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OPTIMIZING THE MIRROR (FUSION-FISSION) HYBRID REACTOR FOR PLUTONIUM PRODUCTION

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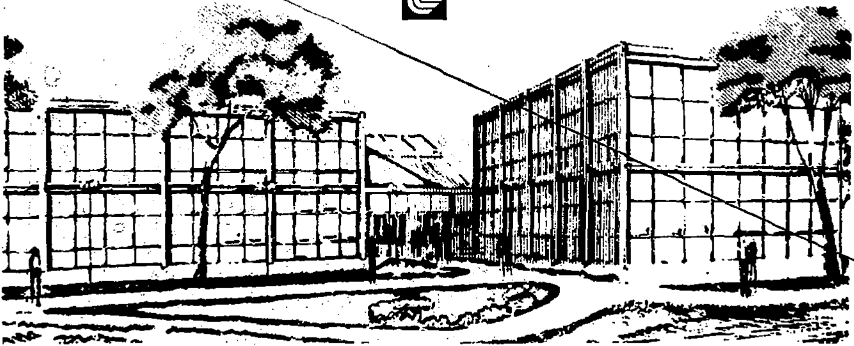

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OPTIMIZING THE MIRROR (FUSION-FISSION) HYBRID REACTOR FOR PLUTONIUM PRODUCTION

Last summer we completed a rather detailed point design of a conceptual Fusion Fission Hybrid reactor[1]. The reactor consists of a Mirror D-T Plasma core surrounded by a Fast Fission Blanket containing uranium and lithium. The principle reactions are D-T fusion producing 14 MeV neutrons which, in turn, induce U238 fission. The additional neutrons produced by fission are captured in Li and U238 producing tritium and Pu239. During the latter stages of that study it became evident we could substantially improve the economic performance by optimizing the performance of both the fusion core and the fission blanket. This presentation summarizes the results to date of our work to optimize this type of Hybrid for the production of Plutonium.

The methods we are using to do the optimization are outlined in Figure 1. An analytic model of the fusion components is used to generate a consistent set of fusion parameters, and component costs as parameters are varied. (This model is discussed by Carlson and Moir in another ANS presentation.)[2] A model of the blanket, based on neutronic and thermal hydraulics, is then used to analyze the trade offs of energy production vs. plutonium production dictated by blanket type and management. The third component of our hybrid analysis consists of an economic package that uses Cash Flow methods to determine Pu costs for various fuel management schemes. The economic package also contains an economic model of LWR's to calculate a consistent value for electricity costs from the hybrid and hybrid-fueled LWR's. The combination of all three models is used to minimize

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the cost of power from the Hybrid and the LWR's it fuels.

In addition to varying fusion core and fission blanket parameters we have also switched to a spherical blanket as shown in Figure 2. This switch was prompted by the desire to reduce the peak-to-average wall loading from ∿ 4/1 realized in the 'previous design', to the present value of ∿ 1/1, where 'previous design' refers to the point design described in UCRL-51797. This factor of 4 reduction in the peak-to-average wall loading allows a factor of 4 increase in the average wall loading without any increase in the peak blanket power density. Figures 3 and 4 show our thoughts of how 'spherical' blanket modules could be replaced.

Results to date of our optimization study are given in Figures 5, 6 and 7. Here again, 'previous' refers to the point design described in UCRL-51797. Economic parameters used to calculate the economic performance are given in Figure 8. The net effect of our optimization (Fig. 7) is nearly a factor of 4 reduction in the cost of Pu (35 $/gm vs. ∿ 130 $/gm) resulting in a 34% reduction (14.5 mills/kwh vs. ∿ 22 mills/kwh) in the cost of power from LWR's fueled by the Hybrid.

Neutronic performance of the blanket with two types of uranium fuel, uranium-carbide (UC) and uranium + 7 w/o molybdenum (U-MOLY) is displayed and compared in Figures 9-13. These results are for a 4 π blanket. The lower numbers listed in Figure 6 are effective numbers that reflect the fact that the blanket covers only 85% of the total spherical area. The U-MOLY fuel performs about 25% better than the UC fuel but the higher U-MOLY performance is partially offset by its temperature limit of ~ 600° C.

Parameter Variations. Figures 15-20 show the effects of varying single fusion component parameters. Figures 15 and 16 show the effect of varying the distance (L) between coil centers. First wall diameter is ~ 6 meters less than L. The 'MILLS/KW-HR' plotted in Figures 15-22 refers to the hybrid produced fissile material component of the cost of power from Hybrid fueled LWR's. The total cost of power from the Hybrid plus hybrid-fueled LWR's is the fissile material component plus 12 mills/kw-hr. The $/gm refer to the unit cost of hybrid produced plutonium 239.

The effect of varying vacuum mirror ratio [R(VAC)] is shown in Figure 17. As predicted, the 3.5 R(VAC) used in the previous design was way off optimum. The optimum mirror ratio is ~ 2.25 and results in about a factor of 3 decrease in Pu production costs.

Figure 18 shows the effect of operation at less than classically predicted confinement. Figures 19 and 20 show how the optimum mirror ratio changes if confinement is one-half the predicted value.

Optimization of blanket fuel management for both the UC and U-MOLY fueled blankets are shown in Figure 21. Here costs are plotted versus average burn up (fissions ÷ initial U atoms) at removal. The minima occur at ~ 0.5% burnup for both fuel types. Which, as shown in Figures 9 and 10, is realized after a 14 meV neutron exposure of ~ 2 MWY/M^2.

All the results given thus far have been for a mature nuclear park in which the average generating capacity is constant in time. We realize in an expanding capacity that hybrids must supply fissile fuel for new cores as well as for refueling. So far we have looked at this requirement in only a simplistic way, namely by setting aside 1 kg Pu 239 per 700 kw_{th} expansion. At a 10% per year expansion rate this results in a 1 $mill/kwh_e$ increase (from 14.5 to 15.5) in the cost of electrical energy produced from Hybrid fueled LWR's.

We have estimated that the mirror hybrid can produce Pu 239 for ~ 40 $/g. To put this cost in some perspective, it can be compared to the cost of U 235 from a diffusion plant. Figure 22 shows how U235 cost might scale with the cost of yellow cake. It appears that when ore prices reach the 70-100 $/lb range, hybrid produced fissile material could be competitive with U235 from enrichment plants.

