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SUBJECT: Fuel Cycle Costs in a Graphite Moderated Slightly Enriched Fused Salt Reactor

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FROM: C. E. Guthrie

Abstract

A fuel cycle economic study has been made for a 315 MW_e graphite moderated slightly enriched fused salt reactor. Fuel cycle costs of less than 1.5 mills may be possible for such reactors operating on a ten year cycle even when the fuel is discarded at the end of the cycle. Recovery of the uranium and plutonium at the end of the cycle reduces the fuel cycle costs to ~1 mill/kwh. Changes in the waste storage cost, reprocessing cost or salt inventory have a relatively minor effect on fuel cycle costs.

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Introduction

One potential advantage of a fluid fueled reactor is a low fuel cycle cost. There are two alternate approaches, both unique to the fluid fuel concepts, one might take to realize this potential: (1) continuous reprocessing, thereby keeping the poisons at a minimum and the conversion (or breeding) ratio at a maximum, or (2) continuous additions of enriched fuel (to make up for burnout and reactivity decrease), thereby attaining very high burnup on the original fuel charge. The latter approach is the one more applicable to the fused salt (LiF, BeF, UF_4) reactor operating on the U^{235}-U^{238} cycle since both plutonium and uranium must be recovered. For fused salt reactors operating on the Th-U cycle either approach can be used since the volatility process could be used to continuously (or semicontinuously) recover the U-235 and U-233.

This study has been made to determine the range of fuel cycle costs anticipated for a graphite moderated fused salt burner reactor operating on the U^{235}-U^{238} cycle. The nuclear calculations and cycle costs for the Th-U^{235} cycle will be worked out and reported at a later date.

Reactor Basis*

The reactor considered is graphite moderated with a fluid fuel consisting of a molten mixture of lithium^7 fluoride, beryllium fluoride and slightly enriched uranium fluoride. During the reactor cycle highly enriched UF_4 is added to the system to supply burnup and make up for the reactivity loss due to accumulated fission products. The inventory of fissile isotopes in the reactor and the U-235 additions as a function of time are shown in Figures 1 and 2, respectively. The other reactor parameters are:

775 MW	Thermal
315 MW	Electrical
700 ft^3	Fused Salt Inventory
80%	Load Factor
1.8%	Initial U-235 Enrichment

Economic Basis

Two cases have been considered, both of which assume no Li^7 recovery.
1) Throw-away cycle - At the end of the reactor cycle (or lifetime) the

*All reactor data supplied by H. G. MacPherson.

