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A TOKAMAK REACTOR COST MODEL BASED ON STARFIRE/WILDCAT COSTING

by

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Fusion Power Program

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ABSTRACT

A cost model is presented which is useful for survey and comparative studies of tokamak reactors. The model is heavily based on STARFIRE¹ and WILDCAT² costing guidelines, philosophies, and procedures and reproduces the costing for these devices quite accurately.

1. INTRODUCTION

This report presents a cost model for tokamak reactors which has a sufficient amount of detail to give a reasonably accurate picture of the relevant cost accounts but which is sufficiently simple to not be cumbersome in use. It is designed to be used for survey and parametric studies of tokamak reactors and should be most useful when used for cost comparisons.

The model is based on the costing assumptions and procedures that were used in STARFIRE¹ and later in WILDCAT.² For comparison purposes the costs are given in constant, 1980 dollars, the same as presented in these studies. A detailed description of the guidelines, procedures, and a breakdown of the cost accounts is given in Refs. 1 and 2, along with much explanatory information, which is not reproduced here. This report treats only the parametrization of these costing studies, not their development. The person most responsible for their development has been Les Waganer, McDonnell Douglas Astronautics Company.

The parametrization consists of simple scaling formulas for each cost account with STARFIRE taken as the base point. The scalings used, however, are ones which also match WILDCAT, a D-D reactor, which is substantially different from STARFIRE in many respects. Having a model which is normalized to these two cases should insure a good degree of validity for a wide range of reactors with similar types of subsystems. If it is desired to model reactors for which some subsystems are essentially different from STARFIRE/WILDCAT, the basic model can still be used with replacement costing formulas for those subsystems.

The basic model matches STARFIRE identically and matches most cost accounts of WILDCAT to better than ten percent. The only less than satisfactory match is for Account 22.01.07, Power Supplies, Switching, and Energy Storage, which is calculated to be nearly twice the actual WILDCAT value. The discrepancy is due to a more cost-effective design in WILDCAT, in particular the use of two power supplies for different parts of the EF current ramp and longer startup and shutdown times. Since these features represent real improvements, a modified model is suggested with the EF power supplies scaled from WILDCAT.

Only steady-state reactors have been considered in this report. There are three types of current drive methods considered, which differ significantly in power required and cost. Accordingly, the rf current drive method is left as an option. Lower-hybrid-wave current drive is scaled from STARFIRE; Alfven-wave current drive is scaled from WILDCAT; and relativistic-electron-beam (REB) current drive is scaled from DEMO.³

A comparison of the basic and modified cost models with the actual STARFIRE and WILDCAT costing is shown in Table I. It can be seen that the "bottom line" parameters such as total cost and cost of energy are matched to about 1% or better, well within the accuracy of the actual costing.

A costing method with a similar level of description has been developed by Science Applications, Inc. for D-D reactors.⁴ Their model is scaled from the WILDCAT costing and is not claimed to be valid for D-T reactors. Study of this model, however, provided much useful guidance and insight for the development of the model presented here.

The remainder of this report is organized as follows: A moderately detailed power flow model relating the reactor thermal power to the auxiliary power requirements and net electric power is described in Sec. 2. These calculations are a prerequisite to the costing. The costing model is described in Sec. 3, and the scaling formulas are presented and discussed to some extent. A computer listing of the subroutine of TRAC-II which calculates the costing is given in the Appendix. TRAC-II is a code developed at Argonne National Laboratory for tokamak reactor analysis. It has been used for both STARFIRE and WILDCAT, as well as for other designs. The subroutine also contains the Science Applications, Inc., D-D, costing algorithm as an option. This subroutine could be easily modified for use with other reactor analysis codes.

2. POWER FLOW MODEL

The power flow model is shown schematically in Fig. 1. The plasma fusion power, P_f , and the additional power, B , generated by neutron energy multiplication in the blanket are inputs and beyond the scope of this costing algorithm to calculate. The thermal power is $P_T = P_f + B$. Other quantities such as the rf heating, H , supplied to the plasma or the limiter energy deposition, L , could be supplied as inputs, but algorithms are given for their calculation.

Table I. Costing Model Results for STARFIRE and WILDCAT

(Costs are in M\$ unless noted.)

Account	Title	Basic Model		Modified Model		WILDCAT Actual
		STARFIRE ^a	WILDCAT	STARFIRE	WILDCAT	
20.	Land	3.30	3.30	3.30	3.30	3.30
21.	Structures	346.58	346.58	346.58	346.58	346.59
22.	Reactor equipment	968.62	1522.14	941.67	1490.13	1496.63
22.01.01	Blanket/first wall	82.36	148.41	82.36	148.41	132.23
22.01.02	Shield	186.07	334.21	186.07	334.21	352.50
22.01.03	Magnets	171.57	342.01	171.57	342.01	352.66
22.01.04	RF heating/current drive	33.49	34.88	33.49	34.88	34.88
22.01.05	Structure	52.74	121.02	52.74	121.02	115.13
22.01.06	Vacuum	4.86	11.50	4.86	11.50	8.68
22.01.07	Power supplies	52.90	62.06	29.86	34.70	32.20
22.01.08	Impurity control	2.45	3.07	2.45	3.07	3.07
22.01.09	ECRH breakdown	2.82	9.45	2.82	9.45	15.60
23.	Turbine equipment	249.68	205.76	249.68	205.76	215.38
24.	Electric equipment	117.28	110.95	227.29	110.95	111.08
25.	Miscellaneous equipment	40.77	40.77	40.77	40.77	39.66
26.	Special materials	0.25	0.25	0.25	0.25	0.25
90.	Total direct cost	1726.48	2229.75	1699.54	2197.74	2212.89
99.	Total cost	2400.27	3099.95	2362.82	3055.45	3076.51
	Net electric, MWe	1202.	803.	1202.	803.	812.
	COE, mills/kWe	35.1	63.5	34.6	62.7	62.8

^aThese are the same as the actual STARFIRE figures.

Fig. 1. Power flow model.

In particular, an estimate for the limiter heating is

$$L = 0.25(P_{w,rad} + P_{w,diff})A_w ,$$

where $P_{w,rad}$ is the radiation wall load and $P_{w,diff}$ is the charged particle wall load due to diffusing plasma particles. According to the above equations, one-fourth of the total heat load to the wall is absorbed by the limiter. The rf heating of the plasma, which occurs as a byproduct of the current drive is given by:

$$H = H(S) (I_p n_e / T_e) / (I_p n_e / T_e)_S \quad (\text{Lower Hybrid})$$

$$H = H(W) (I_p n_e / T_e) / (I_p n_e / T_e)_W \quad (\text{Alfven})$$

$$H = 2P_\Omega \quad (\text{REB}) ,$$

where throughout this paper S denotes STARFIRE values, W denotes WILDCAT values, and D denotes DEMO values. The quantity I_p is the plasma current, n_e is the average electron density, T_e is the average electron temperature, and P_Ω is the Ohmic heating power.

