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EFFECT OF REDUCED U-235 PRICE ON FUEL CYCLE COSTS

L. L. Bennett

ABSTRACT

A study was made to determine the effect of changes in natural uranium cost and in separative work charges on fuel cycle costs in nuclear power plants. Reactors considered were a Dresden-type boiling water reactor (BWR) and a Yankee-type pressurized water reactor (PWR), with net power ratings of 100, 300, and 500 Mwe.

Fuel cycle costs were calculated for these reactors, using either enriched uranium or U-235-thorium as the fuel material. The price schedule for uranium was based on a feed material cost of \$15/kg uranium as UF₆ and separative work costs of \$30/kg uranium (Schedule B) and \$20/kg uranium (Schedule C).

The present AEC price schedule for enriched uranium was also used for purposes of a reference case.

The results indicate that a reduction in present enriched uranium price to that given by Schedule B would reduce fuel cycle costs for the BWR plants by 0.4 to 0.5 mill/kwh for the enriched-uranium cycle, and 0.4 to 0.7 mill/kwh for the thorium cycle. Reductions in fuel cycle costs for the PWR plants were 0.5 to 0.7 and 0.4 to 0.75 mill/kwh, respectively, for the same situations.

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INTRODUCTION

The primary factors determining the price of enriched uranium are the cost of the feed material and the cost of separative work. The present AEC established price schedule for enriched uranium is based on a natural uranium price of \$23.50/kg uranium as UF_6 and a separative work charge of \$37.29/kg uranium. However, the price of natural uranium on the open market (for example, from Canadian sources) is lower than this at the present time, and a price of about \$15/kg seems reasonable for the near future.

The actual cost of separative work in a gaseous diffusion plant has not been published in the open literature. However, for many years the value of \$37.29/kg uranium has been used to calculate the AEC published price schedule for enriched uranium. It seems probable that this cost has been reduced over the years by process improvements and increased efficiency of operation. In order to determine the effect of such reductions, the separative work charges used in the reduced price schedules in this study were arbitrarily set at \$30/kg uranium in one case and \$20/kg in the other.

The fuel cycle costs in a Dresden-type BWR and a Yankee-type PWR were then calculated for these enriched uranium price schedules and compared with the fuel costs calculated with the present AEC price schedule.

The effect of variations in certain other cost parameters was also studied. In particular, calculations were made to determine the effect of private ownership of nuclear fuel on fuel cycle costs; this was done by considering the fuel inventory charge to be 12%/yr.

RESULTS

The detailed results obtained from this study are presented in the tables and graphs in Appendices A and B. It should be noted that in all cases the data tabulated for the U-235 thorium cycle are based on a UF_6 to UO_2 conversion charge of \$200/kg uranium and a chemical reprocessing rate of 600 kg/day. The cost bases which were used to produce the data given by the graphs are specifically indicated in each case.

A discussion of some of the results of particular interest will be given here.

1. Reduction in Fuel Cycle Cost

The primary objective of this study was to determine the reduction in fuel cycle cost which would be obtained by lowering the price of enriched uranium. These results are presented in Tables 1 and 2. Fuel cost reductions obtained in going to Schedule B were in the range 0.4 to 0.7 mill/kwh and for Schedule C were 0.7 to 1.2 mill/kwh.

TABLE 1. FUEL COST REDUCTION FOR BOILING WATER REACTORS

Reactor Output, Mwe	Fuel Lease Charge, %	Price Schedule	Enriched Uranium Fuel		U-235 Thorium Fuel	
			Minimum Fuel Cost mills/kwh	Fuel Cost Reduction mills/kwh	Minimum Fuel Cost mills/kwh	Fuel Cost Reduction mills/kwh
100	4-3/4	A	2.912	(Ref)	2.959	(Ref)
		B	2.456	0.456	2.546	0.413
		C	2.189	0.723	2.218	0.741
300	4-3/4	A	2.822	(Ref)	2.838	(Ref)
		B	2.388	0.434	2.452	0.386
		C	2.135	0.687	2.147	0.691
500	4-3/4	A	2.808	(Ref)	2.823	(Ref)
		B	2.376	0.432	2.435	0.388
		C	2.125	0.683	2.136	0.687
100	12	A	3.442	(Ref)	4.195	(Ref)
		B	2.898	0.544	3.488	0.707
		C	2.599	0.843	2.974	1.221
300	12	A	3.325	(Ref)	4.041	(Ref)
		B	2.810	0.515	3.367	0.674
		C	2.522	0.803	2.874	1.167
500	12	A	3.302	(Ref)	4.029	(Ref)
		B	2.792	0.510	3.359	0.670
		C	2.508	0.794	2.869	1.160