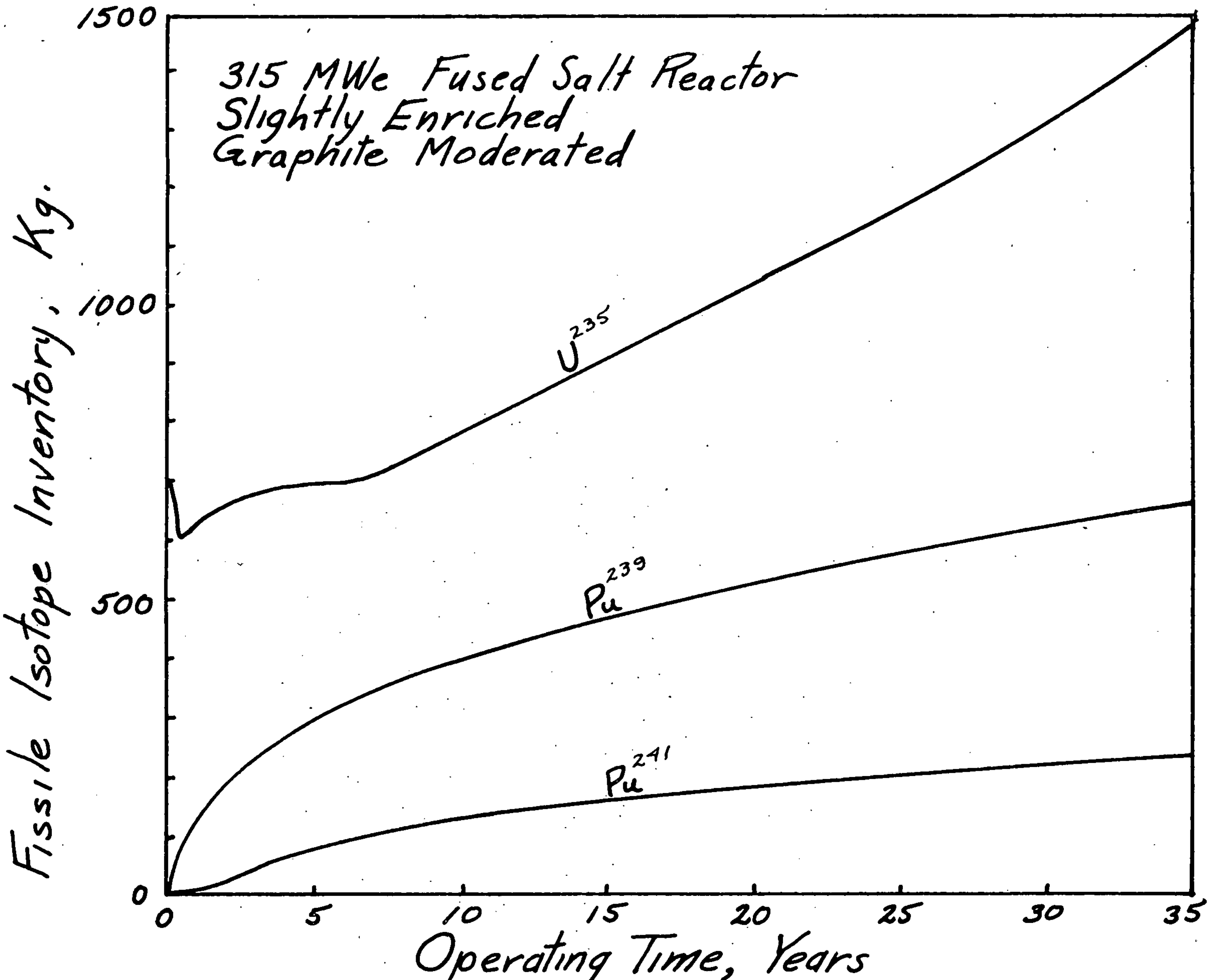

Figure 1. Fissile Isotope Inventory vs. Operating Time

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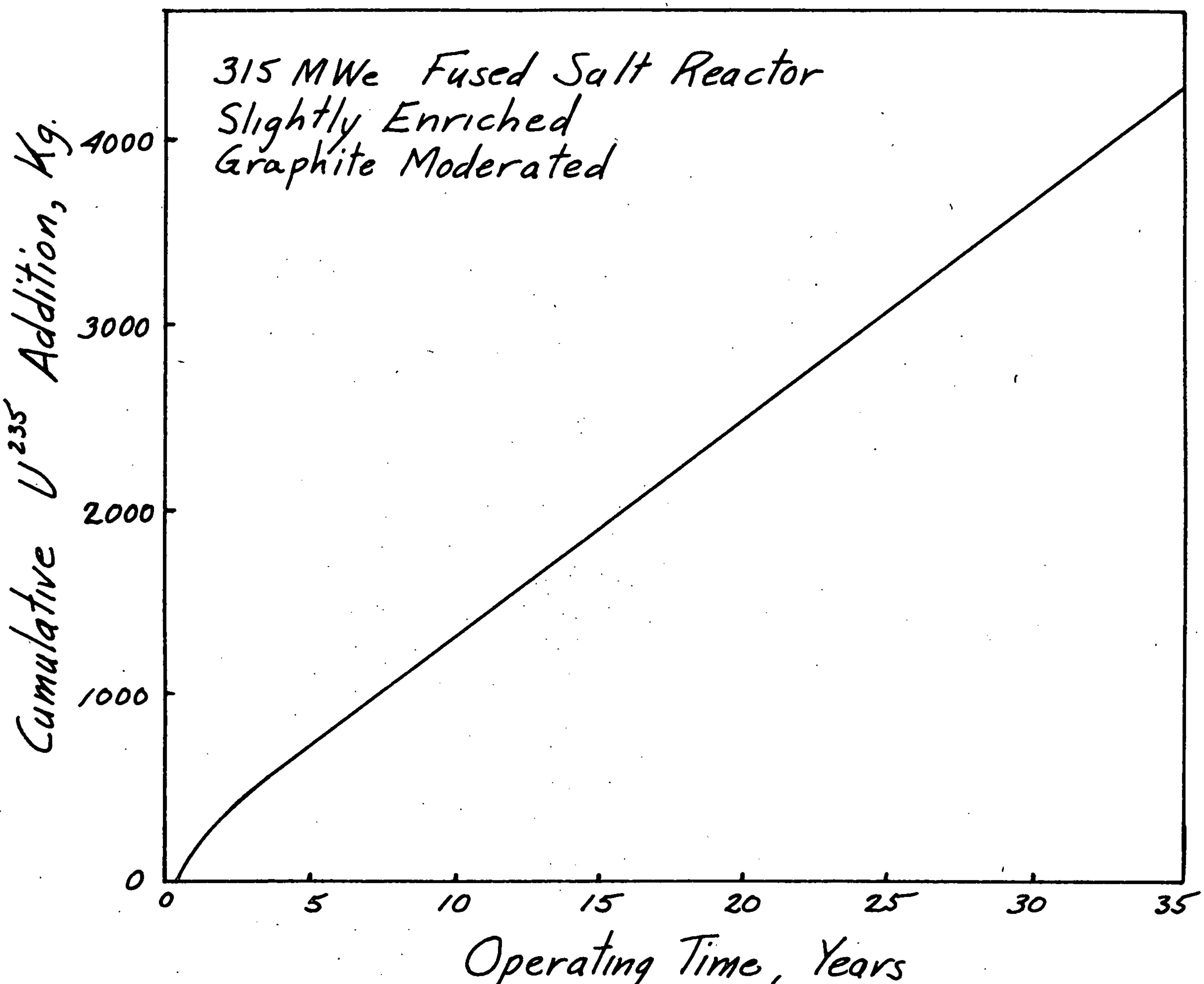