The shield reject heat is given by:

$$R_1 = 65 \text{ MW } P_T / P_T(S) .$$

The primary power input is then

$$P = F + B - L - R_1 ,$$

and the input power to the turbine is

$$I = P + L + A_5 ,$$

where the auxiliary pumping power is given by

$$A_5 = 33 \text{ MW } (L + P) / (L + P)_S .$$

If the thermal efficiency is η , the gross electric power is

$$G = \eta I ,$$

and the waste heat from the turbine is

$$W = (1 - \eta)I .$$

The total heat rejected from the turbine system is

$$R_2 = W + A_6 ,$$

where

$$A_6 = 27 \text{ MW } W/W(S) .$$

The remaining auxiliary power requirements are given by

$$A_1 = 13 \text{ MW}$$

$$A_2 = 5 \text{ MW}$$

$$A_3 = H/\eta_{CD}$$

and

$$A_4 = 7 \text{ MW } V_{TFC}/V_{TFC}(S) ,$$

where η_{CD} is the efficiency of the current drive system, and V_{TFC} is the volume of the toroidal field coils. (The quantity A_4 would scale better as the volume of all of the superconducting coils if that is available.) The total auxiliary power is

$$A = A_1 + A_2 + A_3 + A_4 + A_5 + A_6 ,$$

and the net electric power is

$$E = G - A .$$

3. COST MODEL

The scaling formulas used to calculate the costs of the most important cost accounts are presented in this section. These scaling formulas have been designed to match both STARFIRE and WILDCAT and are based on what the author believes are the relevant quantities involved in the respective costs. There are certainly other scalings, perhaps some more accurate, which would also

give an adequate match to both STARFIRE and WILDCAT, and no claim is made that these are the best or the only scalings possible. Their claim to accuracy lies primarily in the fact that they do match both of the above devices and that they are somewhat reasonable scalings. Many other reasonable scalings were discarded because they did not provide an adequate match. If desired, it should be easy to change the costing for individual accounts if better or different models are available without the necessity of understanding the entire costing algorithm.

The formulas have purposely been kept simple even though a higher level of detail would provide a closer fit in many cases. This has been done to keep the costing model simple and to keep it commensurate with its anticipated use as a parametric cost model with a minimum number of inputs. The inputs used for the model should be available in any tokamak reactor design code. These inputs are listed in Table II for reference. For the most part the scaling formulas used are presented here without an extensive discussion of why they were chosen.

3.1 Land and Land Rights (Account 20)

$$C_{20} = 3.30 \text{ M\$}.$$

3.2 Structures and Site Facilities (Account 21)

$$C_{21} = 346.58 \text{ M\$}.$$

3.3 Reactor Plant Equipment (Account 22)

3.3.1 Reactor Equipment

Blanket and First Wall

$$C_{22,01,01} = 1.27 \text{ M\$ } A_w/A_w(S) \\ + 81.09 \text{ M\$ } \frac{A_w}{A_w(S)} \left\{ 0.1 \frac{[\Delta_B^i(R_w + 0.5 \Delta_B^i)]}{[\Delta_B^i(R_w + 0.5 \Delta_B^i)]_S} \right. \\ \left. + 0.9 \frac{[\Delta_B^o(R_w + 0.5 \Delta_B^o)]}{[\Delta_B^o(R_w + 0.5 \Delta_B^o)]_S} \right\}$$

Table II. Input Parameters, Notation, and STARFIRE Reference Values

Parameter	Symbol	STARFIRE Value
Fusion power	P	3608 MW
Blanket enhancement	B	457 MW
Thermal power	P _T	4065 MW
Limiter heating	L	200 MW
Radiation wall load	P _{w,rad}	0.88 MW/m ²
Charged particle wall load	P _{w,diff}	0.18 MW/m ²
Wall area	A _w	755 m ²
RF heating of plasma	H	90 MW
Plasma current	I _p	10.1 MA ^(a)
Average electron density	n _e	1.18 × 10 ²⁰ m ⁻³ (b)
Average electron temperature	T _e	17.3 keV ^(c)
Ohmic heating of plasma	P _Ω	0.193 MW ^(d)
Turbine thermal efficiency	η	0.357
Current drive efficiency	η _{CD}	0.59
Primary power	P	3800 MW
Turbine input power	I	4033 MW
Total reject heat	R	2620 MW
Turbine waste heat	W	2593 MW
Gross electric power	G	1440 MW
Net electric power	E	1202 MW
Toroidal field at R = R ₀	B _{to}	5.8 T
Toroidal field coil volume	V _{TFC}	781 m ³
Inboard blanket/shield thickness	Δ _{BS} ⁱ	1.20 m
Inboard blanket thickness	Δ _B ⁱ	0.28 m
Inboard shield thickness	Δ _S ⁱ	0.92 m
Outboard blanket/shield thickness	Δ _{BS} ^o	2.60 m
Outboard blanket thickness	Δ _B ^o	0.46 m
Outboard shield thickness	Δ _S ^o	2.14 m
Wall minor radius at midplane	R _w	2.14 m
Plasma volume	V _p	781 m ³
Plasma major radius	R ₀	7.0 m
Plasma minor radius at midplane	a	1.94 m
Plasma elongation ^(e)	κ	1.6
Plasma D-shapedness ^(e)	d	0.5
Plasma height	h	6.22 m
Tritium breeding ratio	TBR	1.0
First-wall/blanket lifetime	τ _R	6 y
Neutron wall load	P _{w,neut}	3.72 MW/m ²
Fuel burnup	f	540 g/day
Plant availability	a	0.75

(a) The WILDCAT value is I_p = 29.9 MA.

(b) The WILDCAT value is n_e = 2.55 × 10²⁰ m⁻³.

(c) The WILDCAT value is T_e = 30.0 keV.

(d) The DEMO value is P_Ω = 0.520 MW.

(e) The plasma boundary is described by Z = κa sin θ and
R = R₀ + a cos(θ + d sin θ).

This scaling assumes that the inboard blanket is behind 10% of the first wall and that the outboard blanket is behind the rest.

Shield

$$\begin{aligned}
 C_{22.01.02} &= 77.29 \text{ M\$ } V_p/V_p(S) \\
 &+ 47.21 \text{ M\$ } \frac{A_w}{A_w(S)} \frac{\Delta_S^i}{\Delta_S^i(S)} \frac{[R_w + \Delta_B^i + 0.5 \Delta_S^i]}{[R_w + \Delta_B^i + 0.5 \Delta_S^i]_S} \\
 &+ 61.57 \text{ M\$ } \frac{A_w}{A_w(S)} \frac{\Delta_S^o}{\Delta_S^o(S)} \frac{[R_w + \Delta_B^o + 0.5 \Delta_S^o]}{[R_w + \Delta_B^o + 0.5 \Delta_S^o]_S} .
 \end{aligned}$$

If the total blanket shield thickness is given, then

$$\begin{aligned}
 \Delta_S^i &= \Delta_{BS}^i - \Delta_B^i \\
 \Delta_S^o &= \Delta_{BS}^o - \Delta_B^o .
 \end{aligned}$$

Both the blanket and shield could be better broken down by the volume of the various materials actually present if that information is available. Shield design, especially, seems to vary greatly, and much of the shield is around the vacuum pumps and hence hard to estimate as to volume.

