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SUBJECT: Fuel Cycle Costs in a Graphite Moderated $U^{235}$-Th Fueled Fused Salt Reactor

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FROM: C. E. Guthrie

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## Abstract

A fuel cycle economic study has been made for a 315 $Mw_e$ graphite moderated $U^{235}$-Th fueled fused salt reactor. Fuel cycle costs of ~1.3 mills/kwh may be possible for such reactors when reprocessed for U-233 and U-235 recovery at the end of a 9-year cycle. Continuous removal of fission products during the reactor cycle does not appear to offer any great economic advantage for the converter reactor considered.




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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 fueled reactors, 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 initial fuel charge. The Th-$U^{235}$ fueled fused salt reactor can use either or both of these approaches.

This study has been made to determine the range of fuel cycle costs anticipated for a graphite moderated fused salt reactor fueled with $U^{235}$-Th and to determine the effect on fuel cycle costs of continuous fission product removal and cost of uranium recovery.

### Reactor Basis*

The reactor considered is graphite moderated with a fluid fused salt fuel. The reactor parameters are:

774 Mw Thermal
315 Mw Electrical
900 $Ft^3$ Fused Salt Inventory
80% Load Factor
71% $Li^7F$ Fused Salt Composition, Mole %
16% $BeF_2$
13% $ThF_4$

Two systems of operation were considered for this reactor. In single reprocessing operation the reactor is drained at the end of the cycle and U-233 and U-235 recovered. During the reactor cycle U-235 is added continuously to make up for burnup and poisons due to fission products and higher isotopes buildup. The U-235 additions and the U-233 and U-235 inventories for this system are shown in Fig. 1.

In the dual reprocessing system the reactor is processed continuously (by CeF exchange or "cold finger") to remove fission products during the cycle and the entire charge is reprocessed (by volatility or solvent extraction) to recover U-233 and U-235. Uranium-235 is added continuously during the cycle to make up for burnup and higher isotope poisons. The U-235 additions and the U-233 and U-235 inventories for the dual reprocessing system are shown in Fig. 2.

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*All reactor data supplied by L. G. Alexander from ORACLE calculations.

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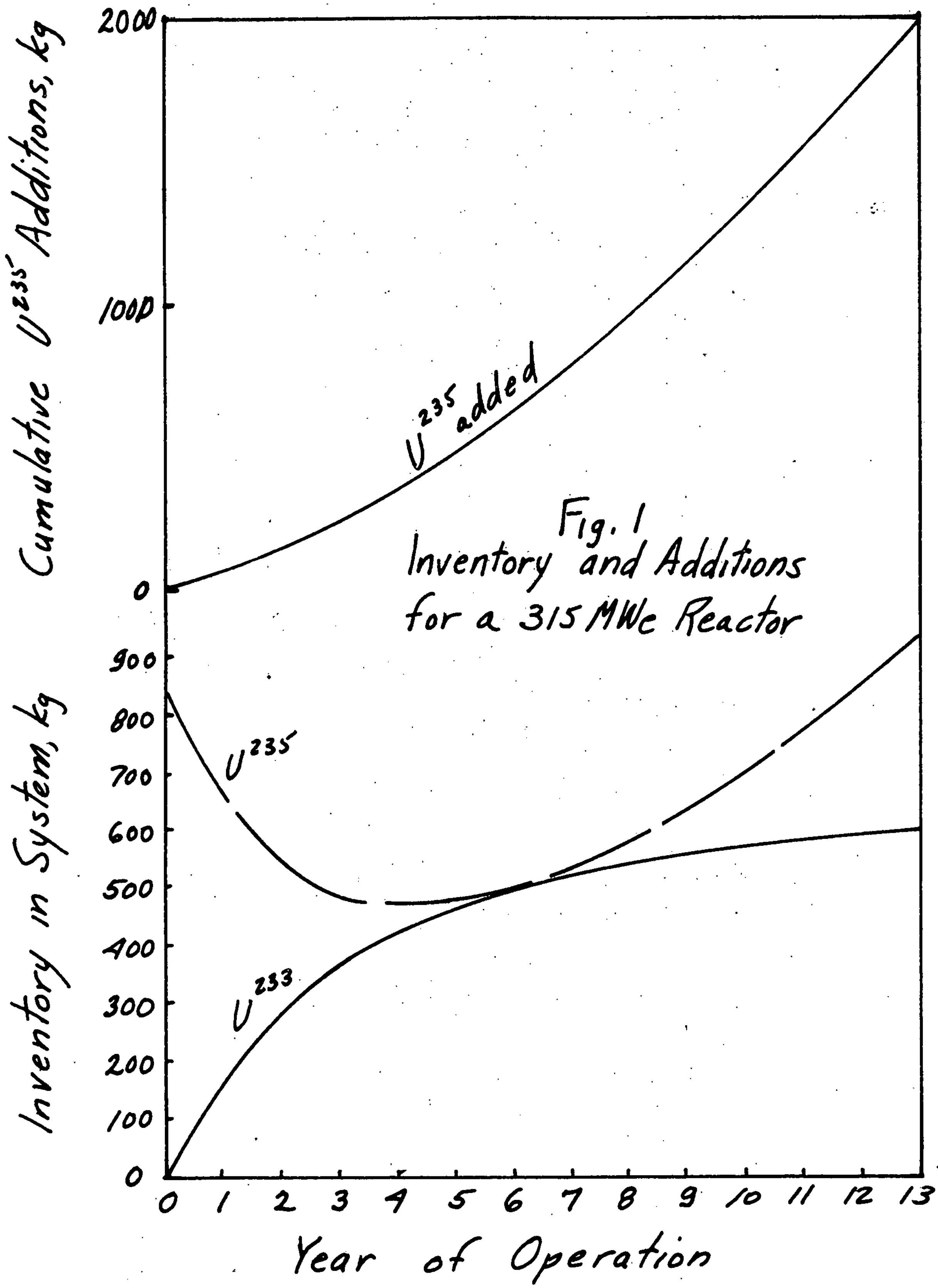