Figure 2. Cumulative U^{235} Addition vs. Operating Time

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reactor salt inventory including fissionable isotopes would be discarded into on-site waste tanks for permanent storage. A $1,000,000 investment has been assumed at the end of the cycle for a storage facility and provision for permanent monitoring.
2) U and Pu recovered at end of cycle - A recovery cost of $100/kg U has been assumed which should be reasonable for current technology.

The economics were calculated on the following basis:

Salt cost $2000/ft^3 (excluding U value).
U value at official price schedule.
Pu credit $12/gm of Pu-239 and Pu-241.
U-235 addition during the cycle was considered to be burnup and was paid for on a current basis.
4% use charge was paid on initial loading of U during the cycle. A 5% interest sinking fund was used to pay for U discard and storage costs or processing costs at the end of the cycle.
The investment in salt was payed off over the cycle with a 10% return (before taxes).

Results

The fuel cycle costs, calculated for each case as a function of cycle time, are shown in Figure 3. Fuel cycle costs of ~1 mill/kwh are predicted for reactor cycles in excess of 10 years when the U and Pu are recovered from the salt at the end of the cycle ($100/kg U recovery cost assumed). Fuel cycle costs are essentially constant for cycles in excess of 10 years. For long cycle times there is little cycle cost difference between the throw away and the U and Pu recovery cycle. For example, recovering the U and Pu at the end of a 20-year cycle reduces the cycle cost only 0.25 mill/kwh. This illustrates the effect of high burnup attained (120,000 MWD/ton on initial charge for 20-year cycle) on the fuel cycle economics.

Errors in the assumed cost of reprocessing, fused salt waste disposal, initial salt cost or salt inventory do not have a major effect on the cycle costs for a reprocessing cycle of 10 years or longer. The following table shows the effect on the 10 year cycle fuel cost of doubling the values assumed for each:

Parameter	Increase	Δ Cycle Cost, Mills/kwh
Reprocessing	$100/kg	+0.15
Waste Disposal Cost	$1,000,000	+0.035
Initial Salt Cost	$2000/ft^3	+0.1
Salt Inventory	700 ft^3	+0.5 (throw-away)
		+0.35 (recovery)
Maximum Total Charge	Throw-away Cycle	0.635 Mills/kwh
	Recovery Cycle	0.6 Mills/kwh

