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TASKA-M is a tandem mirror facility aimed at technology and materials testing with reactor-relevant neutron fluxes and fluences. A high neutron wall loading (1.3 MW/m^2) locally is obtained in the central cell using neutral beam injection at 45° to produce a sloshing ion distribution. The total fusion power is only 6.8 MW. Sufficient space is allocated in the central cell for two blanket test modules and two materials test modules. Electron heating using Landau damping of ion cyclotron waves produces a sufficiently high electron temperature so that electron drag on the hot ions is minimized. In addition, the resulting potential well in the central cell is deep enough to contain a warm plasma which stabilizes the hot mirror-confined plasma against the DCLC mode. MHD stability is obtained by yin-yang anchors at each end of the central cell. In order to simplify the design and to keep the physics as simple as possible, a thermal barrier is <u>not</u> included.

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-B mirror configuration called FERF [1]. This was followed by a 360 MW_t University of Wisconsin tokamak test facility called TETR [2] in 1977, and by the IAEA INTOR [3] 620 MW_t reactor in 1981. In 1982, the 86 MW_t Wisconsin-Karlsruhe tandem mirror test facility study, TASKA [4], was published. This was followed in 1983 by the LLNL 20 MW_t tandem mirror facility, TDF [5]. The purpose of the TASKA-M study is to investigate the smallest and least costly tandem mirror fusion test facility possible, while retaining a considerable degree of reactor relevance. In this paper we survey plasma engineering considerations for TASKA-M; other papers in this conference discuss the engineering aspects of the test modules and of the overall machine.

General Features of TASKA-M

TASKA-M is a tandem mirror with an axisymmetric central cell and two yin-yang cells, as shown in Fig. 1. The central cell contains hot, magnetically trapped deuterium and tritium ions which react via fusion to produce 14.1 MeV neutrons and 3.5 MeV alpha particles. The central cell contains the blanket and materials test modules; the plasma in the anchors and connecting transition regions is only deuterium and has a low neutron yield. The hot D and T ion population in the central cell is sustained by injection of energetic neutral beams at an angle of 45° to the magnetic field; this produces a so-called "sloshing-ion" plasma in which the ion density peaks away from the central cell midplane. This produces an electrostatic potential well which traps warm ions provided by a low energy neutral beam. The warm ions fill the hole in the loss-cone of the hot ions and thereby provide microstability of the central cell plasma. The non-uniform axial density profile of the hot ions also causes a non-uniform neutron source. Test modules located near the density peaks have a higher neutron wall loading.

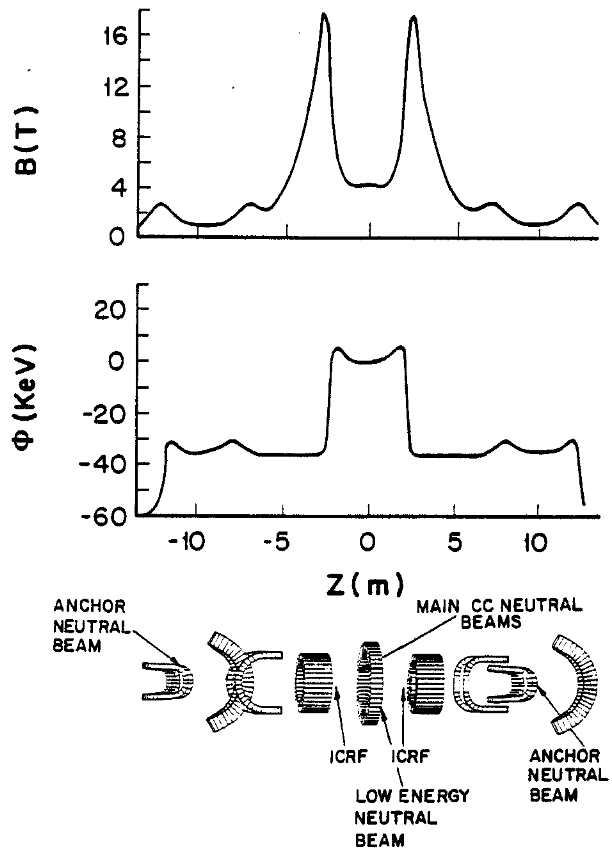

Fig. 1. Magnetic field and electrostatic potential configuration of TASKA-M.