Fig. 1
Inventory and Additions
for a 315 MWe Reactor

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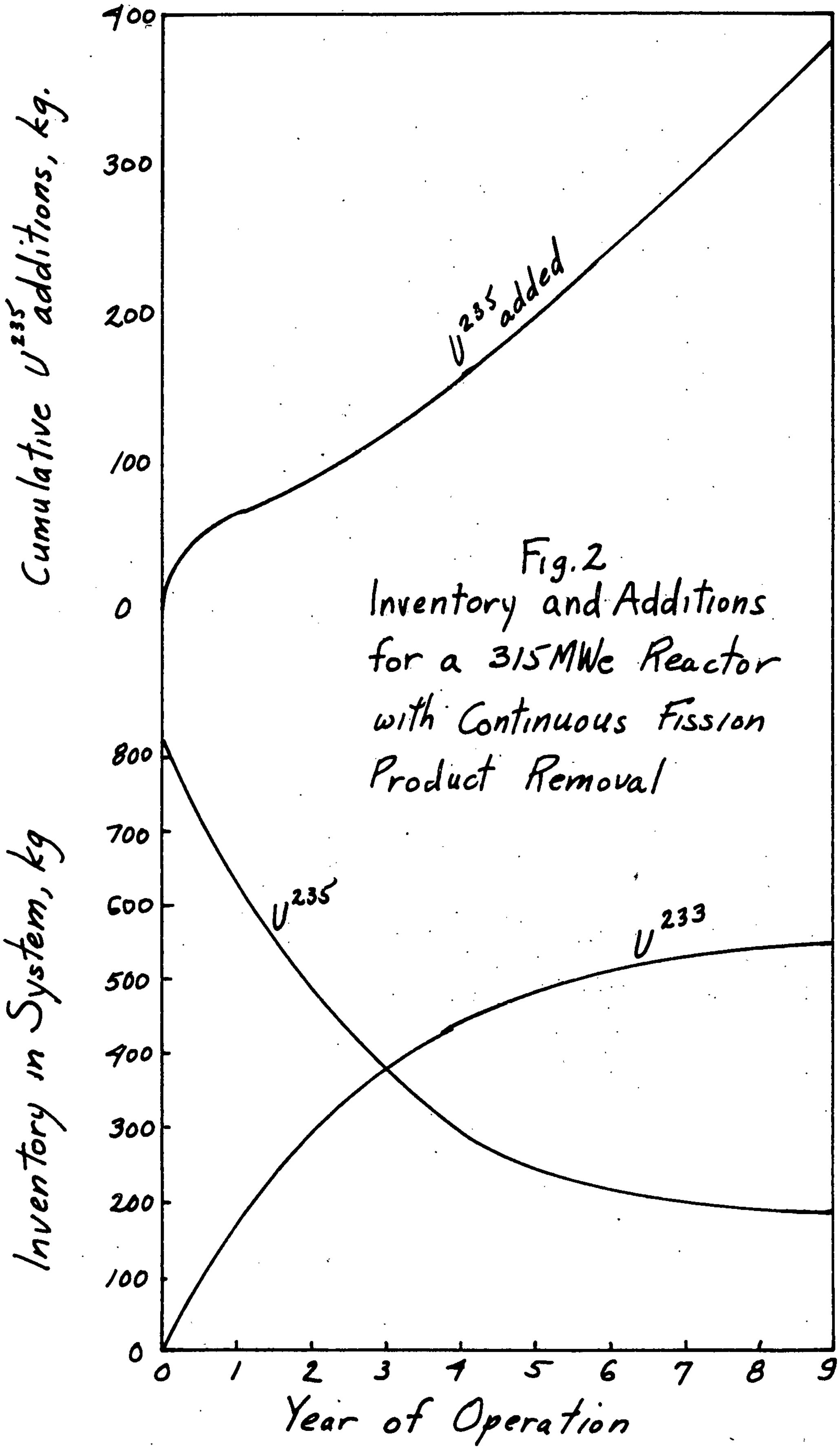


