOLUME 3

THE EFFECT ON FUEL ELEMENT COSTS
WHEN CERTAIN REFERENCE VALUES ARE VARIED

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THE EFFECT ON FUEL ELEMENT COSTS
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SUMMARY

In this study six major variables are examined for their effect on fuel element costs. The results of the study show that the two most important variables are Throughput and Zircaloy Cost; and after them come--in order of importance--Use Charge Rate, Uranium and Plutonium Costs, Working Capital Rate, and High Exposure Plutonium Shielding.

INTRODUCTION

This is the last volume of a three-volume series examining the costs of fabricating a reference oxide fuel element by two processes (vibrational compaction and sintered pellets) incorporating three modes of enrichment (UO_2 and low exposure PuO_2 , and high exposure PuO_2).

This volume shows how the reference fuel element costs in Volume 1 will be affected when the following are varied:

- 1) Throughput (without plant redesign)
- 2) Shielding requirements for high exposure plutonium
- 3) Zircaloy cost
- 4) Uranium and plutonium costs
- 5) Use charge rate
- 6) Working capital rate

In the sections that follow, each of the above inputs will be varied one at a time, with all other inputs being held constant at their respective reference (Volume 1) values. To better understand the effect on fuel element costs, the reader should note that a change of \$1/kg is equivalent to \$250,000 per year for a 1-tonne per day fuel plant (502 fuel elements per year).

CHANGES IN THROUGHPUT

In Volume 1, 2 work shifts were required to produce the reference fuel element at the rate of one metric ton of oxide per day. In Table I of this volume, the throughput is varied from 0.5 to 1.5 tonnes per day, with the corresponding work shifts varying from 1 to 3 shifts per day. While it is theoretically possible to run a 1-tonne per day plant on a 4-shift basis, the maintenance problem would be so severe that it is impractical to consider this possibility.

As shown in Table I, there is about a \$7.00/kg increase in fabrication costs when the throughput is reduced from 1 to 0.5 tonne per day. This increase is primarily due to fixed costs, such as general and administrative costs, maintenance costs, building and occupancy costs, and taxes. Total inventory cost per kilogram will also increase when the throughput is reduced.

On the other hand, when the throughput of the vibrational compaction plants is increased from 1 to 1.5 tonnes per day, the unit fuel element cost decreases only about \$1.80/kg. The cost difference between throughputs of 1 and 0.5 tonnes per day is greater than that between throughputs of 1 and 1.5 tonne per day because both the vibrational compaction and the pellet fuel plants were designed, and their equipment sized, for a 2-shift operation. Thus, in a 3-shift operation, maintenance schedules will disrupt the production effort, and there will be a large amount of overtime pay. This will tend to counteract the savings which are realized from a reduction in fixed costs. Furthermore, a change from 2 to 1 work shifts per day decreases throughput by 100%, whereas a change from 2 to 3 work shifts per day increases the throughput by only 50%. The resulting variation in fuel element costs is plotted in Figure 1.

TABLE I

FUEL ELEMENT FABRICATION COST AS A FUNCTION OF FUEL THROUGHPUT

<u>Throughput, Tonne/Day</u>	<u>Fabrication Process, \$/kg</u>					
	<u>Vibrational Compaction Process</u>			<u>Pellet Process</u>		
	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>
0.5	48.23	57.86	59.57	52.38	60.42	62.25
1.0 *	41.69	50.79	52.40	43.36	51.90	53.47
1.5	39.90	48.83	50.42	**	**	**

* Value used in Volume 1.

** Throughput cannot be increased without the purchase of additional sintering furnaces.

FIGURE 1. Fabrication Cost of Vibrationally Compacted Fuel Elements Enriched with High Exposure Plutonium.

As can be seen in Table I, the pellet plan throughput was not increased beyond that of the designed 2-shift (1 tonne per day) level. The reason for this is that such an increase in throughput would require a major addition to the sintering furnace capacity. Table I also shows that the decrease in throughput from 1.0 to 0.5 tonne per day for the pellet plants increases the fuel element costs by about \$8.75/kg, as compared with an increase of about \$7.00/kg for the vibrational compaction plants. This difference can be attributed to the higher capital investment in the pellet plants; for as the throughput decreases, the fixed costs increase markedly.