Magnets

$$\begin{aligned}
 C_{22.01.03} &= 125.72 \text{ M\$ } V_{TFC}/V_{TFC}(S) \\
 &+ 45.85 \text{ M\$ } (I_p R_o d)/(I_p R_o d)_S .
 \end{aligned}$$

The second term is for the poloidal coils and represents the fact that the poloidal coil requirements vary strongly with the plasma d-shapedness. The plasma boundary is given by

$$\begin{aligned}
 R &= R_o + a \cos(\theta + d \sin \theta) \\
 Z &= ka \sin \theta .
 \end{aligned}$$

Current Drive

$$C_{22.01.04} = 33.49 \text{ M\$ } (I_p n_e / T_e) / (I_p n_e / T_e)_S \quad (\text{Lower Hybrid})$$

$$C_{22.01.04} = 34.88 \text{ M\$ } (I_p n_e / T_e) / (I_p n_e / T_e)_W \quad (\text{Alfven})$$

$$C_{22.01.04} = 12.0 \text{ M\$ } P_\Omega / P_\Omega(D) \quad (\text{REB}).$$

Primary Structure and Support

$$C_{22.01.05} = 21.23 \text{ M\$ } V_{TFC} / V_{TFC}(S) \\ + 31.51 V_p / V_p(S).$$

Vacuum

$$C_{22.01.06} = 4.86 \text{ M\$ } V_p / V_p(S).$$

Power Supplies

$$C_{22.01.07} = 0.3 \text{ M\$ } + 38.2 \text{ M\$ } (I_p d) / (I_p d)_S \\ + 3.0 \text{ M\$ } (R_o h) / (R_o h)_S + 11.4 \text{ M\$}.$$

The second term represents the poloidal coil power supply cost and does not match WILDCAT well due to a more cost-effective design in WILDCAT. The following modified form which scales the poloidal coil power supplies to WILDCAT is recommended:

$$C_{22.01.07} = 0.3 \text{ M\$ } + 18.0 \text{ M\$ } (I_p d) / (I_p d)_W \\ + 3.0 \text{ M\$ } (R_o h) / (R_o h)_S + 11.4 \text{ M\$}.$$

Impurity Control

$$C_{22.01.08} = 2.45 \text{ M\$ } (R_o + a) / (R_o + a)_S .$$

A pumped limiter is assumed.

ECRH Breakdown

$$C_{22.01.09} = 2.82 \text{ M\$ } (R_o h B_{to}^2) / (R_o h B_{to}^2)_S.$$

This does not match WILDCAT well. The WILDCAT ECRH system seems to require too little power relative to STARFIRE.

Total

$$\begin{aligned} C_{22.01} = & C_{22.01.01} + C_{22.01.02} + C_{22.01.03} + C_{22.01.04} \\ & + C_{22.01.05} + C_{22.01.06} + C_{22.01.07} + C_{22.01.08} \\ & + C_{22.01.09}. \end{aligned}$$

3.3.2 Main Heat Transfer and Transport System

Primary Cooling

$$C_{22.02.01} = 63.10 \text{ M\$ P/P(S).}$$

Intermediate Cooling

$$C_{22.02.02} = 0.0 \text{ M\$}.$$

Limiter Cooling

$$C_{22.02.03} = 6.19 \text{ M\$ L/L(S).}$$

Residual Heat Removal

$$C_{22.02.04} = 0.55 \text{ M\$}.$$

Total

$$C_{22.02} = C_{22.02.01} + C_{22.02.02} + C_{22.02.03} + C_{22.02.04}.$$

3.3.3 Cryogenic Cooling System

$$C_{22.03} = 14.90 \text{ M\$ } V_{TFC} / V_{TFC}(S).$$

It would be better to use the volume of all the superconducting coils if that is available.

3.3.4 Radioactive Waste Treatment and Disposal

$$C_{22.04} = 4.8 \text{ M\$}.$$

3.3.5 Fuel Handling and Storage System

$$C_{22.05} = 33.2 \text{ M\$} + 5.4 \text{ M\$ TBR/TBR(S)}.$$

3.3.6 Other Reactor Plant Equipment

$$C_{22.06} = 43.75 \text{ M\$}.$$

3.3.7 Instrumentation and Control

$$C_{22.07} = 23.41 \text{ M\$}.$$

3.3.8 Spare Parts Allowance

$$\begin{aligned} C_{22.98} = & 50.69 \text{ M\$} \\ & + 0.02(C_{22.01} + C_{22.02} + C_{22.03} + C_{22.04} \\ & + C_{22.05} + C_{22.06} + C_{22.07}). \end{aligned}$$

3.3.9 Contingency Allowance

$$\begin{aligned} C_{22.99} = & 0.15(C_{22.01} + C_{22.02} + C_{22.03} + C_{22.04} \\ & + C_{22.05} + C_{22.06} + C_{22.07}). \end{aligned}$$

3.3.10 Total Reactor Plant Equipment

$$\begin{aligned} C_{22} = & C_{22.01} + C_{22.02} + C_{22.03} + C_{22.04} + C_{22.05} \\ & + C_{22.06} + C_{22.07} + C_{22.98} + C_{22.99}. \end{aligned}$$

3.4 Turbine Plant Equipment (Account 23)

3.4.1 Turbine Generators

$$C_{23.01} = 77.33 \text{ M\$ } I^{0.5}/I(S)^{0.5}.$$

3.4.2 Main Heat System

$$C_{23.02} = 4.37 \text{ M\$ } I^{0.5}/I(S)^{0.5}.$$

3.4.3 Heat Rejection System

$$C_{23.03} = 44.34 \text{ M\$ } R/R(S).$$

3.4.4 Condensing Systems

$$C_{23.04} = 19.18 \text{ M\$ } W/W(S).$$

3.4.5 Feed Heating Systems

$$C_{22.05} = 9.39 \text{ M\$ } L/L(S).$$

3.4.6 Other Turbine Plant Equipment

$$C_{23.06} = 50.84 \text{ M\$ } I/I(S).$$

3.4.7 Instrumentation and Control

$$C_{23.07} = 8.70 \text{ M\$}.$$

3.4.8 Spare Parts Allowance

$$C_{23.98} = 0.0159(C_{23.01} + C_{23.02} + C_{23.03} + C_{23.04} \\ + C_{23.05} + C_{23.06} + C_{23.07}) .$$

3.4.9 Contingency Allowance

$$C_{23.99} = 0.15(C_{23.01} + C_{23.02} + C_{23.03} + C_{23.04} \\ + C_{23.05} + C_{23.06} + C_{23.07}).$$

3.4.10 Total Turbine Plant Equipment

$$C_{23} = C_{23.01} + C_{23.02} + C_{23.03} + C_{22.04} + C_{23.05} \\ + C_{23.06} + C_{23.07} + C_{23.98} + C_{23.99}.$$

