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August 16, 1977

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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COST ESTIMATE FOR ELECTROSTATICALLY PLUGGED CUSP REACTOR^{*}

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ABSTRACT

A preliminary design of an electrostatically plugged cusp reactor was presented in Ref. 1. The capital costs of the various components of this reactor are estimated and totaled for two different blanket configurations: one having an energy multiplication factor $M = 1.2$, and the other having $M = 1.68$. The unoptimized direct capital costs for these cases are found to be about 1400 and 950 \$/kWe, respectively.

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^{*} Work performed under the auspices of the U.S. Energy Research and Development Administration under Contract No. W-7405-Eng-48.

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Introduction

It may be possible to construct a fusion reactor using a combination of electric and magnetic fields for plasma confinement. A preliminary design of such a reactor was studied in Ref. 1. The coils for the reactor are illustrated in Fig. 1, and the main parameters are listed in Table 1. The purpose of the present work is to estimate the direct capital costs of the components of such a reactor.

Fig. 1. Toroidal multipole cusp coils with $N = 6$ cusps for an electrostatically plugged cusp fusion reactor (Ref. 1).

Table 1. Parameters of an electrostatically plugged cusp fusion reactor
(Ref. 1)

Configuration: toroidal multipole cusp with $N = 6$ cusps

minor and major plasma radii	2.8 m, 9.5 m
coil current x length	2.3×10^{10} A-m
chamber minor and major radii	3.6 m, 10 m
blanket & shield thickness	1.5 m
magnetic field in cusps	8 T
applied voltage	300 kV
electron density	10^{20} m^{-3}
ion temperature	16.5 keV
electron temperature	17 keV
ion potential barrier	140 keV
electron potential barrier	88 keV
fusion power density	1.9 MW/M^3
first wall neutron power flux	1.6 MW/m^2
power gain ratio Q	5.2
thermal conversion efficiency (assumed)	0.4
input power to cathodes	533 MW
power balance:	see Fig. 2

Power Balance

It is assumed that startup takes 10 sec, fusion burn lasts 75 sec, and flushing takes 15 sec. The input power of 533 MW is on for 85 sec out of the 100 sec cycle, for an average input power of 453 MW. The difference of $533 - 453 = 80$ MW is supplied from an energy storage unit with capacity of $80 \text{ MW} \times 85 \text{ sec} = 6.8 \text{ GJ}$, in order to maintain constant values of recirculating power

and output power. In addition to the 453 MW power input, 30 MW are needed for helium pumping (scaled up from the mirror reactor design²), 34 MW are needed for refrigeration, and it is assumed that 10 MW are needed for other auxiliary systems, for a total of 527 MW of recirculating power.

Two cases are considered: a blanket with multiplication factor $M = 1.2$, and a blanket containing lithium-beryllium fluoride (FLIBE) with $M = 1.68$, as shown in Fig. 2.

The reactor Q is assumed to be constant at 5.2, which was calculated assuming a 1% Al impurity. In reality, the Q would be higher initially, dropping off with time as helium ash and impurities accumulate. The thermal energy capacity of the blanket is used to smooth out the variations of thermal input, including the 25 sec off period for flushing and startup. For example, in the case of $M = 1.68$ blanket, about $3671 \text{ MW} \times 25 \text{ sec} = 92 \text{ GJ}$ are removed from the blanket during the off period. The blanket contains 1860 tons FLIBE with heat capacity of 2.35 J/gm-K , so the blanket temperature drop during this period is about 21 K. This will probably be an acceptable perturbation, since the coolant flow rates can be adjusted to maintain a constant turbine power. (A temperature drop of 50 K was allowed in the PRD³, Princeton Reference Design.)

Buildings and Site Facilities

The reactor building is taken to be a cylinder with radius = height = 35 m, topped by a hemispherical dome, so that its volume is $2.24 \times 10^5 \text{ m}^3$. The cost is estimated from the equation⁸

$$\text{Cost} = 196 \text{ M\$} (\text{Volume}/1.58 \times 10^6 \text{ m}^3)^{0.85} = 37 \text{ M\$} .$$

The hot cell buildings are estimated to cost one-third of this amount, or 12 M\$. The site is estimated to cost 2 \$/kWth; the steam turbine buildings,

M = 1.2 BLANKET CASE

M = 1.68 BLANKET CASE

Fig. 2. Power flow diagrams for cusp reactor. Power flows are in MW.

6 \$/kWth; the auxiliary buildings, 2 \$/kWth; and miscellaneous buildings, 3 \$/kWth, for a total of 13 \$/kWth.

