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SUBJECT: SUMMARY OF LOW-ENRICHMENT RESEARCH REACTOR CALCULATIONS

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SUMMARY OF LOW-ENRICHMENT RESEARCH

REACTOR CALCULATIONS

Critical masses, neutron fluxes, power levels and fuel element specifications have been estimated as a function of uranium enrichment for the following types of research reactors:

1. MTR
2. Swimming Pool
3. Water Boiler
4. CP-5

The critical masses as a function of enrichment are given in Figure 1.

1. MTR

In order to keep the 25/Al ratio and the critical mass of a lower enrichment reactor as small as possible, the sintered UO_2-Al fuel elements should be used in preference to the U-Al alloy type of elements now in the MTR. The core of the sintered elements can contain as much as 50% UO_2 by weight, which gives a U density of 1.91 gms/cm^3 as compared with a maximum of 0.86 gms/cm^3 for the U-Al alloy. Calculations for the U-Al alloy fuel plate core give critical masses which are considerably larger than those for the UO_2-Al elements.

The calculations were made for the sintered elements containing the maximum allowable U; the cladding, spacing between plates and the over-all dimensions of the element were kept fixed to present MTR specifications. The thermal neutron flux was set equal to the MTR flux by keeping the amount of 25 per unit area of fuel plate the same as for the MTR and allowing the thickness of the core of the fuel plate to vary inversely with the fuel enrichment. Small differences in the critical mass can be obtained by changing the amount of 25 per unit area of fuel plate. These calculations are, however, preliminary and we have not attempted to optimize the variables.

The critical masses were calculated for a 30-cm Be + 2% H_2O reflector and for 18% excess reactivity. The results are summarized in Table 1.

In the MTR there are 23 fuel elements containing an average of 187 gms 25/element[1] which gives an average thermal flux in the core of 1.4×10^{14} n/cm^2-sec at 28 Mw. As the enrichment is lowered, the power must, of course, be increased to keep the same flux as shown in Table 1. The results show that fuel enrichments much below 20% lead to rather large critical masses and correspondingly large total powers if one wishes to maintain the high neutron flux of the MTR.

MTR Fuel Element Data

Length of fuel bearing region	24.63 in.
Total cross sectional area	68.26 in.^{2}
Side plate cross sectional area	0.3961 in.^{2}
Width of fuel plate (along arc)	2.772 in.
Thickness of cladding	0.015 in.
Thickness of fuel plate core	0.020 in.
Thickness of water channel	0.1178 in.

[1] J. W. Webster - Private Communication.

TABLE 1

Enrichment (%)	Core Thickness of fuel plate (inches)	number of plates per fuel element	$\frac{V_{Al}}{V_{H_2O}}$	Thermal utilization	Resonance escape probability	k_∞	Critical mass of 25 (kg)	Total Power (Mw)
10.4	.03972	17	.714	.7681	.933	1.498	23	151
20.6	.01998	19	.549	.7926	.959	1.589	6.9	45
35.6	.01159	20	.480	.7996	.973	1.626	4.8	31
MTR (93.5%)	.0200	19	.583	.8040	1.000	1.680	4.3	28

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2. Swimming Pool

The fuel element specifications are the same as those for the MTR type reactor. The excess reactivity requirement, however, is only 5%, resulting in a somewhat lower critical mass. The reflector is 15 cm of Be surrounded by water.

The critical mass for the swimming pool at full enrichment is about 3 kg, which gives an average thermal flux of 0.7×10^{12} n/cm^2-sec at 100 kw power. The total powers required to give the same flux for the lower enrichment fuels and critical masses are given in Table 2.

TABLE 2

Enrichment	Critical mass of 25 (kg)	Total power (kw)
10	8.4	280
20	4.2	140 ← 701 gm U 140 gm 25/el
30	3.4	113
93.5%	3	100

3. Water Boiler

The critical mass of the water boiler increases much less with decreasing U enrichment than does the critical mass of the MTR. Some of E. Greuling's calculations[2] for the minimum mass of 25 as a function of U enrichment, total U concentrations, powers for a thermal flux of 10^{12} n/cm^2-sec, and power densities are given in Table 3.

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[2] E. Greuling, "Theory of Water-Tamped Water Boiler," LA-399.

TABLE 3

Enrichment (%)	M_{25} (kg)	Diameter (cm)	U conc. (gms/l)	Total power (Ave. thermal flux of 10^{12} n/cm^2-sec)	Power Density (kw/l)
5	2.90	50	890	138	2.1
10	1.75	38	610	83	2.9
20	1.30	31	420	62	4.0
93.5	0.98	24	145	47	6.5

4. CP-5

As in the MTR type reactors there is a strong incentive for using the UO_2-Al fuel plates to decrease the neutron losses in Al. There is, however, more leeway in the design of the CP-5 type because of the use of D_2O moderator.