3.5 Electric Plant Equipment (Account 24)

3.5.1 Switchgear

$$C_{24.01} = 12.39 \text{ M\$}.$$

3.5.2 Station Service Equipment

$$C_{24.02} = 17.04 \text{ M\$}.$$

3.5.3 Switchboards

$$C_{24.03} = 7.80 \text{ M\$}.$$

3.5.4 Protective Equipment

$$C_{24.04} = 2.11 \text{ M\$}.$$

3.5.5 Electrical Structures and Wiring Containers

$$C_{24.05} = 11.12 \text{ M\$} + 6.28 \text{ M\$ G/G(S)}.$$

3.5.6 Power and Control Wiring

$$C_{24.06} = 23.0 \text{ M\$} + 13.0 \text{ M\$ G/G(S)}.$$

3.5.7 Electrical Lighting

$$C_{24.07} = 8.20 \text{ M\$}.$$

3.5.8 Spare Parts Allowance

$$C_{24.98} = 0.012(C_{24.01} + C_{24.02} + C_{24.03} \\ + C_{24.04} + C_{24.05} + C_{24.06} + C_{24.07}).$$

3.5.9 Contingency Allowance

$$C_{24.99} = 0.15(C_{24.01} + C_{24.02} + C_{24.03} + C_{24.04} + C_{24.05} + C_{24.06} + C_{24.07}).$$

3.5.10 Total Electric Plant Equipment

$$C_{24} = C_{24.01} + C_{24.02} + C_{24.03} + C_{24.04} + C_{24.05} + C_{24.06} + C_{24.07} + C_{24.98} + C_{24.99}.$$

3.6 Miscellaneous Plant Equipment (Account 25)

$$C_{25} = 40.77 \text{ M\$}.$$

3.7 Special Materials (Account 26)

$$C_{26} = 0.25 \text{ M\$}.$$

3.8 Total Direct Cost (Account 90)

$$C_{90} = C_{20} + C_{21} + C_{22} + C_{23} + C_{24} + C_{25} + C_{26}.$$

3.9 Construction Facilities, Equipment, and Services (Account 91)

$$C_{91} = 0.10 C_{90}.$$

3.10 Engineering and Construction Management Services (Account 92)

$$C_{92} = 0.08 C_{90}.$$

3.11 Other Costs (Account 93)

$$C_{93} = 0.05 C_{90}.$$

3.12 Interest During Construction (Account 94)

$$C_{94} = 0.1303 (C_{90} + C_{91} + C_{92} + C_{93}).$$

Constant year dollars are assumed.

3.13 Escalation During Construction (Account 95)

$$C_{95} = 0.$$

Constant year dollars are assumed.

3.14 Total Capital Cost

$$C_{TC} = C_{90} + C_{91} + C_{92} + C_{93} + C_{94} + C_{95}.$$

3.15 Annual Levelized Capital Cost

$$C_{ALCC} = 0.10 C_{TC}.$$

3.16 Annual Operations and Maintenance Cost (Accounts 40-47)

$$C_{OM} = 19.407 \text{ M\$}.$$

3.17 Annual Scheduled Component Replacement Cost (Accounts 50-51)

$$C_{SCRC} = 17.36 \text{ M\$ } \tau_R(S)/\tau_R.$$

The first-wall/blanket replacement time is assumed to depend on the neutron wall load,

$$\tau_R = 22.7 \text{ y} - 4.5 \text{ y } P_{w,neut}(\text{MW/m}^2).$$

(The first-wall/blanket replacement cost dominates this account and is the only item included here.)

3.18 Annual Fuel Cost (Account 02)

$$C_F = 0.333 \text{ fa}/(\text{fa})_S.$$

3.19 Cost of Capacity

$$C_{CAP} = C_{TC}/E.$$

3.20 Cost of Electricity

$$COE = C_1 (C_{ALCC} + C_{OM} + C_{SCRC} + C_F) / (Ea),$$

where $C_1 = (8760 \times 10^{-6})^{-1}$ if the annual costs are in M\$, the net electric power is in MW, and the COE is in mills/kWh.

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3. M. Abdou, et al., "A Demonstration Tokamak Power Plant Study," ANL/FPP/TM-154, Argonne National Laboratory (1982).
4. D. C. Baxter, et al., "d-d Tokamak Reactor Assessment," SAI25082-213LJ, Science Applications, Inc. (1982).
5. K. Evans, Jr., J. G. Gilligan, and J. Jung, "Tokamak Fusion Reactors with Less Than Full Tritium Breeding," ANL/FPP/TM-169 (1983).

APPENDIX

The following is a listing of a TRAC-II subroutine which calculates the quantities in the costing model. The basic model, the modified model, or the SAI model is calculated depending on whether ICMOD = 1, 2, OR 3. It should be possible to figure out the relevant FORTRAN variables with a little thought. The quantities appearing in the COMMON statements and which are not used can be ignored. The tritium model quantities which are printed are calculated as described in Ref. 5.

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      SUBROUTINE CSTANL(ETA,ETACD,ICD,DELBI,DELBO,DELBSO,
1 ICMOD,IPRINT,ICALL)
C COSTING MODEL
C   ICMOD=1: SAI COSTING BASED ON WILDCAT
C   ICMOD=2: COSTING BASED ON STARFIRE/WILDCAT SCALED TO STARFIRE
C   ICMOD=3: TBR COSTING - SAME AS 2 EXCEPT FOR POWER SUPPLIES
      IMPLICIT REAL*8 (A-H,O-Z)
      COMMON /TFCC/ R1TFC,R2TFC,DELTFC,TFCLEN,UTFC,TFCCUR,HTFC,VTFC
      COMMON /GEOMC/ RMAJ,ASP,RPLAS,ZL,RWALL,RBAR,ABAR,
1 HEIGHT,RV,DELM,DELB,DELS,DELV,DELBSI
      COMMON /MHDC/ FWALL,PROFP,PROFF,PROFN,PROFT,CAPPA,DEITY,
1 ALPHAJ,BETAP,BETAT,QSAFE,PCUR,CLNGTH,VOL,VPRIM(25),
2 DELTA,AREAP,BPLAS,BMAX
      COMMON /IONC/ ZI(8),AI(8),AREduc(8,8),ZEFF,ZEFFAR(25),
1 RNI(7),RNIAR(25,7),RO,ROAR(25),R1,R1AR(25),R2,R2AR(25),
2 R3,R3AR(25),RECYC(5),XLAMP(8),XLAME(8),NIONS,NPART,NIE
      COMMON /TEPMC/ TE,TEAR(25),TI,TIAR(25),AVCONV
      COMMON /DENC/ XN(8)
      COMMON /POWERC/ PDIFF,PHEAT,PBEAM,PBINJ,PBREMS,PCYC,PCOLL,
1 PN1406,PN245,EP1406,EP245,POHM,PT,BAL,QGAIN
      COMMON /OUTDC/ Q00,RM,PRF,NIMP,MHDNUM
      COMMON /COSTC/ TRCC,COE,COC,C22,PNETE
      COMMON /FLUXC/ PW1406,PW245,XJ1406,XJ245,XJW(8),PWC,PWB,AREAW,
1 PWDIFF,PWBREM,PWCYC,PWRAD,FWNEUT,PWTOT
      COMMON /TRITC/ XHAUST,BURNUP,DBURN,PRODUC,FUEL,VUL,VP,VF,VB,
1 VNLIQ,VNSOL,VNS,VNBLIQ,VNBSOL,VNF,TBR
      IF(ICMOD.EQ.1) GO TO 200
C STARFIRE PARAMETERS TO SCALE FROM
      PHTS=90.D0
      PTS=4065.D0
      VTFCs=781.D0
      PRIMs=3800.4D0
      PLIMs=199.6D0
      PWASTS=2593.2D0
      AREAWS=754.976D0
      DELBIS=.28D0
      DELBOS=.46D0
      RWALLS=2.14444D0
      DLBSIS=1.2D0
      DLBSOS=2.60D0
      DELSIS=DLBSIS-DELBIS
      DELSOS=DLBSOS-DELBOS
      VOLs=781.36D0
      PCURS=10.0752D6
      RMAJS=7.00D0
      DEITYS=.5D0
      XNES=1.1774D20
      TES=17.3D0
      POHMS=.193D0
      HEIGHTS=6.22D0
      RPLASS=1.94444D0
      BPLASS=5.80D0
      PINS=4033.D0

