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EFFECT OF PLANT SIZE ON COSTS OF PUREX PROCESSING OF HETEROGENEOUS POWER REACTOR FUEL

J. W. Ullmann

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0.0 ABSTRACT

Cost estimates are given for 1- to 16-ton/day privately owned Purex processing plants. A 4-ton/day plant is estimated to be required to achieve 1 mill/kwh chemical reprocessing costs with fuel irradiated to 2000 Mwd/ton. Such a plant would handle the fuel discharged from sixteen 500-Mw reactors. If the same reactors discharged fuel irradiated to 10,000 Mwd/ton, a chemical reprocessing cost of 0.3 to 0.4 mill/kwh is anticipated. As plant sizes increase, the cost of shipping irradiated fuel becomes a larger fraction of the total reprocessing cost.

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1.0 INTRODUCTION

Purex plants ranging in capacity from 1 to 16 tons/day are used to show the interrelation of plant size, irradiation level, and reprocessing costs for slightly enriched power reactor fuels.

A solvent extraction recovery system is used because of the availability of cost data. The estimates are intended to show gross trends and are not based upon detailed design of a plant.

The costs cover fuel reprocessing only as far as decontaminated uranium and plutonium nitrates and do not include conversion to oxide, fluoride, or metal. A privately owned facility is assumed, and charges are included for shipping, inventory, profit, and taxes. The overall costs are broken down as a function of plant size to indicate which factors become dominant in large-scale processing.

2.0 SUMMARY

A large centralized Purex plant should be built because of the significant unit cost reduction with increased size. For example, with fuel irradiated to 2000 Mwd/ton a recovery plant must process at least 4 metric tons/day to achieve a 1-mill/kwh separation costs. Since this capacity is equivalent to sixteen 500-Mw reactors, higher costs can be anticipated in the early stages of nuclear power development.

Processing costs per kilowatt-hour would be lower with irradiation levels higher than 2000 Mwd/ton, but, for a given nuclear power economy, the reduction is less than linear because smaller tonnages are processed. For example, the same sixteen 500-Mw reactors are expected to pay the equivalent of 0.3 - 0.4 mill/kwh for processing if irradiating to 10,000 Mwd/ton. Because of the problems of radiation damage to fuel elements, it is optimistic to expect 10,000 Mwd/ton for the first few years of nuclear power.

Shipping costs (assumed to average $2040 per metric ton of fuel for a 1000-mile distance between reactor and processing plant) become 20% of the total cost of processing in an 8-ton/day plant. Future shipping costs can probably be reduced by at least a factor of 3.

3.0 CAPITAL INVESTMENT

The study "Project Separation"[1] presented estimates of the capital investment required for 0.1-, 0.5-, and 8.0-ton/day Purex plants. These values, $9,000,000, $20,000,000, and $101,000,000, are plotted in Fig. 1, and the line through the points is used to provide a scale-up factor.

A rough cost estimate of $9,000,000 for a 1-ton/day Purex plant was made by Stockdale.[2] On Fig. 1, a line parallel to the Project Separation data is drawn through this point to indicate capital investment as a function of capacity for this study.

4.0 ANNUAL OPERATING COST

Project Separation operating expenses for 0.1-, 0.5-, and 8.0-ton/day plants of $2,900,000, $6,400,000, and $29,200,000 are plotted in Fig. 2, and a line is drawn through the points to establish a scale-up relation.

The same factors as those used in Project Separation were used in re-estimating an operating expense for an 8.0-ton/day plant, based on the capital investment curve used in this study (see Table 1).

[1] J. E. Vivian, Director, MIT Project Separation, "Processing of Spent Power-Reactor Fuels," MIT-5005 (December, 1954).