In order to provide a sufficiently deep electrostatic well and to minimize the effect of electron drag on the hot ions, the electrons are heated by Landau damping on ion cyclotron waves. These waves are generated by antennae in the central cell. This system utilizes RF power in the ion cyclotron range and avoids the very high frequency (> 84 GHz) associated with ECRH in the central cell. An alternative approach would be to use fundamental electron cyclotron heating in the lower density magnetic field transition region.

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The yin-yang end cells have the sole purpose of providing MHD stability for the entire plasma, and consequently they are called "anchors." Unlike a usual tandem mirror, they do not provide any plugging of the axial loss from the central cell. The anchor plasma is also sustained by energetic neutral beams injected at an angle to produce a sloshing-ion plasma. Trapping of warm plasma in the resulting electrostatic well provides microstability for the anchor plasma.

It should be noted that the TASKA-M configuration does not contain a thermal barrier. The reason for this is two-fold. First, a thermal barrier has not yet been produced and it was our desire to keep the physics as simple as possible and to minimize the extrapolation from the present physics data base. Second, neutral beam pumping of the thermal barrier in TASKA [4] presented considerable complications and expense. Recently, ideas concerning drift pumping [6] of thermal barriers have emerged. These ideas, however, are unproven and would, therefore, be inconsistent with our physics philosophy.

An overall schematic of TASKA-M is shown in Fig. 2. The basic machine parameters of TASKA-M are given in Table I, the physics parameters in Table II, and the heating parameters in Table III. It should be noted that the fusion power is very low -- only 6.8 MW. The total injected power is 44 MW, of which 35 MW are absorbed. The Q (fusion power/absorbed power) is low, but this is not a design consideration. The axial variation of the neutron wall loading, assuming the separation between the hot plasma and the wall is two alpha particle gyroradii, is shown in Fig. 3. The peaks of the wall loading occur under the materials test module and the liquid metal blanket test module.

The magnetic set consists of 3 superconducting (S/C) 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, as shown in Fig. 1. All of the superconducting coils in TASKA-M are either state-of-the-art today (e.g., the yin-yang coils are of the same size and field strength as the MFTF-B coils already constructed) or should be state-of-the-art by the 1985-1990 period. The S/C solenoid coils are roughly the same size as the LCP coils where Nb_3Sn technology will also be proven by the Westinghouse coil [7].

Table I. TASKA-M Machine Parameters

Neutron Wall Loading	
Central cell midplane	0.7 MW/m^2
Central cell maximum	1.3 MW/m^2
Fusion Power	6.8 MW
Magnetic Fields	
Central cell - midplane	4.2 T
Central cell - maximum	17.5 T
Transition region - minimum	2.2 T
Anchor - midplane	1.0 T
Anchor - maximum	2.7 T
Central Cell Dimensions	
Length (peak B to peak B)	5.5 m
Plasma length (peak n to peak n)	3.4 m
Wall radius - midplane	0.25 m
Anchor Dimensions	
Length (peak B to peak B)	5.4 m
Wall radius - midplane	0.37 m

Table II. TASKA-M Plasma Parameters*

Central Cell	
On-axis β	0.50
Radially-averaged β	0.30
Electron temperature	14 keV
Hot ion density	3.3×10^{14} cm^{-3}
Hot ion sloshing density ratio	1.59
Mean hot ion energy	84 keV
$(n\tau)_{Hc}$	1.0×10^{13} sec/cm^3
Warm ion density	3.0×10^{13} cm^{-3}
Mean warm ion energy	5.8 keV
Potential (to ground)	59 kV
Warm ion confining potential	5.3 kV
Plasma radius	12 cm
Anchor	
On-axis β	0.50
Radially-averaged β	0.30
Hot ion density	2.6×10^{13} cm^{-3}
Hot ion sloshing density ratio	1.4
Mean hot ion energy	60 keV
$(n\tau)_{HA}$	3.0×10^{12} cm^{-3}
Warm density	2.6×10^{12} cm^{-3}
Mean warm ion energy	6.6 keV
Potential (to ground)	24 keV
Warm ion confining potential	3.4 keV

*spatially dependent parameters are given on-axis at the midplane.