The total cost of buildings and site facilities for the $M = 1.2$ blanket case ($P = 2.87$ GWth) is 86 M\$. For the $M = 1.68$ blanket case ($P = 3.671$ GWth), the cost is estimated to be 97 M\$.

Superconducting Magnets and Coil Winding

It is assumed that the cost of the magnets, including conductor, insulation, fixtures, winding, and installation, is 0.00348 \$/A-m of conductor, as it is for the mirror reactor design.² Since the cusp reactor requires 2.3×10^{10} A-m, the cost is 80 M\$.

Coil Structural Support

Trusses:

To estimate the required mass of structural material required, the simplified truss design illustrated in Fig. 3 is considered. For simplicity, it is assumed that the joints are pinned, so that all the stress is either tensile or compressive. If rigid joints are made and bending stresses can share the load, then less mass may be required. From analysis of the structural members in Fig. 3, it is found that $F_4 = F_5 = 0.58 F_1$, and F_6 is very small.

The truss is designed to limit coil motion to about 1 cm, which represents a contraction of F_5 and F_4 of about 1.15 cm, or a strain of 0.00577. Assuming that the trusses are located 2 m apart along the coils, the force F_1 is 17.4×10^7 N, and $F_4 = F_5 = 1.01 \times 10^8$ N. Taking the modulus of elasticity to be 2×10^{11} N/m², the required area of truss members F_4 and F_5 is $A = 0.0875$ m². If the cross section were circular, the length-to-diameter ratio would be 6, so buckling will not occur.

Fig. 3. Simplified truss design

The mass of one truss member is then found to be 1400 kg, and the lightly stressed member F_6 is taken to have a mass of 600 kg. The total mass of each truss is therefore 6200 kg. With a spacing of 2 m apart, a total of 188 trusses are required, for a total mass of 1.2×10^6 kg. (The actual truss spacing varies, but the total mass will remain the same, since trusses further apart must be stronger.) It is assumed that the cryogenic stainless steel trusses can be fabricated and installed for 11 \$/kg. The truss cost is therefore 13.2 M\$.

Hoops:

The hoop radius is increased from the original 8.0 m out to 9.5 m, in order to lengthen the fiberglass columns, so the total hoop mass is increased to 5.0×10^6 kg. The hoops may be made of plain carbon steel, since they are at room temperature and well outside the electrode region. It is assumed that the hoops (or bundles of cables) can be fabricated and installed for 6.0 \$/kg, giving a cost of 30 M\$.

Fiberglass columns:

For simplicity, only three fiberglass columns will be used per truss, as illustrated in Fig. 3. For the nominal 2 m truss spacing, the areas of the columns are found to be

$$A_{\text{edge}} = F_2/\sigma = 1.68 \times 10^7 \text{ N} / 7 \times 10^7 \text{ N/m}^2 = 0.24 \text{ m}^2 .$$

$$A_{\text{center}} = F_1/\sigma = 17.4 \times 10^7 \text{ N} / 7 \times 10^7 \text{ N/m}^2 = 2.49 \text{ m}^2 .$$

With the 1.5 m increase in length, the column lengths are $L_{\text{edge}} = 2.0$ m, $L_{\text{center}} = 2.3$ m. The total volume of fiberglass required is

$$V_f = 188(2A_{\text{edge}}L_{\text{edge}} + A_{\text{center}}L_{\text{center}}) = 1260 \text{ m}^3 .$$

Larger truss spacings result in larger required column areas, but fewer columns, and the total required volume remains the same. The density of the fiberglass is about 1900 kg/m^3 , so the total mass of columns is $2.39 \times 10^6 \text{ kg}$. It is assumed that the installed cost of the fiberglass columns will be about $2 \text{ \$/kg}$.¹¹ (This is about twice the materials costs given in Ref. 6). The column cost is then $5 \text{ M\$}$. The total cost of supports is $13 + 30 + 5 = 48 \text{ M\$}$.

Cryostats:

The surface area of the six trapezoidal cryostats is found to be 5880 m^2 . It is assumed that the cryostats (magnet coil thermal shields) can be fabricated and installed for $2000 \text{ \$/m}^2$,² which gives a cost of $12 \text{ M\$}$.

Refrigeration:

The heat leak through the fiberglass columns is calculated from

$$q = 188 \text{ k}\Delta T(2A_{\text{edge}}/L_{\text{edge}} + A_{\text{center}}/L_{\text{center}}) = 19.4 \text{ kW},$$

taking $k = 0.26 \text{ W/m-K}$ and $\Delta T = 300 \text{ K}$.