[2] W. G. Stockdale, "ORNL Metal Recovery Plant Processing Costs," in ORO-144 (October, 1955)

Table 1. Purex Annual Operating Expense

Recovery as 2.0M $UO_2(NO_3)_2$, 8-ton/day plant

Operating labor and supervision	$ 141,000
Other labor services	261,000
Maintenance labor and supervision	970,000
Administration and overhead at 50% of labor	687,000
Maintenance materials	480,000
Chemicals at $770/ton (300 days/year)	1,860,000
Miscellaneous supplies at 1% of investment	290,000
Waste storage	3,200,000
Utilities and miscellaneous	1,500,000
Total	$9,389,000

A line on Fig. 2 through the $9,400,000 point parallel to the Project Separation data defines the operating expense used in this study. This does not include charges for shipping, inventory, profit, and taxes which were estimated as follows:

Shipping

Assume: 40,000 lb gross weight of loaded carrier, 1 metric ton payload

Carrier cost at $1000/ton: $18,900

Carriers required: 2-week travel cycle requires 14 carriers for 1-ton/day plant

Freight rate based on 1000-mile trip from reactor to chemical plant:

Motor freight, $2.20/cwt

Rail freight, $2.17/cwt

Shipping costs based on 1 metric ton of uranium:

Carrier amortization at 15% (300 days/year operation)	$\frac{(14)(18,900)(0.15)}{300}$	=	$ 132
Round trip of 2000 miles at $2.20/cwt for 1000 miles		=	1,760
Loading and unloading at $0.37/cwt		=	148
Total per metric ton of uranium			$2,040

Inventory

Basis: 1.3% U^{235} leased from AEC, held for 90 days

Value: $117,000 per ton

AEC charge: 4% per annum

For 1-ton/day plant operating 300 days/year:

$$300 \frac{\text{tons}}{\text{year}} \times \frac{90}{365} \text{ year} \times \$117,000/\text{ton} \times 0.04/\text{year} = \$345,000/\text{year}$$

Insurance, Taxes, and Profit

Lumped together as 15% of capital investment to allow about 6% profit after taxes and insurance.

5.0 INTERRELATION OF PLANT SIZE, IRRADIATION LEVEL, AND PROCESSING COST

In Table 2 are shown the reprocessing costs based on Figs. 1 and 2 and the other cost items discussed in Sec. 4.0. Plant operation of 300 days/year is assumed. Amortization is calculated for 5%, 10%, and 15% annual depreciation. Inventory has been charged as part of the processing cost since, even if inventory should be debited to the reactor, the cost would still be reflected in the price of power. The conversion from thousands of dollars per ton to mills per kilowatt-hour is made assuming 2000 Mwd/ton irradiation and 25% efficiency in the conversion of heat to electricity.

From Fig. 3, which is a plot of the results of Table 2, the processing cost is seen to fall very sharply as the plant capacity increases from 1 ton/day to the neighborhood of 6 tons/day and then to fall at a more gradual rate. It can also be noted that changing the annual depreciation rate from 15% to 10% reduces the processing cost by only about 0.1 mill/kwh, which is a much smaller difference than between 1- and 2-ton/day recovery costs. The abscissa of Fig. 3 is given both as tons per day and megawatts of electricity, the conversion factor being Mwd/ton x tons/day = Mw.

Figure 4, which shows the processing cost as a function of total megawatts of power and irradiation level in megawatt-days per ton, was derived by determining the plant size in tons per day required for various power economies at three irradiation levels and converting the cost in dollars per ton to mills per kilowatt-hour. From the curves it can be seen that low costs per unit of electricity are possible either by processing the fuel from a large number of reactors or by employing high irradiation levels. Since irradiation levels as high as 10,000 Mwd/ton have not yet been demonstrated for slightly enriched elements, processing costs of the order of 1 mill/kwh can be expected for the initial phases of nuclear power. The figure clearly shows that for a given power economy, doubling the irradiation level will not halve the processing cost, because a plant of only half the capacity will be utilized.