Table III. TASKA-M Neutral Beam and RF Heating Parameters

Central Cell	
High Energy Neutral Beams	
Primary injection energy	90 keV
Total injected power	21 MW
Injection angle	45°
Species	0.5 D/0.5 T
Trapping fraction	0.92
Number of beam lines	4
Low Energy Neutral Beam	
Primary injection energy	12 keV
Total injected power	0.6 MW
Injection angle	70°
Species	D
Trapping fraction	1
Number of beam lines	1
Anchor	
High Energy Neutral Beams	
Primary injection energy	73 keV
Total injected power/anchor	3.5 MW
Injection angle	50°
Species	D
Trapping Fraction	0.37
Number of beam lines/anchor	1
RF Heating	
Absorbed power	12 MW
Frequency	25 MHz

Plasma Parametric Studies

The basic plasma performance of TASKA-M was calculated using a global power and particle balance code, which considers the various species -- hot ions, warm

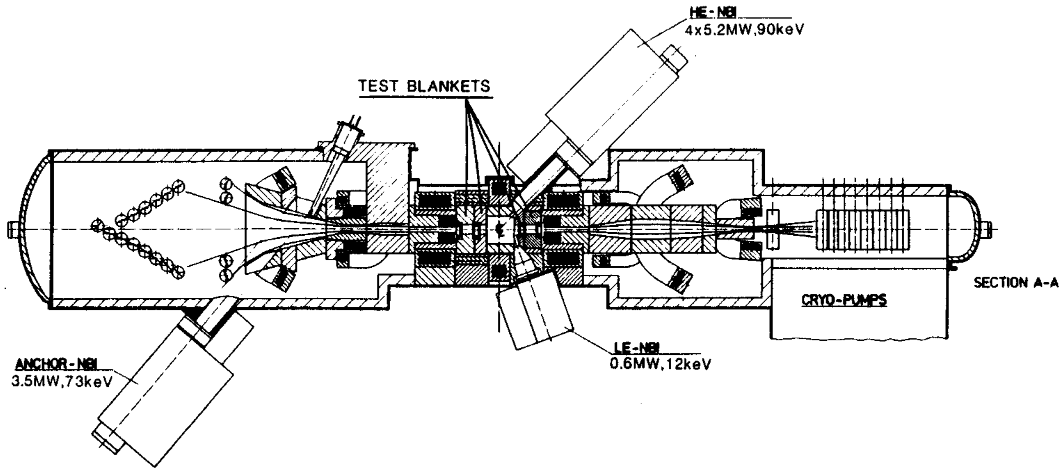

Fig. 2. Schematic of TASKA-M technology test facility.

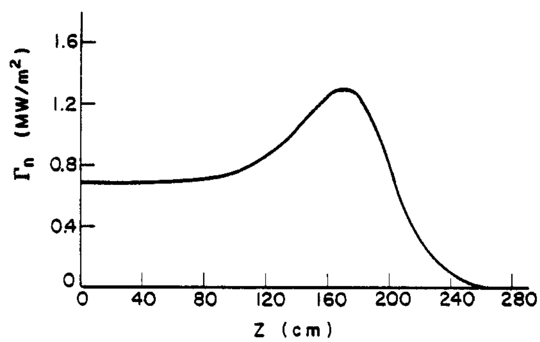

Fig. 3. Axial variation of the neutron wall loading.

ions, and electrons in each cell. The code was used to perform parametric studies in an attempt to consider various trade-offs between performance and cost. Shown in Fig. 4 is the increase in the required neutral beam power and electron heating power as the neutron wall loading is increased. In this variation, the plasma beta and magnetic fields are kept constant; higher wall loading is obtained by increasing the plasma radius. Raising the wall loading substantially above the design value requires a considerable increase in power. The present TASKA-M configuration does not have space for an increase in the high energy neutral beam power; this is one of the limiting factors in TASKA-M. Figure 5 shows the effect of the central cell beta on the required neutral beam and electron heating power. Improvements in beta sharply reduce the neutral beam power; correspondingly, one could obtain a higher wall loading at the same neutral beam power if beta were increased. In order to maintain sufficient MHD stability margin, the volume-averaged beta was limited to 30%, however.

