TASKA-M, A Compact Fusion Technology Test Facility

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The design of a low power (6.8 MW) tandem mirror technology test facility is given. The facility is based on physics presently in hand or that should be available by 1985. Technologies employed by TASKA-M are at the mid-1980's level and the device is designed to achieve a peak damage level of ~ 78 dpa in two materials test modules which have a test volume of ~ 170 liters. In addition, two modules are reserved for blanket testing at nominal wall loadings of ~ 1 MW/m^2. The direct cost of TASKA-M is less than 400 million dollars, making it an attractive next step beyond MFTF-B.

1. INTRODUCTION

The need for a high neutron fluence, large volume 14 MeV neutron technology test facility has been highlighted in every national and international program plan for the past decade. The first attempt to provide such a facility was the LLNL minimum $\overline{B}$ mirror configuration called FERF.[1] This was followed by a 360 MW$_t$ University of Wisconsin tokamak test facility called TETR[2] and the IAEA INTOR 620 MWt reactor in 1981.[14] In 1982, the 86 MW$_t$ Wisconsin-Karlsruhe tandem mirror test facility study, TASKA,[3] was published followed in 1983 by the 20 MW$_t$ LLNL tandem mirror facility called TDF.[4] The purpose of the present study is to investigate the smallest and least costly tandem mirror fusion test facility possible which still retains a considerable degree of reactor relevance.

2. REACTOR DESIGN

2.1 General Features

TASKA-M is designed to produce 6.8 MW of thermonuclear power and is based on a Kelley mode of physics operation. The central cell (CC) is 5.6 m long (peak B to peak B) and the plasma diameter is 24 cm. The neutron wall loading varies from 0.25 to 1.34 MW/m^2 in the area of the test cells. There are 4 test zones, 2 of which are devoted to blanket tests and 2 that are devoted to materials tests. The volume of the test capsules in the materials modules is approximately 170 liters and the maximum design fluence is ~ 10 MW-y/m^2. One of the blanket test modules is devoted to liquid metals and the other is devoted to solid breeders. TASKA-M produces tritium only for demonstration purposes and the low consumption rate of 1.03 g/FPd means that only 2.9 kg of T_2 are required over the anticipated life of the device. More details on TASKA-M are contained in the main report.[5]

2.2 Plasma Physics Basis

The plasma physics basis for TASKA-M stems from either present day or near term experiments. For example, TASKA-M does not require a thermal barrier for operation and it is based on TMX (and TMX-U) physics.[6] Phaedrus[7] and GAMMA-10[8] results on RF heating and microstability should be in hand by mid-1980's.

Finally, TARA[9] should confirm the assumptions made with regard to MHD and trapped particle stability.

The plasma is confined by a 17.5 T magnetic field generated by a hybrid superconducting/normal copper coil set. Figure 1 shows the axial magnetic field and potential profile while the key physics parameters are given in Table 1.

2.3 Magnet Design

The reactor consists of 3 superconducting solenoid coils, 2 normal high field copper choke coil inserts, 2 superconducting Yin-Yang coil sets (4 coils in all) and 2 superconducting transition coils (see Fig. 1). The design features of the coils are listed in Table 2.

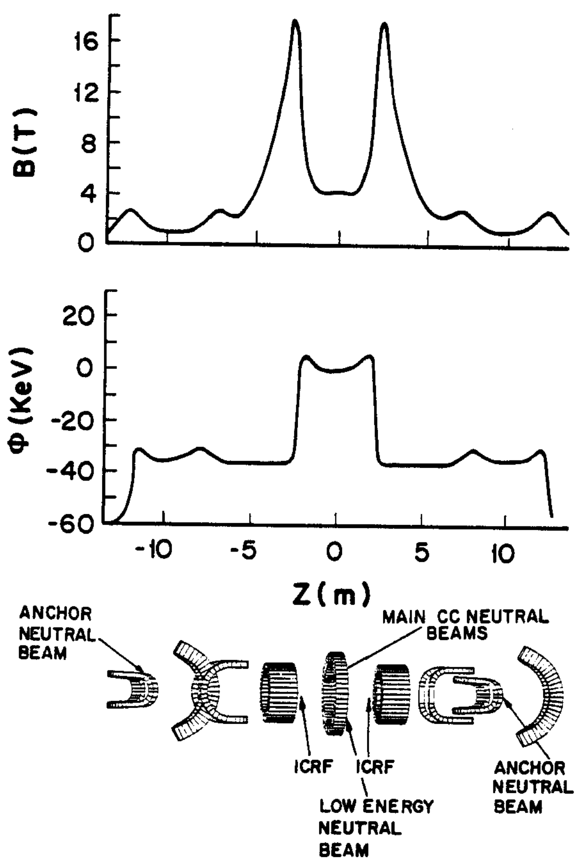

FIGURE 1
Magnet and electrostatic configuration of TASKA-M.