Fig. 2
Inventory and Additions for a 315 MWe Reactor with Continuous Fission Product Removal

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Economic Basis

Two fuel cycle cases, both of which assume no $Li^7$ of Th recovery, have been considered for each system of reactor operation. In each case the cycle repeats with the reactor fueled with fresh salt containing $U^{235}$-Th.

(1) Throw-away cycle - At the end of the reactor cycle (or lifetime) the reactor salt inventory, including fissionable material, is dumped into on-site waste tanks for permanent storage instead of being reprocessed for U recovery. A $1,000,000 investment has been assumed at the end of the cycle for a storage facility and provision for permanent monitoring.

(2) Uranium-233 and U-235 recovered at end of cycle - Recovery costs of $100/kg Th (representative of current solvent extraction recovery cost) and $25/kg Th (central plant volatility reprocessing estimated cost) have been assumed.

The economics were calculated on the following basis:

Salt Cost $2500/Ft$^3$ (excluding U value)
U-235 value at $17/gm
U-233 value at $15/gm
4% use charge paid on initial loading of U-235, U-235 added during cycle, and U-233 built in during cycle.
A 5% interest sinking fund was used to average out use charges and to pay for either U discard and waste storage costs at end of cycle or reprocessing and burnup costs at end of cycle.
The investment in salt was payed off over the cycle with a 10% return (before taxes).

Results:

The fuel cycle costs calculated for the single reprocessing cycle (with no fission product removal during the cycle) are shown in Fig. 3. A minimum fuel cycle cost of ~1.3 mills/kwh is predicted for cycles of 9 years and $25/kg Th reprocessing costs. A recovery cost of $100/kg Th would increase the fuel cycle cost to ~1.4 mills/kwh. In all cases it would pay to recover the fuel at the end of the cycle since the minimun throw-away cycle cost is 2 mills/kwh.

The fuel cycle costs which could result for the dual reprocessing system if the fission products were removed from the reactor continuously at zero cost are shown in Fig. 4. Although the nuclear calculations were not carried out far enough for the economic optimum fuel cycle to be obtained, it appears to be ~1 mill/kwh (not including fission product removal cost). This compares with 1.3 mills/kwh for the single reprocessing