Table 2. Annual Recovery Costs

Uranyl nitrate hexahydrate product, irradiation to 2000 Mwd/ton, 25% conversion efficiency

Capacity, metric tons per day nominal	1			2			4			8			12			16		
Equivalent number of 500 Mw reactors	4			8			16			32			48			64		
Write-off period, years	6-2/3	10	20	6-2/3	10	20	6-2/3	10	20	6-2/3	10	20	6-2/3	10	20	6-2/3	10	20
	Thousands of dollars																	
Depreciation (straight line, no salvage)	1350	900	450	1995	1330	665	2920	1950	975	4350	2900	1450	5480	3660	1830	6450	4300	2150
Operating expenses	3300	3300	3300	4700	4700	4700	6600	6600	6600	9450	9450	9450	11700	11700	11700	13500	13500	13500
Shipping at $2040/ton, (300 days/year, 1000 miles)	612	612	612	1224	1224	1224	2448	2448	2448	4896	4896	4896	7344	7344	7344	9792	9792	9792
Inventory at 4% per year (90 days, $117,000/ton value)	345	345	345	691	691	691	1382	1382	1382	2765	2765	2765	4147	4147	4147	5530	5530	5530
Taxes, insurance, profit (at 15% of investment)	1350	1350	1350	1995	1995	1995	2920	2920	2920	4350	4350	4350	5480	5480	5480	6450	6450	6450
Total	6957	6507	6057	10605	9940	9275	16270	15300	14325	25811	24361	22911	34151	32331	30501	41722	39572	37422
Processing cost, $/ton (300 days/year) x 10^{-3}	23.19	21.69	20.19	17.68	16.57	15.46	13.56	12.75	11.94	10.75	10.15	9.55	9.49	8.98	8.47	8.69	8.24	7.80
Processing cost, mills/kwh	1.93	1.81	1.68	1.47	1.38	1.29	1.13	1.06	1.00	0.90	0.85	0.80	0.79	0.75	0.71	0.72	0.69	0.65

6.0 COST BREAKDOWN

Figure 5 shows the change in percentage of total cost of various cost components as the plant size is increased from 1 to 16 tons/day. Depreciation, taxes, insurance, and profit charges, which depend on capital investment, change from 40% to 31% of the total processing cost. The percentage due to labor, supervision, maintenance, utilities, and other operating expenses is markedly reduced with increased plant size, from 38% to 8%.

Charges for waste, inventory, and chemicals increase with plant size: 6% to 15%, 5% to 13%, and 3% to 9%, respectively.

Shipping increases from 9% to 24% of the total processing cost with the increase in plant size. The shipping cost assumed for this study was one-fifth the cost estimated by Project Separation for present shipping methods. Project Separation assumed 504 lb of fuel in a 20-ton carrier with courier-escort, while this study assumed 2205 lb of fuel in a 20-ton carrier and no escort. Since it is proposed to ship 4 tons of fuel in a 40-ton carrier to the ORNL Metal Recovery Building, a cost reduction of 2 below this study, it is felt that a reduction of at least 3 is feasible. If criticality considerations permit, this could be obtained by increasing the carrier weight to 50 or 60 tons to provide a greater payload per pound of shield transported. Schemes to barge fuel, or to ship a smaller weight on the trip in which the carrier is empty, by using sand or water as part of the shield, may also offer savings.