TABLE 2. FUEL COST REDUCTIONS FOR PRESSURIZED WATER REACTORS

Reactor Output Mwe	Fuel Lease Charge, %	Price Schedule	Enriched Uranium Fuel		U-235 Thorium Fuel	
			Minimum Fuel Cost mills/kwh	Fuel Cost Reduction mills/kwh	Minimum Fuel Cost mills/kwh	Fuel Cost Reduction mills/kwh
100	4-3/4	A	2.835	(Ref)	2.684	(Ref)
		B	2.337	0.498	2.244	0.44
		C	2.038	0.797	1.904	0.780
300	4-3/4	A	2.654	(Ref)	2.495	(Ref)
		B	2.185	0.469	2.098	0.397
		C	1.914	0.740	1.789	0.706
500	4-3/4	A	2.610	(Ref)	2.451	(Ref)
		B	2.149	0.461	2.062	0.389
		C	1.883	0.727	1.761	0.690
100	12	A	3.571	(Ref)	3.972	(Ref)
		B	2.911	0.660	3.227	0.745
		C	2.538	1.033	2.688	1.284
300	12	A	3.311	(Ref)	3.688	(Ref)
		B	2.706	0.605	3.016	0.672
		C	2.362	0.949	2.513	1.175
500	12	A	3.249	(Ref)	3.642	(Ref)
		B	2.654	0.595	2.972	0.670
		C	2.323	0.926	2.483	1.159

2. Effect of Private Ownership of Fuel

If the AEC should adopt a policy of private ownership of special nuclear materials, then the money spent for fuel would normally be considered to have an interest charge of 12 to 13% per year rather than the present AEC use charge of $4\frac{3}{4}\%$ per year. This higher fuel interest charge increased fuel cost by about 0.5 to 0.7 mill/kwh on the enriched uranium cycle and by 0.7 to 1.3 mill/kwh on the U-235 thorium cycle. A comparison of fuel costs on Schedule A at $4\frac{3}{4}\%$ with those on Schedules B and C at 12% indicates that a change to private ownership, with a corresponding reduction in enriched uranium price, would reduce fuel cycle costs for the enriched uranium cycle. On the U-235 thorium cycle, however, the higher interest rate is not completely compensated by the reduction in U-235 price, and the fuel costs are higher with private ownership in all cases.

3. Comparison of Enriched Uranium and U-235 Thorium Cycles

With $4\frac{3}{4}\%$ fuel lease charge, the fuel cost for the enriched uranium cycle and the U-235 thorium cycle are not greatly different. The BWR has slightly lower fuel costs on the enriched uranium cycle, while for the PWR the thorium cycles have fuel costs about 0.1 to 0.2 mill/kwh lower than the enriched uranium cycles. In the PWR, use of thorium as a fertile material is better than U-238 because thorium has a larger thermal absorption cross section and can compete for neutrons more favorably relative to absorptions by the stainless steel cladding. In the BWR, the cladding is Zircaloy, which absorbs very few neutrons in any case; thus, the larger cross section of thorium is not so important.

When the interest charge on fuel is increased to 12%, the high value of the highly enriched uranium used in the thorium cycle results in a high inventory charge. Thus, the fuel costs with the thorium cycle are considerably higher than with enriched uranium for both the PWR and the BWR, with respect to the first cycle.

4. Comparison of Fuel Costs for BWR and PWR

The BWR and PWR have about the same fuel costs on the enriched uranium cycle, although the PWR costs are slightly lower. With U-235 thorium as the fuel, however, the PWR shows a definite cost advantage; here, fuel costs for the PWR are about 0.3 mill/kwh lower than the BWR.

5. Effect of Changes in Conversion Costs

The cost of converting fully enriched uranium from UF_6 to UO_2 is more uncertain than most of the items contributing to fuel cycle costs. In this study, the conversion cost was assumed to be \$200/kg uranium in all the results which were tabulated. A number of the cycles were recalculated using a conversion cost of \$400/kg, and some of these are

presented in the graphs. Since a relatively small amount of uranium is being converted, this change in conversion cost increases fuel costs by only about 0.05 mill/kwh.

6. Effect of Changing Chemical Reprocessing Plant Throughput Rate

Most of the fuel cost calculations made during the ORNL study of U-233 and plutonium fuel values were based on the chemical reprocessing rates given in WASH-743. A number of the U-235 thorium cases in this study were also calculated on this basis for comparison with results obtained with the rates given in the AEC cost handbook. The rates used are listed in Table 3. Fuel costs for the BWR were in the range of 0.04 to 0.08 mill/kwh lower with the WASH-743 rates. Optimum enrichments for the BWR cycles were near 2.5 to 3% U-235, and the WASH-743 rates were higher than 600 kg/day in this range. Fuel costs for the PWR were slightly lower (~ 0.01 mill) with the 600 kg/day processing rate. Optimum enrichments were in the range of 4 to 4.5% U-235, and the WASH-743 rates were less than 600 kg/day in this range.

TABLE 3. CHEMICAL REPROCESSING RATES FOR THORIUM

Enrichment, % Fissile in Th	Chemical Processing Rate, kg/day	
	WASH-743*	Cost Handbook
1	1000	600
2	950	600
3	700	600
4	550	600
5	460	600
6	390	600

*The rates published in WASH-743 have been reduced to allow for the increased reactivity of the U-233 which is bred in.

DETAILS OF CALCULATION

The major reactor characteristics used in this study are presented in Table 4. These parameters were obtained by taking the basic data from the Dresden and Yankee reference designs and varying the core sizes to obtain the desired power level.