TABLE 1
Key Plasma Physics Parameters for TASKA-M

PARAMETER	VALUE
Fusion Power - MW	6.8
CC Plasma Length/Diameter, cm	560/24
CC Magnetic Field (midplane/peak), T	4.2/17.5
CC Ion Density, cm^{-3}	3.2×10^{14}
CC Ion Energy, keV	84
CC <Beta>, %	30
4 Heating & Fueling Beams, kV/MW (ea.)	90/5.2
1 Warm Ion (D) Beam, kV/MW	12/0.6
Electron Heating Power, MHz/MW	25/12.5
2 Plug Beams (D), kV/MW (ea.)	66/3.5

TABLE 2
Key Design Features of TASKA-M Magnets

PARAMETER	VALUE
Superconductors (all LHe-I cooled)	
CC Solenoid Inner/Outer Radius, m	1.8/2.4
CC Solenoid Peak Field, T	7.4
CC Solenoid Materials	NbTi/Al/304SS
Choke Coil Inner/Outer Radius, m	1.15/1.7
Choke Coil Peak Field, T	12
Choke Coil Materials	Nb_3Sn/NbTi/Al/304SS
Yin-Yang Peak Field, T	< 6
Yin-Yang Coil Materials	NbTi/Cu/304SS
Normal Copper Choke Coils	
Inner/Outer Radius, m	0.15/0.65
Peak Magnetic Field, T	18
Magnet Materials	MZC Cu/MgO/304SS
Power Consumption, MW_e	20 (Total)

All of the superconducting coils in TASKA-M are either state-of-the-art today (e.g., the YY coils are the same size and field strength as the MFTF-B coils already in place[10]) or they should be state-of-the-art by the 1985-90 period. The S/C solenoid coils are roughly the same size as the LCP coils where Nb_3Sn technology will also be proven in the Westinghouse coil.[11] The high field normal Cu coils are roughly the same size as those proposed for the MFTF-α upgrade device for operation in the early 1990's.[12]

2.4 Central Cell Shield and Test Module Design

A schematic of the TASKA-M device is shown in Figs. 2 and 3. Some key information is also given in Table 3. The central cell plasma is surrounded by a shield which has penetrations for 5 neutral beams, several ICRF coaxial cables, vacuum pumps and 4 test modules. The bulk shield is an austenitic steel structure (Fe 1422) filled with B_4C and water coolant.

The axial variation of the wall loading is given in Fig. 4. It ranges from 0.25 MW/m^2 at the midplane of the CC to 1.34 MW/m^2 at the materials test module. The test modules are designed to be removed from the side of the reactor between the solenoidal magnets. No tritium breeding is provided for in the shield region and makeup T_2 is obtained from outside sources. The shield, even accounting for neutron streaming up beam ducts, protects the S/C coils so that more than 8 FPY of operation can be obtained with no serious damage (Table 3).

The surface heat flux is highest in the central cell section where the charge exchange between the incoming beams and the CC plasma is the greatest. Values up to 1 kW/cm^2 have been calculated.[13] Recessing of the first wall in the immediate vicinity of the beam interaction region to 70 cm, reduced this peak value to ~ 0.12 kW/cm^2. However, heat fluxes of < 10 W/cm^2 are calculated for the liquid metal test blanket region.

2.5 Tritium System

The key tritium parameters for TASKA-M are summarized in Table 4. At a consumption rate of 1.03 gram per FPd we expect to burn approximately 2.9 kg of T_2 over the lifetime of the device. Accounting for decay, absorption into structures, and losses, indicates that on the order of 3 kg of T_2 (~ 30 million dollars at present prices) will be needed over the 20 calendar years of operation.

