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The preliminary performance of a new Engineering Testing Reactor based on the tandem mirror confinement principle is described. This device, called TASKA, is based on near term (mid 1980's) technology and is designed to test reactor relevant technologies (superconducting magnets, blankets, materials, etc.) for the Demonstration Power Reactor envisioned for the turn of the century. The key operating parameters are a DT power level of 86 MW, a neutron wall loading of 1.5 MW/m^2, and an overall tritium breeding ratio of 1.0. Details of the materials testing program reveal that damage levels approaching 100 dpa can be achieved in less than 15 years of irradiation time. TASKA appears to be an attractive, cost effective way of achieving the near term technology testing goals for the world fusion program.

1. INTRODUCTION

The rapid advance of plasma physics and the expectations of positive results from TFTR, JET, and JT-60 has prompted many scientists to begin planning for prototypical and commercial fusion power plants [1]. However, there is one important step that needs to be taken beyond the mid 1980's class of physics experiments and before the operation of the first large scale power plants; i.e., the construction of an Engineering Test Facility.

There have been several attempts to design such facilities based on the Tokamak concept starting from TETR [2] in 1976, to INTOR in 1980 [3] and FED in 1981 [4]. Recent advances in the physics of tandem mirrors have caused scientists to reexamine the Engineering Test Facility concept; this time based on a device which uses thermal barriers. The objective of this paper is to present the preliminary parameters of TASKA (TAndem Spiegel Studie KArlsruhe), a tandem mirror test facility which meets, or in many cases exceeds, the performance of previous tokamak test facilities. The reader is cautioned that this paper, like others in this Conference, represents the status in the summer of 1981 and future refinements may cause changes in the specific parameters.

2. TASKA OBJECTIVES

TASKA is designed to be the maximum reasonable step beyond the next generation of large mirror machines (AMBAL, TMX-U, Gamma-10, TARA, and MFTF-B) in the world fusion program. This step must demonstrate that the key technologies required for a DT Demonstration Power Reactor (superconducting magnets, beams, remote handling, etc.) can be successfully integrated into one machine. Once that goal is accomplished TASKA will also be a test facility for the blanket, tritium, materials, and plasma engineering technology required for the Demo. Finally, TASKA is designed to demonstrate the safe and reliable operation of a DT reactor.

3. PHYSICS BASIS FOR TASKA

The tandem mirror physics concept has been previously verified on Gamma-6 [5] and TMX [6]. Some aspects of electron heating with ECRH in the end plugs of TMR's has been demonstrated on Phaedrus [7]. The key experiment to demonstrate operation with thermal barriers on a tandem mirror will be performed in 1982 on TMX-U [8]. This device will also advance the understanding of electron heating and the central cell region will be operated in the collisionless diffusion regime.

The MFTF-B device [9], currently under construction, should demonstrate in 1985/6 long pulse operation (>30 seconds) in the TMR-thermal barrier model. The limits on central cell beta will also be investigated. High power, continuous 80 keV neutral beams will be used to achieve an D-T equivalent $Q \sim 1$ in the same time period. MFTF-B will be the first mirror machine to use all superconducting magnets, including the Yin-Yang coils.

The physics relationship of TASKA to past, present, and future devices is shown in Figure 1. The data from WITAMIR-I [1] is also included and it shows that TASKA lies on a reasonable projection of the aforementioned devices. For more detailed discussion on the physics basis of TASKA, see reference [10].

4. BASIC REACTOR PARAMETERS OF TASKA

A schematic of the TASKA coil set is shown in

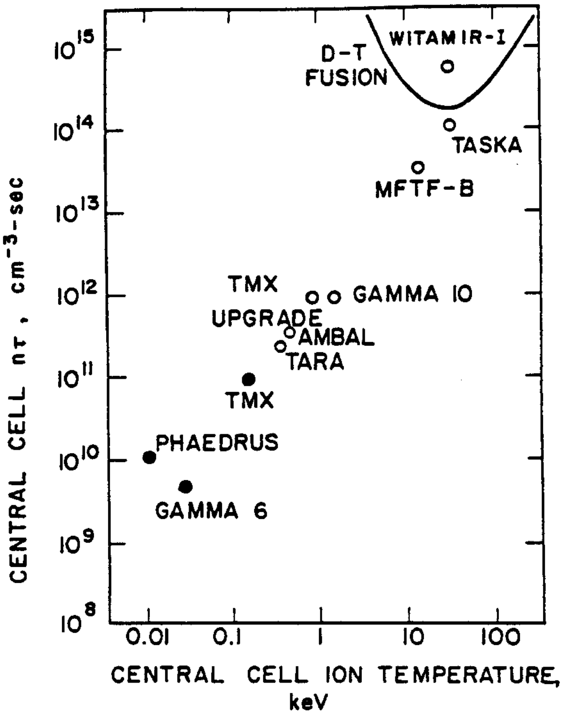

Figure 1. Critical Physics Parameters for Present and Future Tandem Mirrors.