We have considered MTR type fuel elements containing eight plates per assembly. In all cases the core of the fuel plates are 0.02 inch thick and are clad with 0.015 inch of Al. As in the CP-5, the critical mass calculations allow for 11% excess reactivity. The critical mass and power for an average thermal flux of 2.3×10^{13} n/cm^2-sec are given in Table 4.

TABLE 4

Enrichment (%)	Mass of 25 (kg)	Power (kw)
10	1.84	1630
20	1.31	1160
93.5	1.13	1000

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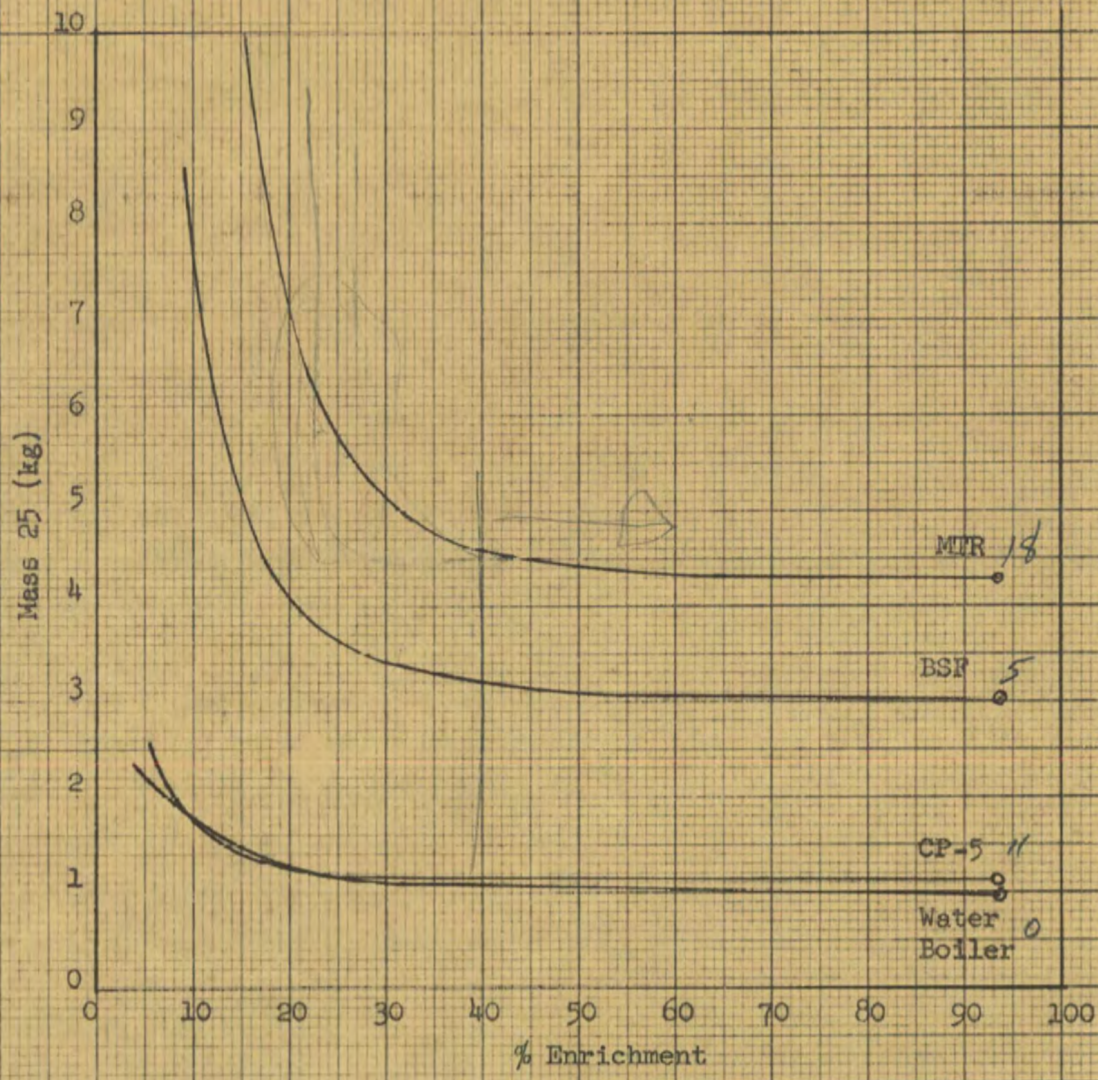

Fig. 1

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