

APPENDIX B

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APPENDIX B

B.1. TABLE OF TITAN-II REACTOR PARAMETERS

1. CHARACTERISTIC MACHINE DIMENSIONS

1.1. Reactor Envelope ⁽¹⁻¹⁾

1.1.1. Height	5.52 m
1.1.2. Outside diameter	12.47 m
1.1.3. Circumference	39.18 m
1.1.4. Volume	674.16 m ³

1.2. Plasma Chamber

1.2.1. Major toroidal radius, R_T	3.90 m
1.2.2. Plasma minor radius, r_p	0.60 m
1.2.3. First wall minor radius, r_{FW}	0.66 m
1.2.4. Plasma volume, V_p	27.71 m ³
1.2.5. Plasma chamber volume	33.53 m ³
1.2.6. First wall surface area ⁽¹⁻²⁾	163.25 m ²
1.2.7. Number of sectors ⁽¹⁻³⁾	3

1.3. Reactor Pool ⁽¹⁻⁴⁾

1.3.1. Average height	33 m
1.3.2. Outside diameter	38 m
1.3.3. Wall thickness	1 m
1.3.4. Circumference	119 m
1.3.5. Volume	29,600 m ³

2. PLASMA PARAMETERS

2.1. Fuel Cycle

DT/Li

2.2. Plasma Dimensions

2.2.1. Major radius, R_T	3.90 m
2.2.2. Minor radius, r_p	0.60 m
2.2.3. Plasma cross section	circular

2.3. Electron Density, n_e ⁽²⁻¹⁾	
2.3.1. Average electron density	$9.3 \times 10^{20} \text{ m}^{-3}$
2.3.2. Central electron density	$1.4 \times 10^{21} \text{ m}^{-3}$
2.4. Ion Density, n_i ⁽²⁻¹⁾	
2.4.1. Average ion density	$8.9 \times 10^{20} \text{ m}^{-3}$
2.4.2. Central ion density	$1.3 \times 10^{21} \text{ m}^{-3}$
2.5. Average Alpha-Particle Density, n_α ⁽²⁻²⁾	$4.5 \times 10^{19} \text{ m}^{-3}$
2.6. Ion Temperature, T_i ⁽²⁻¹⁾	
2.6.1. Average ion temperature	10 keV
2.6.2. Central ion temperature	15 keV
2.7. Electron Temperature, T_e ⁽²⁻¹⁾	
2.7.1. Average electron temperature	10 keV
2.7.2. Central electron temperature	15 keV
2.8. Average Alpha-Particle Energy, E_α ⁽²⁻²⁾	68 keV
2.9. Effective Plasma Ion Charge, Z_{eff} ⁽²⁻³⁾	1.690
2.10. Global Energy-Confinement Time, τ_E ⁽²⁻⁴⁾	0.22 s
2.11. Effective Global Thermal Diffusivity, $\chi_E = (3/16)r_p^2/\tau_E$ ⁽²⁻⁴⁾	$0.31 \text{ m}^2/\text{s}$
2.12. Electron Energy-Confinement Time, τ_{Ee} ⁽²⁻⁴⁾	0.28 s
2.13. Particle Confinement Time at Burn, τ_p	
2.13.1. Without recycling ⁽²⁻⁵⁾	1.10 s
2.13.2. With recycling ⁽²⁻⁶⁾	
2.13.2.1. Fuel ions (average)	3.68 s
2.13.2.2. Helium	1.52 s
2.14. Lawson Parameter, $n_i \tau_E$ ⁽²⁻⁴⁾	$1.92 \times 10^{19} \text{ s/m}^3$
2.15. Plasma Toroidal Current, I_ϕ ⁽²⁻⁷⁾	17.8 MA
2.16. Average Toroidal Current Density, j_ϕ ⁽²⁻⁷⁾	15.7 MA/m^2

2.17. Toroidal Field, B_ϕ ⁽²⁻¹⁾	
2.17.1. Average	3.90 T
2.17.2. At plasma edge	0.38 T
2.17.3. At plasma axis	11.85 T
2.17.4. Peak field on the coil ⁽²⁻⁸⁾	5.1 T
2.18. Poloidal Field, B_θ ⁽²⁻¹⁾	
2.18.1. Average	6.21 T
2.18.2. At plasma edge	5.93 T
2.19. Vertical Field,	
2.19.1. At plasma axis	1.56 T
2.19.2. Decay index, n	0.40
2.19.3. Stray field at startup	2.30 T
2.20. Poloidal Beta, $\beta_\theta = 2\mu_0 p / B_\theta^2(r_p)$	0.22
2.21. Toroidal Beta $\beta = 2\mu_0 p / <B_\phi>^2$	0.52
2.22. Engineering Beta ⁽²⁻⁹⁾	7.75
2.23. Reversal Parameter, F ^{(2-7),(2-10)}	
2.23.1. Mean value at burn	-0.1
2.23.2. During OFCD oscillation	-0.03 to -0.17
2.24. Pinch Parameter, Θ ^{(2-7),(2-10)}	
2.24.1. Mean value at burn	1.56
2.24.2. During OFCD oscillation	1.50 to 1.62
2.25. Safety Factor, $q = rB_\phi / RB_\theta$	
2.25.1. On axis	0.11
2.25.2. At plasma edge	-0.01
2.25.3. Radius of reversal surface ($q = 0$)	0.55 m
2.26. Streaming Parameter, j_ϕ / n	
2.26.1. During startup (maximum value)	6.5×10^{-14} A-m
2.26.2. At burn	1.8×10^{-14} A-m
2.27. Electron Streaming Parameter, $\xi = v_D / v_{th}$	
2.27.1. During startup (maximum value)	2.0×10^{-2}
2.27.2. At burn	1.9×10^{-8}

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2.28. Radiation Fraction ⁽²⁻³⁾	
2.28.1. Core plasma	0.70
2.28.2. Scrape-off layer	0.23
2.28.3. Divertor plasma	0.04
2.28.4. Total radiation fraction	0.97
2.28.5. Radiation fraction to first wall, f_{RAD}	0.95
2.28.6. Radiation fraction to divertor plate	0.02
2.29. Current Drive ⁽²⁻¹¹⁾	
2.29.1. Method	OFCD
2.29.2. Frequency, f	25 Hz
2.29.3. Toroidal-flux swing, $\delta\phi/\phi_o$	0.035
2.29.4. Θ variation	1.50 to 1.62
2.29.5. F variation	-0.03 to -0.17
2.29.6. Input power (toroidal/poloidal circuits)	
2.29.6.1. Real (supplied) power ⁽²⁻¹¹⁾	38.23/4.61 MW
2.29.6.2. Reactive power	1285.71/249.15 MVA
2.29.7. Power-supply dissipation ⁽²⁻¹²⁾	15.34 MW
2.29.8. Current-drive power ⁽²⁻¹¹⁾	54.64 MW
2.29.9. Efficiency, I_ϕ/P_{CD} ⁽²⁻¹³⁾	0.33 A/W
2.30. Plasma Heating Method	Ohmic
2.31. Plasma Ohmic Dissipation	28.5 MW
2.32. Plasma Energy Gain, $Q_p = P_f/P_\Omega$ ⁽²⁻¹⁴⁾	80.2

3. POWER OUTPUT

3.1. Plasma Fusion Power, P_f	2289.8 MW
3.1.1. Neutron power, P_n	1831.3 MW
3.1.2. Alpha-particle power, P_α	458.5 MW
3.2. Blanket Energy Multiplication, M	1.36
3.3. Nuclear Power ($MP_n + P_\alpha$)	2949.1 MW
3.4. Ohmic Heating Power, P_Ω ⁽³⁻¹⁾	28.5 MW

3.5. Power to First Wall	
3.5.1. Surface heating, $f_{RAD}(P_{\alpha} + P_{\Omega})$	462.7 MW
3.5.2. Nuclear heating	
3.5.2.1. Structure	36.6 MW
3.5.2.2. Coolant	258.4 MW
3.5.3. OFCD heating (eddy currents) ⁽³⁻²⁾	nil
3.5.4. Coolant-pumping power ⁽³⁻³⁾	12.5 MW
3.5.5. Total thermal power, P_{FW}	770.2 MW
3.6. Power to Multiplier Zone	
3.6.1. Nuclear heating	
3.6.1.1. Structure	214.5 MW
3.6.1.2. Coolant	690.9 MW
3.6.1.2. Beryllium	819.9 MW
3.6.2. OFCD heating (eddy currents) ⁽³⁻²⁾	0.1
3.6.3. Coolant-pumping power ⁽³⁻³⁾	28.2 MW
3.6.6. Total thermal power, P_{MZ}	1753.6 MW
3.7. Power to Breeder/Reflector Zone	
3.7.1. Nuclear heating	
3.7.1.1. Structure	27.9 MW
3.7.1.2. Coolant	281.2 MW
3.7.2. OFCD heating (eddy currents) ⁽³⁻²⁾	0.1
3.7.3. Coolant-pumping power ⁽³⁻³⁾	5.1 MW
3.7.6. Total thermal power, P_{BZ}	314.3 MW
3.8. Power to Hot Shield	
3.8.1. Nuclear heating	
3.8.1.1. Structure	148.9 MW
3.8.1.2. Coolant	8.3 MW
3.8.2. OFCD heating (eddy currents) ⁽³⁻²⁾	nil
3.8.3. Coolant-pumping power ⁽³⁻³⁾	2.6 MW
3.8.4. Total thermal power, P_{HS}	159.8 MW
3.9. Power to Divertor Plate	
3.9.1. Surface heating, $(1 - f_{RAD})(P_{\alpha} + P_{\Omega})$	24.3 MW
3.9.2. Nuclear heating	
3.9.2.1. Structure	2.8 MW
3.9.2.2. Coolant	1.2 MW
3.9.3. Coolant-pumping power ⁽³⁻³⁾	0.5 MW
3.9.4. Total thermal power, P_{DP}	28.8 MW

3.10. Total Reactor Thermal Power, P_{th}	
3.10.1. First wall thermal power	770.2 MW
3.10.2. Multiplier-zone thermal power	1753.6 MW
3.10.3. Breeding-zone thermal power	314.3 MW
3.10.4. Hot shield thermal power	159.8 MW
3.10.5. Divertor plate thermal power	28.8 MW
3.10.6. Total	3026.7 MW
3.11. Thermal-Cycle Efficiencies, η_{th}	0.350
3.12. Gross Electric Power, P_{ET}	1059.3 MWe
3.13. Recirculating Power	
3.13.1. TF joule losses	16.0 MWe
3.13.2. Divertor joule losses	9.8 MWe
3.13.3. OFCD system ⁽³⁻⁴⁾	54.6 MWe
3.13.4. Coolant-pumping power	48.9 MWe
3.13.5. Auxiliary power ⁽³⁻⁵⁾	30.0 MWe
3.13.6. Total	159.3 MWe
3.14. Recirculating-Power Fraction, ϵ	0.150
3.15. Engineering Q ($= 1/\epsilon$)	6.650
3.16. Net Electric Power	900.0 MWe
3.17. Net Plant Efficiency, $\eta_p = \eta_{th}(1 - \epsilon)$	0.30
3.18. Mass Power Density, MPD ⁽³⁻⁶⁾	806 kWe/tonne
3.19. Plasma Power Density, P_f/V_p	83 MW/m ³