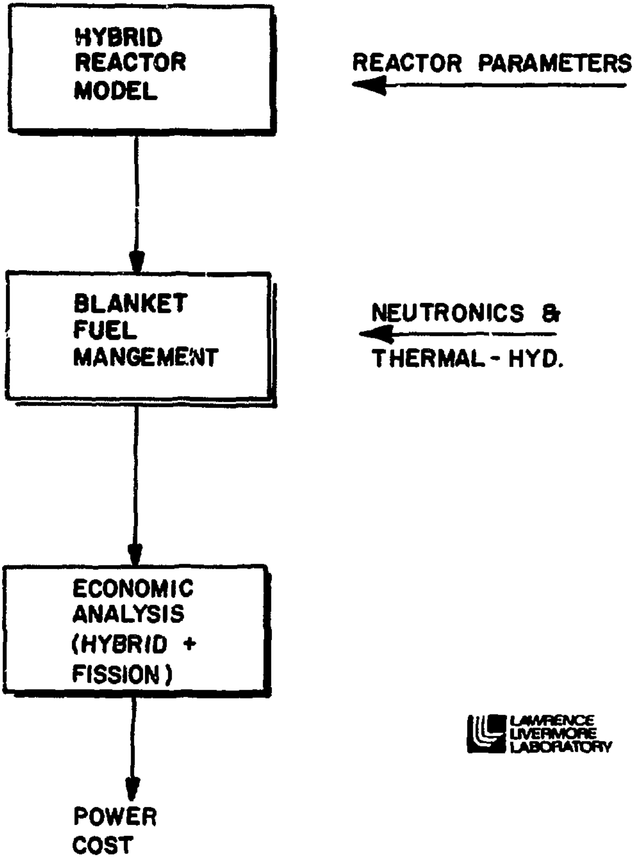
Results of our Mirror Hybrid work is most encouraging. Our efforts to date to optimize the Mirror Hybrid for Pu production have resulted in up to a factor of 4 reduction in Pu production costs (from ~ 150 $/g to 35 $/g) when compared to our previous point design (UCRL-51797).

The fissile producing Mirror does indeed appear to be an attractive concept, one that deserves much more study. A report on this work is in preparation.

REFERENCES

1. Moir, R. W., et al "Progress on the Conceptual Design of a Mirror Hybrid Fusion-Fission Reactor" UCRL-51797 (June 1975).
2. Carlson, G. A. and Moir, R. W., "Mirror Fusion Reactor Study" UCRL-76985 (November 1975)

HYBRID ANALYSIS



HYBRID REACTOR MODEL

REACTOR PARAMETERS

BLANKET FUEL MANGEMENT

NEUTRONICS & THERMAL - HYD.

ECONOMIC ANALYSIS (HYBRID + FISSION)

POWER COST

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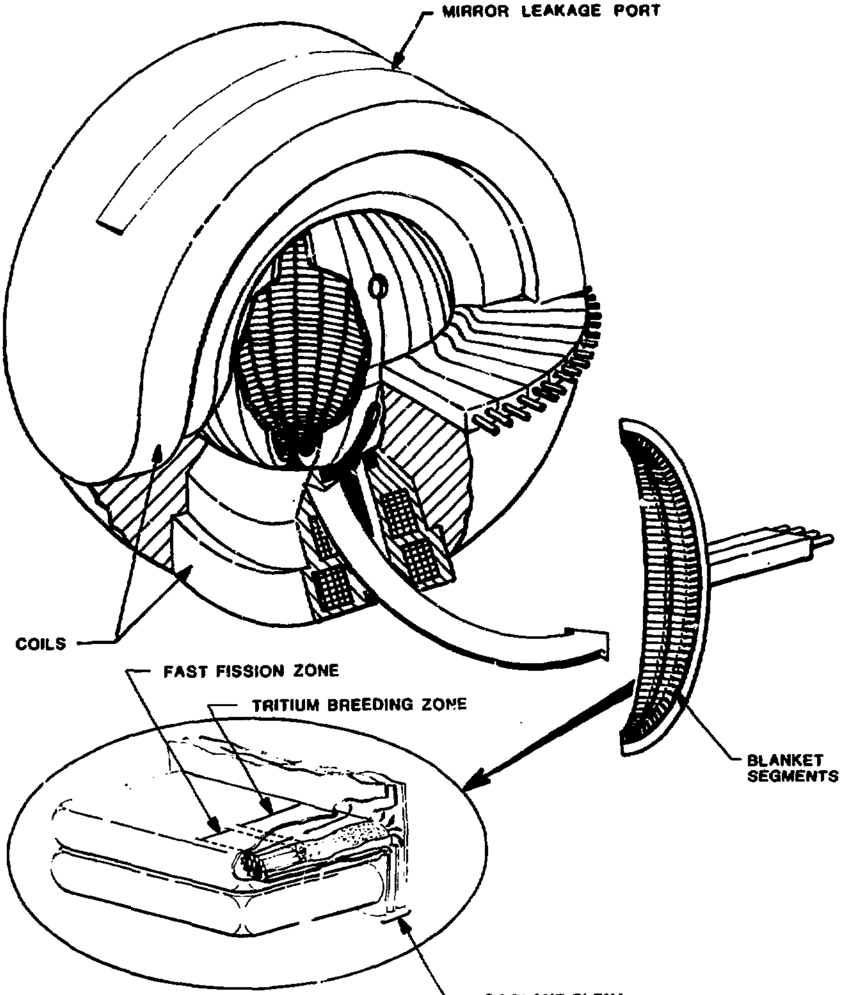
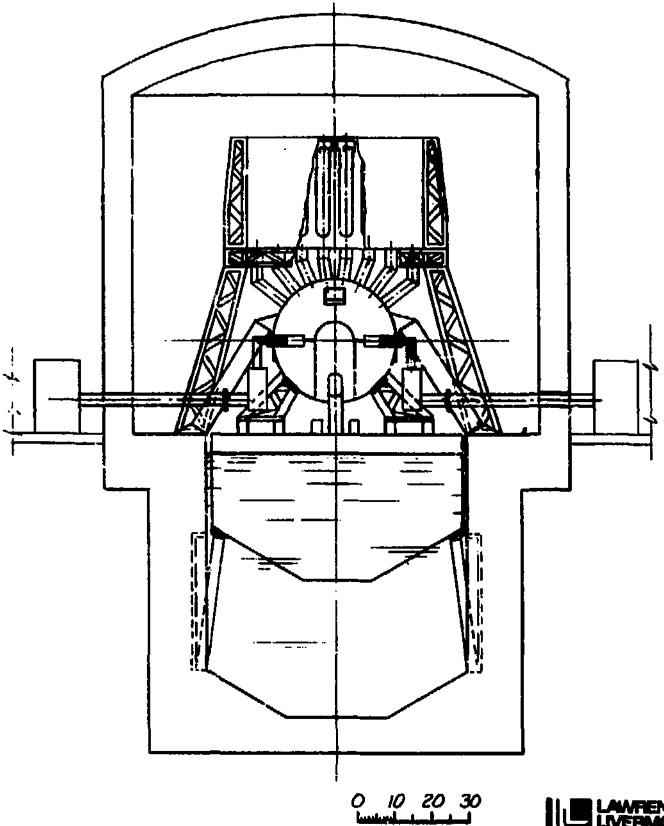