The reactivity lifetime at various enrichments was calculated for each reactor using the Expire¹ code. This calculation assumes that the

TABLE 4. SUMMARY OF REACTOR CHARACTERISTICS

	Dresden-Type BWR			Yankee-Type PWR		
	100	300	500	100	300	500
	Mwe	Mwe	Mwe	Mwe	Mwe	Mwe
<u>Heat Balance</u>						
Total Reactor Power, Mwt	348	1043	1738	356	1069	1782
Net Plant Power, Mwe	100	300	500	100	300	500
Net Plant eff, %	28.75	28.75	28.75	28.06	28.06	28.06
<u>Reactor Core</u>						
Active Height, ft.	7.12	10.28	12.18	7.27	10.48	12.42
Active Radius, ft.	4.42	6.37	7.56	2.99	4.31	5.11
Core Loading, metric tons uranium	28.98	86.94	144.9	18.21	54.63	91.04
Specific Power, kwt/kgU		12.00			19.57	
Power Density, kwt/liter		28.10			61.80	
<u>Fuel Elements</u>						
Fuel Material	UO ₂ Pellets			UO ₂ Pellets		
Clad Material	Zr-2			304 SS		
Pellet Diameter, in.	.493			.290		
Clad Thickness, in.	.030			.021		
<u>Fuel Assemblies</u>						
Total Number	330	686	953	72	148	208
Elements per Assembly		36			305	
Coolant		H ₂ O			H ₂ O	

reactor operates on a batch cycle in which all fuel in the reactor is exposed to the same neutron flux at a given time, and the flux changes with time to maintain a fixed power level. This is commonly called a "uniform batch" cycle.

Using the lifetime and composition results obtained from Expire, an economic analysis of the cycles was made using a modified Epitaph² fuel-cost calculation. The following features are inherent to this calculation:

1. The use charge on nuclear materials is based on the time value of the material as follows:
 - a) initial value of fuel taken for the preirradiation time;
 - b) average value of fuel taken during irradiation (not including plutonium value); and
 - c) value of spent fuel taken for post-irradiation time (including plutonium).
2. Interest charges on fabrication capital are based on a linear write-off of the fabrication cost over the irradiation time.

The following equations were used to compute the price of enriched uranium in which the U-233 may be present:

- a) f_{23} = weight fraction U-233 in total uranium,
- b) f_{25} = weight fraction U-235 in total uranium,
- c) E = $f_{23} + f_{25}$, fissile enrichment,

$$d) \quad C_p(E) = C_{sep} \left[(2E-1) \log \frac{(1-X_0)E}{X_0(1-E)} + \frac{(1-2X_0)(E-X_0)}{X_0(1-X_0)} \right].$$

The value of mixtures containing U-233, U-235 were taken as follows:

- e) If $f_{23} = 0$, i.e., U-235, U-238 mixture

$$V_u = C_p(E), \text{ price of cascade uranium.}$$
- f) If $f_{23} \neq 0$, i.e., contains U-233

$$V_u = \left[f_{25} \cdot v^{25} + f_{23} \cdot v^{23} \right] \cdot \frac{C_p(E)}{E \cdot v^{25}}, \text{ price}$$

taken for uranium containing U-233.

The economics parameters used to calculate the fuel cost are presented in Tables 3, 5, and 6.

The first three schedules listed in Table 5 are of primary interest since the value of bred materials has been kept in proportion to the U-235

value in these. Schedules D and E were included only to show the effect of a reduction in U-235 price while maintaining the U-233 and plutonium prices at high levels. Therefore, in most cases, results will be presented only for Schedules A, B, and C, with results from Schedules D and E included in only a few cases.

TABLE 5. COST PARAMETERS USED IN PRICE SCHEDULES

Cost Sched- ule	Feed Mat'l. Cost, \$/kg U	Sep. Work Cost \$/kg U	Tails Comp. w/f U-235	U-235 Value at 95% Enrich. \$/gm U-235	Pu Price as Nitrate \$/gm	U-233 Price as Nitrate \$/gm
A	23.50	37.29	0.00277	13.70	8.00	15.00
B	15.00	30.00	0.0030	10.25	6.00	11.20
C	15.00	20.00	0.0026	7.82	4.50	8.60
D	15.00	30.00	0.0030	10.25	8.00	15.00
E	15.00	20.00	0.0026	7.82	8.00	15.00

TABLE 6. ECONOMICS PARAMETERS

Preirradiation conversion loss of uranium, %	1.0
Loss during fabrication, %	1.0
Cost of converting low enrichment UF_6 to UO_2	From Figure 450-1 of Vol. 4 of Nuclear Power Plant Cost Evaluation Handbook
Cost of converting fully enriched UF_6 to UO_2	\$200 or \$400/kg U
Preirradiation shipping cost, \$/kg	3.0
Post-irradiation shipping cost, \$/kg	16.0
Chemical reprocessing charge, \$/day	17,000
Post-irradiation losses of uranium* and plutonium, %	1.3% and 1.0%, respectively
Post-irradiation loss of thorium, %	2.0
Preirradiation conversion time, days	30
Core fabrication time, days	135
Preirradiation shipping time, days	45
Post-irradiation cooling time, days	120
Shipping time to chemical reprocessing plant, days	30
Post-irradiation conversion time, days	30
Post-irradiation conversion cost of uranium*, \$/kg	5.6
Post-irradiation conversion cost of thorium, \$/kg	2.2
Interest rate on purchased thorium, %/yr	12
Interest rate on borrowed money, %/yr	12
Interest rate on uranium and plutonium, %/yr	4-3/4 or 12.0
Value of U-235, \$/kg of uranium	Based on ideal diffusion plant cost equation with parameters listed in Table 5
Value of bred materials	See Table 5
Value of thorium, \$/kg	22
Load factor	0.8
Fabrication cost of fuel, not including conversion or preirradiation inventory charges or preirradiation losses, \$/kg of uranium	
	<u>Reactor</u> <u>Cost</u>
	BWR 105.0
	PWR 95.0

*Highly enriched uranium containing U-233 is sold as the nitrate; losses are 1% and no conversion cost.