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PREJS=2620.2D0
PGES=1439.8D0
BLIFES=6.D0
DBURNS=539.5D0
AVAILS=.75D0
C WILDCAT PARAMETERS TO SCALE FROM
PHTW=107.D0
PGEW=1017.D0
PTW=2915.D0
BMAXW=14.35D0
BPLASW=8.23D0
RMAJW=8.58D0
ASPW=3.25D0
RPLASW=RMAJW/ASPW
PRFW=107.D0
DBSIW=.82D0
RMW=4.92D0
PCURW=29.9D6
DEITYW=.2D0
XNEW=2.55D20
TEW=30.D0
AVAILW=.75D0
THRUW=1.D0
VSPDW=1.D0
C DEMO PARAMETERS TO SCALE FROM
POHMD=.520D0
C STARFIRE/WILDCAT COSTING
C POWER BALANCE MODEL
PLIM=.25D0*AREAW*(PWDIFF+PWRAD)
PBKT=(EP1406-1.D0)*PN1406+(EP245-1.D0)*PN245
PF=PT-PBKT
PSCHLD=65.D0*PT/PTS
PRIM=PF+PBKT-PSCHLD-PLIM
C LOWER HYBRID
IF(ICD.EQ.1) PHT=PHTS*(PCUR*XN(NIE)/TE)/
1 (PCURS*XNES/TES)
C ALFVEN WAVES (SCALED TO WILDCAT)
IF(ICD.EQ.2) PHT=PHTW*(PCUR*XN(NIE)/TE)/
1 (PCURW*XNEW/TEW)
C REB (SCALED TO DEMO)
IF(ICD.EQ.3) PHT=2.D0*POHM
AUX1=13.D0
AUX2=5.D0
AUX3=PHT/ETACD
AUX4=7.D0*VTFC/VTFC5
AUX5=33.D0*(PLIM+PRIM)/(PLIMS+PRIMS)
PIN=PRIM+AUX5+PLIM
PGE=ETA*PIN
PWAST=(1.D0-ETA)*PIN
AUX6=27.D0*PWAST/PWASTS
AUX=AUX1+AUX2+AUX3+AUX4+AUX5+AUX6
PNETE=PGE-AUX
PREJ=PWAST+AUX6

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      PREJH=AUX3-PHT
      REJECT=PSCHLD+PREJ+PREJH
      IF(IPRINT.EQ.0) GO TO 500
C FORMATS FOR POWER FLOW
110  FORMAT(1H1,T55,'POWER FLOW FOR ICALL=',I2/)
111  FORMAT(' PLASMA FUSION POWER',T35,F10.1)
112  FORMAT(' BLANKET NEUTRON POWER',T35,F10.1)
113  FORMAT(' PLASMA HEATING',T35,F10.1)
114  FORMAT(' LIMITER HEATING',T35,F10.1)
131  FORMAT(' SHIELD REJECT HEAT',T35,F10.1)
115  FORMAT(' PRIMARY',T35,F10.1)
116  FORMAT(' TURBINE INPUT',T35,F10.1)
117  FORMAT(' GROSS ELECTRIC',T35,F10.1)
118  FORMAT(' TURBINE WASTE HEAT',T35,F10.1)
119  FORMAT(' TURBINE REJECT HEAT',T35,F10.1)
120  FORMAT(' HEATING REJECT HEAT',T35,F10.1)
121  FORMAT(' BOP AUXILLIARIES',T35,F10.1)
122  FORMAT(' MAGNETS',T35,F10.1)
123  FORMAT(' HEATING',T35,F10.1)
124  FORMAT(' CRYOGENICS',T35,F10.1)
125  FORMAT(' PUMPING',T35,F10.1)
126  FORMAT(' HEAT TRANSPORT AND CONDENSATION',T35,F10.1)
127  FORMAT(' THERMAL POWER',T35,F10.1)
128  FORMAT(' RECIRCULATING POWER',T35,F10.1)
129  FORMAT(' TOTAL REJECT HEAT',T35,F10.1)
130  FORMAT(' NET ELECTRIC',T35,F10.1)
      PRINT 110,ICALL
      PRINT 111,PF
      PRINT 112,PBKT
      PRINT 113,PHT
      PRINT 114,PLIM
      PRINT 131,PSCHLD
      PRINT 101
      PRINT 115,PRIM
      PRINT 116,PIN
      PRINT 117,PGE
      PRINT 101
      PRINT 118,PWAST
      PRINT 119,PREJ
      PRINT 120,PREJH
      PRINT 101
      PRINT 121,AUX1
      PRINT 122,AUX2
      PRINT 123,AUX3
      PRINT 124,AUX4
      PRINT 125,AUX5
      PRINT 126,AUX6
      PRINT 101
      PRINT 127,PT
      PRINT 128,AUX
      PRINT 129,REJECT
      PRINT 130,PNETE
C TRITIUM MODEL
210  FORMAT(/////T53,'TRITIUM MODEL FOR ICALL=',I2/)