MIRROR FUSION-FISSION HYBRID REACTOR



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REACTOR - UPRIGHT DESIGN

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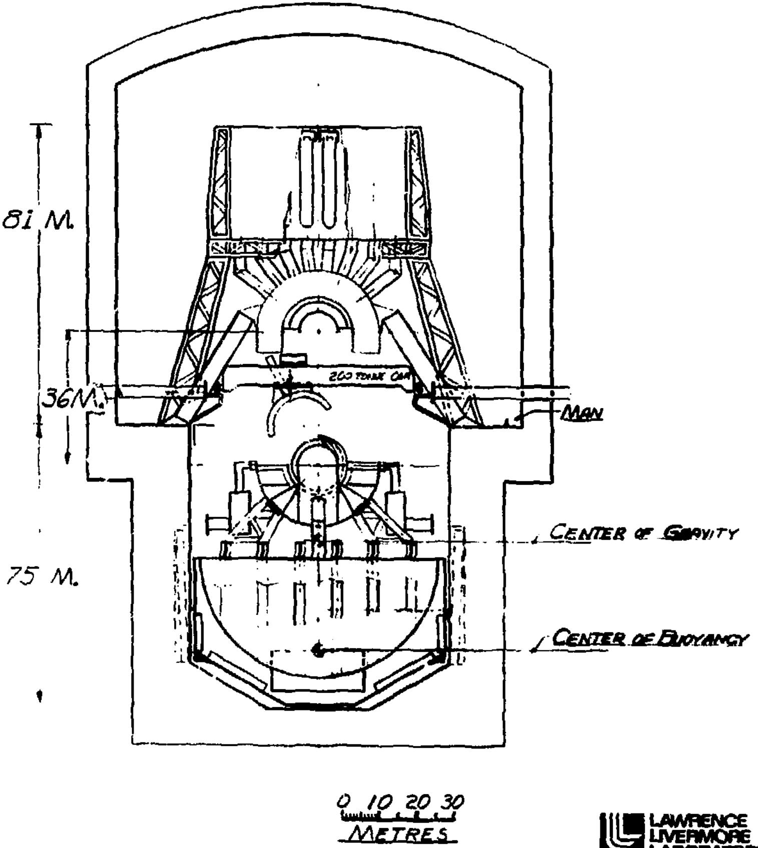

REACTOR - OPENED POSITION

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MIRROR HYBRID REACTOR

FUSION SYSTEM	NEW	PREVIOUS
MIRROR RATIO, VAC	2.25	3.50
PLASMA	4.33	7.83
DISTANCE BETWEEN MIRRORS (M)	17.5	25.0
INJECTION ENERGY, D^0 (KEV)	100.	100.
CONDUCTOR FIELD (T)	8.1	8.1
β	0.73	0.80
$n\tau$ (SEC/CC)	1.85×10^{13}	2.7×10^{13}
Q	0.64	0.94
CENTRAL PLASMA DENSITY (CM^{-3})	1.30×10^{14}	5.9×10^{13}
FUSION POWER DENSITY ($\mathrm{W/CM}^3$)	10.9	2.33
FUSION POWER (MW)	578.	210.
FIRST WALL FLUX ($\mathrm{MW/M}^2$)	1.15	0.84 x 0.06

	--NEW--		PREVIOUS
BLANKET	U-MOLY	UC	UC
NET Pu 239 BREEDING RATE (ATOMS/FUSION)	1.48	1.11	1.05
TRITIUM BREEDING RATE (ATOMS/FUSION)	1.00	1.00	1.25
FERTILE BURNUP (%)	0.5	0.5	4.0
ENERGY MULTIPLICATION, AVG.	10.4	8.0	12.0
PEAK FUEL POWER DENSITY (w/cc)	200.	150.	300.
THERMAL POWER (MW)	4170.	3220.	2020.
BLANKET AREA (M^2)	345.	345.	660.

	--NEW--		PREVIOUS
HYBRID OUTPUT	U-MOLY	UC	UC
FISSILE MATL (KG/YR)	3060.	2290.	690.
POWER (MWE) HYBRID	755.	604.	611.
THERMAL EFFICIENCY	0.176	0.181	0.30
NUCLEAR PARK OUTPUT (HYBRID + LWR'S)			
POWER (MWE)	6675.	5024.	1941.
THERMAL EFFICIENCY	0.293	0.293	0.313
COSTS			
CAPITAL COST ($KWE) HYBRID	2110.	2470.	1990.
NUCLEAR PARK	682.	737.	970.
ELECTRICITY (MILLS/KW-HR)	14.5	15.2	~22.
FISSILE MATL ($/GM)	34.6	44.2	~130.

ECONOMIC PARAMETERS

LWR

CAPITAL COST	500 \$/KWE
THERMAL EFFICIENCY	0.32
CONVERSION RATIO	0.5
GROSS FISSILE CONSUMPTION	0.41 KG/MW_T-YR
O & M	1 MILL/KW-HR
FUEL CYCLE w/o FISSILE MATL	1 MILL/KW-HR
CAPITAL COST CHARGES	10 MILLS/HW-HR

HYBRID

CAPITAL COST CHARGES	0.14/YR
INCOME TAX	0.5
LOCAL CHARGES	0.03/YR

(DISCOUNT FACTOR 6%/YR)