MHD Stability

MHD stability was analyzed using the interchange stability criterion. The curvature of the magnetic field was calculated using the vacuum fields; finite beta effects and ballooning mode stability were not calculated, but were allowed for by not encroaching too close to the interchange stability criterion boundary.

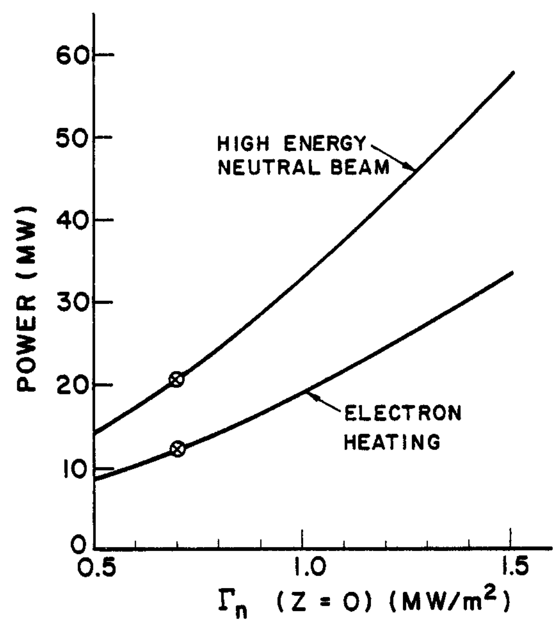

Fig. 4. Variation of the neutral beam and electron heating power with neutron wall loading.

The stability boundary is shown in Fig. 6 in terms of the on-axis central cell, anchor, and transition region beta. The TASKA-M design point is considered to be reasonably prudent with respect to interchange stability.

Sloshing Ion Distribution

The sloshing ion plasma in the central cell and in the anchors is maintained by injecting the main neutral beams at an angle to the magnetic field. The resulting density profile peaks off the midplane and produces an electrostatic well which traps warm plasma. The density dip is maintained by charge exchange between ions with pitch angle ≈ 90° and neutral atoms in the beam.

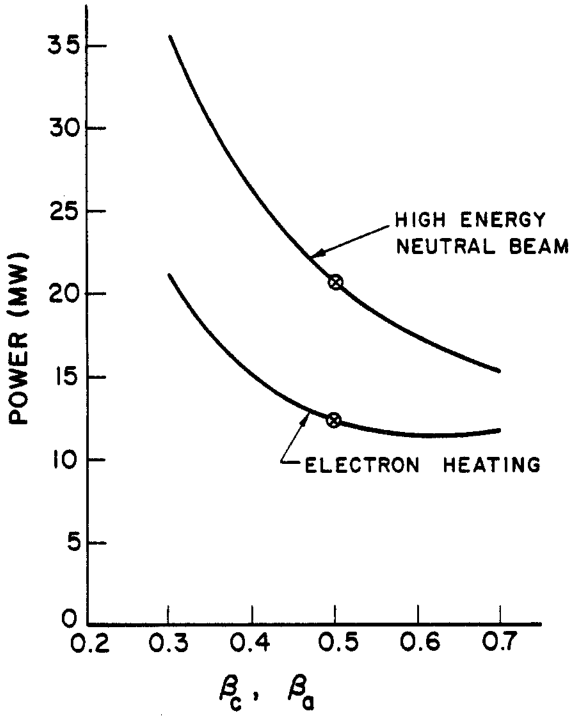

Fig. 5. Variation of the neutral beam and electron heating power with on-axis beta ($\beta_a = \beta_c$).