4. REACTOR COOLANT SYSTEM

4.1. First Wall System ⁽⁴⁻¹⁾Semi-circular channels separated from blanket lobes
single-pass, poloidal coolant flowAqueous LiNO₃ Solution ($A_{Li} = 6.4\%$)

Ferritic Steel (9-C)

4.1.1. Coolant	
4.1.2. Structural material	
4.1.3. Channel outer diameter ⁽⁴⁻¹⁾	30.0 mm
4.1.4. Channel inner diameter ⁽⁴⁻¹⁾	27.0 mm
4.1.5. Erosion allowance	0.25 mm
4.1.6. Number of channels	840
4.1.7. Structure volume fraction	0.17
4.1.8. Coolant volume fraction	0.62
4.1.9. Void volume fraction	0.21
4.1.10. Structure volumetric heating	202 MW/m ³
4.1.11. Coolant volumetric heating	270 MW/m ³
4.1.12. Outlet temperature	603 K
4.1.13. Inlet temperature	571 K
4.1.14. Outlet pressure	7 MPa
4.1.15. Inlet pressure ⁽⁴⁻²⁾	8 MPa
4.1.16. Pressure drop	0.5 MPa
4.1.17. Maximum primary stress	98 MPa
4.1.18. Maximum secondary stress	363 MPa
4.1.19. Maximum wall temperature	776 K
4.1.20. Coolant flow rate (total)	1150 kg/s
4.1.21. Coolant flow velocity	22.6 m/s
4.1.22. Reynolds number, Re	1.49×10^6
4.1.23. Nusselt number, Nu	2360
4.1.24. Prandtl number, Pr	16.5
4.1.25. Critical heat flux	8.3 MW/m ²
4.1.26. Subcooling at exit	16.5 °C

4.2. Multiplier-Zone System ⁽⁴⁻¹⁾First zone of the blanket lobes
single-pass, poloidal coolant flowAqueous LiNO₃ Solution ($A_{Li} = 6.4\%$)

Ferritic Steel (9-C)

Beryllium

4.2.1. Coolant	
4.2.2. Structural material	
4.2.3. Multiplier Material	
4.2.4. Lobe width	30.0 mm
4.2.5. Zone radial dimension	200.0 mm
4.2.6. Lobe wall thickness	1.4 mm
4.2.7. Number of Lobes	840
4.2.8. Structure volume fraction ⁽⁴⁻³⁾	0.12
4.2.9. Coolant volume fraction ⁽⁴⁻³⁾	0.29
4.2.10. Multiplier volume fraction ⁽⁴⁻³⁾	0.59

4.2.11. Structure volumetric heating ⁽⁴⁻⁴⁾	180 MW/m ³
4.2.12. Coolant volumetric heating ⁽⁴⁻⁴⁾	140 MW/m ³
4.2.13. Beryllium volumetric heating ⁽⁴⁻⁴⁾	240 MW/m ³
4.2.14. Outlet temperature	603 K
4.2.15. Inlet temperature	571 K
4.2.16. Outlet pressure	7 MPa
4.2.17. Inlet pressure ⁽⁴⁻²⁾	8 MPa
4.2.18. Pressure drop ⁽⁴⁻⁴⁾	1 MPa
4.2.19. Maximum beryllium temperature	846 K
4.2.20. Coolant flow rate (total)	2.6×10^4 kg/s
4.2.21. Coolant flow velocity ⁽⁴⁻⁴⁾	14 m/s
4.2.22. Reynolds number, Re ⁽⁴⁻⁴⁾	2.7×10^5
4.2.23. Nusselt number, Nu ⁽⁴⁻⁴⁾	601
4.3. Breeder/Reflector-Zone System ⁽⁴⁻¹⁾	Second zone of the blanket lobes single-pass, poloidal coolant flow Aqueous LiNO ₃ Solution ($A_{Li} = 6.4\%$) Ferritic Steel (9-C)
4.3.1. Coolant	
4.3.2. Structural material	
4.3.3. Lobe width	30.0 mm
4.3.4. Zone radial dimension	100.0 mm
4.3.5. Lobe wall thickness	1.4 mm
4.3.6. Number of Lobes	840
4.3.7. Structure volume fraction	0.09
4.3.8. Coolant volume fraction	0.91
4.3.9. Structure volumetric heating	40 MW/m ³
4.3.10. Coolant volumetric heating	40 MW/m ³
4.3.11. Outlet temperature	603 K
4.3.12. Inlet temperature	571 K
4.3.13. Outlet pressure	7 MPa
4.3.14. Inlet pressure ⁽⁴⁻²⁾	8 MPa
4.3.15. Coolant flow rate (total)	4660 kg/s
4.3.15. Pressure drop	5.0×10^{-4} MPa
4.3.16. Maximum wall temperature	621 K
4.3.18. Coolant flow velocity	1.0 m/s
4.3.19. Reynolds number, Re	1.5×10^6
4.3.20. Nusselt number, Nu	376

4.4. Hot Shield System ⁽⁴⁻¹⁾	Two-piece shield, welded to from blanket container with two rows of coolant channels single-pass, poloidal coolant flow Aqueous LiNO ₃ Solution ($A_{Li} = 6.4\%$) Ferritic Steel (9-C)
4.4.1. Coolant	
4.4.2. Structural material	
4.4.3. Radial thickness	100 mm
4.4.4. Channel inner diameter	
4.4.4.1. 1st row	12.7 mm
4.4.4.2. 2nd row	19.0 mm
4.4.5. Structure volume fraction	0.90
4.4.6. Coolant volume fraction	0.10
4.4.7. Structure volumetric heating	
4.4.7.1. 1st row	22 MW/m ³
4.4.7.2. 2nd row	9 MW/m ³
4.4.8. Coolant volumetric heating	
4.4.8.1. 1st row	10 MW/m ³
4.4.8.2. 2nd row	5 MW/m ³
4.4.9. Outlet temperature	603 K
4.4.10. Inlet temperature	571 K
4.4.11. Outlet pressure	7 MPa
4.4.12. Inlet pressure ⁽⁴⁻²⁾	8 MPa
4.4.13. Pressure drop	
4.4.13.1. 1st row	2.2×10^{-2} MPa
4.4.13.2. 2nd row	4.7×10^{-3} MPa
4.4.14. Maximum wall temperature	
4.4.14.1. 1st row	682 K
4.4.14.2. 2nd row	700 K
4.4.15. Coolant flow rate (total)	2440 kg/s
4.4.16. Coolant flow velocity	
4.4.16.1. 1st row	6.5 m/s
4.4.16.2. 2nd row	3.7 m/s
4.4.17. Reynolds number, Re	
4.4.17.1. 1st row	3.3×10^5
4.4.17.2. 2nd row	2.8×10^5
4.4.18. Nusselt number, Nu	
4.4.18.1. 1st row	706
4.4.18.2. 2nd row	619

4.5. Divertor Plate System ⁽⁴⁻⁵⁾

The armor is brazed to
a bank of circular tubes with
multiple-pass, radial/toroidal coolant flow
Aqueous LiNO₃ Solution ($A_{Li} = 6.4\%$)

4.5.1. Coolant	
4.5.2. Structural material	
4.5.2.1. Armor	W-26Re
4.5.2.2. Coolant tube	W-26Re
4.5.3. Coolant-tube outer diameter	10.0 mm
4.5.4. Coolant-tube inner diameter	8.0 mm
4.5.5. Armor thickness	1.0 mm
4.5.6. Outlet temperature	618 K
4.5.7. Inlet temperature	591 K
4.5.8. Outlet pressure	14 MPa
4.5.9. Inlet pressure ⁽⁴⁻⁶⁾	15 MPa
4.5.10. Maximum primary stress	83 MPa
4.5.11. Maximum secondary stress	505 MPa
4.5.12. Maximum wall temperature	1052 K
4.5.13. Coolant flow rate (total)	433 kg/s
4.5.14. Maximum coolant flow velocity ⁽⁴⁻⁷⁾	20 m/s

4.6. Coolant-Circulator Type

4.6.1. First wall, blanket, hot shield	Single-stage centrifugal pump
4.6.2. Divertor Plate	Double-stages centrifugal pump

4.7. Power Input to Each Circulator ⁽⁴⁻⁸⁾

4.7.1. First wall, blanket, hot shield	48.4 MWe
4.7.2. Divertor Plate	0.5 MWe

4.8. Thermal-Energy Storage

not required

4.9. Peak Temperature During a Loss-of-Flow Accident (LOFA) ⁽⁴⁻⁹⁾

4.9.1. First wall	621 K
4.9.2. Beryllium zone	617 K
4.9.3. Hot shield	613 K

4.10. Peak Temperature During a Loss-of-Coolant Accident (LOCA) ⁽⁴⁻¹⁰⁾

4.10.1. First wall	1005 K
4.10.2. Beryllium zone	754 K
4.10.3. Hot shield	603 K

5. INTERMEDIATE COOLANT SYSTEM ⁽⁵⁻¹⁾

5.1. Secondary Coolant none

6. STEAM GENERATION SYSTEM

6.1. Steam Outlet Temperature 581 K

6.2. Steam Outlet Pressure 7.2 MPa

6.3. Total Steam Flow Rate 1466 kg/s

6.4. Feedwater Inlet Temperature 514 K

6.5. Number of Steam Generators per sector 1

6.6. Gross Thermal-Power Efficiency 0.350

6.7. Gross Electric Output 1059.3 MWe

7. SHIELD COOLANT SYSTEM ⁽⁷⁻¹⁾

7.1. EFC-Shield ⁽⁷⁻²⁾ None

8. REACTOR AUXILIARY SYSTEM**8.1. Vacuum Pumping System**

8.1.1. Vacuum and plasma chamber pressure

8.1.1.1. Base plasma chamber pressure 10^{-5} mtorr

8.1.1.2. Divertor duct pressure ⁽⁸⁻¹⁾ 20 – 100 mtorr

8.1.2. Temperature of neutral gas 700 K

8.1.3. Plasma chamber volume 33.6 m^3

8.1.4. Vacuum chamber volume ⁽⁸⁻²⁾ $110. \text{ m}^3$

8.1.5. Particle throughput ⁽⁸⁻³⁾

8.1.5.1. DT $6.7 \times 10^{21} \text{ s}^{-1}$

8.1.5.2. Helium $8.2 \times 10^{20} \text{ s}^{-1}$

8.1.6. Conductance of the divertor duct

8.1.6.1. For DT $215 \text{ m}^3/\text{s}$

8.1.6.2. For He $224 \text{ m}^3/\text{s}$

8.1.7. Type of pumps ⁽⁸⁻⁴⁾ Turbo-molecular

8.1.8. Number of vacuum pumps ^{(8-4),(8-5)} 16

8.1.9. Helium pumping speed (per pump) ⁽⁸⁻⁶⁾ $20 \text{ m}^3/\text{s}$

8.2. Magnet Cooling System

8.2.1. Toroidal-field coils ⁽⁸⁻⁷⁾	
8.2.1.1. Coolant	Water
8.2.1.2. Cooling load	19.6 MW
8.2.2. Divertor-field coils ⁽⁸⁻⁷⁾	
8.2.2.1. Coolant	Water
8.2.2.2. Cooling load	14.1 MW
8.2.3. Ohmic-heating coils ⁽⁸⁻⁷⁾	
8.2.3.1. Coolant	Water
8.2.3.2. Peak Cooling load during startup	200 to MW
8.2.3.3. Cooling load during normal operation	2.7 MW
8.2.4. Equilibrium-field coils ⁽⁸⁻⁸⁾	
8.2.4.1. Coolant	Liquid helium
8.2.4.2. Cooling load ⁽⁸⁻⁹⁾	