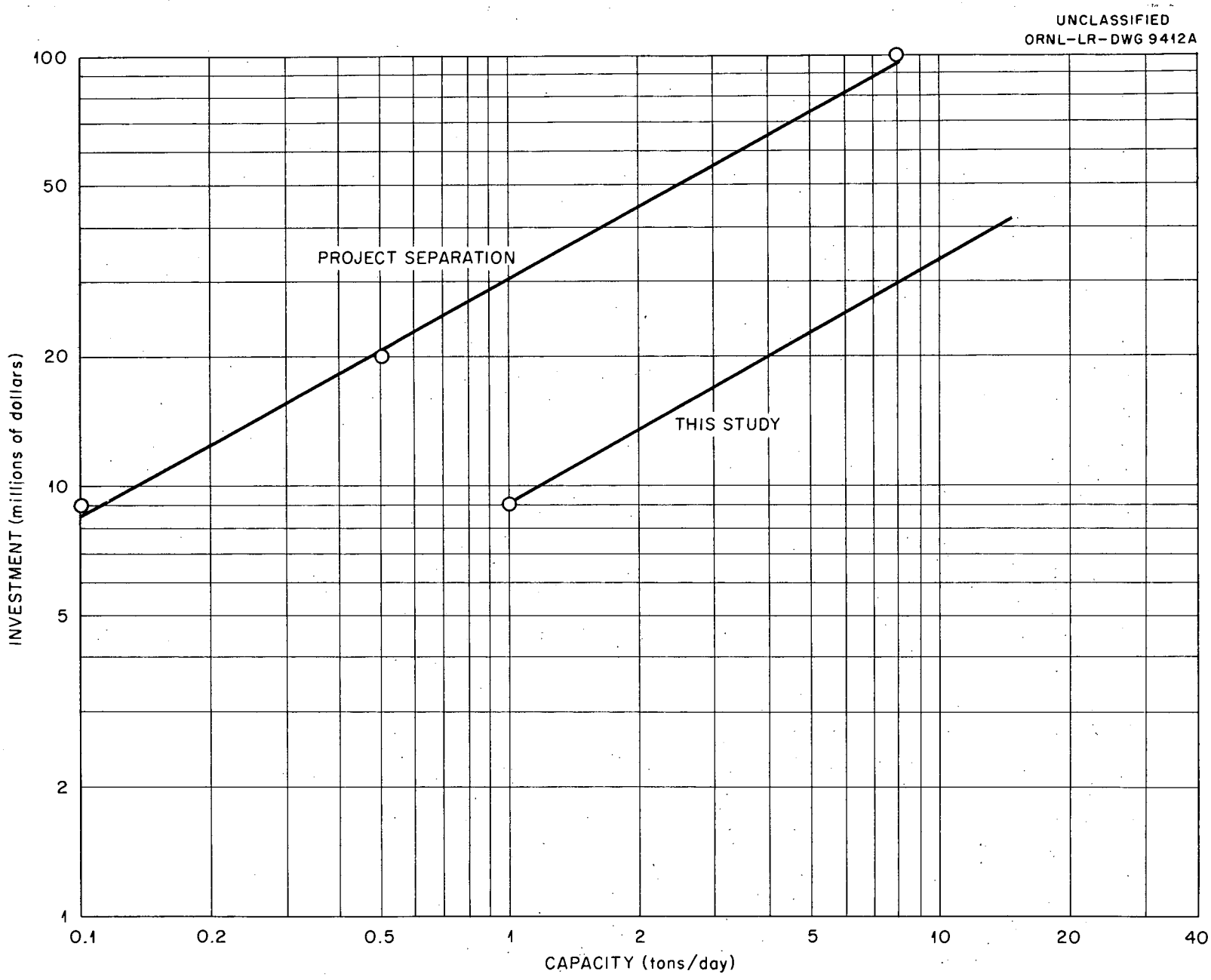

Fig. 1. Capital Investment as a Function of Plant Capacity.