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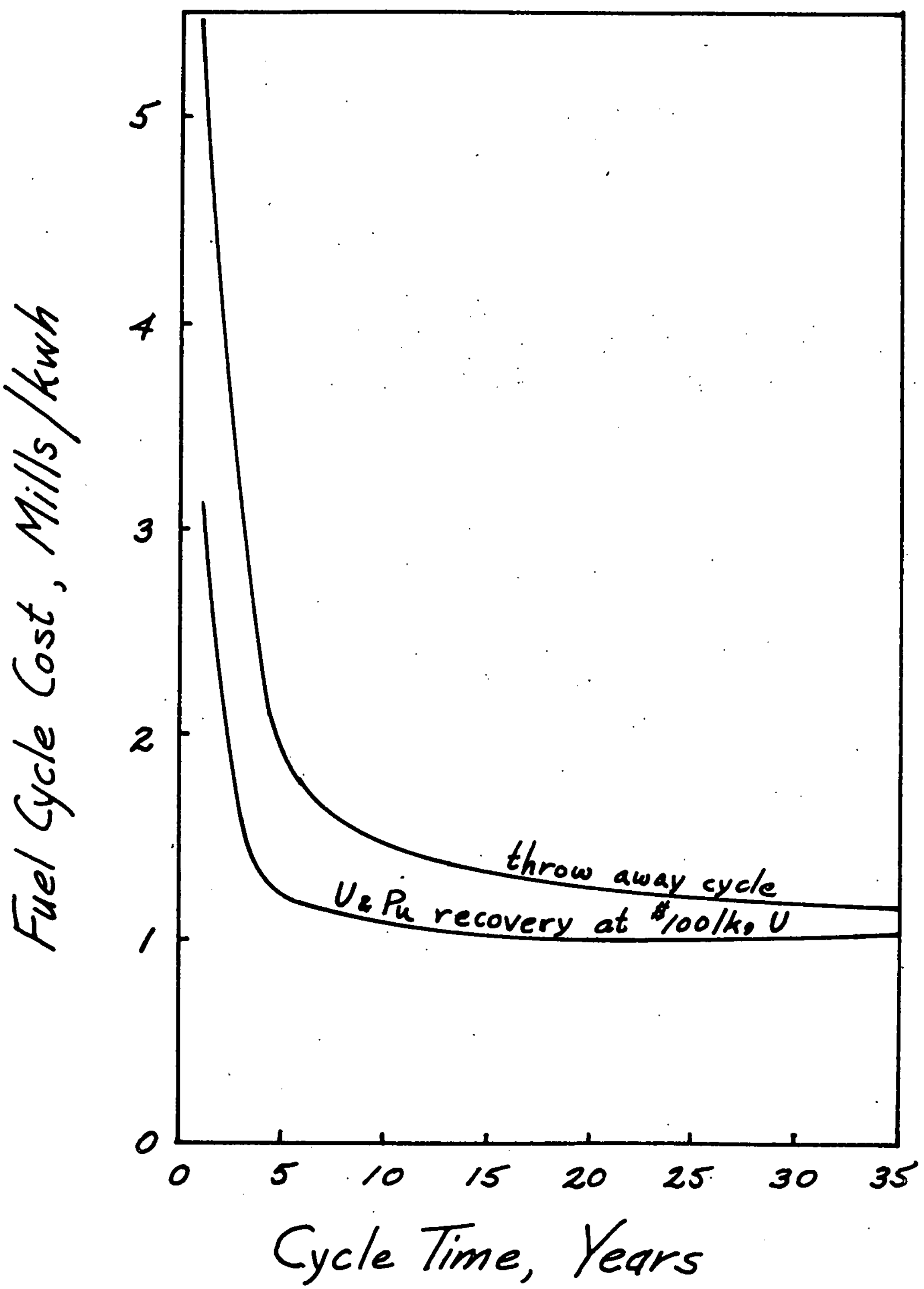

Figure 3. Fuel Cycle Cost vs. Cycle Time
315 MWe Fused Salt Reactor

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Most of the fuel cycle cost in the reactor is U-235 burnup cost. The conversion ratio is therfore one of the most important reactor parameters.

It is interesting to compare these fuel cycle costs, which are for a single reactor with present reprocessing technology, with the fuel cycle costs anticipated for solid fueled reactors at the present time. Two such reactors which are typical are the Yankee with a 7.1 mill/kwh[(1)] fuel cost and the Indian Point with a 5.8 mill/kwh[(2)] fuel cost. These costs will be reduced by the mass production of fuel elements and large scale reprocessing possible in a large nuclear economy. It will probably take, however, a nuclear economy in the order of 10^5 MW_e (1980-2000) to reduce solid fueled reactor fuel cycle costs to 1-1.5 mills/kwh.

(1) Schoupp, W. E., Advanced Pressurized Water Systems Proceedings of Atomic Energy Management Conference, March 17-19, 1958, Chicago, Ill., p. 142.

(2) J. F. Fairman, Estimated Costs of Indian Point Nuclear Power Plant, Ibid, p. 357.

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