8.3. Plasma-Fueling System ⁽⁸⁻¹⁰⁾

8.3.1. Type	DT pellet
8.3.2. Fuel composition	50% D, 50% T
8.3.3. Fueling rates	0.035 g/s
8.3.4. Pellet diameter	3.4 mm
8.3.5. Pellet speed	2.1 km/s
8.3.6. Pellet injection frequency	6.25 s ⁻¹

8.4. Tritium-Processing and Recovery System

8.4.1. Type	Vapor-phase catalytic exchange
8.4.2. Total tritium inventory ⁽⁸⁻¹¹⁾	4.00 kg
8.4.3. Tritium handling rate	0.46 kg/d
8.4.4. Water processing rate	9.64×10^4 kg/d
8.4.5. Primary-coolant tritium concentration	50 Ci/kg
8.4.6. Blanket detritiation factor	0.93 per pass

9. REACTOR COMPONENTS

9.1. First wall, Blanket, and Shield ⁽⁹⁻¹⁾

9.1.1. Structural material	Ferritic Steel (9-C)
9.1.2. Breeding material ⁽⁹⁻²⁾	Aqueous LiNO ₃ Solution ($A_{Li} = 6.4\%$)
9.1.3. Neutron multiplier material	Beryllium
9.1.4. Tritium breeding ratio (TBR) ⁽⁹⁻³⁾	1.22
9.1.5. Number of modules ⁽⁹⁻⁴⁾	1
9.1.6. Weight of modules	180 tonnes
9.1.7. Largest single component ⁽⁹⁻⁴⁾	
9.1.7.1. Weight	180 tonnes
9.1.7.2. Dimensions (diameter×height)	10.0 × 2.3 m
9.1.9. Lifetime ⁽⁹⁻⁵⁾	1 y

9.2. Divertor

9.2.1. Type	Toroidal-field divertors
9.2.2. Number of divertors	3
9.2.3. Neutralizer plate	
9.2.3.1 Armor	W-26Re
9.2.3.2 Coolant tube	W-26Re
9.2.3.3 Coolant	Aqueous LiNO ₃ Solution ($A_{Li} = 6.4\%$)
9.2.4. Weight of each divertor	10 tonnes
9.2.5. Dimensions (diameter×height)	3 × 3 m
9.2.6. Lifetime ⁽⁹⁻⁵⁾	1 y

9.3. Magnets

9.3.1. Ohmic-heating coils ^{(9-6),(9-7)}	
9.3.1.1. Type	Normal
9.3.1.2. Number	13
9.3.1.3. Conductor	Copper
9.3.1.4. Structure	Steel
9.3.1.5. Insulator	Spinel (MgAl ₂ O ₄)
9.3.1.6. Coolant	Water
9.3.1.7. Operating temperature	20 – 80 °C
9.3.1.8. Maximum stress in coil	33 MPa
9.3.1.9. Mean coil radius	2.42 – 5.66 m
9.3.2. Equilibrium-field coils ⁽⁹⁻⁸⁾	
9.3.2.1. Type	Superconducting
9.3.2.2. Number	2
9.3.2.3. Conductor	Nb-Ti
9.3.2.4. Structure	Steel
9.3.2.5. Stabilizer	Copper
9.3.2.6. Coolant	Liquid helium
9.3.2.7. Operating temperature	4 K
9.3.2.8. Mean stress in coil ⁽⁹⁻⁸⁾	
9.3.2.9. Mean coil radius	5.94 m
9.3.3. Toroidal-field coils ⁽⁹⁻⁵⁾	
9.3.3.1. Type	Normal
9.3.3.2. Number	30
9.3.3.3. Conductor	Copper
9.3.3.4. Structure	Steel
9.3.3.5. Insulator	Spinel (MgAl ₂ O ₄)
9.3.3.6. Coolant	Water
9.3.3.7. Operating temperature	20 – 80 °C
9.3.3.8. Mean stress in coil ⁽⁹⁻⁹⁾	
9.3.3.9. Mean coil radius	1.12 m

9.3.4. Divertor-field coils	
9.3.4.1. Type	Normal
9.3.4.2. Number	9
9.3.4.3. Conductor	Copper
9.3.4.4. Structure	Steel
9.3.4.5. Insulator	Spinel (MgAl_2O_4)
9.3.4.6. Coolant	Water
9.3.4.7. Operating temperature	20 – 80 °C
9.3.4.8. Mean stress in coil ⁽⁹⁻⁹⁾	
9.3.4.9. Mean coil radius	0.8 m
9.3.5. Maximum force transmitted to building ⁽⁹⁻¹⁰⁾	
9.3.6. Maximum toroidal field	
9.3.6.1. At plasma axis	11.85 T
9.3.6.2. At plasma edge	0.38 T
9.3.6.3. At TF coil	0.38 T
9.3.7. Total stored energy ⁽⁹⁻¹¹⁾	
9.3.7.1. Poloidal field	3.6 GJ
9.3.7.2. Toroidal field	0.7 GJ
9.3.8. Largest single component ⁽⁹⁻¹²⁾	
9.3.8.1. Weight	250 tonnes
9.3.8.2. Dimensions (diameter×height)	5.9 × 0.80 m
9.4. Energy Transfer and Storage	None
9.5. Plasma Heating	
9.5.1. Type	Ohmic
9.5.2. Frequency	—
9.5.3. Power to plasma ⁽⁹⁻¹³⁾	35 MW
9.5.4. Transmission method	
9.5.5. Power reflected from plasma	—
9.5.6. Power loss in transmission	—
9.5.7. Power loss in amplifiers	—
9.5.8. Power loss in power supplies ⁽⁹⁻¹⁴⁾	5 MW
9.5.9. System input power ⁽⁹⁻¹³⁾	500 MW
9.5.10. Heating time ⁽⁹⁻¹⁵⁾	11 s

10. ELECTRICAL-POWER REQUIREMENTS

10.1. Cold-Plasma Startup Power from Grid ⁽¹⁰⁻¹⁾	500 MW
10.2. Auxiliary Power Requirements (Normal Operation)	
10.2.1. Electrical energy storage	None
10.2.2. Toroidal-field coils	16.0 MW
10.2.3. Divertor-field coils	9.8 MW
10.2.4. OFCD ⁽¹⁰⁻²⁾	54.6 MW
10.2.5. First wall, blanket, and shield coolant circulators	48.4 MW
10.2.6. Divertor plate coolant circulators	0.5 MW
10.2.7. Other auxiliary systems ⁽¹⁰⁻⁸⁾	30.0 MW
10.2.8. Total	159.3 MW

11. BUILDINGS

11.1. Reactor Pool ⁽¹¹⁻¹⁾	
11.1.1. Characteristic dimensions	
11.1.1.1. Outside diameter	38 m
11.1.1.2. Height	33 m
11.1.2. Enclosed volume	29600 m ³
11.1.3. Minimum wall thickness	1 m
11.1.4. Internal pressure	1 atm
11.1.5. Containment atmosphere	Air
11.2. Turbine Building ⁽¹¹⁻²⁾	
11.2.1. Characteristic dimensions	
11.2.1.1. Length	86 m
11.2.1.2. Width	40 m
11.2.1.3. Height	32 m
11.2.2. Total enclosed volume	2.64×10^5 m ³
11.3. Reactor Service Building	
11.3.1. Characteristic dimensions ⁽¹¹⁻³⁾	

12. REACTOR MAINTENANCE**12.1. First Wall, Blanket, Shield, and Divertor**

12.1.1. Lifetime

1 y

12.1.2. Weight

180 tonnes

12.2. OH and EF Magnet12.2.1. Lifetime ⁽¹²⁻¹⁾

40 y

12.2.2. Weight

332 tonnes

12.3. Radioactive Material Storage for Life of Plant ⁽¹²⁻¹⁾12.3.1. Total Class C ⁽¹²⁻²⁾

12.3.1.1. Weight

2642 tonnes

12.3.1.2. Volume

328 m³12.3.2. Total non-Class C ⁽¹²⁻³⁾

12.3.2.1. Weight

11 tonnes

12.3.2.2. Volume

1 m³**12.4. Overall Plant Availability**

0.76

FOOTNOTES TO TABLE B.1

- 1-1) The reactor envelope is defined by the cylinder enclosed by the upper and lower EF coils.
- 1-2) The first wall is corrugated, therefore, the total plasma-facing area is $\frac{\pi}{2} (2\pi R_T) 2\pi(r_{FW} + d/2)$, where d is the outer diameter of the first-wall channels.
- 1-3) Sectors are used only for factory manufacturing and shipment to the site. Each sector consists of four blanket modules. These sectors, together with divertor modules, are assembled on-site into a single torus and tested to full operational condition prior to installation into the reactor vault.
- 1-4) The TITAN-II fusion power core is submerged in a pool of water (1 atm) to achieve a high level of safety assurance.

- 2-1) During the startup, plasma profiles are assumed to be

$$\begin{aligned} n(r)/n_o &= (1 - r/r_p)^{2.5} \\ T(r)/T_o &= (1 - r/r_p)^4 \\ \mu(r)/\mu_o &= (1 - r/r_p)^8 . \end{aligned}$$

During the steady-state burn, TITAN-II operates with a highly radiative plasma (through injection of xenon impurities). The plasma profiles at burn are computed in Section 5.3. and are:

$$\begin{aligned} n(r)/n_o &= 1.00 - 0.86(r/r_p)^{3.44} \\ T(r)/T_o &= \begin{cases} 1.00 - 3.26(r/r_p)^{2.85} & \text{for } 0.00 < r/r_p < 0.25 \\ 1.12 - 0.71(r/r_p) & \text{for } 0.25 < r/r_p < 0.83 \\ 0.56 - 0.55(r/r_p)^{14.02} & \text{for } 0.83 < r/r_p < 1 \end{cases} \\ \mu(r)/\mu_o &= 1.00 - 0.44(r/r_p)^6 - 0.56(r/r_p)^8 . \end{aligned}$$

- 2-2) Averaged value over both fast and thermal components.
- 2-3) The TITAN-II design operates with a highly radiative plasma by deliberately doping the plasma with xenon impurities.
- 2-4) Assuming a beta-limited confinement time of the form $\tau_E = c_\nu I_\phi^\nu r_p^2 f(\beta_\theta)$.
- 2-5) Assumed to be $\tau_p \simeq 4\tau_{E*}$.
- 2-6) Based on self-consistent core-plasma, edge-plasma, and neutral-particle transport calculations.
- 2-7) Represents the mean value during the OFCD cycle (see item 2.29).
- 2-8) Including the poloidal field. The field produced by the coil is 0.4 T.
- 2-9) The engineering beta is defined as the ratio of the average plasma pressure to the maximum field strength on the toroidal-field coils.

- 2-10) The reversal parameter is held constant during the startup (by adjusting the toroidal-field strength), and the values of the pinch parameter are from equilibrium calculations.
- 2-11) Results of detailed calculations assuming full-coverage TF coils (Section 7). The results of Section 7 are scaled to include the effects of discreteness of the TF coils and the currents in the divertor coils which should be also oscillated to keep the separatrix in its position. For this case, the total supplied real power is 54.6 MW, including 28.55 MW delivered to the plasma (26.8 MW by the toroidal-field circuit and 1.76 MW by the poloidal-field circuit), 4.3 MW to oscillate the divertor coils, 15.34 MW dissipation in the power supplies and bussing, and 3.60, 2.66, and 0.19 MW joule heating in TF coils, in poloidal-field coils, and in the first wall and blanket by eddy currents. The power to TF and divertor coils represent the AC component of the currents in these coils.
- 2-12) Assuming a power supply efficiency, $Q = 100$.
- 2-13) A "wall-plug" efficiency including power-supply losses and the power to the divertor coils (see footnote 2-10)
- 2-14) All of the current-drive power deposited in the plasma appears as ohmic heating power.