The low burnup fraction of 0.33% requires 313 g of T_2 to be injected by the beams each FPd. Both the low burnup fraction and the inefficiency of the NBI place a heavy load on

TABLE 3
Key Central Cell Design Parameters for TASKA-M

PARAMETER	VALUE
Max. n Wall Loading, MW/m^2	1.34
Max, Thickness CC Shield, m	0.80
First Wall Material/Coolant	316SS/H_2O
Max. First Wall Temperature, °C	300
Tritium Breeding	None
Max. Nuclear Heating S/C Coil, mW/cm^3	0.05
Max. dpa Rate, S/C Coil, FPY^{-1}	1.0×10^{-4}
Max. Exposure, Elect. Insulation, Rads/FPY	2×10^7

TABLE 4
Key Tritium Parameters for TASKA-M

PARAMETER	VALUE
Burn Rate, g/FPd	1.03
Burn Fraction, %	0.33
Injection Rate into Plasma, g/FPd	313
Total Tritium Handled, g/FPd	1464
Method of Impurity Control	Halo Plasma
Active T_2 Inventory, g	< 134
Cryopumps (Exhaust + NBI)	122
Structure	< 10
Plasma Dump	< 1
Coolant H_2O	1
Storage (1 FPd), g	1464

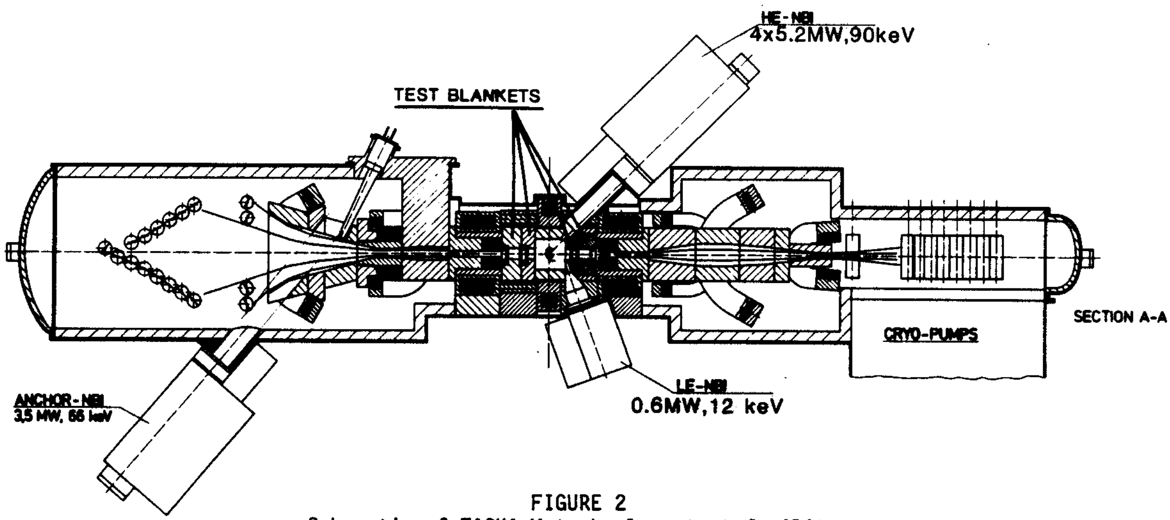

FIGURE 2
Schematic of TASKA-M technology test facility.

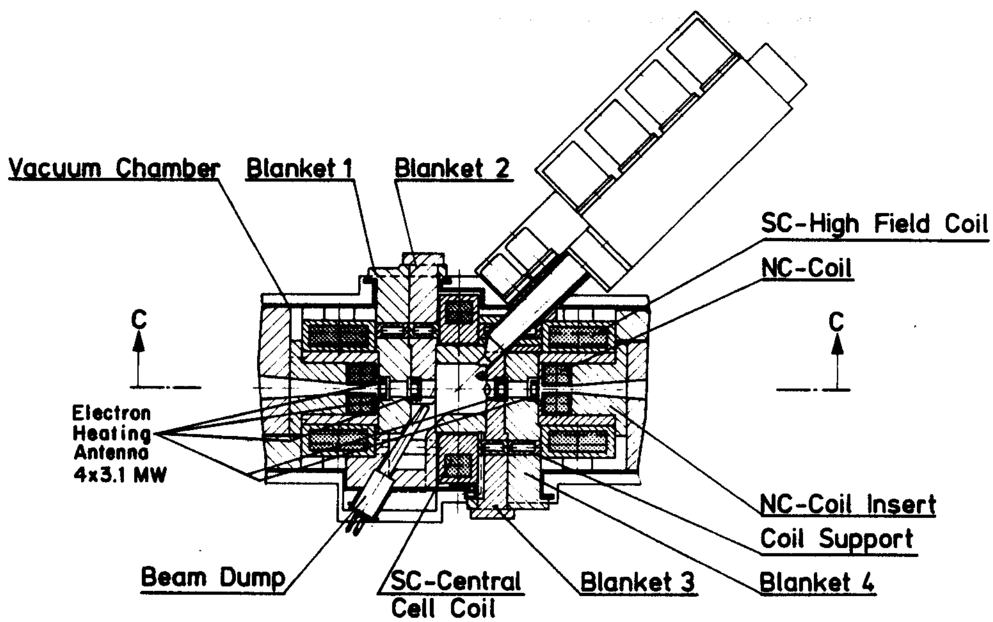

FIGURE 3
Schematic of TASKA-M central cell area.