FUEL CYCLE

NATURAL U	\$23/KG
FABRICATION	\$70/KG HM (UC) \$50/KG HM (U/M)
PROCESSING	\$40/KG HM
SPENT FUEL SHIPPING	\$ 5/KG HM

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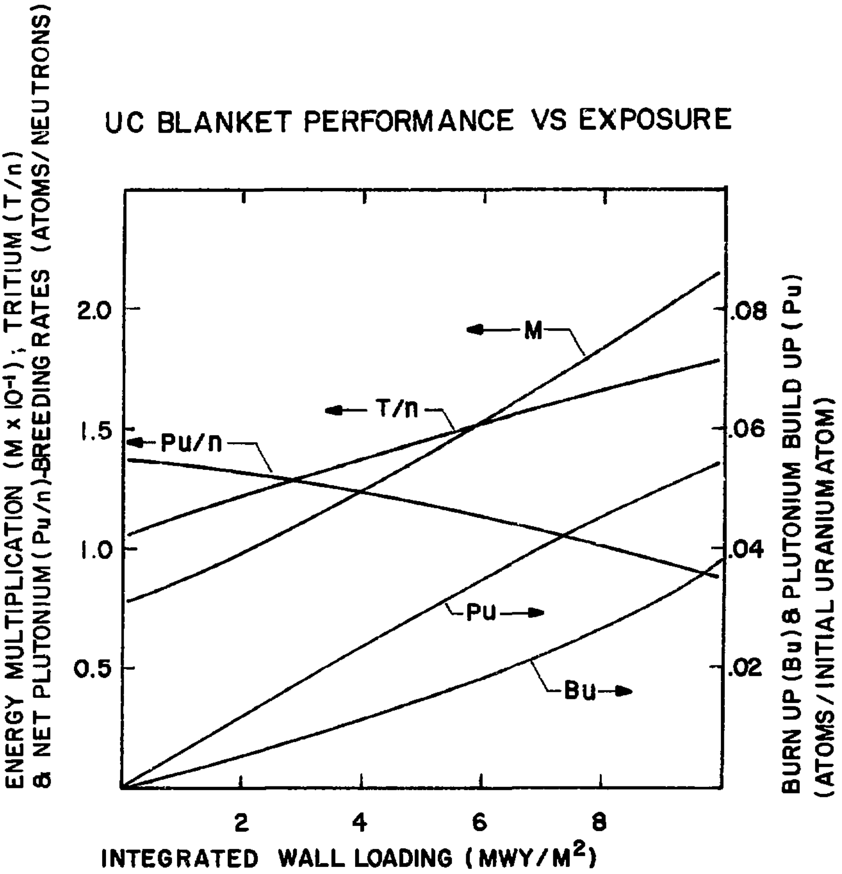
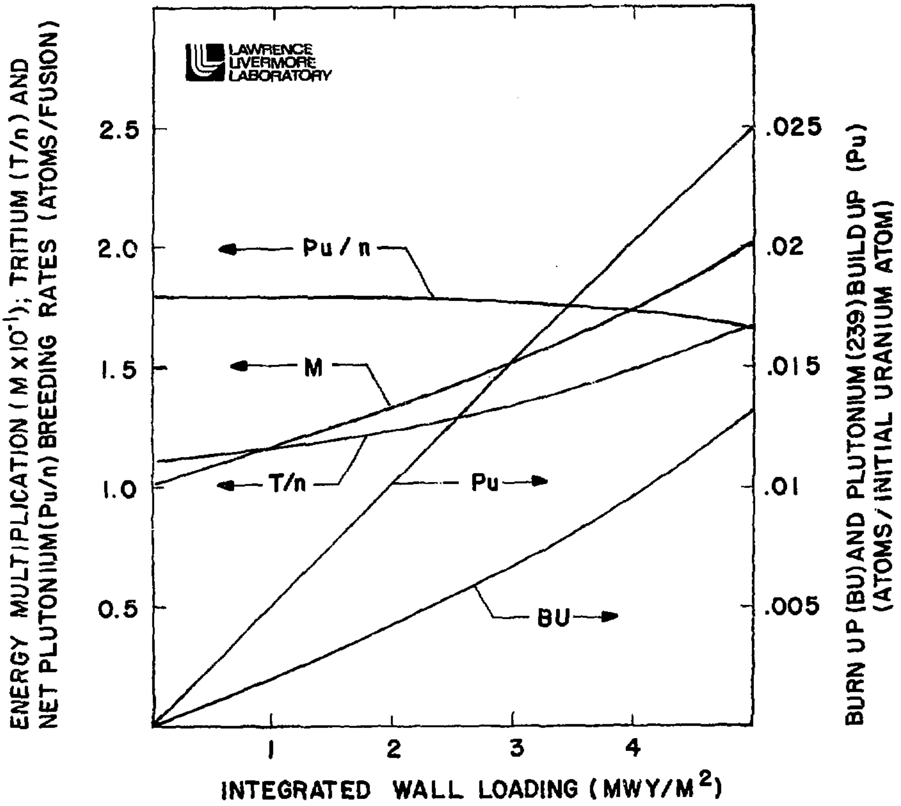
UC BLANKET PERFORMANCE VS EXPOSURE



U-MOLY BLANKET PERFORMANCE VS EXPOSURE



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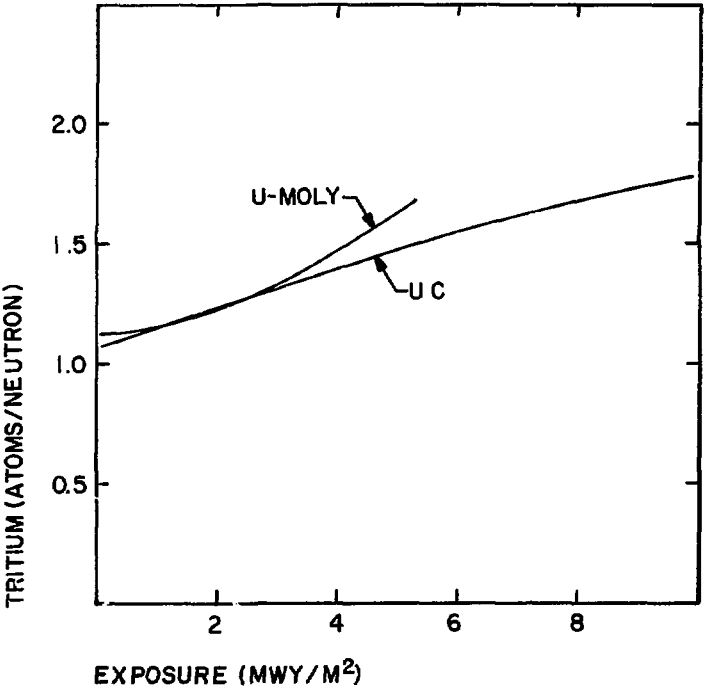
TRITIUM BREEDING RATIO