- 3-1) All of the current-drive power deposited in the plasma appears as ohmic heating power.
- 3-2) Heating by eddy currents induced in the first wall and blanket by OFCD cycles.
- 3-3) Assuming an efficiency of 90% for coolant-circulation pumps.
- 3-4) Including the losses in the divertor coils (see footnote 2-10).
- 3-5) Allocated for housekeeping and auxiliary functions.
- 3-6) Mass power density is defined as the ratio of the net electric output to the mass of the FPC which includes the first wall, blanket, shield, divertor modules, coils, and related structure.

- 4-1) The first wall and blanket of the TITAN-II are integrated in the form of blanket lobes. The first 20 cm of the blanket lobe behind the first wall region (the multiplier zone) include 7 beryllium rods (diameter of 26 mm) clad in ferritic steel 9-C (cladding thickness of 0.25 mm). The last 10 cm of the blanket lobe is the breeder/reflector zone. 70 blanket lobes are staggered side by side to form a blanket module. Four blanket modules are assembled together into a sector. Each sector is supported by a two-piece shield that form a blanket container. TITAN-II reactor torus has three sectors, separated by three divertor modules. The ^6Li enrichment level in the coolant is 12%.
- 4-2) Inlet pressure of the first-wall, blanket, and shield coolant circuit. The pressure at the inlet of each component is reduced to the design level by orifices in order to use one pump system for all components.
- 4-3) Averaged over the entire system.
- 4-4) Values for the first multiplier cell.
- 4-5) The TITAN-II divertor plate is made of an armor which is brazed to a bank of circular, constant-cross-section tubes. Manifolds and headers are not included.

- 4-6) Inlet pressure of the divertor-plate coolant circuit is set by the maximum pressure drops in divertor-coolant tubes. The pressure at the inlet of some of the divertor-coolant tubes are lower than 15 MPa and orifices are used to reduce the pressure to the desired value at the inlet of these tubes.
- 4-7) The maximum coolant flow velocity, imposed as a constraint on the thermal-hydraulic design of the divertor plate. The coolant-flow velocity in most of tubes are lower than this value.
- 4-8) The efficiency of circulating pumps is assumed to be 90%.
- 4-9) In the presence of the low-pressure pool. Peak temperatures are reached 355 seconds after the initiation of the accident.
- 4-10) In the presence of the low-pressure pool. Peak temperatures are reached 300 seconds after the initiation of the accident (a re-flood time of 300 s is assumed).

- 5-1) Because the pressure in the steam generator (7.2 MPa) is larger than the primary coolant pressure (7.0 MPa), an intermediate heat exchanger deemed unnecessary. The divertor plate power, however, are deposited in the primary coolant circuit through a heat exchanger.

- 7-1) Power is recovered from the hot shield (see item 4.3.)
- 7-2) The EF shield is cooled by the pool water.

- 8-1) The pressure in the vacuum duct varies in the poloidal direction.
- 8-2) Not including the vacuum ducts.
- 8-3) Based on neutral transport calculations (Section 5.5). Particle throughput is enriched by about a factor 3 in He (with respect to DT throughput) and also by a factor of about 3 in D (with respect to T).
- 8-4) The turbo-molecular pumps are backed by 12 scroll pumps with pumping speed of 600 m³/hr, operating between 50 mtorr and atmospheric pressure.
- 8-5) Based on the required total pumping speed of 260 m³/s, only 13 pumps are needed. The additional 3 pumps are in reserve.
- 8-6) Assuming out-gassing rate of 10⁻¹¹ to 10⁻¹² torr-l/s, the required pumping speed to maintain the base pressure in the plasma chamber is in the range 3 to 35 m³/s, much lower than the required pumping speed of 260 m³/s for removal of the He ash.
- 8-7) Includes both steady state and OFCD contributions.
- 8-8) A pair of normal-conducting, EF trim coils are used during startup and OFCD cycles. Cooling loads for these coils are included in item 8.2.3.
- 8-9) The EF coils are based on present day technology with Nb-Ti conductor. Detailed design for these coils, therefore, was not performed.

- 8-10) The neutral-transport calculation of plasma exhaust shows some enrichment in D in the exhaust (Section 5). The effect of this enrichment is not included in this item. Also, plasma-driven permeation of D and T ions through the first wall is ignored.
- 8-11) Including tritium in storage (1 kg) and in the low-pressure pool (0.94 kg).
- 9-1) The first-wall and blanket of the TITAN-II are integrated in the form of blanket lobes. The first 20 cm of the blanket lobe behind the first wall region (the multiplier zone) include 7 beryllium rods (diameter of 26 mm) clad in ferritic steel 9-C (cladding thickness of 0.25 mm). The last 10 cm of the blanket lobe is the breeder/reflector zone. 70 blanket lobes are staggered side by side to form a blanket module. Four blanket modules are assembled together into a sector. Each sector is supported by a two-piece shield that form a blanket container. TITAN-II reactor torus has three sectors, separated by three divertor modules. The ^6Li enrichment level in the coolant is 12%.
- 9-2) With a ^6Li enrichment level of 12% in the coolant.
- 9-3) Based on 1-D neutronics calculations of the final design.
- 9-4) The reactor torus is assembled on-site from 3 pre-fabricated sectors interlinked by the 3 divertor. The reactor torus is installed and removed as one single piece.
- 9-5) Based on a lifetime of 15 MW-y/m².
- 9-6) Also act as the driver coils for the OFCD system.
- 9-7) Includes a pair of normal-conducting, EF trim coils which are used during startup and OFCD cycles.
- 9-8) The EF coils are based on present day technology with Nb-Ti conductor. Detailed design for these coils, therefore, was not performed.
- 9-9) The TF and divertor coils are based on present day technology with water-cooled copper conductor. Detailed design for these coils, therefore, was not performed.
- 9-10) Primarily caused by the weight of the FPC.
- 9-11) Including the plasma stored energy. The poloidal magnetic energies stored in the system are 0.3 GJ internal to the plasma and 3.2 GJ external in the plasma, noting that the plasma current and the EFC current are flowing in opposite directions. The toroidal magnetic stored energy internal to the plasma is 0.4 GJ and external to the plasma is 0.02 GJ.
- 9-12) The largest component is the EF coil, including the EFC shield.
- 9-13) Maximum value during startup.
- 9-14) Assuming an efficiency of 99% for power supplies.
- 9-15) Time from cold startup to ignition.
- 10-1) Maximum value during startup.
- 10-2) Including the losses in the divertor coils (see footnote 2-10).

- 10-3) Includes the refrigeration systems, vacuum systems, tritium-extraction systems, feed-water pumps, heat-rejection systems, and other miscellaneous reactor auxiliary systems.
- 11-1) The TITAN-II fusion power core is submerged in a pool of water (1 atm) to achieve a high level of safety assurance.
- 11-2) Turbine-building dimensions were scaled from those of the MARS reactor design (B. G. Logan *et al.*, Lawrence Livermore National Laboratory report, UCRL-53480, 1984).
- 11-3) Not calculated.
- 12-1) Assuming 30 full-power-year operation with 76% availability.
- 12-2) Including first wall, blanket, shield, and magnets.
- 12-3) The divertor target plates, if they have to be disposed of separately.

B.2. SYSTEMS CODE PARAMETERS OF TITAN-II

1 TITAN Reversed-Field Pinch Reactor calculations (ver. 9.q)
 1 1 0 0 0 0 1 1 0 01/12/88

plasma parameters

plasma aspect ratio, A	6.500
plasma minor radius (m)	0.600
plasma toroidal major radius (m)	3.900
plasma volume (m ³)	27.714
plasma/first-wall radius ratio, x	0.909
plasma current (MA)	17.797
toroidal current density (MA/m ²)	15.736
plasma ion temperature (keV)	10.000
plasma electron temperature (keV)	9.500
plasma fus. prod. temperature (keV)	65.000
plasma impurity temperature (keV)	10.000
Lawson parameter * t2 (1.0e22 s keV ⁻² /m ³)	1.917
Lawson parameter (1.0e20 s/m ³)	1.917
plasma (total) ion density (1.0e20/m ³)	8.912
plasma electron density (1.0e20/m ³)	9.309
ion (D,T,He3,He4,Xe) density fractions:	
0.48484 0.48484 0.00000 0.03000 0.00033	
effective plasma charge, Zeff	1.690
energy confinement time (s)	0.215
alpha ion particle confinement time (steady state) (s)	0.857
thermal diffusivity (m ² /s)	0.314
dt fusion power density (MW/m ³)	82.623
fusion power, Pf (MW)	2289.807
alpha power (MW)	458.482
bremsstrahlung power (MW)	131.824
poloidal beta (incl. fus. prods. and imps., Zeff>1.0)	0.220
poloidal beta (only fuel ions and electrons, Zeff=1.0)	0.200
pinch parameter, theta	1.556
reversal parameter, F	0.100
streaming parameter (1.0e-14 A m)	1.766
streaming function (1.0e-3)	1.858
plasma ohmic dissipation during burn (MW)	28.462
plasma loop voltage (V)	1.599
gdt, gohm, gbr = 1.403 2.924 1.172	
OFCD plasma Poynting power (tor/pol) (MW)	3947.656 246.545
OFCD FW dissipated power (tor/pol) (MW)	0.000 0.011
OFCD blanket dissipated power (tor/pol) (MW)	0.011 0.191
OFCD coil dissipated power (OHC/TFC/PEFC/SEFC) (MW)	
0.171 18.804 0.000 2.482	
OFCD total dissipated power (tor/pol) (MW)	18.815 2.855
OFCD terminal real(lost) power (OHC/TFC/PEFC/SEFC) (MW)	
1.147 32.930 0.000 3.450	
OFCD power-supply dissipated power, pcdps (MW)	9.929
OFCD total dissipated power, pcdd (MW)	46.436
OFCD terminal reactive power (OHC/TFC/PEFC/SEFC) (MW)	
101.674 744.569 0.000 146.706	
OFCD total reactive power, pcdr (MW)	992.949
OFCD power-supply q-value, Q(PS)	100.000
OFCD circuit q-value, Q(C)	21.383
OFCD q-value, Q(CD)	1.632
OFCD efficiency figure of merit (A/W)	0.383