REFERENCES

1. Jaye, S., "Expire - A Reactivity Lifetime Calculation," ORNL-CF-60-10-113, October 13, 1960.
2. Bennett, L. L., "Epitaph - A Reactor Fuel Cost Calculation," ORNL-CF-61-3-105, March 21, 1961.
3. USAEC, Nuclear Power Plants Cost Evaluation Handbook, Volume 4, "Fuel Cycle Costs," December 31, 1961.
4. "AEC Reference Fuel Processing Plant," WASH-743, October 1957.

APPENDIX A

DETAILED RESULTS FOR BOILING WATER

REACTOR CASES

TABLE A-1

FUEL CYCLE COST FOR BOILING WATER REACTORS

FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 4-3/4%

Cost sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)							Net Fuel Cost
		Fabri- cation	Shipping	Burnup	Chem. Proc.	Inven- tory	Interest	Pu Credit	
A	100	.714	.125	1.468	.163	.362	.395	.315	2.912
	300	.686	.120	1.435	.138	.358	.393	.308	2.822
	500	.680	.119	1.428	.134	.360	.393	.306	2.808
B	100	.610	.106	1.115	.140	.311	.389	.215	2.456
	300	.588	.102	1.092	.120	.308	.388	.210	2.388
	500	.584	.102	1.087	.116	.309	.387	.209	2.376
C	100	.537	.093	.906	.124	.291	.387	.149	2.189
	300	.519	.090	.890	.107	.289	.386	.146	2.135
	500	.516	.089	.886	.104	.290	.385	.145	2.125
D	100	.610	.106	1.115	.141	.312	.389	.286	2.387
	300	.588	.102	1.092	.121	.310	.388	.280	2.321
	500	.584	.102	1.087	.117	.312	.387	.279	2.310
E	100	.607	.106	.879	.141	.254	.384	.286	2.085
	300	.586	.102	.862	.121	.253	.383	.280	2.027
	500	.516	.089	.886	.105	.294	.385	.258	2.017

TABLE A-2

FUEL CYCLE COST FOR BOILING WATER REACTORS

FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 12%

Cost Sched- ule	Power Level Mwe	Cost Breakdown, mills/kwhr(e)							Net Fuel Cost
		Fabri- cation	Shipping	Burnup	Chem. Proc.	Inven- tory	Interest	Pu Credit	
A	100	.869	.155	1.408	.200	.747	.418	.355	3.442
	300	.829	.148	1.372	.169	.738	.416	.347	3.325
	500	.920	.165	1.326	.184	.663	.414	.370	3.302
B	100	.710	.125	1.073	.161	.657	.408	.236	2.898
	300	.825	.148	.998	.168	.528	.403	.260	2.810
	500	.816	.146	.992	.162	.532	.403	.259	2.792
C	100	.707	.125	.849	.160	.535	.400	.177	2.599
	300	.680	.120	.831	.136	.529	.399	.173	2.522
	500	.673	.119	.826	.132	.532	.398	.172	2.508
D	100	.710	.125	1.073	.162	.662	.408	.315	2.825
	300	.825	.148	.998	.169	.536	.403	.347	2.732
	500	.816	.146	.992	.163	.541	.403	.345	2.716
E	100	.707	.125	.849	.162	.544	.400	.315	2.472
	300	.680	.120	.831	.138	.540	.399	.308	2.400
	500	.673	.119	.826	.133	.545	.398	.306	2.388

TABLE A-3

FUEL CYCLE COST FOR BOILING WATER REACTORS

FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)						Net Fuel Cost
		Fabri- cation	Shipping	Total Burnup Cost	Chem. Proc.	Inven- tory	Interest	
A	100	.620	.116	.731	.206	.903	.383	2.959
	300	.569	.106	.705	.173	.905	.380	2.838
	500	.556	.104	.698	.166	.920	.379	2.823
B	100	.509	.095	.652	.165	.751	.374	2.546
	300	.564	.106	.536	.170	.706	.370	2.452
	500	.551	.104	.530	.163	.718	.369	2.435
C	100	.469	.088	.522	.151	.621	.367	2.218
	300	.473	.089	.476	.140	.605	.364	2.147
	500	.465	.087	.472	.135	.613	.364	2.136
D	100	.554	.104	.387	.183	.777	.373	2.378
	300	.564	.106	.310	.172	.761	.370	2.283
	500	.551	.104	.308	.165	.775	.369	2.272
E	100	.550	.104	.082	.182	.671	.365	1.954
	300	.560	.106	.017	.171	.662	.363	1.879
	500	.548	.104	.019	.164	.677	.362	1.874