Taking the layer of superinsulation on the cryostats to be 3 cm thick, the heat leak through the cryostat faces is

$$q = kA\Delta T/\Delta x = 1.5 \times 10^{-6} \text{ W/K-cm}(5.86 \times 10^7 \text{ cm}^2)300 \text{ K} / 3 \text{ cm} = 8.8 \text{ kW}.$$

The heat deposited in the PRD coils is 95 kW , from a wall loading of 1.76 MW/m^2 (neutrons). The cusp reactor with the $M = 1.68$ blanket has the same blanket and shield, but a wall loading of 1.6 MW/m^2 (neutrons), so the heat deposited should be 86 kW . It is assumed that the $M = 1.2$ blanket case will have the same heat load.

The heat load on the liquid-helium-cooled cryopanel is 0.44 W/m^2 (1000 m^2) = 0.4 kW . The total heat load is

$$q = 19 + 9 + 86 + 0.4 = 114 \text{ kW},$$

which must be removed by the refrigeration system. For large cryogenic refrigeration systems, each thermal Watt removed required about 300 W of electrical power,⁶ so 34 MW of refrigeration power are required for the cusp reactor.

The cost of the refrigeration system is estimated from the equation²

$$\text{Cost} = 3(2.1) 6000(P_{\text{in}, \text{KW}})^{0.7} = 56.2 \text{ M\$} .$$

A major cost reduction can be attained by reducing the neutron heat load on the superconducting coils from 86 kW to below 10 kW.

Vacuum Chambers:

For a cylindrical steel vacuum chamber in which stiffeners are used to give an effective length/diameter ratio of one, the required ratio of thickness to diameter is about 0.0042. Since PE-16 was chosen as the $M = 1.68$ blanket structural material, it will be used for the vacuum chamber walls, too. The lengths, diameters, thicknesses, and volumes of the various chambers are summarized in Table 2. The density of PE-16 is 8020 kg/m^3 , so the total mass required is $2.41 \times 10^6 \text{ kg}$. It is assumed that the chambers can be fabricated and installed for a cost of 11 \$/kg, resulting in a cost of 26.5 M\$. An additional 5 M\$ will be added on for a first wall radiation shield, which has not been designed, bringing the vacuum chamber cost up to 32 M\$. The same vacuum chamber cost is assumed for the $M = 1.2$ blanket case.

Table 2, Vacuum chamber steel volume requirements

<u>chamber</u>	<u>L(m)</u>	<u>D(m)</u>	<u>t(m)</u>	<u>volume of one</u>	<u>number required</u>	<u>total volume(m³)</u>
main	$2\pi R = 63$	7.2	.030	43	1	43
sidewalls	63	height=4	.030	7.6	12	91
pumping ducts	8.4	1	.004	.106	48	5
ion collector (hemi- spherical ends)	6	3.5	.015	1.28	24	31
electron gun (hemi- spherical ends)	5	2.5	.011	.540	48	26
HV feedthrough tubes	2	1.5	.007	.066	288	19
TOTAL FOR ALL CHAMBERS						215 m ³

This is multiplied by a factor of 1.4, to account for stiffeners, flanges, etc., so the required volume is estimated to be 301 m³.

Vacuum System

To keep the pressure in the vacuum pumping chambers below 10^{-5} Torr during flushing, the cryopanel pumping speed must be 10^5 m³/sec. The pumping speed of baffled cryopanels is 1/11 that of a "black hole" (orifice), so

$$S \text{ (m}^3\text{/sec)} = 1170 A / 11 = 106 A$$

where A = panel area (m²). The required panel area is therefore 943 m². We will use 1000 m² of panels. The unit cost of cryopanels (at liquid He temperature), liquid nitrogen panels, and thermal shields is 175 \$/ft² = 1880 \$/m². Thus, the total cost of the cryopumps is 1.9 M\$. The peak throughput is 3.5×10^{20} molecules/sec = 142 Pa-m³/sec.

The cryopumps are to be backed up by turbomolecular pumps, each having a 1500 liter/sec speed. Taking the pressure between the cryopanel and the turbopumps to be 10^{-3} Torr, their total pumping speed is

$$S = Q/P = (140 \text{ Pa-m}^3/\text{sec})/0.13 \text{ Pa} = 1090 \text{ m}^3/\text{sec}.$$

The required number of turbopumps is $1090/1.5 = 730$. Their cost is about 5 k\$ each, for a total cost of 3.7 M\$. During operation at times other than flushing, the throughput and pressures will be an order of magnitude lower. It is assumed that mechanical pumps, valves, gages, etc. will cost another 3 M\$, so the total cost of vacuum equipment is $1.9 + 3.7 + 3 = 8.6$ M\$.