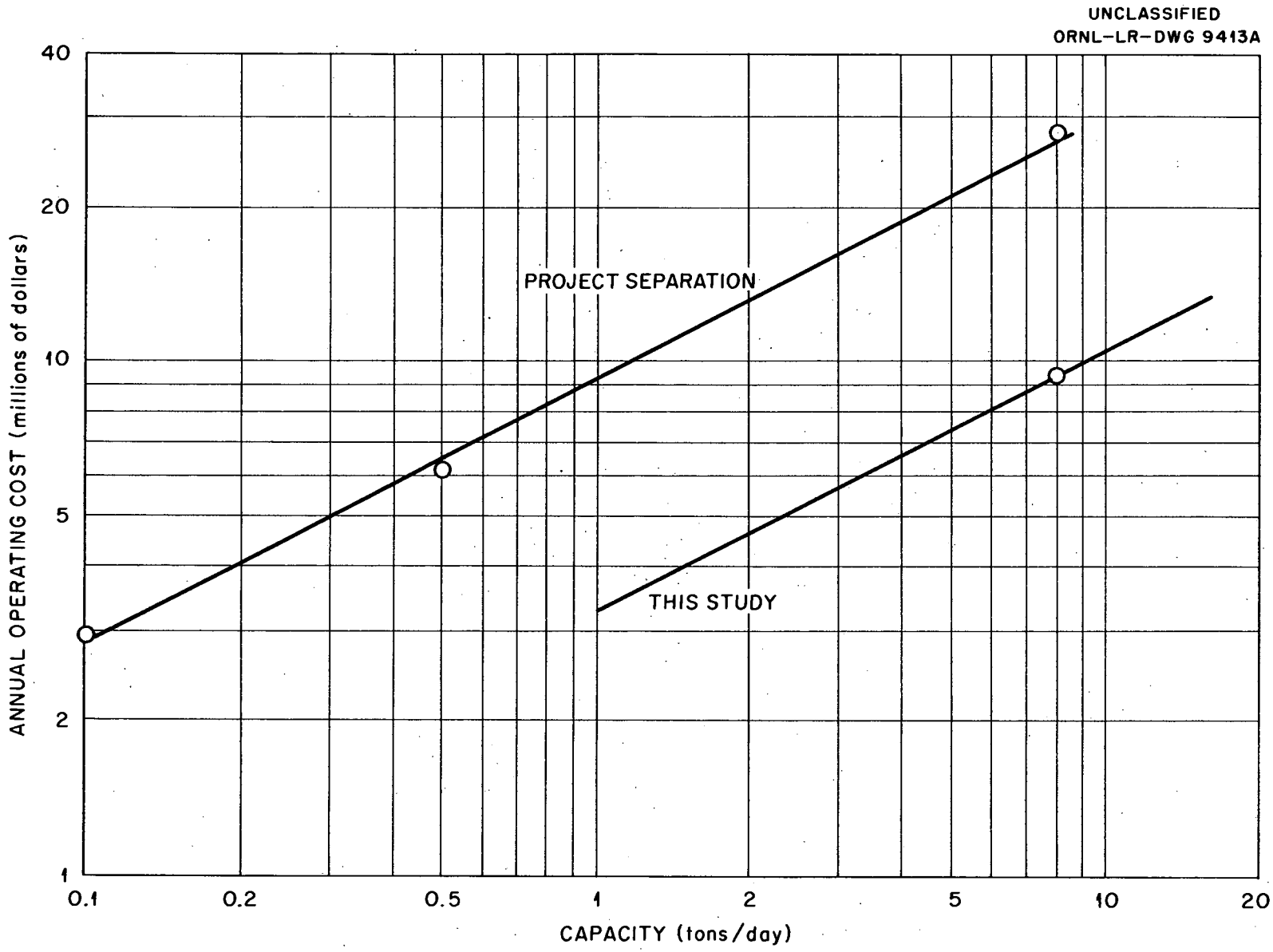

Fig. 2. Annual Operating Cost as a Function of Plant Capacity. Shipping, depreciation, profit, taxes, inventory, and insurance not included.