1 poloidal field quantities

OH-coil thickness (m)	0.373
average minor radius of coil (m)	1.365
OH coil center offset	0.439
vertical field (T)	1.560
magnetic field level at the coil (T)	2.608
magnetic field level at the plasma surface (T)	5.932
OH coil back-bias power ratio, $f_{gridp}=(I_{OH+}/I_{OH-})^2$	1.000
OH coil factor for resistive flux dissipated in startup	0.109
OH coil factor	0.391
OH-coil current swing (MA)	42.685
OH- coil current (MA)	21.342
OH- coil current density (MA/m ²)	9.233
coil stress (MPa)	73.850
OH+ coil current (MA)	21.342
OH+ coil current density (MA/m ²)	9.233
OH coil power supply requirement (MVA)	387.482
mass of OH coil set (tonne)	413.473
ohmic dissipation during back-bias (MW)	107.153
volumetric heating during back-bias (MW/m ³)	1.892
EF coil current (MA)	18.621
EF coil current density (MA/m ²)	20.554
EF coil power supply requirement (MVA)	312.278
mass of EF coil set (tonne)	246.668
magnetic energy stored in coil (MJ)	4138.053
ohmic dissipation during burn (MW)	0.000
volumetric heating during burn (MW/m ³)	0.000
plasma startup risetime (s)	8.000
Ref,zef,delef (m) =	5.9363e+00 2.3622e+00 6.7303e-01

0 toroidal field quantities

TF-coil thickness (m)	0.046
average minor radius of coil (m)	1.105
mass of coil (tonne)	40.832
initial toroidal bias field (T)	3.406
reversed-toroidal field during the burn (T)	0.381
magnetic energy stored in the coil (MJ)	434.327
TF-coil current (MA)	7.436
TF coil current density (MA/m ²)	9.233
ohmic dissipation during burn (MW)	13.625
volumetric heating during burn (MW/m ³)	2.436

0 impurity control

first-wall surface area (m ²)	101.617
total divertor plate surface area (m ²)	N= 3 6.965
first-wall/divertor surface heat flux (MW/m ²)	4.552 3.495
radiation fraction, frad	0.950
scrape-off thickness (m)	0.060
DF-coil current (MA)	0.596
DF coil current density (MA/m ²)	35.700
mass of coil (tonne)	1.960
ohmic dissipation during burn (MW)	11.979

1	engineering summary	
	thermal conversion efficiency	0.350
	auxiliary site power fraction of P_g , faux	0.060
	primary loop pumping power fraction of P_g , fmpm	0.010
	engineering q-value, QE	7.198
	recirculating power fraction, $\epsilon = 1/QE$	0.139
	net plant efficiency	0.301
	ohmic q-value, Q_t	41.453
	plasma q-value, Q_p	80.452
	total thermal power, P_{th} (MW)	2986.301
	fusion power, P_f (MW)	2289.807
	tritium burnup (kg/day)	0.352
	fractional burnup	0.057
	tritium thru-put (no recycle) (kg/day)	6.192
	blanket LM 6Li enrichment	0.300
	14.06-MeV neutron load, I_w (MW/m ²)	18.022
	14.06-MeV neutron energy multiplication in blanket, M	1.360
	2.45-MeV neutron load (MW/m ²)	0.000
	2.45-MeV neutron energy multiplication in blanket, M	0.000
	first-wall radius (m)	0.660
	FW/SW/blanket/gap/reflector/gap/shield thickness (m)	0.412
	shield/coil gap thickness (m)	0.010
	TF-coil thickness (m)	0.046
	TF-coil/OH-coil gap thickness (m)	0.050
	OH-coil thickness (m)	0.373
	minor radius of system (m)	1.552
	blanket volume (m ³)	19.744
	reflector volume (m ³)	14.203
	shield volume (m ³)	13.067
	EF-coil shield volume (m ³)	47.726
	TF-coil volume (m ³)	5.593
	OH-coil volume (m ³)	56.640
	EF-coil volume (m ³)	33.790
	DF-coil volume (m ³)	0.269
	mass of FW/SW/blanket (tonne)	21.265
	mass of reflector (tonne)	14.750
	mass of OHC shield (tonne)	91.140
	mass of EFC shield (tonne)	286.356
	mass of TF coil set (tonne)	40.832
	mass of OH coil set (tonne)	413.473
	mass of EF coil set (tonne)	246.668
	mass of DF coil set (tonne)	1.960
	total coil-set mass (tonne)	702.934
	FPC (FW/SW/B/R/S/C) mass (tonne) -	1116.855
	mass power density, MPD (kWe/tonne)	805.835
	system power density (MWt/m ³)	16.114
	mass utilization (tonne/MWt)	0.374
	mass of FPC structure (tonne)	466.208
	blanket power density (MW/m ³)	54.280
	magnetic energy recovery time (s)	1.531

B.3. COST SUMMARY OF TITAN-II REACTOR

fusion reactor economic evaluation (ver. 4.5)

• 01/12/88

acc. no.	account title	million dollars (1986)
20. 1.	land & privilege acquisition	4.500
20. 2.	relocation of buildings, utilities, highways, etc.	0.500
20.	land & land rights	5.000
21. 1. 1.	general yard improvements	
21. 1. 2.	waterfront improvements	
21. 1. 3.	transportation access (off site)	
21. 1.	site improvements & facilities	15.208
21. 2. 1.	basic building structures	69.001
21. 2. 2.	building services	2.696
21. 2. 3.	containment structures	40.446
21. 2. 4.	architectural	10.111
21. 2.	reactor building	122.255
21. 3. 1.	basic building structures	40.446
21. 3. 2.	building services	2.696
21. 3. 3.	architectural	2.022
21. 3.	turbine building	45.165
21. 4. 1.	intake structures	
21. 4. 2.	discharge structures	
21. 4. 3.	unpressurized intake & discharge conduits	
21. 4. 4.	recirculating structures	
21. 4. 5.	cooling tower systems	
21. 4.	cooling system structures	9.747
21. 5. 1.	basic building structures	10.826
21. 5. 2.	building services	0.715
21. 5. 3.	architectural	0.809
21. 5.	power supply & energy storage building	12.350
21. 6. 1.	reactor auxiliaries building(incl. switchgear bay)	4.395
21. 6. 2.	hot cell building	72.749
21. 6. 3.	fuel storage building	11.635
21. 6. 4.	control room building	4.179
21. 6. 5.	diesel generator building	2.764
21. 6. 6.	administration building	1.173
21. 6. 7.	service building	2.535
21. 6. 8.	cryogenics building	1.227
21. 6. 9.	miscellaneous structures & building work	2.481
21. 6.	miscellaneous buildings	103.137
21. 7.	ventilation stack	2.440
21.98.	spare parts allowance	
21.99.	contingency allowance	
21.	structures & site facilities	310.301

22. 1. 1. 1.	breeding material(incl. tritium breeding)	0.895	
22. 1. 1. 2.	first wall & structural material	1.063	
22. 1. 1. 3.	attenuators, reflectors, & multipliers	8.686	
22. 1. 1. 4.	wall modifiers(coatings, liners, limiters, etc.)		
22. 1. 1. 5.	reflector	3.689	
22. 1. 1. 6.	other		
22. 1. 1.	FW/SW/blanket/reflector		14.332
22. 1. 2. 1.	primary	22.793	
22. 1. 2. 2.	secondary	6.051	
22. 1. 2.	shield		28.844
22. 1. 3. 1.	toroidal field coils	3.578	
22. 1. 3. 2.	ohmic-heating coils	36.236	
22. 1. 3. 3.	equilibrium field coils	43.238	
22. 1. 3. 4.	diverter field coils	0.172	
22. 1. 3. 5.	other coils		
22. 1. 3.	magnets		83.224
22. 1. 4. 1.	beam heating(neutral, ion or electron)		
22. 1. 4. 2.	rf heating	0.000	
22. 1. 4. 3.	laser heating		
22. 1. 4. 4.	other heating systems		
22. 1. 4.	supplemental heating systems		
22. 1. 5. 1.	reactor structure		
22. 1. 5. 2.	equipment support structure		
22. 1. 5.	primary structure & support		11.785
22. 1. 6. 1.	plasma chamber vacuum(incl. pumps/comp./pipe)		
22. 1. 6. 2.	magnet dewar vacuum(incl. pumps/comp./pipe)		
22. 1. 6. 3.	suppl. heating vacuum(incl. pumps/comp./pipe)		
22. 1. 6. 4.	direct convertor vacuum(incl. pumps/comp./pipe)		
22. 1. 6. 5.	reactor vacuum system(low grade)		
22. 1. 6. 6.	reactor vacuum wall	10.189	
22. 1. 6.	reactor vacuum systems(unless integral elsewhere)		10.189
22. 1. 7. 1.	EF-coil power supplies	9.958	
22. 1. 7. 2.	OH-coil power supplies	9.691	
22. 1. 7. 3.	TF-coil power supplies	0.682	
22. 1. 7. 4.	DF-coil power supplies	0.599	
22. 1. 7. 5.	other power supplies	1.348	
22. 1. 7. 6.	current drive power supplies	49.650	
22. 1. 7. 7.	control system		
22. 1. 7. 8.	central energy storage		
22. 1. 7. 9.	other incl. busbars		
22. 1. 7.	power supply, switching & energy storage		71.927
22. 1. 8.	impurity control		6.198
22. 1. 9. 1.	vacuum tank		
22. 1. 9. 2.	direct convertor modules		
22. 1. 9. 3.	thermal panels		
22. 1. 9. 4.	power conditioning equipment		
22. 1. 9.	direct energy conversion system		
22. 1.10.	ecrh breakdown system		2.142
22. 1.	reactor equipment		228.641

22. 2. 1. 1.	pumps & motor drives(modular & nonmodular)	
22. 2. 1. 2.	piping	
22. 2. 1. 3.	heat exchangers	
22. 2. 1. 4.	tanks(dump,make-up,clean-up,trit.,hot storage)	
22. 2. 1. 5.	clean-up system	
22. 2. 1. 6.	thermal insulation, piping & equipment	
22. 2. 1. 7.	tritium extraction	
22. 2. 1. 8.	pressurizer	
22. 2. 1. 9.	other	
22. 2. 1.	primary coolant system	83.655
22. 2. 2. 1.	pumps & motor drives(modular & nonmodular)	
22. 2. 2. 2.	piping	
22. 2. 2. 3.	heat exchangers	
22. 2. 2. 4.	tanks(dump,make-up,clean-up,trit.,hot storage)	
22. 2. 2. 5.	clean-up system	
22. 2. 2. 6.	thermal insulation, piping & equipment	
22. 2. 2. 7.	tritium extraction	
22. 2. 2. 8.	pressurizer	
22. 2. 2. 9.	other	
22. 2. 2.	intermediate coolant system	
22. 2. 3. 1.	pumps & motor drives(modular & nonmodular)	
22. 2. 3. 2.	piping	
22. 2. 3. 3.	heat exchangers	
22. 2. 3. 4.	tanks(dump,make-up,clean-up,trit.,hot storage)	
22. 2. 3. 5.	clean-up system	
22. 2. 3. 6.	thermal insulation, piping & equipment	
22. 2. 3. 7.	tritium extraction	
22. 2. 3. 8.	pressurizer	
22. 2. 3. 9.	other	
22. 2. 3.	secondary coolant system	0.000
22. 2.	main heat transfer & transport systems	83.655
22. 3. 1. 1.	refrigeration	
22. 3. 1. 2.	piping	
22. 3. 1. 3.	fluid circulation driving system	
22. 3. 1. 4.	tanks	
22. 3. 1. 5.	purification	
22. 3. 1.	magnet cooling system	
22. 3. 2. 1.	refrigeration	
22. 3. 2. 2.	piping	
22. 3. 2. 3.	fluid circulation driving system	
22. 3. 2. 4.	tanks	
22. 3. 2. 5.	purification	
22. 3. 2.	shield & structure cooling system	2.697
22. 3. 3. 1.	refrigeration	
22. 3. 3. 2.	piping	
22. 3. 3. 3.	fluid circulation driving system	
22. 3. 3. 4.	tanks	
22. 3. 3. 5.	purification	
22. 3. 3.	supplemental heating system cooling system	
22. 3. 4. 1.	refrigeration	
22. 3. 4. 2.	piping	
22. 3. 4. 3.	fluid circulation driving system	
22. 3. 4. 4.	tanks	
22. 3. 4. 5.	purification	
22. 3. 4.	power supply cooling system	
22. 3. 5.	other cooling systems (ECCS)	100.009
22. 3.	auxiliary cooling systems	102.707