TABLE A-4

FUEL CYCLE COST FOR BOILING WATER REACTORS

FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 12%

Cost Sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)						Net Fuel Cost
		Fabri- cation	Shipping	Total Burnup Cost	Chem. Proc.	Inven- tory	Interest	
A	100	.620	.116	.731	.206	2.096	.426	4.195
	300	.745	.141	.540	.230	1.968	.417	4.041
	500	.719	.136	.533	.218	2.007	.416	4.029
B	100	.615	.116	.556	.202	1.594	.405	3.488
	300	.633	.120	.479	.192	1.543	.400	3.367
	500	.616	.117	.474	.183	1.570	.399	3.359
C	100	.550	.104	.454	.179	1.295	.392	2.974
	300	.560	.106	.401	.167	1.253	.387	2.874
	500	.548	.104	.397	.161	1.273	.386	2.869
D	100	.615	.116	.318	.204	1.722	.405	3.380
	300	.633	.120	.231	.194	1.680	.400	3.258
	500	.616	.117	.230	.186	1.715	.399	3.263
E	100	.698	.133	-.076	.234	1.391	.390	2.770
	300	.735	.141	-.166	.227	1.345	.387	2.669
	500	.710	.136	-.161	.215	1.385	.386	2.671

TABLE A-5

COST PARAMETERS OF OPTIMUM CASES FOR BOILING

WATER REACTORS FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235	Final wt. % U-235	Final Pu gm/kgU, final	Exposure Mwd/MT	Lifetime, days at full power	$\frac{\text{kgU final}}{\text{kgU initial}}$
A	100	3.0	0.784	6.98	24,910	2080	.9656
	300	3.0	0.732	7.11	25,920	2165	.9644
	500	3.0	0.720	7.17	26,160	2185	.9640
B	100	3.5	0.856	7.54	29,400	2455	.9601
	300	3.5	0.800	7.65	30,470	2545	.9587
	500	3.5	0.788	7.68	30,710	2565	.9584
C	100	4.0	0.933	8.04	33,710	2815	.9547
	300	4.0	0.873	8.15	34,840	2910	.9533
	500	4.0	0.861	8.17	35,080	2930	.9530
D	100	3.5	0.856	7.54	29,400	2455	.9601
	300	3.5	0.800	7.65	30,470	2545	.9587
	500	3.5	0.788	7.68	30,710	2565	.9584
E	100	3.5	0.856	7.54	29,400	2455	.9601
	300	3.5	0.800	7.65	30,470	2545	.9587
	500	4.0	0.861	8.17	35,080	2930	.9530

TABLE A-6

COST PARAMETERS OF OPTIMUM CASES FOR BOILING

WATER REACTORS FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 12%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235	Final wt. % U-235	Final Pu gm/kgU, final	Exposure Mwd/MT	Lifetime, days at full power	kgU final KgU initial
A	100	2.5	0.720	6.36	20,180	1685	.9715
	300	2.5	0.670	6.48	21,130	1765	.9703
	500	2.25	0.628	6.20	18,920	1580	.9731
B	100	3.0	0.784	6.98	24,910	2080	.9656
	300	2.5	0.670	6.48	21,130	1765	.9703
	500	2.5	0.658	6.52	21,370	1785	.9700
C	100	3.0	0.784	6.98	24,910	2080	.9656
	300	3.0	0.732	7.11	25,920	2165	.9644
	500	3.0	0.720	7.17	26,160	2185	.9640
D	100	3.0	0.784	6.98	24,910	2080	.9656
	300	2.5	0.670	6.48	21,130	1765	.9703
	500	2.5	0.658	6.52	21,370	1785	.9700
E	100	3.0	0.784	6.98	24,910	2080	.9656
	300	3.0	0.732	7.11	25,920	2165	.9644
	500	3.0	0.720	7.17	26,160	2185	.9640

TABLE A-7

COST PARAMETERS OF OPTIMUM CASES FOR BOILING WATER

REACTORS FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235 in fuel	Final wt. % U in fuel	wt. % U-235 in Fi- nal U	wt. % U-233 in final U	Final kg fuel initial kg fuel	Expo- sure Mwd/MT	Lifetime, days at full power
A	100	3.0	2.544	29.82	48.00	.9706	26,910	2260
	300	3.0	2.527	26.21	50.11	.9680	29,350	2465
	500	3.0	2.523	25.33	50.60	.9671	30,000	2520
B	100	3.5	2.740	27.97	47.02	.9639	32,930	2765
	300	3.0	2.527	26.21	50.11	.9680	29,350	2465
	500	3.0	2.523	25.33	50.60	.9671	30,000	2520
C	100	3.75	2.837	27.48	46.34	.9609	35,670	2995
	300	3.5	2.719	25.06	48.62	.9614	35,190	2955
	500	3.5	2.714	24.34	49.00	.9608	35,790	3005
D	100	3.25	2.643	28.64	47.64	.9671	30,070	2525
	300	3.0	2.527	26.21	50.11	.9680	29,350	2465
	500	3.0	2.523	25.33	50.60	.9671	30,000	2520
E	100	3.25	2.643	28.64	47.64	.9671	30,070	2525
	300	3.0	2.527	26.21	50.11	.9680	29,350	2465
	500	3.0	2.523	25.33	50.60	.9671	30,000	2520