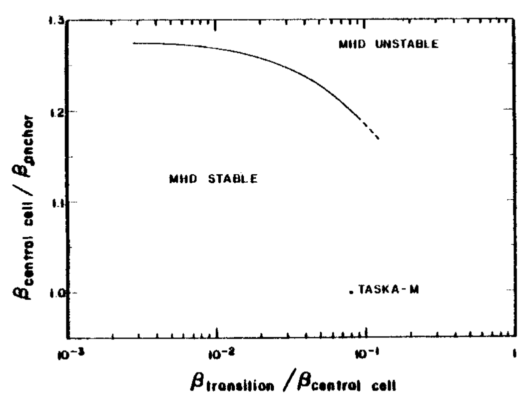

Fig. 6. MHD interchange stability limit.

The neutral beam, since it is injected at the midplane, "charge exchange pumps" the midplane density as well as sustaining the sloshing density. Figure 7 shows the sloshing ion distribution function at the central cell midplane.

Microstability

Microstability has been historically the Achilles' heel of mirror-confined plasmas. The approach used in TASKA-M to obtain microstability is the use of a sloshing ion distribution and electrostatic potential well which contains warm plasma created by injection of a

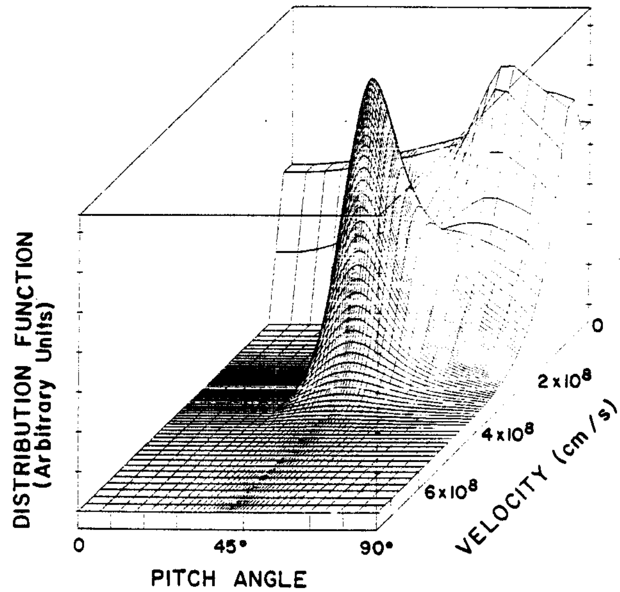

Fig. 7. Ion distribution function showing the hot ion and warm ion components.

low energy neutral beam. The warm plasma density is about 10% of the hot-ion density. According to theoretical calculations, this should be adequate to suppress the drift-cyclotron loss-cone mode, at least between the two peaks of the sloshing-ion density profile. The Alfvén ion-cyclotron mode is also suppressed because of the increased $p_{\parallel}/p_{\perp}$ associated wth the sloshing distribution. TMX-Upgrade [8] has operated with sloshing-ion plugs and achieved a very low level of fluctuations due to microinstabilities. The uncertainty in microstability occurs in the region between the density peaks and the mirror throats. In this region, the loss-cone is essentially empty. Stability depends on the shortness of this region compared with the localization length of possible modes. This question requires further investigation.

Trapped Particle Stability

A recent theoretical development in tandem mirror physics is the trapped particle instability, which is associated with particles trapped in regions of bad magnetic curvature. This instability is stabilized by maintaining a sufficient fraction of particles which pass between regions of good and bad magnetic curvature. In TASKA-M the anchor plasma density is maintained at a level to satisfy this criterion for low azimuthal mode numbers. There is a possibility of the plasma being unstable at an azimuthal mode number of 4 or 5, but this can be cured by appropriate control of the electrostatic potential at the end plasma dumps. This instability has not yet been investigated experimentally; the TARA [9] experiment should provide a good test.

Conclusions

The preliminary design of TASKA-M shows that an attractive tandem mirror test facility can be designed with a low fusion power and total cost. The plasma physics of this device represents a minimal extrapolation from the present experimental data base. There are unresolved questions concerning microstability and trapped particle stability, but the TMX-Upgrade experiment, which is in operation, and MFTF-B and TARA, which are under construction, should provide resolution of these questions and thereby a basis on which to proceed with a TASKA-M type test facility in the early 1990's.

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