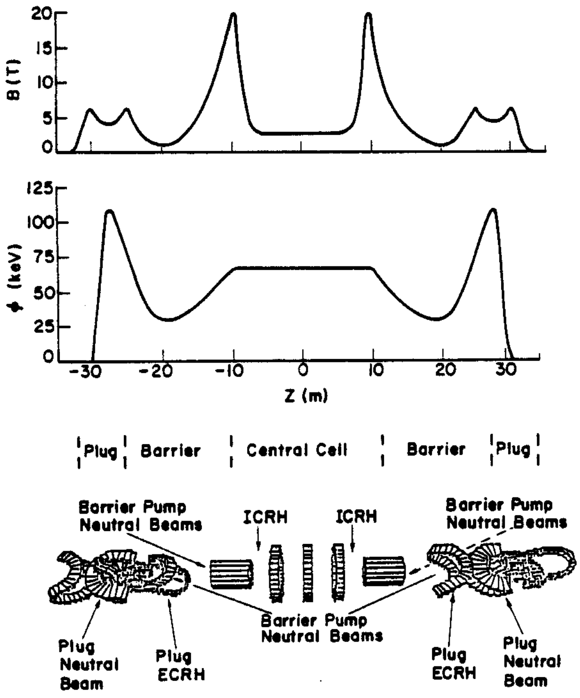

Figure 2. Magnet and Electrostatic Configuration of TASKA.

Table 1

Selected Key Parameters of TASKA

General	
DT power level	86 MW
First wall neutron wall loading	1.5 MW/m^2
Total heating power	110 MW
Plasma	
Central cell density	1.9×10^{14} cm^{-3}
Central cell ion temp.	30 keV
Central cell beta	50%
Minimum barrier density	6.8×10^{12} cm^{-3}
Plug density	6.3×10^{13} cm^{-3}
Plug ion temp.	388 keV
Plug electron temp.	59 keV
Heating	
Plug power	5 MW
Plug energy	250 keV
Plug species	P
Barrier power	50/7 MW
Barrier energy	50/76 keV
Barrier species	D-T/D
ECRH power	15 MW
ECRH freq.	56 GHz
ICRH power	40 MW
ICRH Freq.	21 MHz
Dimensions	
Central cell length	19.2 m
Central cell inner radius	0.46 m
Total length (w/o power dump)	80 m
Magnetic Fields (on axis)	
Central cell	2.7 T.
Barrier max (14 T from S/C, 6 T from Cu)	20 T
Barrier min	0.8 T
Plug max	6.25 T
Plug min	4 T
Central Cell Permanent Blanket	
Structural material	HT-9
Coolant (90% Li-6)	$Pb_{83}Li_{17}$
Inlet/outlet temp.	300/400°C
T_2 breeding ratio (including test modules)	> 1.0
Tritium inventory - blanket	20 g
First wall heat flux	2 W/cm^2
Test Modules	
No. of blanket test modules (BTM)	2
Width/Thickness of each BTM	1 m/1 m
Volume of each BTM	5700×10^3 cm^3
No. of materials test modules (MTM)	1
Width/Thickness of each MTM	0.8 m/0.2 m
Volume of MTM	507×10^3 cm^3
Number of capsules per MTM	351
Max dpa per FPY (test spec.)	17
Max appm He per FPY (test spec.)	179

Figure 2 along with the confining magnetic fields and electric potentials. The end plugs consist of an inside thermal barrier, anchored by a Yin-Yang coil set. There are 3 circular central cell coils. The details of this configuration are discussed in the full TASKA report [11]. A selective list of TASKA operating parameters is given in Table 1. Some of the key features of TASKA are listed below:

- The DT power level is 86 MW, far below the 620 MW of INTOR [3] or 180 MW of FED [4]. This lower power level greatly eases the tritium requirements and reduces the overall costs compared to previous test devices.
- The neutron wall loading is 1.5 MW/m^2. This relatively high wall loading will allow reactor relevant testing to be performed in both blanket and materials modules.
- The barrier region is pumped with neutral beams and the electrons in the end plug region are heated with both ECRH at 56 GHz and proton beams at 250 keV.
- One of the key features of the machine that allows such a favorable performance is the use of a high field, room temperature copper insert which raises the field in the barrier coil from 14 T produced by the superconductor to 20 T. The life limiting feature of this coil is radiation damage to the ceramic insulation of 10^{12} rad. The projected life is 10 years at 25% availability or 5 years at 50% availability.
- The tritium for this device is provided by circulating $Pb_{83}Li_{17}$ alloy in HT-9 ferritic steel tubes (see Figure 3). The overall breeding ratio of the machine is 1 so that no net tritium consumption is incurred over the life of the machine. The low solubility of T_2 in $Pb_{83}Li_{17}$ [12] results in only a 20 g inventory in the blanket.
- There are two modules devoted to blanket testing and one module devoted to materials testing. These test modules are placed between the central cell coils for ease of access and maintenance. More details of the materials test module are given in section 5.
- The secondary heat transfer loop contains an organic material, HB-40. Normally, the approximately 60 MW from the central cell breeding blanket is dumped to cooling towers but provisions have been made to generate electricity with the 350°C steam. Roughly 15 MWe can be generated in this manner.
- Normally, the energy of the plasma ions and electrons leaking from the plasma is deposited in heat dumps at either end of the machine but provisions have been made to test various direct convertors on one end. The operation of TASKA does not depend on the successful operation of the direct convertor.

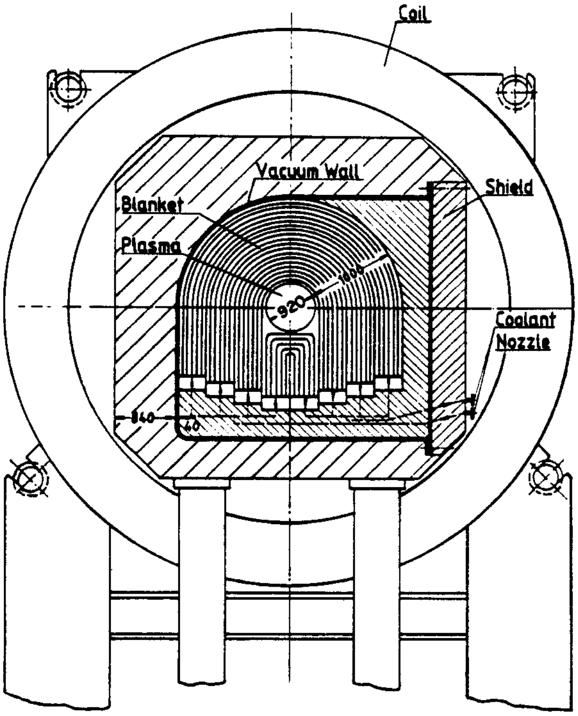

Figure 3. TASKA Central Cell Cross Section.

As an illustration of TASKA's contribution to the materials program we will now examine its materials testing capabilities in more detail.

5. MATERIALS TESTING IN TASKA

Before outlining TASKA's capabilities, we must be clear on the extent of testing that will be required. There are two approaches one might take; 1) TASKA could test materials for the mirror program only or, 2) TASKA could provide a generic testing bed for the tokamak program as well. The main difference between the two approaches is that in 2), fatigue and crack growth specimens are included. While the number of such specimens is not great, the volume per specimen is large. This is illustrated in Table 2 where the proposed materials test program for TASKA is outlined. More detail on the test program is given elsewhere [11] but the following features emerge.

	Mirror Program	Tokamak+Mirror
# of Spec.	27,720	29,548
# of Capsules	105	313

On the basis of the above requirements, capsules were designed to fit into the test module as outlined in Figure 4.