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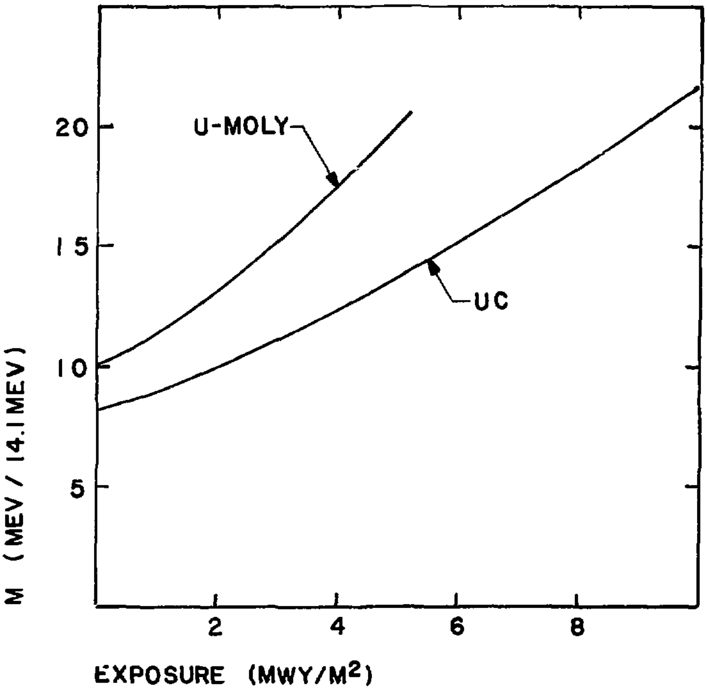
ENERGY MULTIPLICATION (M)



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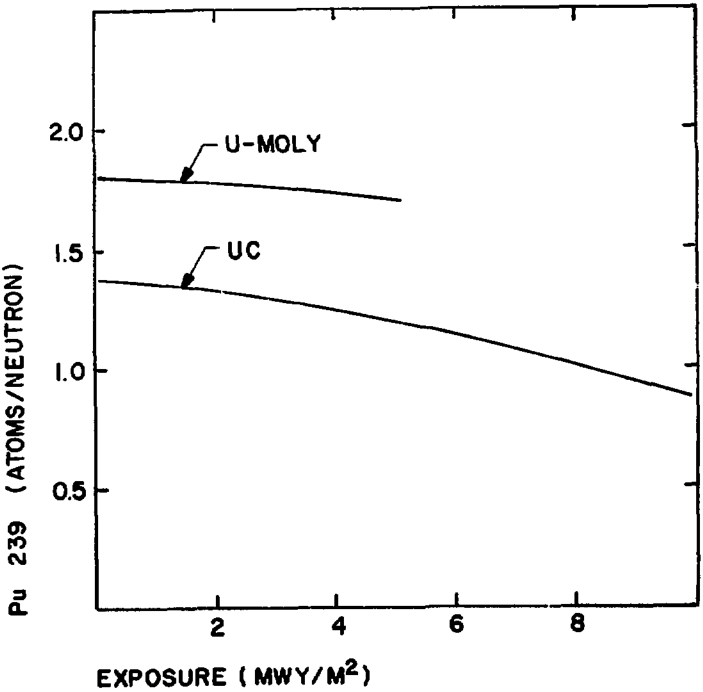
PLUTONIUM PRODUCTION RATIO (NET)