22. 4. 1.	liquid waste processing & equipment	
22. 4. 2.	gaseous wastes & off-gas processing system	
22. 4. 3.	solid waste processing equipment	
22. 4.	radioactive waste treatment & disposal	4.831
22. 5. 1.	fuel injection systems	10.001
22. 5. 2.	fuel processing systems	13.656
22. 5. 3.	fuel storage	5.000
22. 5. 4.	atmospheric tritium recovery	2.119
22. 5. 5.	water tritium recovery systems	139.549
22. 5. 6.	blanket tritium recovery systems	
22. 5. 7.	other	
22. 5.	fuel handling & storage systems	170.326
22. 6. 1. 1.	blanket & coil maintenance equipment	
22. 6. 1. 2.	components rotated into service to allow maint.	
22. 6. 1. 3.	other maintenance equipment	
22. 6. 1.	maintenance equipment	
22. 6. 2.	special heating systems(start-up,trace, etc.)	
22. 6. 3.	coolant receiving, storage & make-up systems	
22. 6. 4.	gas systems	
22. 6. 5.	building vacuum systems	
22. 6.	other reactor plant equipment	44.041
22. 7. 1.	reactor i&c equip.(burn control, diagnostics, etc.	
22. 7. 2.	radiation monitoring systems	
22. 7. 3.	isolated indicating & recording gauges, etc.	
22. 7.	instrumentation & control(i&c)	31.561
22.98.	spare parts allowance	
22.99.	contingency allowance	
22.	reactor plant equipment	665.762

B.3. COST SUMMARY OF TITAN-II REACTOR

B-29

23. 1. 1.	turbine-generators & accessories	
23. 1. 2.	foundations	
23. 1. 3.	standby exciters	
23. 1. 4.	lubricating system	
23. 1. 5.	gas systems	
23. 1. 6.	reheaters	
23. 1. 7.	shielding	
23. 1. 8.	weather-proof housing	
23. 1.	turbine-generators	83.263
23. 2.	main steam (or other fluid) system	6.755
23. 3. 1.	water intake common facilities	
23. 3. 2.	circulating water systems	
23. 3. 3.	cooling towers	
23. 3. 4.	other systems which reject heat to the atmosphere	
23. 3.	heat rejection systems	36.377
23. 4. 1.	condensers	
23. 4. 2.	condensate system	
23. 4. 3.	gas removal system	
23. 4. 4.	turbine by-pass systems(excl. piping)	
23. 4.	condensing systems	19.356
23. 5. 1.	regenerators & recuperators	
23. 5. 2.	pumps	
23. 5. 3.	tanks	
23. 5.	feed heating system	10.628
23. 6. 1.	turbine auxiliaries	
23. 6. 2.	auxiliaries cooling system(excl. piping)	
23. 6. 3.	make-up treat. system(excl. piping)	
23. 6. 4.	chemical treat. & condensate purification systems	
23. 6. 5.	central lubrication service system(excl. piping)	
23. 6.	other turbine plant equipment	56.620
23. 7.	instrumentation & control(isc) equipment	10.656
23.98.	spare parts allowance	
23.99.	contingency allowance	
23.	turbine plant equipment	223.656

24. 1. 1.	generator circuits	
24. 1. 2.	station service	
24. 1.	switchgear	12.116
24. 2. 1.	station service & startup transformers	
24. 2. 2.	low voltage unit substation & lighting transformer	
24. 2. 3.	battery system	
24. 2. 4.	diesel engine generators	
24. 2. 5.	gas turbine generators	
24. 2. 6.	motor generator sets	
24. 2.	station service equipment	20.006
24. 3. 1.	main control board for electric system	
24. 3. 2.	auxiliary power & signal boards	
24. 3.	switchboards (incl. heat tracing)	7.608
24. 4. 1.	gen. station grounding sys. & cathodic protection	
24. 4.	protective equipment	2.845
24. 5. 1.	concrete cable tunnels, trenches & envelopes	
24. 5. 2.	cable trays & support	
24. 5. 3.	conduit	
24. 5. 4.	other structures	
24. 5.	electrical structures & wiring containers	21.140
24. 6. 1.	generator circuits wiring	
24. 6. 2.	station service power wiring	
24. 6. 3.	control wiring	
24. 6. 4.	instrument wiring	
24. 6. 5.	containment penetrations	
24. 6.	power & control wiring	43.736
24. 7. 1.	reactor building lighting	
24. 7. 2.	turbine building lighting	
24. 7. 3.	reactor auxiliaries building lighting	
24. 7. 4.	radioactive waste building lighting	
24. 7. 5.	fuel storage building lighting	
24. 7. 6.	miscellaneous buildings lighting	
24. 7. 7.	yard lighting	
24. 7.	electrical lighting	11.055
24.98.	spare parts allowance	
24.99.	contingency allowance	
24.	electric plant equipment	118.505

B.3. COST SUMMARY OF TITAN-II REACTOR

B-31

25. 1. 1.	cranes, hoists, monorails, & conveyors	
25. 1. 2.	railway	
25. 1. 3.	roadway equipment	
25. 1. 4.	watercraft	
25. 1. 5.	vehicle maintenance equipment	
25. 1.	transportation & lifting equipment	21.140
25. 2. 1.	air systems(excl. piping)	
25. 2. 2.	water systems(excl. piping)	
25. 2. 3.	auxiliary heating boilers(excl. piping)	
25. 2.	air & water service systems	16.650
25. 3. 1.	local communications systems	
25. 3. 2.	signal systems	
25. 3.	communications equipment	8.386
25. 4. 1.	safety equipment	
25. 4. 2.	shop, laboratory, & test equipment	
25. 4. 3.	office equipment & furnishings	
25. 4. 4.	change room equipment	
25. 4. 5.	environmental monitoring equipment	
25. 4. 6.	dining facilities	
25. 4.	furnishings & fixtures	1.618
25.98.	spare parts allowance	
25.99.	contingency allowance	
25.	miscellaneous plant equipment	47.794
26. 1.	reactor coolant	16.901
26. 2.	intermediate coolant	
26. 3.	turbine cycle working fluids	
26. 4.	other materials	0.337
26. 5.	Ar reactor-building cover gas	
26.98.	spare parts allowance	
26.99.	contingency allowance	
26.	special materials	17.239

Los Alamos fusion reactor economic evaluation (ver. 4.5)

• 01/12/88

acc. no.	account title	million dollars (1986)
20.	land & land rights	5.000
21.	structures & site facilities	310.301
22.	reactor plant equipment	665.762
22. 1. 1.	FW/SW/blanket/reflector	14.332
22. 1. 2.	shield	28.844
22. 1. 3.	magnets	83.224
22. 1. 4.	supplemental heating systems	0.000
22. 1. 5.	primary structure & support	11.785
22. 1. 6.	reactor vacuum systems(unless integral elsewhere)	10.189
22. 1. 7.	power supply, switching & energy storage	71.927
22. 1. 8.	impurity control	6.198
22. 1. 9.	direct energy conversion system	0.000
22. 1.10.	ecrh breakdown system	2.142
22. 1.	reactor equipment	228.641
23.	turbine plant equipment	223.656
24.	electric plant equipment	118.505
25.	miscellaneous plant equipment	47.794
26.	special materials	17.239
90.	direct cost (not incl. spares and contingency)	1388.258
91.	construction services & equipment	138.826
92.	home office engineering & services	138.826
93.	field office engineering & services	138.826
94.	owner's cost	69.413
96.	project contingency	138.826
97.	interest during construction (IDC)	226.258
99.	total cost	2239.232

		-----		constant	then-current
thermal power (MWth)	= 2986.30	unit direct cost (\$/kWe)	[90]=	1542.51	1542.51
gross electric power (MWe)	= 1045.21	unit base cost (\$/kWe)	[94]=	2236.64	2236.64
net electric power (MWe)	= 900.00	unit total cost (\$/kWe)	[99]=	2488.11	3409.59
1/recirculating power fraction QE=	7.198	capital return (mill/kWeh)	=	29.94	69.75
plant availability factor	= 0.759	O&M(2.00%) (mill/kWeh) [40-47,51]=		6.73	9.54
construction= 6 yr: constant then-current		W/B/R replace. (mill/kWeh) [50]=		1.25	1.78
FCR= 0.0800 0.1360		decommissioning allowance	=	0.00	0.00
fIDC= 0.1124 0.2444		deuterium fuel (mill/kWeh) [02]=		0.05	0.05
fEDC= 0.0000 0.2800		COE (mill/kWeh)	=	37.96	81.12

B.4. COST DATA BASE FOR TITAN-II REACTOR

cost data base (ver. 4.5)

date:01/12/88

acc. no.	account title UC(1986) = 1.348 x UC(1980)	unit cost(1980)	no. of units	refs.
20. 1. 0. 0	land & privilege acquisition	3.338e+03 \$/acre	1.000e+03 10	
20. 2. 0. 0	relocation of buildings, utilities, highways, etc.	3.710e+02 \$/acre	1.000e+03 10	
20. 0. 0. 0	land & land rights	0.	1.000e+00	
21. 1. 1. 0	general yard improvements	0.	1.000e+00	
21. 1. 2. 0	waterfront improvements	0.	1.000e+00	
21. 1. 3. 0	transportation access (off site)	0.	1.000e+00	
21. 1. 0. 0	site improvements & facilities	1.128e+07 \$	1.000e+00 10	
21. 2. 1. 0	basic building structures	3.000e+02 \$/m ³	1.706e+05 13,18	
21. 2. 2. 0	building services	2.000e+06 \$	1.000e+00 13,14,+	
21. 2. 3. 0	containment structures	3.000e+07 \$	1.000e+00 13,14,+	
21. 2. 4. 0	architectural	7.500e+06 \$	1.000e+00 13,14,+	
21. 2. 0. 0	reactor building	0.	1.000e+00	
21. 3. 1. 0	basic building structures	3.000e+07 \$	1.000e+00 13,14,18	
21. 3. 2. 0	building services	2.000e+06 \$	1.000e+00 13,14,+	
21. 3. 3. 0	architectural	1.500e+06 \$	1.000e+00 13	
21. 3. 0. 0	turbine building	0.	1.000e+00	
21. 4. 1. 0	intake structures	0.	1.000e+00	
21. 4. 2. 0	discharge structures	0.	1.000e+00	
21. 4. 3. 0	unpressurized intake & discharge conduits	0.	1.000e+00	
21. 4. 4. 0	recirculating structures	0.	1.000e+00	
21. 4. 5. 0	cooling tower systems	0.	1.000e+00	
21. 4. 0. 0	cooling system structures	8.982e+05 \$/unit	8.049e+00 2,13,14	
21. 5. 1. 0	basic building structures	8.030e+06 \$	1.000e+00 13,14	
21. 5. 2. 0	building services	5.300e+05 \$	1.000e+00 13,14	
21. 5. 3. 0	architectural	6.000e+05 \$	1.000e+00 13	
21. 5. 0. 0	power supply & energy storage building	0.	1.000e+00	
21. 6. 1. 0	reactor auxiliaries building(incl. switchgear bay)	3.260e+06 \$	1.000e+00 13,14	
21. 6. 2. 0	hot cell building	5.396e+07 \$	1.000e+00 13,14	
21. 6. 3. 0	fuel storage building	8.630e+06 \$	1.000e+00 13,14	
21. 6. 4. 0	control room building	3.100e+06 \$	1.000e+00 13,14	
21. 6. 5. 0	diesel generator building	2.050e+06 \$	1.000e+00 13,14	
21. 6. 6. 0	administration building	8.700e+05 \$	1.000e+00 13,14	
21. 6. 7. 0	service building	1.880e+06 \$	1.000e+00 13,14	
21. 6. 8. 0	cryogenics building	9.100e+05 \$	1.000e+00 13,14	
21. 6. 9. 0	miscellaneous structures & building work	1.840e+06 \$	1.000e+00 13,14	
21. 6. 0. 0	miscellaneous buildings	0.	1.000e+00	
21. 7. 0. 0	ventilation stack	1.810e+06 \$	1.000e+00 13,14	
21.98. 0. 0	spare parts allowance	0. fraction	-1.000e+00 2,13,14	
21.99. 0. 0	contingency allowance	0. fraction	-1.000e+00 2,13,14	
21. 0. 0. 0	structures & site facilities	0.	1.000e+00	