CHANGES IN SHIELDING REQUIREMENTS FOR
HIGH EXPOSURE PLUTONIUM

Experience at Battelle-Northwest Laboratory has demonstrated that 0.6 cm thick lead glass is more than adequate to meet the shielding requirements of low exposure plutonium. However, the 1.2 cm thick lead glass indicated in Volume 1 for shielding high exposure plutonium might be in error by as much as a factor of 2. If so, then Table II shows how the reference fuel element costs will be affected if the lead glass thickness is varied. Table II also shows that no change in paraffin thickness is required to thermalize neutrons. (When neutrons are thermalized the effective dose rate is reduced by a factor of 150.)

As indicated in Table II \$0.03/kg is saved if the lead glass thickness is reduced from 1.2 (the reference value) to 0.6 cm, however, \$0.06/kg must be added to the unit fuel element cost if the glass thickness increases from 1.2 to 2.4 cm.

It is worth noting that if the lead glass thickness is reduced from 1.2 to 0.6 cm, the total savings for a vibrational-compaction plant will be \$74,170, as compared with \$77,600 for a pellet fuel plant. But if the lead glass thickness of 1.2 cm is doubled, the capital investment in the vibrational-compaction and pellet fuel plants will increase \$148,340 and \$155,200 respectively. Hence, extra shielding causes a corresponding increase in the capital costs of the two plants. Although a variation in the thickness of lead glass changes the capital costs, it does not change the labor costs as long as the higher dose rate does not overexpose the hands of personnel working in glove boxes. With the degree of mechanization provided in both plant designs, glove-box operations seem clearly feasible.

TABLE II

FUEL ELEMENT FABRICATION COST AS
A FUNCTION OF SHIELDING REQUIREMENTS

Lead Glass Thickness, cm	Paraffin Thickness, cm	Fabrication Cost, \$/kg	
		Vibrational Compaction Process	Pellet Process
		High-Exposure Plutonium Enrichment	High-Exposure Plutonium Enrichment
0.6	10.0	52.37	53.44
1.2 [*]	10.0	52.40	53.47
2.4	10.0	52.46	53.53

* Value used in Volume 1.

CHANGES IN ZIRCALOY COST

As the nuclear industry grows, the cost of Zircaloy tubing will probably decrease, because of higher demand and greater competition. Moreover, the "learning curves" observed for other metal fabrication processes suggest that the fabrication of Zircaloy will become even more efficient than at present.

Table III shows that fuel element fabrication costs are very sensitive to Zircaloy costs over the range of \$25/lb (the reference value) to \$15/lb. It should be pointed out that the incremental cost of handling plutonium becomes more apparent with reduced Zircaloy costs, since it then constitutes a larger percentage of the total fabrication cost. In Table III, for example, it is shown that when the vibrational compaction process uses Zircaloy priced at \$25/lb, the cost of high exposure plutonium-enriched fuel relative to the cost of uranium-enriched fuel is 1.26 (\$52.40/kg divided by \$41.69/kg). But when the Zircaloy cost decreases to \$15/lb, the relative cost increases to 1.30 (\$46.87/kg divided by \$36.16/kg).

TABLE III

FUEL ELEMENT FABRICATION COST
AS A FUNCTION OF ZIRCALOY PRICE

Zircaloy Price, \$/lb	Fabrication Cost, \$/kg					
	<u>Vibrational Compaction Process</u>			<u>Pellet Process</u>		
	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>
25.00*	41.69	50.79	52.40	43.36	51.90	53.47
20.00	38.92	48.02	49.64	40.59	49.19	50.72
15.00	36.16	45.25	46.87	37.84	46.44	47.98

* Value used in Volume 1.