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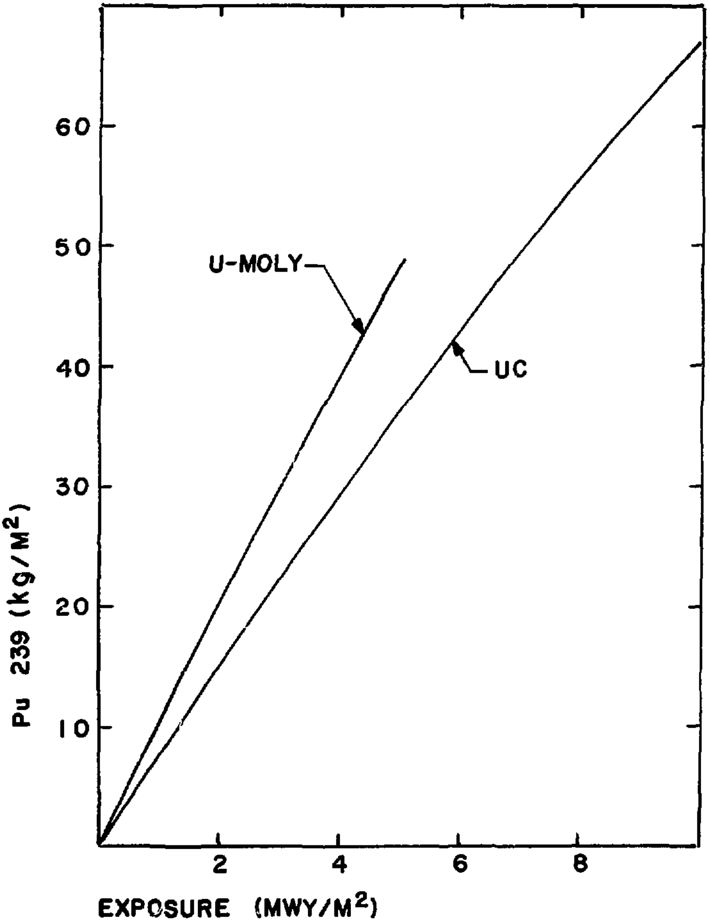
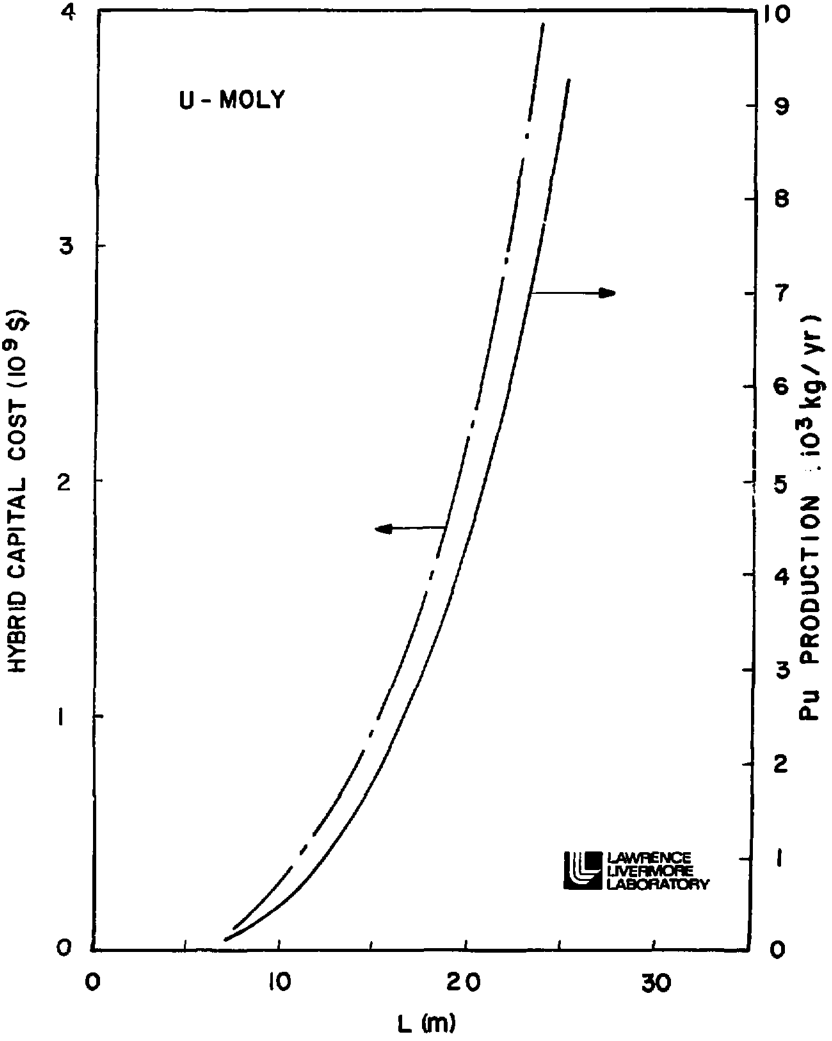
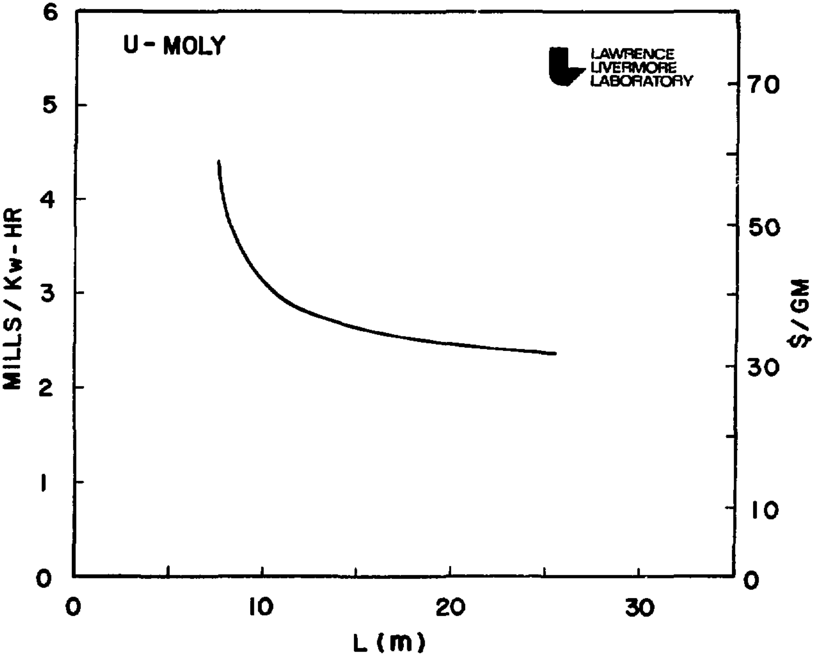
PLUTONIUM (239) ACCUMULATION