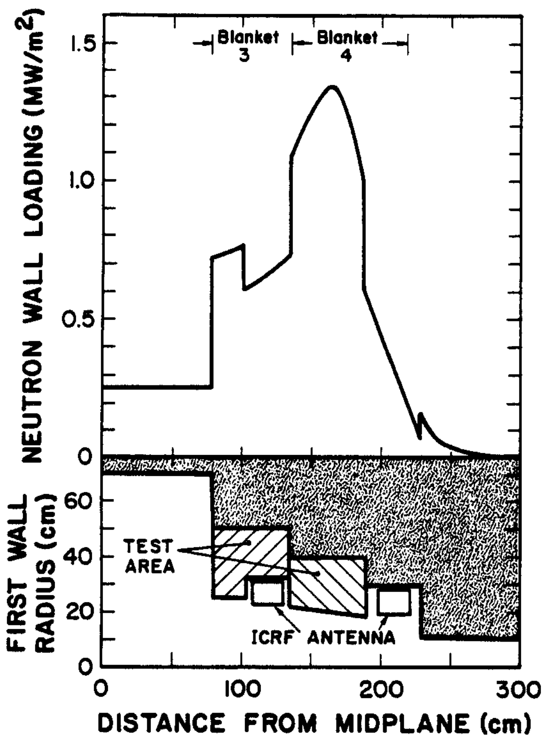

FIGURE 4
Axial variation of neutron wall loading in TASKA-M (right side of midplane only).

the vacuum exhaust system where the tritium inventory may approach 122 g in the cryopumps.

3. TESTING CAPABILITIES OF TASKA-M

The 4 test modules in TASKA-M (see Fig. 3) have the following missions:

#1 Liquid Metal Blanket Testing
#2 Solid Breeder Blanket Testing
#3 Long Term, Large Specimen Materials Testing
#4 High Damage, Thermal, Stress, and Compatibility Testing of Materials.

More details on the test modules are given in the main report[5] and Table 5.

The two materials test modules are filled with test capsules which can control the local temperature, stress, and corrosive environment of the test specimens. The capsules in module #4 are 5 cm in diameter and 20 to 24 cm long.

TABLE 5
Key Test Parameters of TASKA-M

MATERIALS TEST MODULES	#3	#4
FW n Loading, MW/m^2	0.6-0.78	1.0-1.34*
Inner/Outer Radius Test zone, cm	25-32.5/45	18-22/42
Structural Material/ Coolant	316SS/He	HT-9/He
Max. dpa/appm He per FPY	7.5/70	10/120
Total Number Capsules	341	220
Total Volume, ℓ	93	90.7
Total dpa-ℓ (7.8 FPY)	2452	2733
BLANKET TEST MODULES	#1(SOLID)	#2(LIQUID)
Ave. FW n Loading, MW/m^2	0.73	0.84
Inner/Outer Radius Test Zone, cm	25/40	22-25/ 67-85
Breeder/Coolant	Li_2O/H_2O	$Li_{17}Pb_{83}$ or Li
TBR (Local)	0.71	1.15 or 1.19
T_{max} Breeder, °C	NA	500
Structure	316SS	HT-9

*In Test Zone Only

The axis of the capsule is placed perpendicular to the plasma axis and there are 220 capsules in module #4 which provide 90.7 liters of high grade test volume. The damage profile, as calculated by Monte Carlo techniques, is shown in Fig. 5. These profiles reveal that the peak damage in the materials modules will be ~ 10 dpa/FPY and it may drop to ~ 1.5 dpa/FPY at the back of the capsule. The variation in the helium production is from ~ 120 appm per FPY in the front to ~ 15 appm per FPY in the back of the capsule.

The capsules have been allocated to the test matrix shown in Table 6. Considering all the variations in material composition (i.e., different commercial heats), irradiation temperature, fluences, imposed stresses and allowances for duplicates we find that approximately 34,500 specimens can be irradiated.