Blanket

The blanket and shield thicknesses are taken to be 0.74 and 0.80 m. The blanket volume is calculated from its thickness t_b , the wall radius $r_w = 3.6$ m, and major radius $R = 10$ m to be

$$V_b = 2\pi^2 R [(r_w + t_b)^2 - r_w^2] = 1160 \text{ m}^3.$$

For the $M = 1.68$ case, the blanket of the PRD³ is used. That blanket was estimated to cost 20.4 k\$/m³. Assuming an escalation factor of 1.3, the cost is 27 k\$/m³, for a total cost of 31 M\$.

For the $M = 1.2$ case, the blanket is assumed to consist of 70% lithium aluminate (density 2550 kg/m³) costing 25 \$/kg, 18% stainless steel (density 7900 kg/m³) costing 22 \$/kg, and 12% helium void.^{9,10} These figures give an average cost of 76 k\$/m³, and a total blanket cost of 88 M\$.

That the $M = 1.2$ blanket appears to cost more than the $M = 1.68$ blanket is probably due to the different assumptions used in the cost estimates. In Ref. 3 (the basis for the $M = 1.68$ case) the minimum probable

costs were used, while the cost bases used in Ref. 9 (the basis for the M = 1.2 case) are probably overestimates.

Shield

The shield volume, including shields in the cusp gaps with the $x = 1$ m and length $y = 2$ m, is calculated to be

$$V_s = 2\pi^2 R[(r_w + t_b + t_s)^2 - (r_w + t_b)^2] + 12(2\pi Rxy) = 3382 \text{ m}^3.$$

The shield is chosen to be identical to that of the PRD³, composed of iron and heavy, borated concrete, at a unit cost of 12 k\$/m³. It is assumed that additional biological shielding will cost about 5 M\$, bringing the total shielding cost to 46 M\$.

Electrodes, Feedthroughs, Collimators

No analysis has been made of these items. It is assumed that they will cost about 2 M\$.

Instrumentation and Control Systems

Instrumentation and control systems are assumed to cost 7 \$/kWth, as for the mirror reactor², which gives costs of 20 and 26 M\$ for the M = 1.2 and M = 1.68 cases.

Power Supplies

The plugging cathodes require 1.78 kA at 300 kV direct current (533 MW). The current cost of an 8 MW high voltage dc supply is around 75 \$/kW for the transformer-rectifier tank, and about 28 \$/kW for the

regulator/control system.¹⁰ The tanks for a 550 MW system are estimated to cost about 40 \$/kW, and the regulators would cost less than the above 28 \$/kW.¹⁰ Therefore, we will assume a cost of about 70 \$/kW for the high voltage power supplies, which comes to 39 M\$ for a capacity of 550 MW.

Energy Storage System

The 6.8 GJ energy storage system is chosen to have a capacity of 14 GJ, so that only half the energy is drained off during normal operation. The cost is estimated on the basis of 15 M\$/3.6 GJ plus 15 \$/kWe for the ac-dc conversion system (here 550 MW) to be 67 M\$.

Heat Transfer System

Assuming a cost of 37 \$/kWth, the cost of the heat transfer systems comes to 106 M\$ for the $M = 1.2$ case, and 136 M\$ for the $M = 1.68$ case.

Thermal Conversion System

The cost of the turbines, generators, feed heaters, condensers, cooling towers, etc. is assumed to be 28 \$/kWth, as for the mirror reactor. This gives costs of 80 and 103 M\$ for the $M = 1.2$ and $M = 1.68$ cases.

Electric Plant Equipment

The electrical plant equipment, including switchgear, switchboards, station service equipment, protective equipment, and wiring, is estimated from the equation²

$$\text{Cost} = 6.8 P_{th}(\text{kW}) + .25 (\text{total building cost}) .$$

The electric plant equipment cost estimates are thus 46 and 54 M\$ for the $M = 1.2$ and $M = 1.68$ cases.