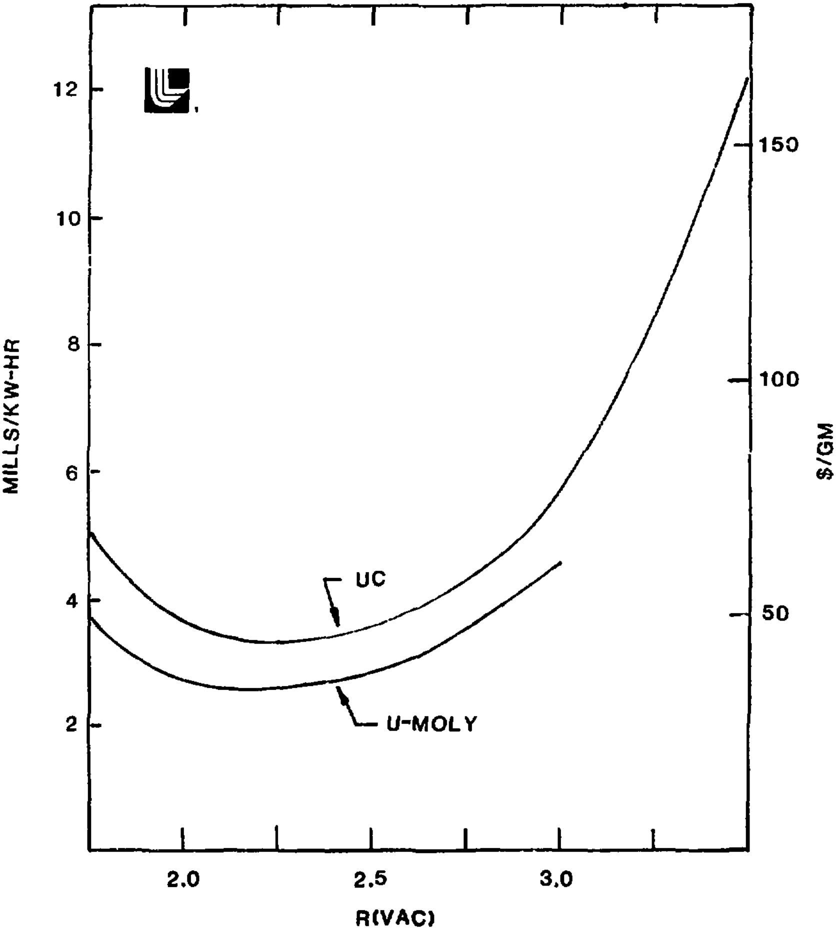
SIZE VARIATION OPTIMUM REACTOR & FM



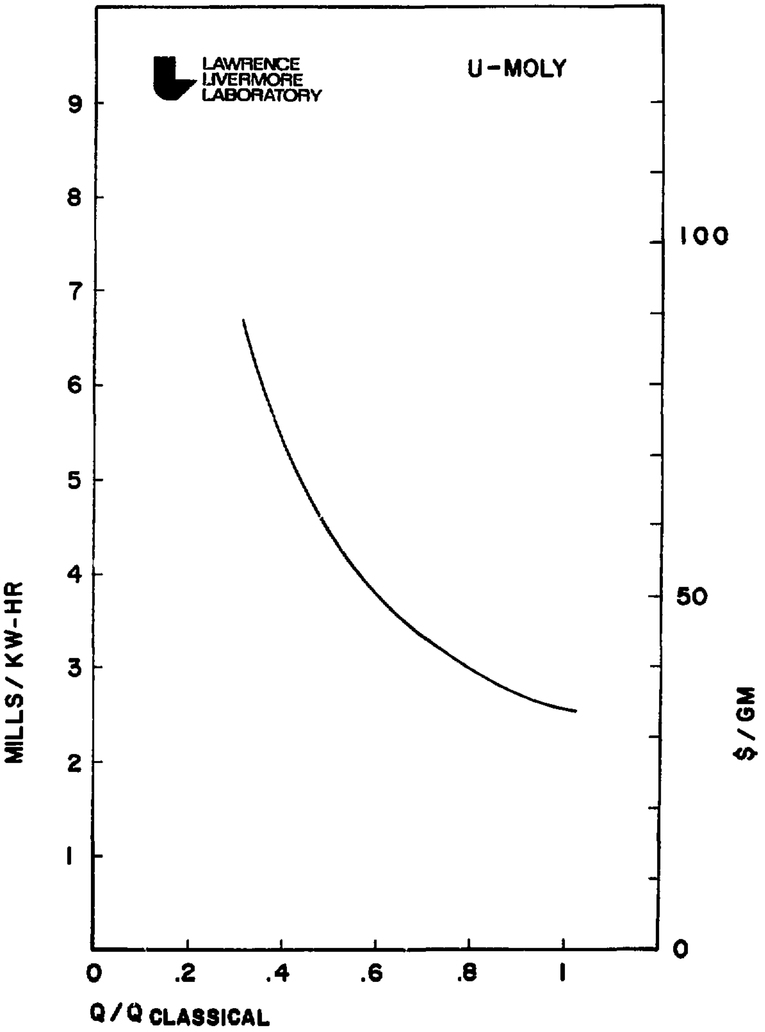
SIZE VARIATION OPTIMUM REACTOR & FM



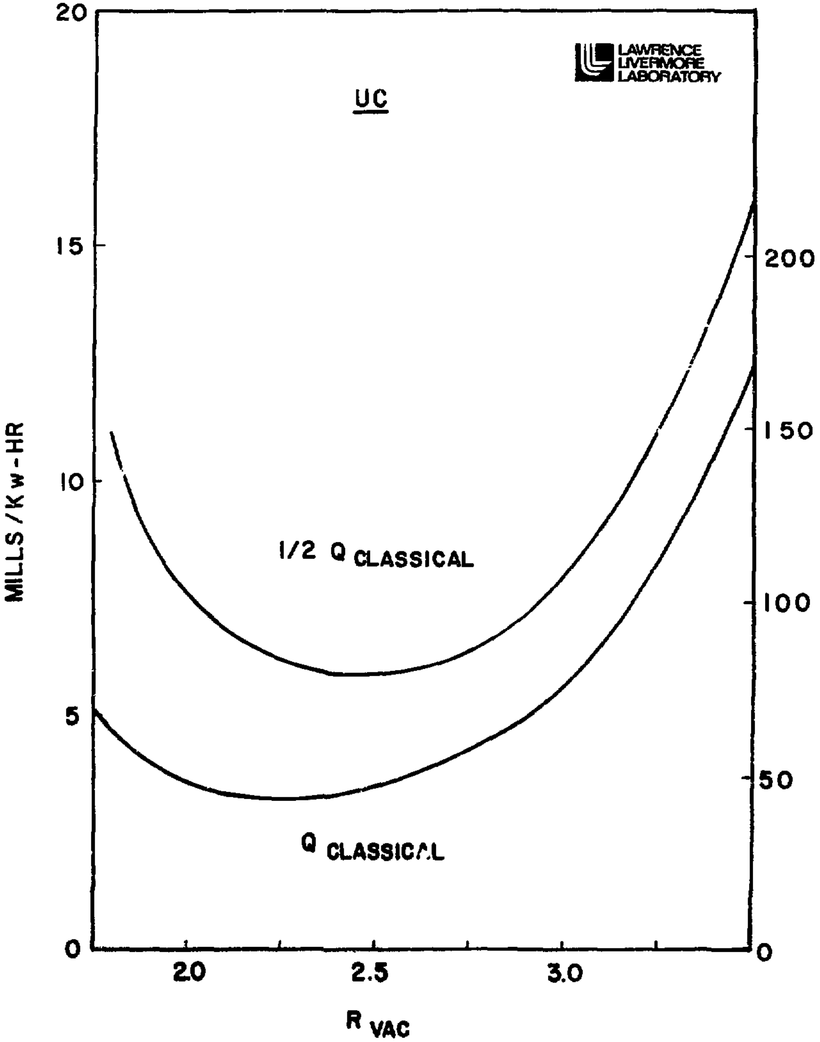
MIRROR RATIO VARIATION

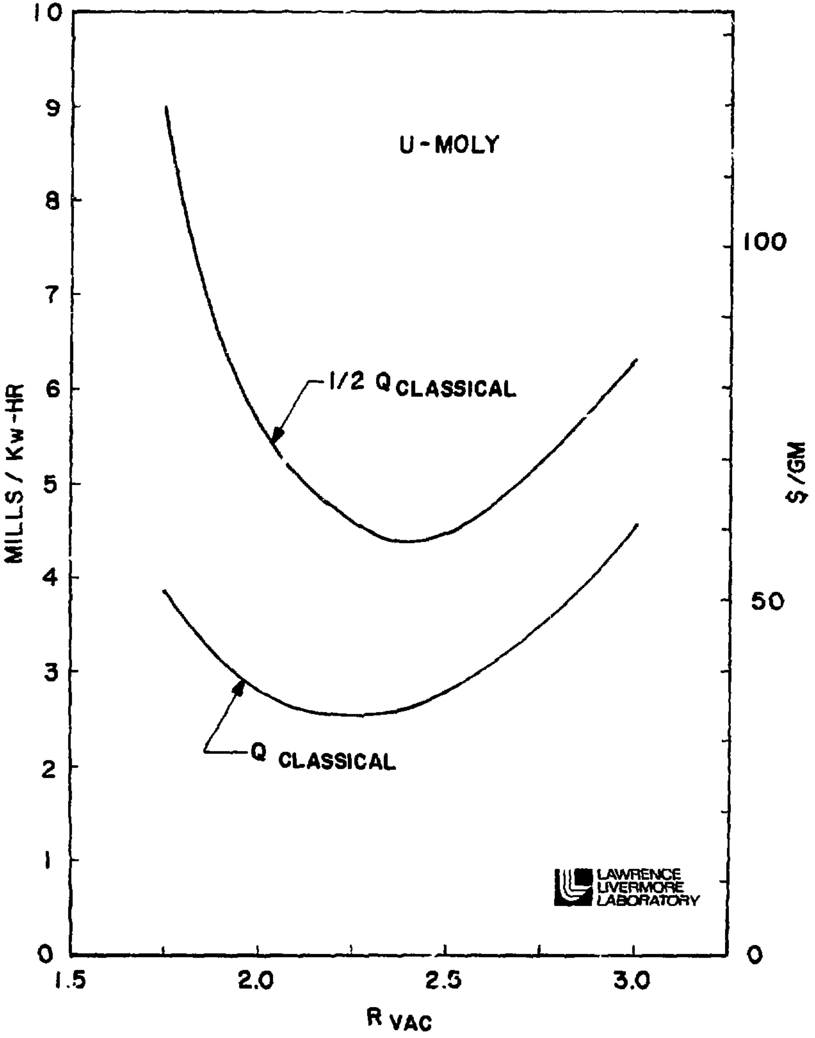


LOSS RATE OPTIMUM REACTOR & FM