CHANGES IN URANIUM AND PLUTONIUM COSTS

Uranium and plutonium prices affect fuel element costs because of (1) the use charges on uranium and plutonium, and (2) the nuclear materials lost during processing. In Volume 1, a U_3O_8 price of \$8/lb was used, but this price will undoubtedly fluctuate in a free market environment. As for plutonium, volume 1 assumed its price to be \$10/g fissile, which is 83% of the price of fully (90%) enriched uranium. This ratio of .83 has been shown to be constant over a large range of U_3O_8 prices when plutonium is recycled in thermal reactors.⁽¹⁾ It is this ratio, therefore, that is used in Table IV, which shows how changes in U_3O_8 prices will affect the price of plutonium and 3% enriched uranium. Table V shows that a \$2.00/lb change in the price of U_3O_8 could increase or decrease the plutonium-enriched reference fuel element costs by about \$0.40/kg. It is interesting to note that the uranium-enriched fuel element costs are slightly more sensitive to the same charges --about \$0.50/kg. This can be attributed to the higher fissile inventory costs of the uranium fuels. The inventory costs will be seen again in the next section, where the use charge rate is varied.

(1) E. A. Eschbach, M. F. Kanninen. Uranium Price Schedules and Bred Fuel Values. H.W. 72219, December 1964

TABLE IV

THE PRICE OF NUCLEAR MATERIALS
AS A FUNCTION OF U_3O_8 PRICE

Natural Uranium as UF_6		Enriched Uranium at 90.0 wt% U_{235}		Fissile Plutonium at 83% of Fully Enriched Uranium \$/g Fissile
U_3O_8 \$/lb	\$/lb	3.0 wt% U_{235} \$/kg- UF_6	\$/g- U_{235}	
6.00	18.30	222.35	10.85	9.05
8.00*	23.50	254.30**	12.05**	10.00
10.00	28.70	284.85	13.15	10.90

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* Value used in Volume 1.

** Present AEC Price Schedule.

TABLE V

FUEL ELEMENT FABRICATION COST
AS A FUNCTION OF U_3O_8 PRICE

U_3O_8 Price \$/lb	Fabrication Cost \$/kg					
	<u>Vibrational Compaction Process</u>			<u>Pelletizing Process</u>		
	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>	<u>Uranium Enrichment</u>	<u>Low- Exposure Plutonium Enrichment</u>	<u>High- Exposure Plutonium Enrichment</u>
6.00	41.18	50.35	51.97	42.83	51.45	53.02
8.00 [*]	41.69	50.79	52.40	43.36	51.90	53.47
10.00	42.17	51.20	52.82	43.87	52.33	53.90

* Value used in Volume 1.

CHANGES IN USE CHARGE RATE

The Atomic Energy Commission currently charges a fabricator 4.75% per year on the value of the nuclear materials he holds. However, this may not be the use charge rate after the year 1973, when private ownership of nuclear materials becomes mandatory.

Table IV shows that when the working capital rate is fixed, an increase in the use charge rate will have a marked effect on the reference fuel element costs. This is to be expected since the use charges are being accrued on a fissile inventory of about \$120,000 per fuel element. These charges more profoundly affect fuel element costs than do the U_3O_8 prices discussed in the preceding section. It should be noted, however, that the use charge rates are being varied over a range of 300 percent, whereas the U_3O_8 prices are only varied 170% (from \$6/lb to \$10/lb). Even when this is taken into account, the use charges are still more important than the uranium costs.