TABLE A-8

COST PARAMETERS OF NEAR-OPTIMUM CASES FOR BOILING

WATER REACTORS FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 12%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235 in fuel	Final wt. % U in fuel	wt. % U-235 in Fi- nal U	wt. % U-233 in Fi- nal U	Final <u>kg fuel</u> initial kg fuel	Expo- sure Mwd/MT	Lifetime, days at full power
A	100	3.0	2.544	29.82	48.00	.9706	26,910	2260
	300	2.5	2.317	29.95	50.16	.9759	22,090	1855
	500	2.5	2.315	28.61	50.98	.9751	22,850	1920
B	100	3.0	2.544	29.82	48.00	.9706	26,910	2260
	300	2.75	2.422	27.61	50.51	.9716	25,960	2180
	500	2.75	2.423	26.49	51.09	.9709	26,700	2240
C	100	3.25	2.643	28.64	47.64	.9671	30,070	2525
	300	3.0	2.527	26.21	50.11	.9680	29,350	2465
	500	3.0	2.523	25.33	50.60	.9671	30,000	2520
D	100	3.0	2.544	29.82	48.00	.9706	26,910	2260
	300	2.75	2.422	27.61	50.51	.9716	25,960	2180
	500	2.75	2.423	26.49	51.09	.9709	26,700	2240
E	100	2.75	2.546	30.40	45.78	.9756	23,400	1965
	300	2.5	2.317	29.95	50.16	.9759	22,090	1855
	500	2.5	2.315	28.61	50.98	.9751	22,850	1920

ORNL-LR-Dwg. 67937
Unclassified

ORNL-LR-Dwg. 67938

Unclassified

FIG. 2a FUEL CYCLE COST FOR BWR PLANTS

FIG. 3a FUEL CYCLE COST FOR BWR PLANTS

FIG. 4a FUEL CYCLE COST FOR BWR PLANTS

ORNL-LR-Dwg. 67941
Unclassified

ORNL-LR-Dwg. 67943
Unclassified

FIG. 8a FUEL CYCLE COST FOR BWR PLANTS

FIG. IIa FUEL CYCLE COST FOR BWR PLANTS

ORNL-LR-Dwg. 67949
Unclassified

FIG. 13a FUEL CYCLE COST FOR BWR PLANTS

ORNL-LR-Dwg. 67951
Unclassified

FIG. 15a FUEL CYCLE COST FOR BWR PLANTS

FIG. 18d FUEL CYCLE COST FOR BWR PLANTS

ORNL-LR-Dwg. 67955
Unclassified

APPENDIX B

DETAILED RESULTS FOR PRESSURIZED WATER

REACTOR CASES

TABLE B-1

FUEL CYCLE COST FOR PRESSURIZED WATER REACTORS

FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	<u>Cost Breakdown, mills/kwhr(e)</u>							Net Fuel Cost
		Fabri- cation	Shipping	Burnup	Chem. Proc.	Inven- tory	Interest	Pu Credit	
A	100	.537	.096	1.708	.157	.517	.260	.440	2.835
	300	.541	.098	1.617	.133	.450	.255	.440	2.654
	500	.525	.096	1.596	.125	.448	.248	.434	2.610
B	100	.531	.096	1.260	.153	.376	.251	.330	2.337
	300	.479	.087	1.207	.117	.361	.248	.314	2.185
	500	.466	.084	1.193	.110	.360	.247	.311	2.149
C	100	.445	.079	1.010	.129	.357	.250	.232	2.038
	300	.475	.087	.941	.116	.288	.243	.236	1.914
	500	.463	.084	.931	.109	.287	.242	.233	1.883
D	100	.531	.096	1.260	.154	.379	.251	.440	2.231
	300	.479	.087	1.207	.118	.364	.248	.419	2.084
	500	.466	.084	1.193	.110	.364	.247	.414	2.051
E	100	.445	.079	1.010	.131	.362	.250	.413	1.864
	300	.475	.087	.941	.118	.293	.243	.419	1.738
	500	.463	.084	.931	.110	.293	.242	.414	1.709

TABLE B-2

FUEL CYCLE COST FOR PRESSURIZED WATER REACTORS

FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 12%

Cost Sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)							Net Fuel Cost
		Fabri- cation	Shipping	Burnup	Chem. Proc.	Inven- tory	Interest	Pu Credit	
A	100	.696	.129	1.673	.200	1.076	.285	.488	3.571
	300	.724	.136	1.580	.174	.916	.276	.495	3.311
	500	.704	.132	1.555	.163	.912	.275	.492	3.249
B	100	.596	.110	1.244	.171	.863	.273	.346	2.911
	300	.612	.114	1.174	.147	.742	.266	.349	2.706
	500	.592	.110	1.157	.137	.738	.264	.344	2.654
C	100	.593	.110	.971	.169	.690	.264	.259	2.538
	300	.532	.098	.930	.128	.661	.260	.247	2.362
	500	.516	.110	.918	.120	.658	.259	.244	2.323
D	100	.596	.110	1.244	.172	.870	.273	.461	2.804
	300	.612	.114	1.174	.148	.751	.266	.465	2.600
	500	.592	.110	1.157	.138	.748	.264	.458	2.551
E	100	.593	.110	.971	.171	.702	.264	.461	2.350
	300	.532	.098	.930	.130	.675	.260	.440	2.185
	500	.516	.096	.918	.122	.674	.259	.434	2.151