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209  FORMAT(' TRITIUM BREEDING RATIO',T35,F10.3)
211  FORMAT(' PLASMA EXHAUST',T35,F10.1)
212  FORMAT(' TRITIUM BURNUP',T35,F10.1)
213  FORMAT(' DEUTERIUM BURNUP',T35,F10.1)
214  FORMAT(' TRITIUM PRODUCTION',T35,F10.1)
215  FORMAT(' FUEL THROUGHPUT',T35,F10.1)
216  FORMAT(' VULNERABLE INVENTORY',T35,F10.1)
217  FORMAT('     VACUUM PUMPS',T35,F10.1)
218  FORMAT('     FUELING',T35,F10.1)
219  FORMAT('     BLANKET PROCESSING',T35,F10.1)
220  FORMAT(' NONVULNERABLE INVENTORY (LIQUID)',T35,F10.1)
221  FORMAT(' NONVULNERABLE INVENTORY (SOLID)',T35,F10.1)
222  FORMAT('     STORAGE',T35,F10.1)
223  FORMAT('     BLANKET',T35,F10.1)
224  FORMAT('     FUEL PROCESSING',T35,F10.1)
      PRINT 210,ICALL
      PRINT 209,TBR
      PRINT 211,XHAUST
      PRINT 212,BURNUP
      PRINT 213,DBURN
      PRINT 214,PRODUC
      PRINT 215,FUEL
      PRINT 101
      PRINT 216,VUL
      PRINT 217,VP
      PRINT 218,VF
      PRINT 219,VB
      PRINT 101
      PRINT 220,VNLIQ
      PRINT 222,VNS
      PRINT 223,VNBLIQ
      PRINT 224,VNF
      PRINT 101
      PRINT 221,VNSOL
      PRINT 222,VNS
      PRINT 223,VNBSOL
      PRINT 224,VNF
500  CONTINUE
C PRELIMINARY CALCULATIONS
      AVAIL=.75
      PRF=PHT
C ACCT 20
      C20=3.3D0
C ACCT 21
      C21=346.58D0
C ACCT 22
C ACCT 2201
      C22101=1.27D0*AREAW/AREAWS+81.09D0*AREAW/AREAWS*
1  (.1D0*DELBI/DELBIS*(RWALL+DELBI/2.D0)/(RWALLS+DELBIS/2.D0)
2  +.9D0*DELBO/DELBOS*(RWALL+DELBO/2.D0)/(RWALLS+DELBOS/2.D0))
      DELSI=DELBSI-DELBI
      DELSO=DELBSO-DELBO
      C22102=47.21D0*AREAW/AREAWS*(RWALL+DELBI+DELSI/2.D0)/

```

1 (RWALLS+DELBIS+DELSIS/2.DO)*DELSI/DELSIS
 2 +61.57D0*AREAW/AREAWS*(RWALL+DELBO+DELBO/2.DO)/
 3 (RWALLS+DELBOS+DELSOS/2.DO)*DELBO/DELSOS
 4 +77.29D0*VOL/VOLS
 C22103=125.72*VTFC/VTFC
 1 +45.85D0*PCUR/PCURS*RMAJ/RMAJS*DEITY/DEITYS
 C LOWER HYBRID
 IF(ICD.EQ.1) C22104=33.49D0*(PCUR*XN(NIE)/TE)/
 1 (PCURS*XNES/TE)
 C ALFVEN WAVES (SCALED TO WILDCAT)
 IF(ICD.EQ.2) C22104=34.88*(PCUR*XN(NIE)/TE)/
 1 (PCURW*XNEW/TEW)
 C REB (SCALED TO DEMO)
 IF(ICD.EQ.3) C22104=12.D0*POHM/POHMD
 C22105=21.23D0*VTFC/VTFC+31.51D0*VOL/VOLS
 C22106=4.86D0*VOL/VOLS
 C22107=.3D0+38.2D0*PCUR/PCURS*DEITY/DEITYS
 1 +3.D0*RMAJ/RMAJS*HEIGHT/HEIGHTS+11.4D0
 IF(ICMOD.GE.3) C22107=.3D0+18.0D0*PCUR/PCURW*DEITY/DEITYW
 1 +3.D0*RMAJ/RMAJS*HEIGHT/HEIGHTS+11.4D0
 C22108=2.45D0*(RMAJ+RPLAS)/(RMAJS+RPLASS)
 C22109=2.82*RMAJ/RMAJS*HEIGHT/HEIGHTS*(BPLAS/BPLASS)**2
 C2201=C22101+C22102+C22103+C22104+C22105+C22106+
 1 C22107+C22108+C22109
 C ACCT 22.02
 C22201=63.10D0*PRIM/PRIMS
 C22202=0.D0
 C22203=6.19D0*PLIM/PLIMS
 C22204=.55D0
 C22205=C22201+C22202+C22203+C22204
 C22203=14.90D0*VTFC/VTFC
 C22204=4.8D0
 C22205=33.2D0+5.4D0*TBR
 C22206=43.75D0
 C22207=23.41D0
 C22208=C22201+C22202+C22203+C22204+C22205+C22206+C22207
 C22208=50.69D0+.02D0*C22208
 C22209=.15D0*C22208
 C22210=C22208+C22209+C22210
 C ACCT 23
 C2301=77.33D0*DSQRT(PIN/PINS)
 C2302=4.37D0*DSQRT(PIN/PINS)
 C2303=44.34D0*PREJ/PREJS
 C2304=19.18D0*PWAST/PWASTS
 C2305=9.39D0*PLIM/PLIMS
 C2306=50.84D0*PIN/PINS
 C2307=8.70D0
 C2308=C2301+C2302+C2303+C2304+C2305+C2306+C2307
 C2309=.0159D0*C2308
 C2310=.15D0*C2308
 C2311=C2308+C2310+C2311
 C ACCT 24
 C2401=12.39D0

C2402=17.04D0
 C2403=7.8D0
 C2404=2.11D0
 C2405=11.12D0+6.28D0*PGE/PGES
 C2406=23.0D0+13.0D0*PGE/PGES
 C2407=8.20D0
 C24S=C2401+C2402+C2403+C2404+C2405+C2406+C2407
 C2498=.012D0*C24S
 C2499=.15D0*C24S
 C24=C24S+C2498+C2499
 C ACCT 25
 C25=40.77D0
 C ACCT 26
 C26=.25D0
 C OVERALL ACCTS
 C90=C20+C21+C22+C23+C24+C25+C26
 C91=.10D0*C90
 C92=.08D0*C90
 C93=.05D0*C90
 C94=.1303D0*(C90+C91+C92+C93)
 C95=0.D0
 C CAPITAL COST
 TRCC=C90+C91+C92+C93+C94+C95
 C ANNUAL CAPITAL COST
 CAC=.1D0*TRCC
 C OPERATIONS AND MAINTENENCE COST
 COM=19.407D0
 C SCHEDULED COMPONENT REPLACEMENT COST
 BLIFE=22.6906-4.484*PWNEUT
 CSRC=17.36D0*BLIFES/BLIFE
 C FUEL COST
 CF=.333D0*DBURN/DBURNS*AVAIL/AVAILS
 C COST OF CAPACITY
 COC=TRCC/PNETE*1.D3