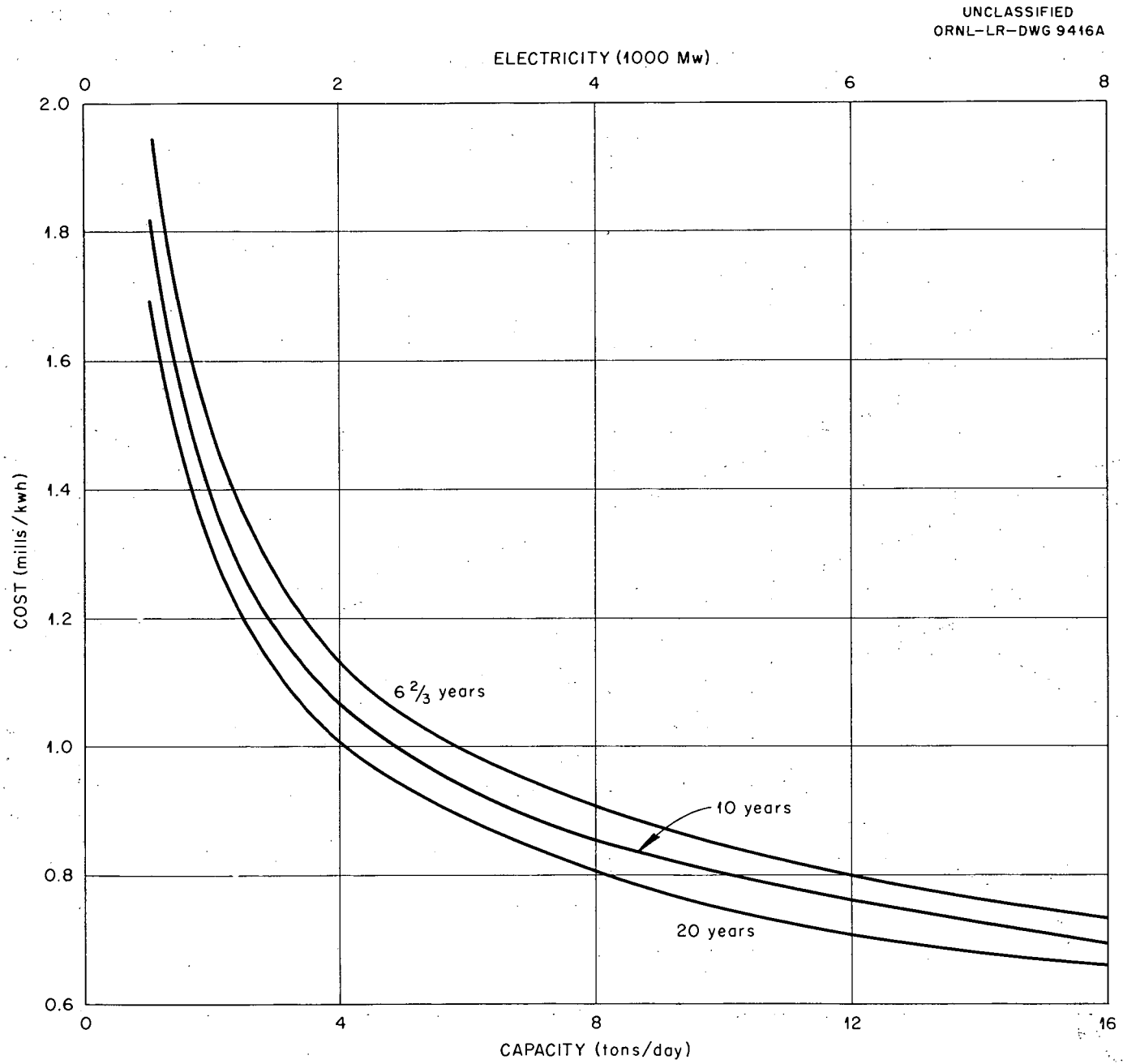

Fig. 3. Processing Cost as a Function of Capacity and Amortization Period. Basis: 2000 Mwd/ton