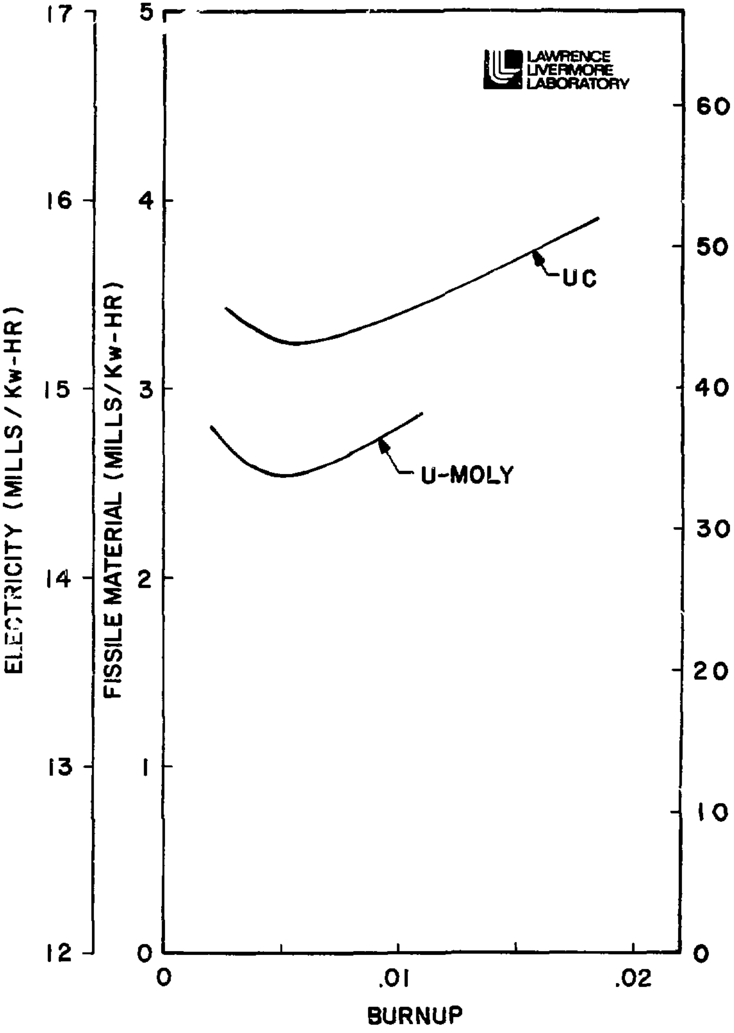
PARAMETER VARIATION OPTIMUM FM



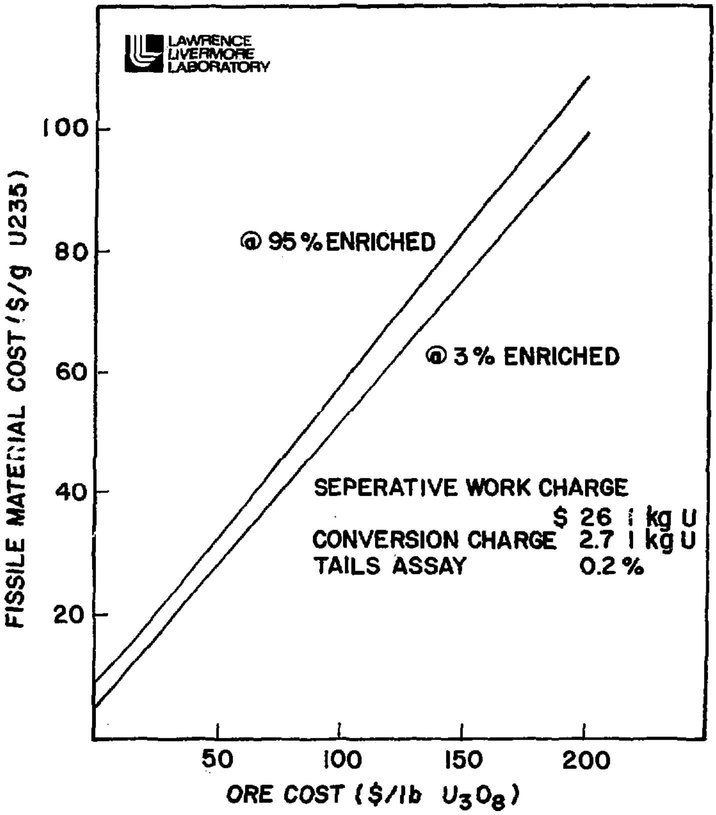


PARAMETER VARIATION OPTIMUM FM

FUEL MANAGEMENT



FISSILE URANIUM COST FROM A DIFFUSION PLANT VS ORE COST



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