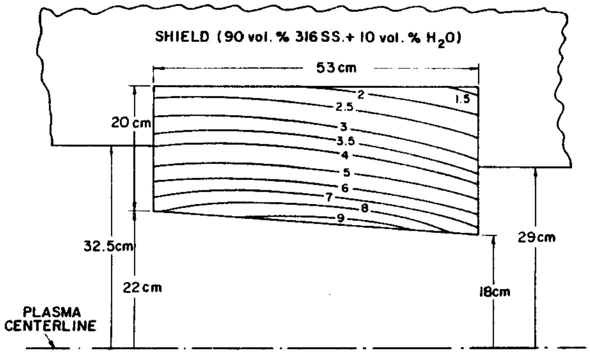

FIGURE 5
Spatial variation in the displacement damage in materials test module #4.

This will require approximately 500 capsules and TASKA-M has a capability of 561 capsules for materials testing alone (~ 180 ℓ).

The time integrated dpa and dpa-ℓ values for TASKA-M, are given in Fig. 6. It can be seen that in the 7.8 FPY operating scenario, the maximum damage accumulated is ~ 78 dpa in steel. A very important quantity is the product of the average displacement damage times the total capsule volume. This number reflects the total space available not only for specimens but for temperature, stress, and environmental control. The value of ~ 5200 dpa-ℓ or ~ 670 dpa-ℓ per FPY of operation can be compared to other proposed fusion facilities as below.

		dpa-ℓ/FPY
INTOR[14]	-	182
TASKA	-	1510
FMIT[15]	-	5
RTNS-II[16]	-	0.0003
TASKA-M	-	670

4. COSTS OF TASKA-M

The detailed cost breakdown for TASKA-M is contained in the main report.[5] The total direct cost (in 1983 $) is approximately 400 million dollars. This is roughly a factor of

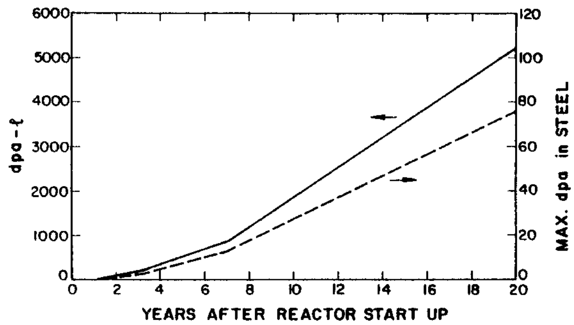

FIGURE 6
Accumulated damage parameters for TASKA-M.

2 less than TASKA and a factor of 3-4 less than INTOR.

5. CONCLUSIONS

The preliminary design of TASKA-M shows that an attractive tandem mirror test facility can be designed for less than 400 M$ in direct costs. The device is approximately the same size as MFTF-B and utilizes present day or near term (within the next 5 years) physics. The magnets, beams, RF devices, and tritium technology all are 1980's state of the art technology and since the power level of the device is so low (~ 6.8 MW) no tritium breeding is required. The testing capabilities for materials over the 20 year schedule (7.8 FPY's) provide for more than 500 individual capsules and over 34,000 specimens. The two blanket test modules should allow for several liquid metal and solid breeders to be tested. Finally, the TASKA-M device represents a logical step beyond the MFTF-B/GAMMA-10 class of tandem mirrors and could be built by a single government unit or through an international collaborative effort such as JET.

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TABLE 6

Materials Test Matrix for TASKA-M

TYPE	MAT. VAR.	DUP.	TEMP.	FLUENCE	OTHER	# OF SPEC.	CAPSULES #3	CAPSULES #4
Structural								
Tensile	5	3	6	5	6 rates	2,700	---	10
Fatigue Crack Growth	6	3	7	5	4 stresses	2,496	26	---
Fracture	4	3	4	4	4 temps	768	20	---
Swelling	10	5	10	5	4 post irr.	10,000	---	5
Stress Relax	6	4	6	--	5 stresses	720	---	3
Creep-Rupture	6	2	6	--	5 stresses	360	---	2
In Situ-Cyclic	4	2	2	--	4 stresses	64	---	64
						17,108	46	84
Other (Ceramic, Electrical, Heat Dump)								
Tensile	15	3	6	4	4 rates	4,320	---	15
Fatigue	10	3	6	6	4 strains	4,320	99	---
Dimemsional Stability	15	5	6	4	4 post tests	7,200	---	4
Creep	10	2	6	--	4 stresses	480	---	2
In Situ-Cyclic	6	2	4	--	4 stresses	192	192	---
Fracture	3	2	2	2	6 temps	144	---	7
Electrical Properties	6	3	2	4	3 tests	432	---	18
Thermal Conductivity	6	3	4	4	--	288	---	12
						17,376	291	78
					Total	34,484	337	162
					Capability		341	220

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