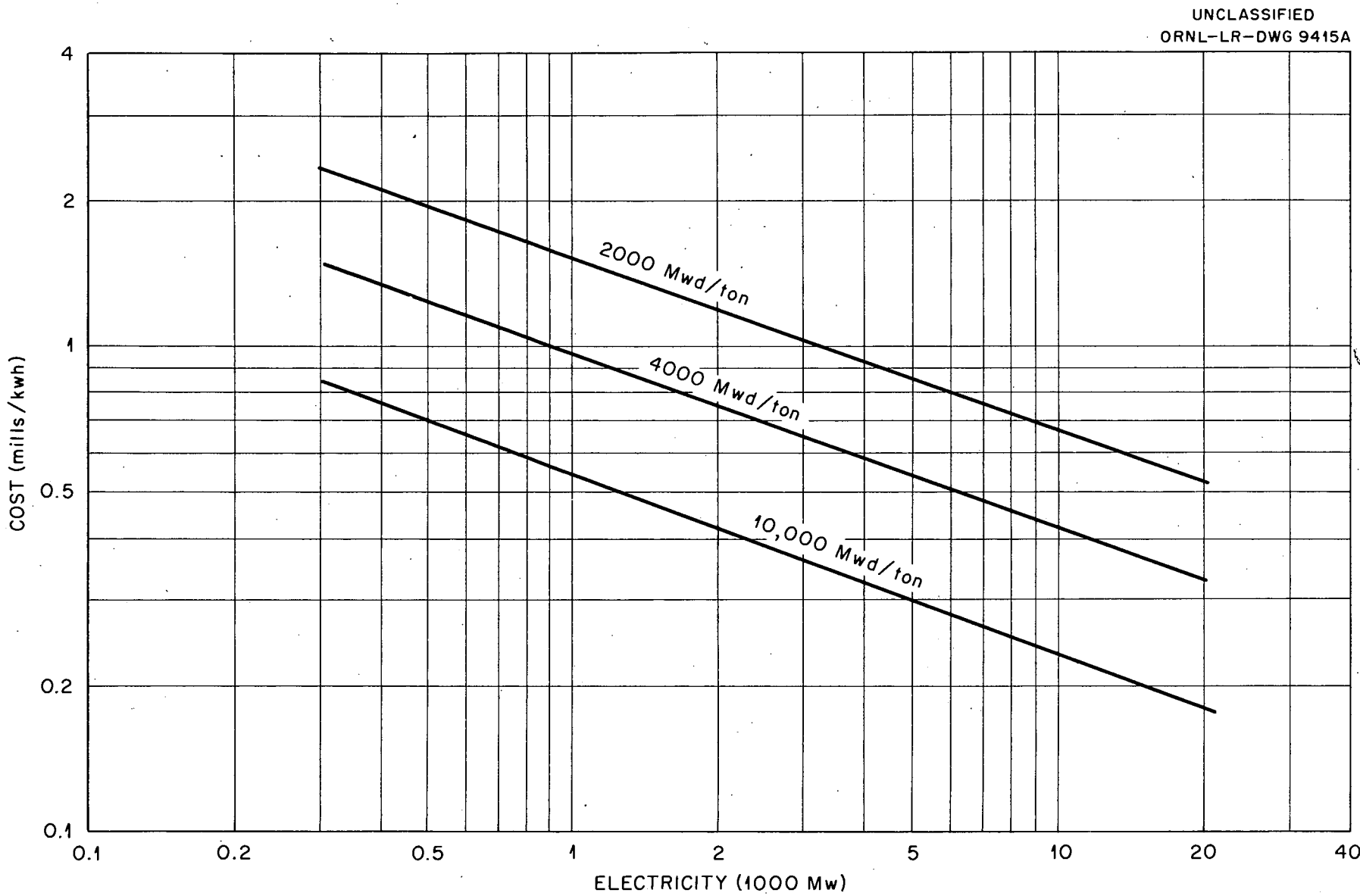

Fig. 4. Recovery Cost as a Function of Irradiation Level and Size of Nuclear Power Economy. Basis: $6\frac{2}{3}$-year Amortization.