 C COST OF ELECTRICITY
 COE=(CAC+COM+CSRC+CF)/(PNETE*AVAIL*8760.D-6)
 GO TO 300
 C SAI COSTING (MATCHES WILDCAT)
 200 CONTINUE
 C PRELIMINARY CALCULATIONS
 PGE=ETA*PT
 ETACD=1.D0
 PRF=PRFW*RMAJ/RMAJW*XN(NIE)/XNEW*29.48D0/
 1 (1.D0+171D0/3.33D0/DSQRT(ASP))*PCUR/PCURW/ETACD
 ETARF=.52195122D0
 PNETE=PGE-PRF/ETARF
 AVAIL=.75D0
 VSPD=1.D0
 THRU=1.D0
 C ACCT 20
 C20=3.3D0
 C ACCT 21
 C2101=11.15D0

C2102=120.38D0*RMAJ/RMAJW+40.D0
 C2103=35.92D0*(PGE/PGEW)**.7
 C2104=6.38D0*PT/PTW
 C2105=4.D0+2.58D0*DSQRT(BMAX/BMAXW)+2.58D0*DSQRT(PRF/PRFW)
 C2106=3.26D0
 C2107=55.39D0
 C2108=1.88D0
 C2109=.57D0
 C2110=6.9D0
 C2111=3.1D0
 C2112=2.05D0
 C2113=.87D0
 C2114=.87D0
 C2115=.5D0+.99D0*RMAJ/RMAJW*DSQRT(BMAX/BMAXW)
 C2116=.31D0
 C2117=0.D0
 C2198=1.96D0
 C21S=C2101+C2102+C2103+C2104+C2105+C2106+C2107+
 1 C2108+C2109+C2110+C2111+C2112+C2113+C2114+C2115+
 2 C2116+C2117
 C2199=.15D0*C21S
 C21=C21S+C2198+C2199
 C ACCT 22
 C ACCT 2201
 C22101=132.23*RMAJ/RMAJW*(RPLAS+.4D0)/(RPLASW+.4D0)
 C22102=352.5*RMAJ/RMAJW*(RMAJ-RM)/(RMAJW-RMW)*DELBSI/DBSIW
 CP=59.64D0*(RMAJ*RPLAS**2*CAPPA*PCUR)/
 1 (RMAJW*RPLASW**2*1.6D0*PCURW)
 CT=293.02D0*DSQRT(XNTFC/12.D0)*(BPLAS**2*RMAJ*(RMAJ-RM)**2
 1 *CAPPA)/(BPLASW**2*RMAJW*(RMAJW-RMW)**2*1.6D0)
 C22103=CP+CT
 C22104=34.88D0*PCUR/PCURW*XN(NIE)/XNEW/TE*TEW
 C22105=115.13*((BPLAS/BPLASW)/(RMAJ-RPLAS)*(RMAJW-RPLASW))**2
 1 *(RMAJ/RMAJW)**4
 C22106=8.68D0*VSPD/VSPDW
 C22107=32.2D0
 C22108=3.07*PT/PTW
 C22109=15.6*RMAJ/RMAJW*(RPLAS/RPLASW)**2
 C2201=C22101+C22102+C22103+C22104+C22105+C22106+
 1 C22107+C22108+C22109
 C2202=51.92D0*DSQRT(PT/PTW)
 C2203=30.07D0*(RMAJ/RMAJW)**3*BMAX/BMAXW
 C2204=4.80D0
 C2205=3.D0+9.D0*THRU/THRUW+19.7D0*(RMAJ/RMAJW)**2
 C2206=38.3D0+.24D0+.08D0+2.0D0+1.58D0+.93D0
 C2207=23.41D0
 C2298=.02D0*C22101+.25D0*CP+.16D0*C22104+.04D0*C22105+
 1 52.11D0
 C22S=C2201+C2202+C2203+C2204+C2205+C2206+C2207
 C2299=.15D0*C22S
 C22=C22S+C2298+C2299
 C ACCT 23
 C23=3.D0+212.38D0*(PGE/PGEW)**.75
 C ACCT 24

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      C24=53.17D0*(PGE/PGEW)**.6+
      1 57.91D0*PCUR/PCURW*XN(NIE)/XNEW*TE/TEW
C ACCT 25
      C25=39.66D0*(RMAJ/RMAJW)**.7
C ACCT 26
      C26=.25D0
C OVERALL ACCTS
      C90=C20+C21+C22+C23+C24+C25+C26
      C91=.10D0*C90
      C92=.08D0*C90
      C93=.05D0*C90
      C94=.1303D0*(C90+C91+C92+C93)
      C95=0.D0
C CAPITAL COST
      TRCC=C90+C91+C92+C93+C94+C95
C ANNUAL CAPITAL COST
      CAC=.1D0*TRCC
C OPERATIONS AND MAINTENENCE COST
      COM=19.407D0
C SCHEDULED COMPONENT REPLACEMENT COST
      CSRC=7.665D0
C FUEL COST
      CF=.406D0*PT/PTW*AVAIL/AVAILW
C COST OF CAPACITY
      COC=TRCC/PNETE*1.D3
C COST OF ELECTRICITY
      COE=(CAC+COM+CSRC+CF)/(PNETE*AVAIL*8760.D-6)
C OUTPUT FORMATS
300  IF(IPRINT.EQ.0) RETURN
100  FORMAT(1H1,T53,'COST ANALYSIS FOR ICALL=',I2/)
101  FORMAT(1X)
1    FORMAT(1X,'20.',T11,
1    1 'LAND ACQUISITION AND RELOCATION',T70,F8.2)
2    FORMAT(1X,'21.01',T11,
1    1 'SITE IMPROVEMENTS AND FACILITIES',T62,F8.2)
3    FORMAT(1X,'21.02',T11,
1    1 'REACTOR BUILDING',T62,F8.2)
4    FORMAT(1X,'21.03',T11,
1    1 'TURBINE BUILDING',T62,F8.2)
5    FORMAT(1X,'21.04',T11,
1    1 'COOLING SYSTEM STRUCTURES',T62,F8.2)
6    FORMAT(1X,'21.05',T11,
1    1 'ELECTRICAL AND POWER SUPPLY BUILDING',T62,F8.2)
7    FORMAT(1X,'21.06',T11,
1    1 'PLANT AUXILLIARY SYSTEMS BUILDING',T62,F8.2)
8    FORMAT(1X,'21.07',T11,
1    1 'HOT CELL BUILDING',T62,F8.2)
9    FORMAT(1X,'21.08',T11,
1    1 'REACTOR SERVICE BUILDING',T62,F8.2)
10   FORMAT(1X,'21.09',T11,
1    1 'SERVICE WATER PUMP',T62,F8.2)
11   FORMAT(1X,'21.10',T11,
1    1 'FUEL HANDLING AND STORAGE BUILDING',T62,F8.2)
12   FORMAT(1X,'21.11',T11,

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1 'CONTROL ROOM BUILDING',T62,F8.2)
13  FORMAT(1X,'21.12',T11,
1 'ONSITE POWER SUPPLY BUILDING',T62,F8.2)
14  FORMAT(1X,'21.13',T11,
1 'ADMINISTRATION BUILDING',T62,F8.2)
15  FORMAT(1X,'21.14',T11,
1 'SITE SERVICE BUILDING',T62,F8.2)