Tritium Handling Systems

The tritium containment and handling systems for the PRD were costed to be 7.9 M\$, and the cost estimate for the mirror reactor is 60 M\$. The difference is due to the fact that the mirror reactor design is very conservative (that is, ultrasafe), and the mirror reactor building to be flushed and filtered is much larger. We will use a formula based on the mirror reactor design:

$$\text{Cost} = 30 \text{ M\$} + (V/V_m) 30 \text{ M\$}$$

where V and V_m are the reactor building volume and the mirror reactor building volume. For the cusp reactor, V/V_m is about 0.4, so we will use a cost of 42 M\$ for tritium handling systems. Substantial savings are available if less stringent requirements are used than were used in the mirror reactor design study.

Radioactive Waste Handling System

The radwaste system is estimated to cost 2 \$/kWth, as for the mirror reactor.² This amounts to 6 M\$ and 7 M\$ for the $M = 1.2$ and $M = 1.68$ cases.

Miscellaneous Power Equipment

The category "miscellaneous power equipment", including transportation and lifting equipment, air and water service equipment, communication equipment, and furnishings and fixtures, is estimated to cost 2 \$/kWth, as for the mirror reactor.² This amounts to 6 and 7 M\$ for the $M = 1.2$ and $M = 1.68$ cases.

Cost Summary

Only the "direct capital costs" are calculated here. Figures for engineering, contingency, and interest during construction are omitted.

(Estimates of total capital cost range from 1.5 to 2.5 times the "direct capital cost", depending on interest rates, construction time, etc.) The direct capital costs for the cusp reactor are summarized in Table 3. The resultant direct capital cost per kWe for the $M = 1.2$ and $M = 1.7$ cases are 1403 and 950 \$/kWe, respectively.

These capital cost estimates for the cusp reactor are compared with the corresponding direct capital cost estimates for the Field Reversed Mirror Reactor⁵, the Tandem Mirror Reactor⁹, and the UWMAK-III Tokamak Reactor⁷ in Table 4.

The parameters and cost figures for the cusp reactor have not been optimized.

Table 3. Summary of capital costs for cusp reactor (M\$)

	<u>M = 1.2</u>	<u>M = 1.68</u>
buildings and site facilities	86	97
magnet coil conductor and winding	80	80
coil structural supports	48	48
cryostats	12	12
refrigeration	56	56
vacuum chambers	32	32
vacuum system	9	9
blanket	88	31
shield	46	46
electrodes, feedthroughs, collimators	2	2
instrumentations and control systems	20	26
power supplies (300 kV dc)	39	39
heat transfer system	106	136
thermal conversion system	80	103
energy storage system	67	67
electric plant equipment	46	54
tritium handling system	42	42
radioactive waste system	6	7
miscellaneous power plant equipment	6	7
total "direct" capital cost	871	894
electrical power output (MW)	621	941
direct capital cost per kW (\$/kWe)	1403	950

Table 4. Comparison of estimated direct capital costs of various fusion reactors, \$/kWe.

	M = 1.2	M = 1.7
cusp reactor	1400	950
tandem mirror reactor	1300	
field reversed mirror reactor	900	700
UWMAK-III Tokamak reactor	1200	

Acknowledgement

I am grateful to G. A. Carlson and R. W. Moir for advice and guidance.

REFERENCES

1. T. J. Dolan, Design Study of Electrostatically Plugged Cusp Fusion Reactor, UCRL-52142 (1976).
2. R. W. Moir, et al, Design Study of the Standard Mirror Fusion Reactor, to be published as a Lawrence Livermore Laboratory report (1977).
3. R. G. Mills, editor, A Fusion Power Plant, MATT-1050 (1974).
4. R. W. Moir et al, Progress on the Conceptual Design of a Mirror Hybrid Fusion-Fission Reactor, UCRL-51797 (1975).
5. W. C. Condit et al, Preliminary Design Calculations for a Field-Reversed Mirror Reactor, UCRL-52170 (1976).
6. J. R. Powell and P. Bezler, A Comparison of Warm- and Cold-Reinforcement Magnet Systems for Tokamak Fusion Reactors, Technology of Controlled Thermonuclear Fusion Experiments and the Engineering Aspects of Fusion Reactors, CONF-721111, USAEC (1974) p. 358.
7. B. Badger et al, UWMAK-III, A Noncircular Tokamak Power Reactor Design, UWFD-150, University of Wisconsin (1976)
8. G. A. Carlson, personal communication, 1977.
9. G. A. Carlson, Parametric Design Study of Tandem Mirror Fusion Reactors, preprint UCRL-79092 (1977).
10. Richard Reid, Hippotronics Corporation, personal communication, July 1977.
11. Martin Renwick, sales representative, Wallace Murray Corp., personal communication, July 1977.

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Available from
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Springfield, VA 22161
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