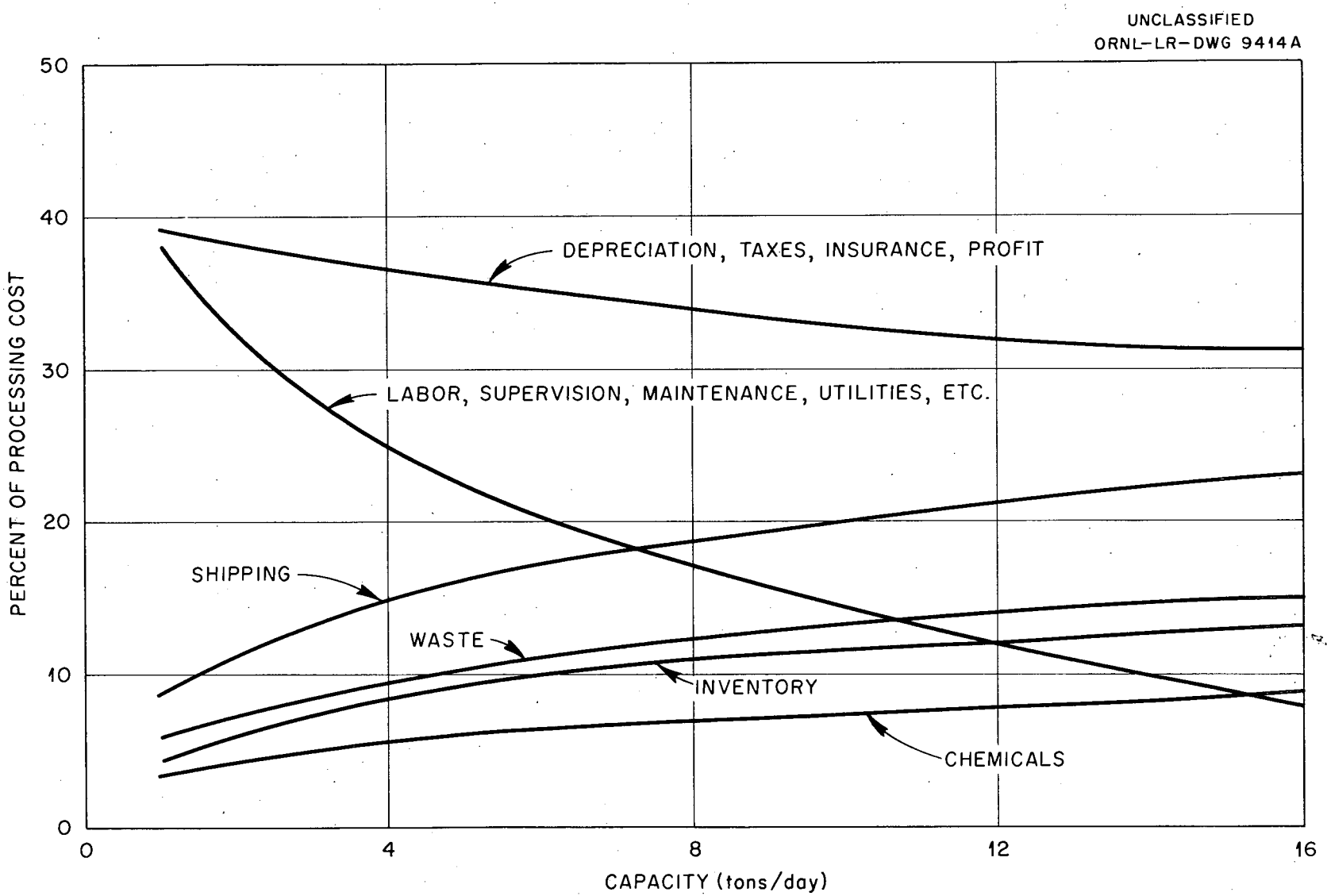

Fig. 5. Cost Breakdown as a Function of Plant Size. Basis: $6\frac{2}{3}$-year Amortization, 2000 Mwd/ton.