16  FORMAT(1X,'21.15',T11,
1 'CRYOGENICS BUILDING',T62,F8.2)
17  FORMAT(1X,'21.16',T11,
1 'SECURITY BUILDING',T62,F8.2)
18  FORMAT(1X,'21.17',T11,
1 'VENTILATION STACK',T62,F8.2)
19  FORMAT(1X,'21.98',T11,
1 'SPARE PARTS',T62,F8.2)
20  FORMAT(1X,'21.99',T11,
1 'CONTINGENCIES',T62,F8.2)
21  FORMAT(1X,'21.',T11,
1 'STRUCTURES AND SITE FACILITIES',T70,F8.2)
22  FORMAT(1X,'22.01.01',T11,
1 'BLANKET AND FIRST WALL',T54,F8.2)
23  FORMAT(1X,'22.01.02',T11,
1 'REACTOR SHIELD',T54,F8.2)
24  FORMAT(1X,'22.01.03',T11,
1 'MAGNETS',T54,F8.2)
25  FORMAT(1X,'22.01.04',T11,
1 'RF HEATING AND/OR CURRENT DRIVE',T54,F8.2,T100,'PRF=',F8.1)
26  FORMAT(1X,'22.01.05',T11,
1 'PRIMARY STRUCTURE AND SUPPORT',T54,F8.2)
27  FORMAT(1X,'22.01.06',T11,
1 'REACTOR VACUUM SYSTEM',T54,F8.2)
28  FORMAT(1X,'22.01.07',T11,
1 'POWER SUPPLY, SWITCHING, AND ENERGY STORAGE',T54,F8.2)
29  FORMAT(1X,'22.01.08',T11,
1 'IMPURITY CONTROL SYSTEM',T54,F8.2)
30  FORMAT(1X,'22.01.09',T11,
1 'ECRH BREAKDOWN',T54,F8.2)
31  FORMAT(1X,'22.01',T11,
1 'REACTOR EQUIPMENT',T62,F8.2)
32  FORMAT(1X,'22.02',T11,
1 'MAIN HEAT TRANSFER AND TRANSPORT',T62,F8.2)
33  FORMAT(1X,'22.03',T11,
1 'CRYOGENIC COOLING SYSTEM',T62,F8.2)
34  FORMAT(1X,'22.04',T11,
1 'RADIOACTIVE WASTE TREATMENT AND DISPOSAL',T62,F8.2)
35  FORMAT(1X,'22.05',T11,
1 'FUEL HANDLING AND STORAGE',T62,F8.2)
36  FORMAT(1X,'22.06',T11,
1 'OTHER REACTOR PLANT EQUIPMENT',T62,F8.2)
37  FORMAT(1X,'22.07',T11,
1 'INSTRUMENTATION AND CONTROL',T62,F8.2)
38  FORMAT(1X,'22.98',T11,
1 'SPARE PARTS',T62,F8.2)
39  FORMAT(1X,'22.99',T11,

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1 'CONTINGENCIES',T62,F8.2)
40  FORMAT(1X,'22.',T11,
1 'REACTOR PLANT EQUIPMENT',T70,F8.2)
41  FORMAT(1X,'23.',T11,
1 'TURBINE PLANT EQUIPMENT',T70,F8.2)
42  FORMAT(1X,'24.',T11,
1 'ELECTRIC PLANT EQUIPMENT',T70,F8.2)
43  FORMAT(1X,'25.',T11,
1 'MISCELLANEOUS PLANT EQUIPMENT',T70,F8.2)
44  FORMAT(1X,'26.',T11,
1 'SPECIAL MATERIALS',T70,F8.2)
45  FORMAT(1X,'90.',T11,
1 'TOTAL REACTOR DIRECT COST',T78,F8.2)
46  FORMAT(1X,'91.',T11,
1 'CONSTRUCTION FACILITIES EQUIPMENT AND SERVICES',T78,F8.2)
47  FORMAT(1X,'92.',T11,
1 'ENGINEERING AND CONSTRUCTION MANAGEMENT SERVICES',T78,F8.2)
48  FORMAT(1X,'93.',T11,
1 'OTHER COSTS',T78,F8.2)
49  FORMAT(1X,'94.',T11,
1 'INTEREST DURING CONSTRUCTION',T78,F8.2)
50  FORMAT(1X,'95.',T11,
1 'ESCALATION DURING CONSTRUCTION',T78,F8.2)
51  FORMAT(1X,'99.',T11,
1 'TOTAL REACTOR CAPITAL COST',T86,F8.2)
52  FORMAT(1X,T11,'ANNUAL CAPITAL COST',T62,F8.2)
53  FORMAT(1X,T11,'OPERATIONS AND MAINTENANCE COST',T62,F8.2)
54  FORMAT(1X,T11,'SCHEDULED COMPONENT REPLACEMENT COST',T62,F8.2)
55  FORMAT(1X,T11,'FUEL COST',T62,F8.2)
56  FORMAT(1X,T11,'NET ELECTRIC POWER,MWE',T62,F8.1)
57  FORMAT(1X,T11,'TOTAL CAPITAL COST,M$',T62,F8.1)
58  FORMAT(1X,T11,'COST OF ELECTRICITY,MILLS/KWH',T62,F8.1,
1 T100,'AVAILABILITY=',F5.3)
59  FORMAT(1X,T11,'COST OF CAPACITY,$/KWE',T62,F8.1)
C PRINT OUTPUT
  PRINT 100,ICALL
  PRINT 1,C20
  IF(ICMOD.NE.1) GO TO 60
  PRINT 2,C2101
  PRINT 3,C2102
  PRINT 4,C2103
  PRINT 5,C2104
  PRINT 6,C2105
  PRINT 7,C2106
  PRINT 8,C2107
  PRINT 9,C2108
  PRINT 10,C2109
  PRINT 11,C2110
  PRINT 12,C2111
  PRINT 13,C2112
  PRINT 14,C2113
  PRINT 15,C2114
  PRINT 16,C2115

```

60 PRINT 17,C2116
PRINT 18,C2117
PRINT 19,C2198
PRINT 20,C2199
CONTINUE
PRINT 21,C21
PRINT 22,C22101
PRINT 23,C22102
PRINT 24,C22103
PRINT 25,C22104,PRF
PRINT 26,C22105
PRINT 27,C22106
PRINT 28,C22107
PRINT 29,C22108
PRINT 30,C22109
PRINT 31,C2201
PRINT 32,C2202
PRINT 33,C2203
PRINT 34,C2204
PRINT 35,C2205
PRINT 36,C2206
PRINT 37,C2207
PRINT 38,C2298
PRINT 39,C2299
PRINT 40,C22
PRINT 41,C23
PRINT 42,C24
PRINT 43,C25
PRINT 44,C26
PRINT 45,C90
PRINT 46,C91
PRINT 47,C92
PRINT 48,C93
PRINT 49,C94
PRINT 50,C95
PRINT 51,TRCC
PRINT 101
PRINT 52,CAC
PRINT 53,COM
PRINT 54,CSRC
PRINT 55,CF
PRINT 101
PRINT 56,PNETE
PRINT 57,TRCC
PRINT 59,COC
PRINT 58,COE,AVAIL
RETURN
END

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