22. 1. 1. 1	breeding material(incl. tritium breeding)	2.927e+02 \$/kg	2.267e+03 15,18
22. 1. 1. 2	first wall & structural material	3.709e+01 \$/kg	2.126e+04 10
22. 1. 1. 3	attenuators, reflectors, & multipliers	3.338e+02 \$/kg	1.930e+04 10
22. 1. 1. 4	wall modifiers(coatings, liners, limiters, etc.)	0.	1.000e+00
22. 1. 1. 5	reflector	1.855e+02 \$/kg	1.475e+04 6
22. 1. 1. 6	other	0.	1.000e+00
22. 1. 1. 0	FW/SW/blanket/reflector	0.	1.000e+00
22. 1. 2. 1	primary	0.	1.000e+00
22. 1. 2. 2	secondary	1.855e+02 \$/kg	9.114e+04 10
22. 1. 2. 0	shield	1.567e+01 \$/kg	2.864e+05 10
22. 1. 3. 1	toroidal field coils	0.	1.000e+00
22. 1. 3. 2	ohmic-heating coils	6.500e+01 \$/kg	4.083e+04 10
22. 1. 3. 3	equilibrium field coils	6.500e+01 \$/kg	4.135e+05 10
22. 1. 3. 4	divertor field coils	1.300e+02 \$/kg	2.467e+05 10
22. 1. 3. 5	other coils	6.500e+01 \$/kg	1.960e+03 10
22. 1. 3. 0	magnets	0.	1.000e+00
22. 1. 4. 1	beam heating(neutral, ion or electron)	0.	1.000e+00
22. 1. 4. 2	rf heating	0.	1.000e+00
22. 1. 4. 3	laser heating	1.654e+00 \$/W	0. 16,17
22. 1. 4. 4	other heating systems	0.	1.000e+00
22. 1. 4. 0	supplemental heating systems	0.	1.000e+00
22. 1. 5. 1	reactor structure	0.	1.000e+00
22. 1. 5. 2	equipment support structure	0.	1.000e+00
22. 1. 5. 0	primary structure & support	0.	1.000e+00
22. 1. 6. 1	plasma chamber vacuum(incl. pumps/comp./pipe)	1.125e+05 \$/m ³	7.770e+01 13,14
22. 1. 6. 2	magnet dewar vacuum(incl. pumps/comp./pipe)	0.	1.000e+00
22. 1. 6. 3	suppl. heating vacuum(incl. pumps/comp./pipe)	0.	1.000e+00
22. 1. 6. 4	direct converter vacuum(incl. pumps/comp./pipe)	0.	1.000e+00
22. 1. 6. 5	reactor vacuum system(low grade)	0.	1.000e+00
22. 1. 6. 6	reactor vacuum wall	0.	1.000e+00
22. 1. 6. 0	reactor vacuum systems(unless integral elsewhere)	2.500e+06 \$/unit	3.023e+00 9
22. 1. 7. 1	EF-coil power supplies	0.	1.000e+00
22. 1. 7. 2	OH-coil power supplies	2.365e+01 \$/kVA	3.123e+05 10
22. 1. 7. 3	TF-coil power supplies	1.855e+01 \$/kVA	3.875e+05 10
22. 1. 7. 4	DF-coil power supplies	3.709e+01 \$/kVA	1.363e+04 10
22. 1. 7. 5	other power supplies	3.709e+01 \$/kVA	1.198e+04 10
22. 1. 7. 6	current drive power supplies	1.000e+06	1.000e+00
22. 1. 7. 7	control system	3.709e+01 \$/kVA _r	9.929e+05 10
22. 1. 7. 8	central energy storage	0.	1.000e+00
22. 1. 7. 9	other incl. busbars	0.	1.000e+00
22. 1. 7. 0	power supply, switching & energy storage	0. \$	1.000e+00
22. 1. 8. 0	impurity control	0.	1.000e+00
22. 1. 9. 1	vacuum tank	6.600e+05 \$/m ²	6.965e+00 10
22. 1. 9. 2	direct converter modules	0.	1.000e+00
22. 1. 9. 3	thermal panels	0.	1.000e+00
22. 1. 9. 4	power conditioning equipment	0.	1.000e+00
22. 1. 9. 0	direct energy conversion system	0.	1.000e+00
22. 1.10. 0	scrh breakdown system	0.	1.000e+00
22. 1. 0. 0	reactor equipment	1.589e+06 \$	1.000e+00 13
		0.	1.000e+00

22. 2. 1. 1	pumps & motor drives(modular & nonmodular)	0.	1.000e+00	
22. 2. 1. 2	piping	0.	1.000e+00	
22. 2. 1. 3	heat exchangers	0.	1.000e+00	
22. 2. 1. 4	tanks(dump,make-up,clean-up,trit.,hot storage)	0.	1.000e+00	
22. 2. 1. 5	clean-up system	0.	1.000e+00	
22. 2. 1. 6	thermal insulation, piping & equipment	0.	1.000e+00	
22. 2. 1. 7	tritium extraction	0.	1.000e+00	
22. 2. 1. 8	pressurizer	0.	1.000e+00	
22. 2. 1. 9	other	0.	1.000e+00	
22. 2. 1. 0	primary coolant system	2.078e+04 \$/MWth	2.986e+03	10
22. 2. 2. 1	pumps & motor drives(modular & nonmodular)	0.	1.000e+00	
22. 2. 2. 2	piping	0.	1.000e+00	
22. 2. 2. 3	heat exchangers	0.	1.000e+00	
22. 2. 2. 4	tanks(dump,make-up,clean-up,trit.,hot storage)	0.	1.000e+00	
22. 2. 2. 5	clean-up system	0.	1.000e+00	
22. 2. 2. 6	thermal insulation, piping & equipment	0.	1.000e+00	
22. 2. 2. 7	tritium extraction	0.	1.000e+00	
22. 2. 2. 8	pressurizer	0.	1.000e+00	
22. 2. 2. 9	other	0.	1.000e+00	
22. 2. 2. 0	intermediate coolant system	0.	1.000e+00	
22. 2. 3. 1	pumps & motor drives(modular & nonmodular)	0.	1.000e+00	
22. 2. 3. 2	piping	0.	1.000e+00	
22. 2. 3. 3	heat exchangers	0.	1.000e+00	
22. 2. 3. 4	tanks(dump,make-up,clean-up,trit.,hot storage)	0.	1.000e+00	
22. 2. 3. 5	clean-up system	0.	1.000e+00	
22. 2. 3. 6	thermal insulation, piping & equipment	0.	1.000e+00	
22. 2. 3. 7	tritium extraction	0.	1.000e+00	
22. 2. 3. 8	pressurizer	0.	1.000e+00	
22. 2. 3. 9	other	0.	1.000e+00	
22. 2. 3. 0	secondary coolant system	5.220e+05 \$/MWth	2.986e-04	10
22. 2. 0. 0	main heat transfer & transport systems	0.	1.000e+00	
22. 3. 1. 1	refrigeration	7.546e+01 \$/unit	3.303e-03	23
22. 3. 1. 2	piping	0.	1.000e+00	
22. 3. 1. 3	fluid circulation driving system	0.	1.000e+00	
22. 3. 1. 4	tanks	0.	1.000e+00	
22. 3. 1. 5	purification	0.	1.000e+00	
22. 3. 1. 0	magnet cooling system	0.	1.000e+00	
22. 3. 2. 1	refrigeration	0.	1.000e+00	
22. 3. 2. 2	piping	0.	1.000e+00	
22. 3. 2. 3	fluid circulation driving system	0.	1.000e+00	
22. 3. 2. 4	tanks	0.	1.000e+00	
22. 3. 2. 5	purification	0.	1.000e+00	
22. 3. 2. 0	shield & structure cooling system	6.700e+02 \$/MWth	2.986e+03	13
22. 3. 3. 1	refrigeration	0.	1.000e+00	
22. 3. 3. 2	piping	0.	1.000e+00	
22. 3. 3. 3	fluid circulation driving system	0.	1.000e+00	
22. 3. 3. 4	tanks	0.	1.000e+00	
22. 3. 3. 5	purification	0.	1.000e+00	
22. 3. 3. 0	supplemental heating system cooling system	0.	1.000e+00	
22. 3. 4. 1	refrigeration	0.	1.000e+00	
22. 3. 4. 2	piping	0.	1.000e+00	
22. 3. 4. 3	fluid circulation driving system	0.	1.000e+00	
22. 3. 4. 4	tanks	0.	1.000e+00	
22. 3. 4. 5	purification	0.	1.000e+00	
22. 3. 4. 0	power supply cooling system	0.	1.000e+00	
22. 3. 5. 0	other cooling systems (ECCS)	7.418e+07 \$	1.000e+00	
22. 3. 0. 0	auxiliary cooling systems	0.	1.000e+00	