One test module is designed to accept 351 capsules, each of which has individual temperature

Table 2

Proposed Materials Test Matrix -TASKA

	Mat. Var.[a]	Dup.[b]	Temp.[c]	Fluence[d]	Conditions	Total Specimens		Total Capsule[g]	
						Mirror[e]	Tokamak[f]	Mirror[e]	Tokamak[f]
Materials Surveillance									
Tensile	3	2	2	2	2 rate/temp.	48	48	3	3
Fatigue	0(3)	0(2)	0(2)	0(2)	0(4) stress	0	96	0	4
Crack growth	1(2)	2	2	3	3 stress levels	36	72	1	2
Fracture	2	2	2	2	2 temp.	32	32	4	4
					Subtotal	116	248	8	13
Structural Materials									
Tensile	5	3	6	5	6 rate/temp.	2700	2700	10	10
Fatigue (High Cycle)	0(8)	0(3)	0(2)	0(4)	0(4) stress	0	768	0	29
Crack growth	3(6)	2	4	4	3 stress levels	288	576	3	6
Fracture	4	3	4	2	2 temp.	192	192	5	5
Swelling	10	5	10	5	4 post irr. tests	10,000	10,000	5	5
Stress relax.	6	4	6	-	5 stresses	720	720	3	3
Creep-rupture	6	2	6	-	5 stresses	360	360	2	2
In situ-cyclic	0(4)	0(2)	0(2)	-	0(4) stress levels	0	64	0	64
					Subtotal	14,260	15,380	28	124
Other Materials[h]									
Fatigue	5	3	4	4	2 strain range	480	960	11	22
Tensile	15	3	6	4	4 rate/temp.	4,320	4,320	15	15
Dimensional stab.	15	5	6	4	4 post tests	7,200	7,200	4	4
Creep	10	2	6	-	4 stresses	480	480	2	2
In situ-cyclic	0(6)	0(2)	0(2)	-	0(4) stresses	0	96	0	96
Fracture	3	2	2	2	6 temp.	144	144	7	7
Elect. prop.	6	3	2	4	3 tests	432	432	18	18
Therm. Cond.	6	3	4	4	---	288	288	12	12
					Subtotal	13,344	13,920	69	176
					Total	27,720	29,548	105	313

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[a] Materials x variations
[b] Duplication
[c] Number of irradiation temperatures
[d] Fluence levels
[e] Specifically for the Mirror Program
[f] Required for both Mirror and Tokamak Programs
[g] Capsule volume-390 cm^3
[h] Ceramics, electrical, and heat dump materials
( ) Addition for tokamak program

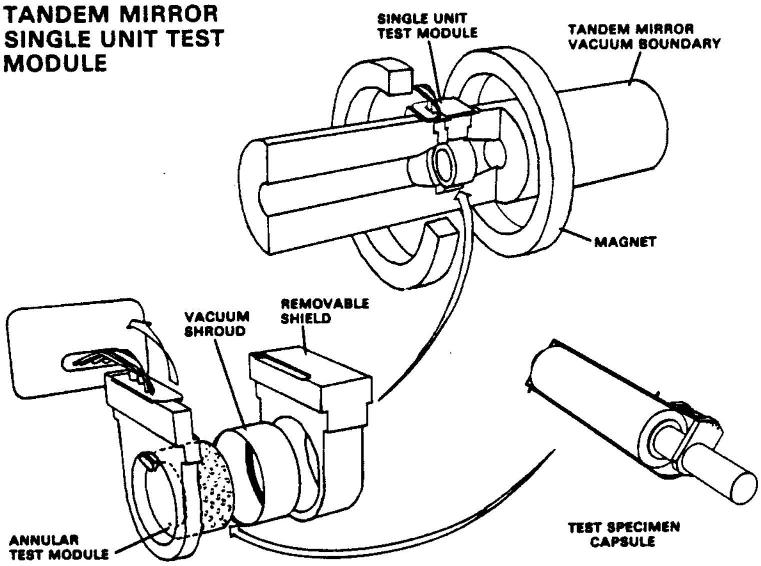

Figure 4. Schematic of TASKA Materials Test Module.

control and instrumentation. At specified intervals the module is removed, selected capsules are removed and fresh capsules are inserted.

The damage in the test specimens can be conveniently expressed in two different ways; the total dpa accumulated as a function of time (dpa/FPY) or, the sum of the product of the dpa level times the volume of the test zone that produces that damage level (e.g., dpa-liters). The first parameter reflects only the severity of the damage while the second parameter attempts to account for the number of specimens that can be irradiated to high levels.

We have assumed that TASKA will operate on the following conservative schedule (identical to INTOR [3]).