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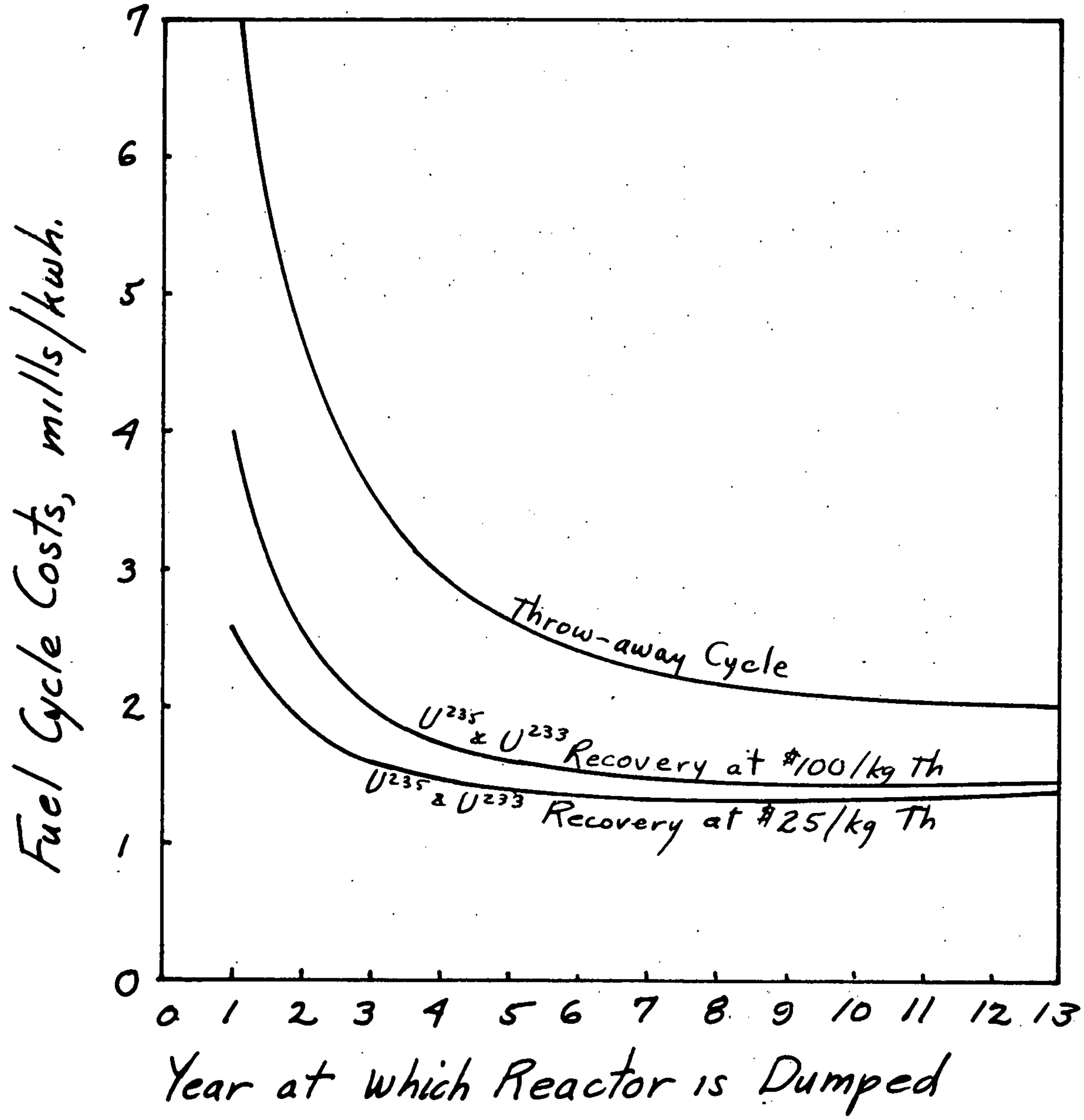


