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MASTER

THE LONG PULSE TECHNOLOGY TOKAMAK*

THE LPTT GROUP

Presented by

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ABSTRACT

The LPTT tokamak is a non-circular tokamak (R = 1.5 m, a = .45 m) proposed by ORNL for extended pulse operation at high β (5%) and reactor level wall power loading (40 w/cm^2). The toroidal field coils are superconducting and a superconducting bundle divertor is proposed for active impurity control. All systems are designed for continuous operation which will provide pulse lengths > 20 seconds with a 6 — 10 weber flux swing. Experimental access and flexibility in operation are primary design goals.

Conceptual design studies are underway at Oak Ridge National Laboratory in preparation for a proposal for the Long Pulse Technology Tokamak (LPTT). LPTT is intended to complement present research toward a fusion reactor by providing an experimental basis for some areas of general relevance to magnetic fusion and some areas specifically related to tokamaks. Three general experimental goals have been formulated.

The first is to develop and demonstrate the capability to run a tokamak for long pulses at reactor level thermal wall loadings while maintaining clean plasma conditions ($Z_{eff} \lesssim 2$). Fusion reactor studies[1,2] have given typical reactor start up times as 1 to 10 seconds and burn times of 10 to 1000 seconds. Long pulse operation will be defined as pulses $\gtrsim$ 20 seconds. Hydrogen plasmas will be used. Neutron damage results must be obtained elsewhere. To obtain reactor level wall loadings of 40 w/cm^2 supplemental heating will be used. For these pulse lengths and wall loadings, active density and impurity control seem essential to maintain the density, remove wall generated impurities, and demonstrate removal of helium introduced into the discharge.

The second experimental goal is to demonstrate the ability to run a tokamak for long pulses at high β ($\sim$ 5%). Low toroidal fields will be used since high β is easier to obtain at low field. Recent results from ISX[3] and DITE[4] give confidence that confinement will be adequate at low toroidal field. Extrapolating from the ISX energy confinement time of 30 ms at β = 12 kG and a = 26 cm, LPTT with β = 15 kG, a $\gtrsim$ 40 cm and b/a $\lesssim$ 1.6 should provide $\tau_E \sim$ 60 – 100 ms.

The third experimental goal is to develop reactor relevant components and techniques in collaboration with plasma technology development groups and industry. LPTT will develop and test first wall materials, divertors, divertor targets and pumping, heating, and fueling systems. These systems and components must be reliable and easy to maintain, particularly in a remotely handleable environment. The entire tokamak system must be integrated within the constraints of the superconducting toroidal field system, including the ability to minimize the effects of disruptions. Also methods to extend the pulse length beyond the limits of the core flux swing will be tested.

To meet these goals LPTT will provide a pulse length $\gtrsim$ 20 seconds with enough neutral injection heating to provide a wall loading of 40 Wcm^{-2}. It will be large enough to include a hot central region with radius $\gtrsim$ 30 cm with a $\gtrsim$ 10 cm edge region. In the present design, bundle divertors are proposed to control plasma density and impurities. The central toroidal field will be 15 kG. Good access and experimental flexibility will be provided for divertor and component development. Superconducting TF coils and steady state capability for the poloidal and divertor systems ensure that the core flux will be the only pulse length limitation.

LPTT will be as small as possible consistent with physics and technological constraints. A smaller device will cost less and can produce results more quickly. It is felt that the key physics and technological goals will not be prejudiced by going to a smaller device.

Several design concepts have been analyzed for LPTT. The present concept is summarized in Table 1. Two views of LPTT are shown in Figures 1 and 2. The small number of toroidal field coils is a consequence of the desire to maximize access to the plasma and internal components. The non-circular plasma should provide higher stable β limits and better use of the low ripple volume of the toroidal field coils.

LPTT should provide quite impressive plasma parameters. With $I_p = 0.4$ MA and $B_{TF} = 15$ kG and with 5 MW of neutral injection, $\langle n\rangle_v = 4.5 \times 10^{13}$, $T_e(0) =$

2.5 keV, $T_i(0) = 2.5$ keV, $\tau_E = 62$ ms and $\langle\beta\rangle \simeq 2.7\%$ assuming "Alcator scaling" for the electrons and "spoiled neoclassical" scaling (PDX) for the ions. With 12 MW of neutral injection, $\langle n\rangle_v = 4.5 \times 10^{13}$, $T_e(0) = 3.7$ keV, $T_i(0) = 3.9$ keV, and $\langle\beta\rangle \simeq 5\%$. Even with $Z_{eff} = 2$, the loop voltage will be 0.2 volts which implies only 5 of the 6 to 10 weber flux swing will be used for a 20 second pulse.

The superconducting bundle divertors will be arranged to provide zero net force on the central limbs of the divertor.[5] The chosen layout also minimizes the current density for configurations having ∿ 10 cm between the coils and the plasma. It appears possible to fit superconducting bundle divertors working with an average current density ∿ 3 kA cm^{-2} and a maximum field at the coil $\lesssim$ 50 kG for a central TF field of 15 kG.