TABLE B-3

FUEL CYCLE COST FOR PRESSURIZED WATER REACTORS

FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)						Net Fuel Cost
		Fabri- cation	Shipping	Total Burnup Cost	Chem. Proc.	Inven- tory	Interest	
A	100	.432	.083	.833	.163	.912	.261	2.684
	300	.435	.085	.721	.148	.851	.255	2.495
	500	.415	.081	.710	.137	.854	.254	2.451
B	100	.395	.077	.658	.147	.716	.251	2.244
	300	.395	.078	.578	.131	.670	.246	2.098
	500	.379	.074	.570	.122	.672	.245	2.062
C	100	.346	.067	.528	.126	.592	.245	1.904
	300	.342	.067	.473	.111	.556	.240	1.789
	500	.350	.069	.447	.111	.546	.238	1.761
D	100	.425	.083	.404	.161	.745	.250	2.068
	300	.430	.085	.314	.146	.703	.246	1.924
	500	.410	.081	.313	.135	.708	.244	1.891
E	100	.421	.083	.085	.160	.632	.243	1.624
	300	.425	.085	.011	.145	.601	.239	1.506
	500	.446	.090	-.035	.148	.592	.238	1.479

TABLE B-4

FUEL CYCLE COST FOR PRESSURIZED WATER REACTORS

FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 12%

Cost Sched- ule	Power Level, Mwe	Cost Breakdown, mills/kwhr(e)						Net Fuel Cost
		Fabri- cation	Shipping	Total Burnup Cost	Chem. Proc.	Inven- tory	Interest	
A	100	.470	.091	.797	.179	2.131	.304	3.972
	300	.480	.094	.678	.164	1.979	.293	3.688
	500	.455	.090	.667	.151	1.987	.292	3.642
B	100	.463	.091	.607	.174	1.610	.282	3.227
	300	.474	.094	.518	.159	1.497	.274	3.016
	500	.450	.090	.509	.147	1.503	.273	2.972
C	100	.391	.077	.493	.144	1.313	.270	2.688
	300	.391	.078	.432	.128	1.221	.263	2.513
	500	.375	.074	.426	.120	1.226	.262	2.483
D	100	.463	.091	.364	.177	1.721	.282	3.098
	300	.474	.094	.265	.162	1.614	.274	2.883
	500	.450	.090	.265	.149	1.627	.273	2.854
E	100	.509	.102	-.012	.195	1.407	.267	2.468
	300	.470	.094	-.043	.161	1.348	.261	2.291
	500	.446	.090	-.035	.148	1.366	.260	2.275

TABLE B-5

COST PARAMETERS OF OPTIMUM CASES FOR PRESSURIZED

WATER REACTORS FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 4-3/4%

Cost Schedule	Power Level, Mwe	Initial wt. % U-235	Final wt. % U-235	Final Pu gm/kgU, final	Exposure Mwd/MT	Lifetime, days at full power	$\frac{\text{kgU final}}{\text{kgU initial}}$
A	100	5.0	2.003	12.32	33,270	1700	.9518
	300	4.5	1.680	12.62	32,490	1660	.9529
	500	4.5	1.626	12.84	33,470	1710	.9517
B	100	5.0	2.003	12.32	33,270	1700	.9518
	300	5.0	1.791	13.70	36,890	1885	.9470
	500	5.0	1.738	13.91	37,870	1935	.9457
C	100	6.0	2.302	14.94	40,610	2075	.9418
	300	5.0	1.791	13.70	36,890	1885	.9470
	500	5.0	1.738	13.91	37,870	1935	.9457
D	100	5.0	2.003	12.32	33,270	1700	.9518
	300	5.0	1.791	13.70	36,890	1885	.9470
	500	5.0	1.738	13.91	37,870	1935	.9457
E	100	6.0	2.302	14.94	40,610	2085	.9418
	300	5.0	1.791	13.70	36,890	1885	.9470
	500	5.0	1.738	13.91	37,870	1935	.9457

TABLE B-6

COST PARAMETERS OF OPTIMUM CASES FOR PRESSURIZED

WATER REACTORS FUELED WITH ENRICHED URANIUM

Use Charge on Uranium and Plutonium: 12%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235	Final wt. % U-235	Final Pu gm/kgU final	Exposure Mwd/MT	Lifetime, days at full power	$\frac{\text{kgU final}}{\text{kgU initial}}$
A	100	4.0	1.757	10.55	24,850	1270	.9632
	300	3.5	1.470	10.15	23,300	1195	.9651
	500	3.5	1.419	10.32	24,170	1235	.9641
B	100	4.5	1.876	11.76	29,160	1490	.9574
	300	4.0	1.571	11.38	28,000	1430	.9590
	500	4.0	1.516	11.61	28,960	1480	.9577
C	100	4.5	1.876	11.76	29,160	1490	.9574
	300	4.5	1.680	12.62	32,490	1660	.9529
	500	4.5	1.626	12.84	33,470	1710	.9517
D	100	4.5	1.876	11.76	29,160	1490	.9574
	300	4.0	1.571	11.38	28,000	1430	.9590
	500	4.0	1.516	11.61	28,960	1480	.9577
E	100	4.5	1.876	11.76	29,160	1490	.9574
	300	4.5	1.680	12.62	32,490	1660	.9529
	500	4.5	1.626	12.84	33,470	1710	.9517