Year	% Availability
1	10% (hydrogen operation)
2-3	15%
4-7	25%
8-15	50%

Combining these availability values with a start-up date of 1990 and a wall loading of 1.5 MW/m^2 yields the cumulative dpa values given in Figure 5. Comparison between TASKA and FMIT, INTOR, and RTNS-II reveals that while RTNS-II will be the only device yielding high energy neutron data up to the mid 1980's, it will be quickly surpassed by FMIT. Assuming INTOR and TASKA start at the same time with the same operating schedule, they both will produce significant damage levels in metallic specimens by the mid 1990's. There are 3 main reasons why the TASKA numbers are higher than INTOR; 1) the wall loading is higher (1.5 vs. 1.3 MW/m^2), 2) TASKA is steady state vs. a 0.7 to 0.8 duty cycle for INTOR [3], and 3) the higher heat flux in INTOR requires a thick (several cm), separate water cooled first wall which attenuates the neutron flux to the sample.

Figure 5 shows the average displacement damage incurred in samples contained in the capsule volumes indicated on the curve. Obviously, it is one thing to produce 100 dpa in one small specimen and quite another to produce 10 dpa in 10 large specimens. Another way of comparing this data is to multiply the test volume which will produce a certain damage level times that level and sum up over the test volume. When this is done (Figure 6) we see that in terms of achieving both a high dpa level (Figure 5) and providing a large testing volume, TASKA is clearly superior to the other devices regardless of the method of cooling. This does not mean that the other devices are unimportant, but rather, that we should perceive testing devices in terms of their original design goals. FMIT was designed to produce high fluence damage early, but not to generate the large volumes of confirmatory data necessary for qualifying Demo materials. RTNS was designed to help correlate fission neutron data with high energy neutron damage. INTOR was designed to test tokamak specific effects (pulsing, high heat flux, cyclic behavior, etc.). All are important in the quest for a workable CTR structural material.

6. CONCLUSIONS

The preliminary design of TASKA has shown that

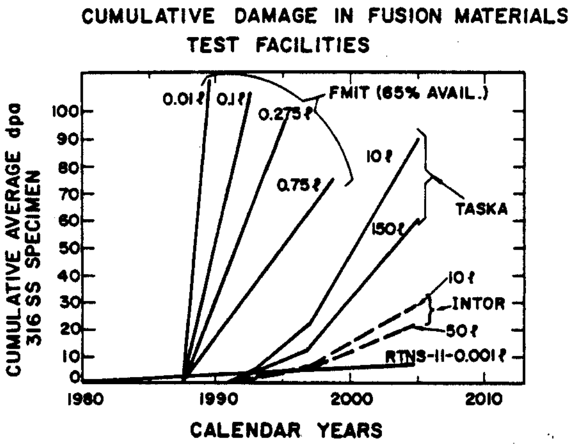

Figure 5. Cumulative Damage in Fusion Materials Test Facilities. Only Volume of Test Capsule Indicated.

it could be a valuable test facility for fusion blankets and materials as well as providing a meaningful test of integrating heating technologies, superconducting magnets, remote maintenance equipment, etc., into one machine. In particular, the materials testing capabilities are very attractive. A large volume (>100 liters) of high damage level (up to ~100 dpa) testing space is available in TASKA and it can accommodate the specimens needed to qualify the leading alloys and non-metallic materials for a demonstration plant operating around the turn of the century.

ACKNOWLEDGMENT

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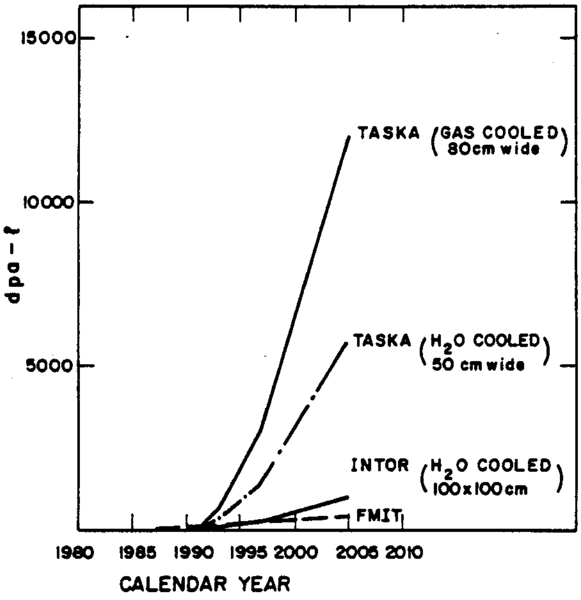

Figure 6. Cumulative Damage x Test Capsule Volume for Fusion Materials Test Facilities.

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