TABLE VI

FUEL ELEMENT FABRICATION COST
AS A FUNCTION OF INTEREST RATES

Working Capital Rate, %/yr	Fabrication Cost, \$/kg							
	<u>Vibrational Compaction Process</u>				<u>Pellet Process</u>			
	(Uranium Enrichment)				(Uranium Enrichment)			
	Use Charge Rate, %/yr				Use Charge Rate, %/yr			
	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>
12*	41.69	42.12	43.50	44.89	43.36	43.77	45.15	46.53
14	41.78	42.21	43.60	44.98	43.43	43.86	45.24	46.62
16	41.87	42.30	43.69	45.08	43.52	43.95	45.34	46.72
18	41.96	42.40	43.79	45.18	43.61	44.05	45.43	46.82
 (Low-Exposure Plutonium Enrichment)								
	Use Charge Rate, %/yr				Use Charge Rate, %/yr			
	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>
12*	50.79	50.90	52.64	54.06	51.90	52.35	53.78	55.22
14	50.90	51.34	52.76	54.18	52.03	52.46	53.90	55.34
16	51.02	51.46	52.88	54.30	52.13	52.58	54.02	55.46
18	51.13	51.58	53.00	54.43	52.24	52.70	54.14	55.58
 (High-Exposure Plutonium Enrichment)								
	Use Charge Rate, %/yr				Use Charge Rate, %/yr			
	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>	<u>4.75*</u>	<u>6.00</u>	<u>10.00</u>	<u>14.00</u>
12*	52.40	52.85	54.26	55.68	53.47	53.92	55.35	56.79
14	52.52	52.97	54.39	55.80	53.59	54.04	55.49	56.91
16	52.64	53.09	54.51	55.93	53.71	54.16	55.60	57.04
18	52.76	53.21	54.63	56.06	53.83	54.28	55.72	57.16

* Value used in Volume 1.

CHANGES IN THE WORKING CAPITAL RATE

The working capital rate used in Volume 1 was 12%, which is the approximate rate paid by private utilities. Table VI shows that when the use charge rate is held constant and when the working capital rate is varied from 12% up to 18%, the effect on the reference fuel element costs is not very great, especially when compared with the use charge effects discussed in the previous section. This is because working capital rates are varied only 150% while the use charge varies over a 300% range. Also, the working capital charges are applied to the labor, material, and overhead items, which total about \$25,000. By contrast, the use charges are applied to nuclear values of about \$120,000 per fuel element.

CONCLUSIONS

The range of values considered and the effects on cost of the variables studied are summarized in Table VII. As can be seen in this table, the variations in Throughput and Zircaloy Cost have the greatest effects on fabrication costs. Use Charge Rates also have a strong influence on fabrication costs while Uranium Cost, Working Capital Rates and Shielding have a lesser influence.

TABLE VII
THE EFFECT ON VOLUME 1 FUEL ELEMENT COSTS WHEN
VOLUME 3 VALUES ARE USED

Variable	Volume 1 Reference Value	Volume 3 Values	Uranium Enrich- ment, \$/kg	Vibrational Compaction Process		Uranium Enrich- ment, \$/kg	Pelletizing Process		Uranium Enrich- ment, \$/kg
				Low- Exposure Plutonium Enrich- ment, \$/kg	High Exposure Plutonium Enrich- ment, \$/kg		Low- Exposure Plutonium Enrich- ment, \$/kg	High Exposure Plutonium Enrich- ment, \$/kg	
Throughput	1 tonne/ day	1.5 0.5	-1.79	-1.96 7.07	-1.98 7.17	--*	--*	--*	--*
Shielding	1.2 cm lead glass (High ex- posure plu- tonium)	0.6 2.4		--* --	-0.03 +0.06		--* --	-0.03 +0.06	
Zircaloy	\$25/lb	15.00 25.00	-5.53 +0.00	-5.54 +0.00	-5.53 +0.00	-5.52 +0.00	-5.49 +0.00	-5.49 +0.00	
Uranium and Plu- tonium	\$/lb- U ₃ O ₈	6.00 10.00	-0.51 +0.48	-0.36 +0.33	-0.35 +0.34	-0.56 +0.48	-0.37 +0.35	-0.34 +0.38	
Use Charge	4.75%/yr	4.75 14.00	-0.00 +3.20	-0.00 +3.27	-0.00 3.28	-0.00 +3.17	-0.00 +3.32	-0.00 +3.32	
Working Capital	12%/yr	12.00 18.00	-0.00 +0.27	-0.00 +0.34	-0.00 +0.36	-0.00 +0.25	-0.00 +0.34	-0.00 +0.36	

* Throughput cannot be increased without the purchase of additional sintering furnaces.

** 0.6 cm thick lead glass is known to be adequate for working with low exposure plutonium.

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