Fig. 3 Fuel Cycle Costs for 315 MWe Molten Salt Reactor

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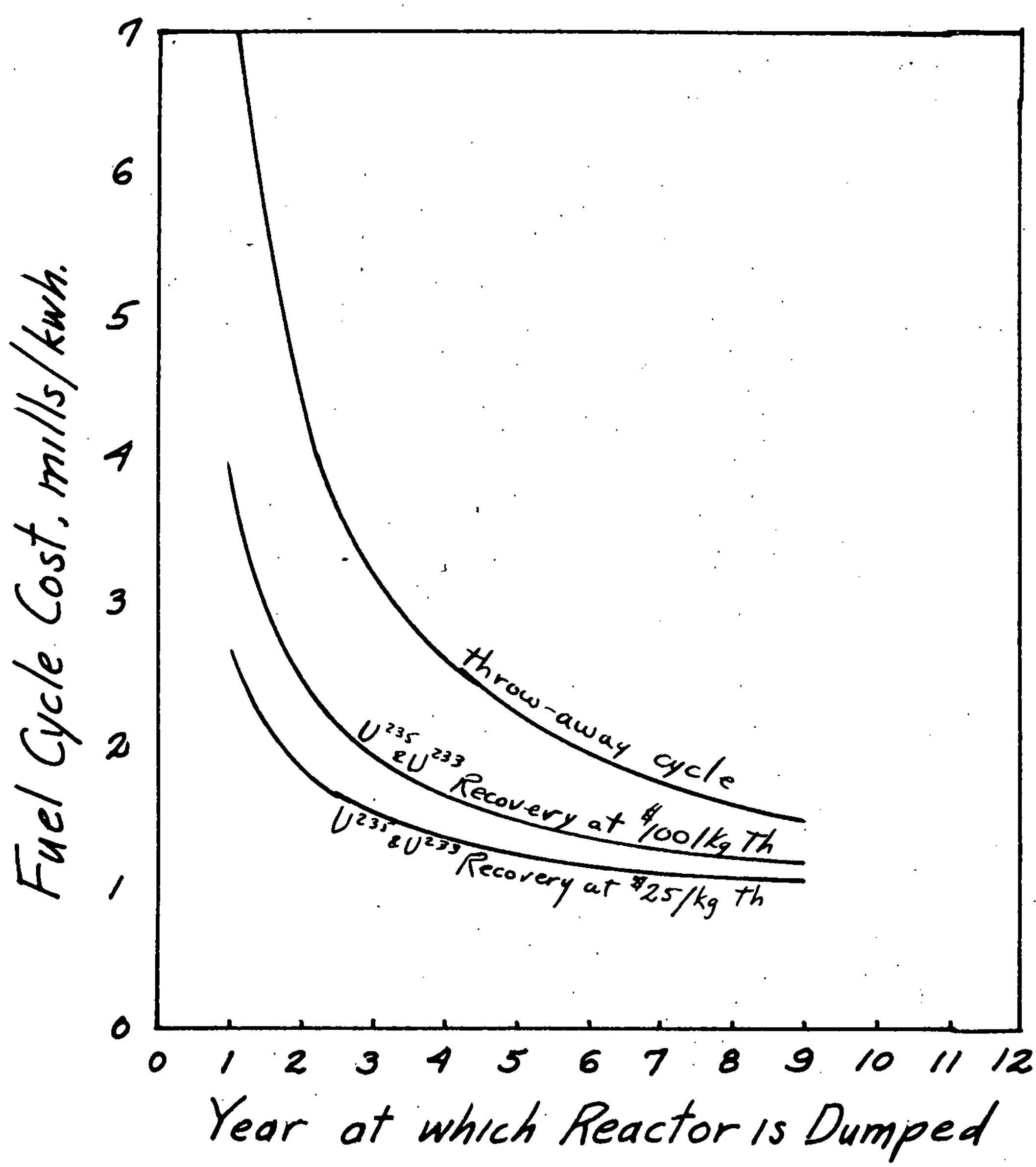


Fig. 4 Fuel Cycle Costs for 315 MWe Molten Salt Reactor with Continuous Fission Product Removal at Zero Cost

system. Thus ~0.3 mill/kwh is available to pay for the continuous fission product removal. This would be completely used up by either of the following:

(1) A $2,000,000 investment and $300,000 annual operating cost.
(2) A 60% increase in salt volume.

It is difficult to predict the additional investment, operating costs, and salt volume required for continuous fission product removal from the salt. It appears, however, that because of these additional costs there is not a strong economic justification for continuous reprocessing in this reactor. There may, however, be other reactor designs or justifications, such as preventing heat transfer fouling by precipitated fission products, for inclusion of a continuous fission product removal process. The following table shows a breakdown of the cycle costs for a 9-year cycle:

Nine-Year Fuel Cycle Cost Breakdown

| | Single Processing Cycle | Dual Processing Cycle |
|---|---|---|
| Use Charge on Initial U-235 Loading | 0.26 mills/kwh | >0.26 mills/kwh |
| Use Charge on U-235 Added on U-233 Buildup | 0.26 | 0.17 |
| Salt Amortization | 0.18 | >0.18 |
| U-235 Burnup | 0.58 | 0.37 |
| End of Cycle Reprocessing at $25/kg Th | .04 | .04 |
| Continuous F. P. Removal Charges | None | ? |
| | 1.32 | >1.02 |

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