22. 4. 1. 0	liquid waste processing & equipment	0.	1.000e+00	
22. 4. 2. 0	gaseous wastes & off-gas processing system	0.	1.000e+00	
22. 4. 3. 0	solid waste processing equipment	0.	1.000e+00	
22. 4. 0. 0	radioactive waste treatment & disposal	1.200e+03 \$/MWth	2.986e+03	13,14
22. 5. 1. 0	fuel injection systems	3.709e+06 \$	2.000e+00	10
22. 5. 2. 0	fuel processing systems	3.709e+04 \$/unit	2.731e+02	10
22. 5. 3. 0	fuel storage	3.709e+06 \$	1.000e+00	10
22. 5. 4. 0	atmospheric tritium recovery	1.484e+04 \$/m ³ /hr	1.059e+02	10
22. 5. 5. 0	water tritium recovery systems	4.520e-02 \$/W	2.290e+09	
22. 5. 6. 0	blanket tritium recovery systems	0.	1.000e+00	
22. 5. 7. 0	other	0.	1.000e+00	
22. 5. 0. 0	fuel handling & storage systems	0.	1.000e+00	
22. 6. 1. 1	blanket & coil maintenance equipment	0.	1.000e+00	
22. 6. 1. 2	components rotated into service to allow maint.	0.	1.000e+00	
22. 6. 1. 3	other maintenance equipment	0.	1.000e+00	
22. 6. 1. 0	maintenance equipment	0.	1.000e+00	
22. 6. 2. 0	special heating systems(start-up,trace, etc.)	0.	1.000e+00	
22. 6. 3. 0	coolant receiving, storage & make-up systems	0.	1.000e+00	
22. 6. 4. 0	gas systems	0.	1.000e+00	
22. 6. 5. 0	building vacuum systems	0.	1.000e+00	
22. 6. 0. 0	other reactor plant equipment	1.094e+04 \$/MWth	2.986e+03	13,14
22. 7. 1. 0	reactor i&c equip.(burn control, diagnostics, etc.)	0.	1.000e+00	
22. 7. 2. 0	radiation monitoring systems	0.	1.000e+00	
22. 7. 3. 0	isolated indicating & recording gauges, etc.	0.	1.000e+00	
22. 7. 0. 0	instrumentation & control(i&c)	2.341e+07 \$	1.000e+00	13,14
22.98. 0. 0	spare parts allowance	0. fraction	-1.000e+00	2,13,14
22.99. 0. 0	contingency allowance	0. fraction	-1.000e+00	2,13,14
22. 0. 0. 0	reactor plant equipment	0.	1.000e+00	

23. 1. 1. 0	turbine-generators & accessories	0.	1.000e+00	
23. 1. 2. 0	foundations	0.	1.000e+00	
23. 1. 3. 0	standby exciters	0.	1.000e+00	
23. 1. 4. 0	lubricating system	0.	1.000e+00	
23. 1. 5. 0	gas systems	0.	1.000e+00	
23. 1. 6. 0	reheaters	0.	1.000e+00	
23. 1. 7. 0	shielding	0.	1.000e+00	
23. 1. 8. 0	weather-proof housing	0.	1.000e+00	
23. 1. 0. 0	turbine-generators	4.758e+05 \$/unit	1.298e+02	2,13,14
23. 2. 0. 0	main steam (or other fluid) system	1.678e+03 \$/MWh	2.986e+03	12
23. 3. 1. 0	water intake common facilities	0.	1.000e+00	
23. 3. 2. 0	circulating water systems	0.	1.000e+00	
23. 3. 3. 0	cooling towers	0.	1.000e+00	
23. 3. 4. 0	other systems which reject heat to the atmosphere	0.	1.000e+00	
23. 3. 0. 0	heat rejection systems	6.319e+04 \$/unit	4.270e+02	10
23. 4. 1. 0	condensers	0.	1.000e+00	
23. 4. 2. 0	condensate system	0.	1.000e+00	
23. 4. 3. 0	gas removal system	0.	1.000e+00	
23. 4. 4. 0	turbine by-pass systems(excl. piping)	0.	1.000e+00	
23. 4. 0. 0	condensing systems	2.753e+04 \$/unit	5.215e+02	2,13,14
23. 5. 1. 0	regenerators & recuperators	0.	1.000e+00	
23. 5. 2. 0	pumps	0.	1.000e+00	
23. 5. 3. 0	tanks	0.	1.000e+00	
23. 5. 0. 0	feed heating system	0.	1.000e+00	
23. 6. 1. 0	turbine auxiliaries	2.640e+03 \$/unit	2.986e+03	2,13,14
23. 6. 2. 0	auxiliaries cooling system(excl. piping)	0.	1.000e+00	
23. 6. 3. 0	make-up treat. system(excl. piping)	0.	1.000e+00	
23. 6. 4. 0	chemical treat. & condensate purification systems	0.	1.000e+00	
23. 6. 5. 0	central lubrication service system(excl. piping)	0.	1.000e+00	
23. 6. 0. 0	other turbine plant equipment	6.482e+05 \$/unit	6.479e+01	2,13,14
23. 7. 0. 0	instrumentation & control(i&c) equipment	9.820e+05 \$/unit	8.049e+00	2,13,14
23.98. 0. 0	spare parts allowance	0.	-1.000e+00	2,13,14
23.99. 0. 0	contingency allowance	0.	-1.000e+00	2,13,14
23. 0. 0. 0	turbine plant equipment	0.	1.000e+00	

24. 1. 1. 0	generator circuits	0.	1.000e+00	
24. 1. 2. 0	station service	0.	1.000e+00	
24. 1. 0. 0	switchgear	8.600e+03 \$/unit	1.045e+03	2,13,14
24. 2. 1. 0	station service & startup transformers	0.	1.000e+00	
24. 2. 2. 0	low voltage unit substation & lighting transformer	0.	1.000e+00	
24. 2. 3. 0	battery system	0.	1.000e+00	
24. 2. 4. 0	diesel engine generators	0.	1.000e+00	
24. 2. 5. 0	gas turbine generators	0.	1.000e+00	
24. 2. 6. 0	motor generator sets	0.	1.000e+00	
24. 2. 0. 0	station service equipment	1.420e+04 \$/unit	1.045e+03	13,16
24. 3. 1. 0	main control board for electric system	0.	1.000e+00	
24. 3. 2. 0	auxiliary power & signal boards	0.	1.000e+00	
24. 3. 0. 0	switchboards (incl. heat tracing)	5.400e+03 \$/unit	1.045e+03	2,13,14
24. 4. 1. 0	gen. station grounding sys. & cathodic protection	0.	1.000e+00	
24. 4. 0. 0	protective equipment	2.110e+06 \$	1.000e+00	13,14
24. 5. 1. 0	concrete cable tunnels, trenches & envelopes	0.	1.000e+00	
24. 5. 2. 0	cable trays & support	0.	1.000e+00	
24. 5. 3. 0	conduit	0.	1.000e+00	
24. 5. 4. 0	other structures	0.	1.000e+00	
24. 5. 0. 0	electrical structures & wiring containers	1.568e+07 \$	1.000e+00	13,14,+
24. 6. 1. 0	generator circuits wiring	0.	1.000e+00	
24. 6. 2. 0	station service power wiring	0.	1.000e+00	
24. 6. 3. 0	control wiring	0.	1.000e+00	
24. 6. 4. 0	instrument wiring	0.	1.000e+00	
24. 6. 5. 0	containment penetrations	0.	1.000e+00	
24. 6. 0. 0	power & control wiring	3.244e+07 \$	1.000e+00	13,14,+
24. 7. 1. 0	reactor building lighting	0.	1.000e+00	
24. 7. 2. 0	turbine building lighting	0.	1.000e+00	
24. 7. 3. 0	reactor auxiliaries building lighting	0.	1.000e+00	
24. 7. 4. 0	radioactive waste building lighting	0.	1.000e+00	
24. 7. 5. 0	fuel storage building lighting	0.	1.000e+00	
24. 7. 6. 0	miscellaneous buildings lighting	0.	1.000e+00	
24. 7. 7. 0	yard lighting	0.	1.000e+00	
24. 7. 0. 0	electrical lighting	8.200e+06 \$	1.000e+00	13,14,+
24.98. 0. 0	spare parts allowance	0. fraction	-1.000e+00	2,13,14
24.99. 0. 0	contingency allowance	0. fraction	-1.000e+00	2,13,14
24. 0. 0. 0	electric plant equipment	0.	1.000e+00	

25. 1. 1. 0	cranes, hoists, monorails, & conveyors	0.	1.000e+00	
25. 1. 2. 0	railway	0.	1.000e+00	
25. 1. 3. 0	roadway equipment	0.	1.000e+00	
25. 1. 4. 0	watercraft	0.	1.000e+00	
25. 1. 5. 0	vehicle maintenance equipment	0.	1.000e+00	
25. 1. 0. 0	transportation & lifting equipment	1.568e+07 \$	1.000e+00	13,14
25. 2. 1. 0	air systems(excl. piping)	0.	1.000e+00	
25. 2. 2. 0	water systems(excl. piping)	0.	1.000e+00	
25. 2. 3. 0	auxiliary heating boilers(excl. piping)	0.	1.000e+00	
25. 2. 0. 0	air & water service systems	1.235e+07 \$	1.000e+00	13,14
25. 3. 1. 0	local communications systems	0.	1.000e+00	
25. 3. 2. 0	signal systems	0.	1.000e+00	
25. 3. 0. 0	communications equipment	6.220e+06 \$	1.000e+00	13,14
25. 4. 1. 0	safety equipment	0.	1.000e+00	
25. 4. 2. 0	shop, laboratory, & test equipment	0.	1.000e+00	
25. 4. 3. 0	office equipment & furnishings	0.	1.000e+00	
25. 4. 4. 0	change room equipment	0.	1.000e+00	
25. 4. 5. 0	environmental monitoring equipment	0.	1.000e+00	
25. 4. 6. 0	dining facilities	0.	1.000e+00	
25. 4. 0. 0	furnishings & fixtures	1.200e+06 \$	1.000e+00	2
25.98. 0. 0	spare parts allowance	0.	fraction	-1.000e+00 2,13,14
25.99. 0. 0	contingency allowance	0.	fraction	-1.000e+00 2,13,14
25. 0. 0. 0	miscellaneous plant equipment	0.	1.000e+00	
26. 1. 0. 0	reactor coolant	2.927e+02 \$/kg	4.283e+04	15,18
26. 2. 0. 0	intermediate coolant	0.	1.000e+00	
26. 3. 0. 0	turbine cycle working fluids	0.	1.000e+00	
26. 4. 0. 0	other materials	2.500e+05 \$	1.000e+00	13,14
26. 5. 0. 0	Ar reactor-building cover gas	0.	1.000e+00	
26.98. 0. 0	spare parts allowance	0.	fraction	-1.000e+00
26.99. 0. 0	contingency allowance	0.	fraction	-1.000e+00
26. 0. 0. 0	special materials	0.	1.000e+00	

90. 0. 0. 0	direct cost (not incl. spares and contingency)	0.		1.000e+00	
91. 0. 0. 0	construction services & equipment	1.000e-01	fraction	-1.000e+00	4,10
92. 1. 0. 0	systems engineering	0.		-1.000e+00	
92. 2. 0. 0	management	0.		-1.000e+00	
92. 3. 0. 0	quality assurance	0.		-1.000e+00	
92. 4. 0. 0	safety & environmental engineering	0.		-1.000e+00	
92. 0. 0. 0	home office engineering & services	1.000e-01	fraction	-1.000e+00	4,10
93. 1. 0. 0	construction management	0.		-1.000e+00	
93. 2. 0. 0	inspection	0.		-1.000e+00	
93. 3. 0. 0	preoperational testing	0.		-1.000e+00	
93. 0. 0. 0	field office engineering & services	1.000e-01	fraction	-1.000e+00	4,10
94. 1. 0. 0	project administration	0.		-1.000e+00	
94. 2. 0. 0	staff training & plant startup	0.		-1.000e+00	
94. 3. 0. 0	inventories & spares	0.		-1.000e+00	
94. 0. 0. 0	owner's cost	5.000e-02	fraction	-1.000e+00	4,10
95. 0. 0. 0	process contingency	0.	fraction	-1.000e+00	4,10
96. 0. 0. 0	project contingency	1.000e-01	fraction	-1.000e+00	4,10
97. 0. 0. 0	interest during construction (IDC)	1.124e-01	fraction	-1.000e+00	4,10
98. 0. 0. 0	escalation during construction (EDC)	0.	fraction	-1.000e+00	4,10
99. 0. 0. 0	total cost	0.		9.000e+02	

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