TABLE B-7

COST PARAMETERS OF NEAR-OPTIMUM CASES FOR PRESSURIZED

WATER REACTORS FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 4-3/4%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235 in fuel	Final wt. % U in fuel	wt. % U-235 in Fi- nal U	wt. % U-233 in Fi- nal U	Final kg fuel initial	Expo- sure Mwd/MT	Lifetime, days at full power
A	100	4.75	4.058	38.26	40.57	.9592	38,240	2095
	300	4.25	3.739	34.31	44.01	.9602	37,300	2045
	500	4.25	3.722	32.50	45.04	.9582	39,150	2145
B	100	5.0	3.759	37.39	40.53	.9558	41,430	2270
	300	4.5	3.863	33.25	44.00	.9563	40,900	2240
	500	4.5	3.846	31.66	44.89	.9545	42,600	2335
C	100	5.5	4.435	36.18	40.19	.9491	47,500	2600
	300	5.0	4.108	32.03	43.48	.9492	47,370	2595
	500	4.75	3.969	31.08	44.59	.9508	45,910	2515
D	100	4.75	4.058	38.26	40.57	.9592	38,240	2095
	300	4.25	3.739	34.31	44.01	.9602	37,300	2045
	500	4.25	3.722	32.50	45.04	.9582	39,150	2145
E	100	4.75	4.058	38.26	40.57	.9592	38,240	2095
	300	4.25	3.739	34.31	44.01	.9602	37,300	2045
	500	4.0	3.595	33.72	44.99	.9623	35,400	1940

TABLE B-8

COST PARAMETERS OF NEAR-OPTIMUM CASES FOR PRESSURIZED

WATER REACTORS FUELED WITH U-235 IN THORIUM

Use Charge on Uranium: 12%

Cost Sched- ule	Power Level, Mwe	Initial wt. % U-235 in fuel	Final wt. % U in fuel	wt. % U-235 in Fi- nal U	wt. % U-233 in Fi- nal U	Final kg fuel initial	Expo- sure Mwd/MT	Lifetime, days at full power
A	100	4.5	3.929	39.48	40.39	.9628	34,850	1910
	300	4.0	3.610	35.73	43.80	.9643	33,600	1840
	500	4.0	3.595	33.72	44.99	.9623	35,400	1940
B	100	4.5	3.929	39.48	40.39	.9628	34,850	1910
	300	4.0	3.610	35.73	43.80	.9643	33,600	1840
	500	4.0	3.595	33.72	44.99	.9623	35,400	1940
C	100	5.0	3.759	37.39	40.53	.9558	41,430	2270
	300	4.5	3.863	33.25	44.00	.9563	40,900	2240
	500	4.5	3.846	31.66	44.89	.9545	42,600	2335
D	100	4.5	3.929	39.48	40.39	.9628	34,850	1910
	300	4.0	3.610	35.73	43.80	.9643	33,600	1840
	500	4.0	3.595	33.72	44.99	.9623	35,400	1940
E	100	4.25	3.800	41.18	39.92	.9667	31,210	1710
	300	4.0	3.610	35.73	43.80	.9643	33,600	1840
	500	4.0	3.595	33.72	44.99	.9623	35,400	1940

FIG. 1b FUEL CYCLE COST FOR PWR PLANTS

FIG. 2b FUEL CYCLE COST FOR PWR PLANTS

FIG. 4b FUEL CYCLE COST FOR PWR PLANTS

FIG. 5b FUEL CYCLE COST FOR PWR PLANTS

FIG. 6b FUEL CYCLE COST FOR PWR PLANTS

ORNL-LR-Dwg. 67954
Unclassified

FIG. 8b FUEL CYCLE COST FOR PWR PLANTS

FIG. 11b FUEL CYCLE COST FOR PWR PLANTS

FIG. 16b FUEL CYCLE COST FOR PWR PLANTS

FUEL: U-235 IN THORIUM
USE CHARGE ON U: 4-3/4%
CHEM. PROC. RATE: WASH-743
CONV. COST U: 200 / KG

Fig. 17b Fuel Cycle Cost for PWR Plants

ORNL-LR-Dwg. 67974
Unclassified

Distribution

1.	L. G. Alexander	51.	H. W. Savage
2.	S. E. Beall	52.	A. W. Savolainen
3.	M. Bender	53.	M. J. Skinner
4-18.	L. L. Bennett	54.	O. L. Smith
19.	A. L. Boch	55.	I. Spiewak
20.	R. B. Briggs	56.	J. A. Swartout
21.	R. S. Carlsmith	57.	M. Tobias
22.	W. L. Carter	58.	D. B. Trauger
23.	R. D. Cheverton	59.	Marina Tsagaris
24.	H. C. Claiborne	60.	R. Van Winkle
25.	J. G. Delene	61.	D. R. Vondy
26.	T. B. Fowler	62.	A. M. Weinberg
27.	A. P. Fraas	63-64.	Central Research Library
28.	E. H. Gift	65-67.	Y-12 Doc. Ref. Section
29.	D. R. Gilfillan	68-70.	Laboratory Records Dept.
30-34.	P. R. Kasten	71.	(LRD-RC)
35.	T. W. Kerlin		
36-40.	J. A. Lane		
41.	R. N. Lyon		
42.	H. G. MacPherson		
43.	W. D. Manly		
44.	A. J. Miller		
45.	E. A. Nephew		
46.	C. W. Nestor		
47.	A. M. Perry		
48.	P. H. Pitkanen		
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