The poloidal field system is designed for long pulses and minimum changing fields on the TF coils. The required flux swing is 6 – 10 webers. The poloidal coils will be internal to the toroidal coils to minimize the changing magnetic fields at the superconductor. Eddy current shielding will further reduce the changing fields at the superconductor. The initial LPTT concepts used an iron core to minimize the changing fields. The present small size and long pulse length appear incompatible with an iron core. In the present design an air core with an "inverted conducting shell" is being evaluated. The plasma is on the inside surrounded by the poloidal field coils which in turn are surrounded by a conducting shell with a time constant ∿ 0.1 second. The plasma breakdown and current rise utilize the rapidly changing flux between the poloidal coils and the shell. The flat top voltage and any slow plasma current rise utilize the slowly varying flux outside the shell. This concept produces $B \approx 1 - 2$ T/sec at the superconducting coils. Such changing fields can be tolerated only because of the low toroidal field.

In summary, the LPTT device will provide excellent opportunities for investigating key issues both of general and of tokamak specific relevance for fusion reactors. Reactor relevant pulse lengths and thermal wall loading will be provided. LPTT will provide a test bed for first-walls, divertor targets and pumping systems. Reactor relevant heating and fueling techniques will be tried. Tokamak systems integration with superconducting coils will be demonstrated. LPTT will pursue a collaborative type of program with other fusion laboratories and industry. Finally, LPTT will act as a focal point for technology development at ORNL.

TABLE I

LPTT DESIGN PARAMETERS

Number of coils	9
Toroidal field kG	~ 15
R cm	150
a cm	45
b/a	$\lesssim 1.6$
CURRENT MA	~ 0.4
Volt seconds	6 → 10
No. of divertors	3
Additional power MW	→ 12

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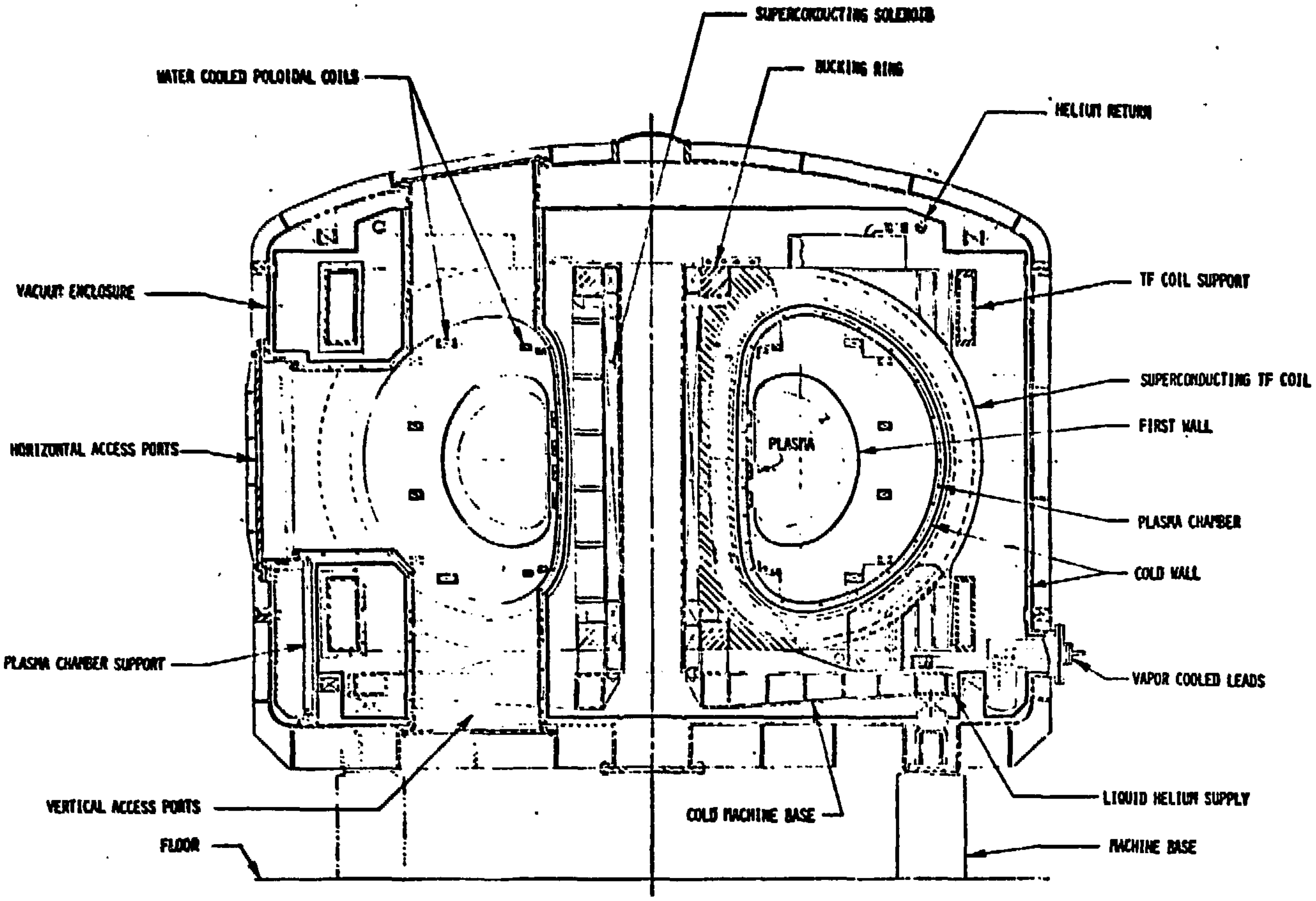

FIG. 1 LPTT elevation view

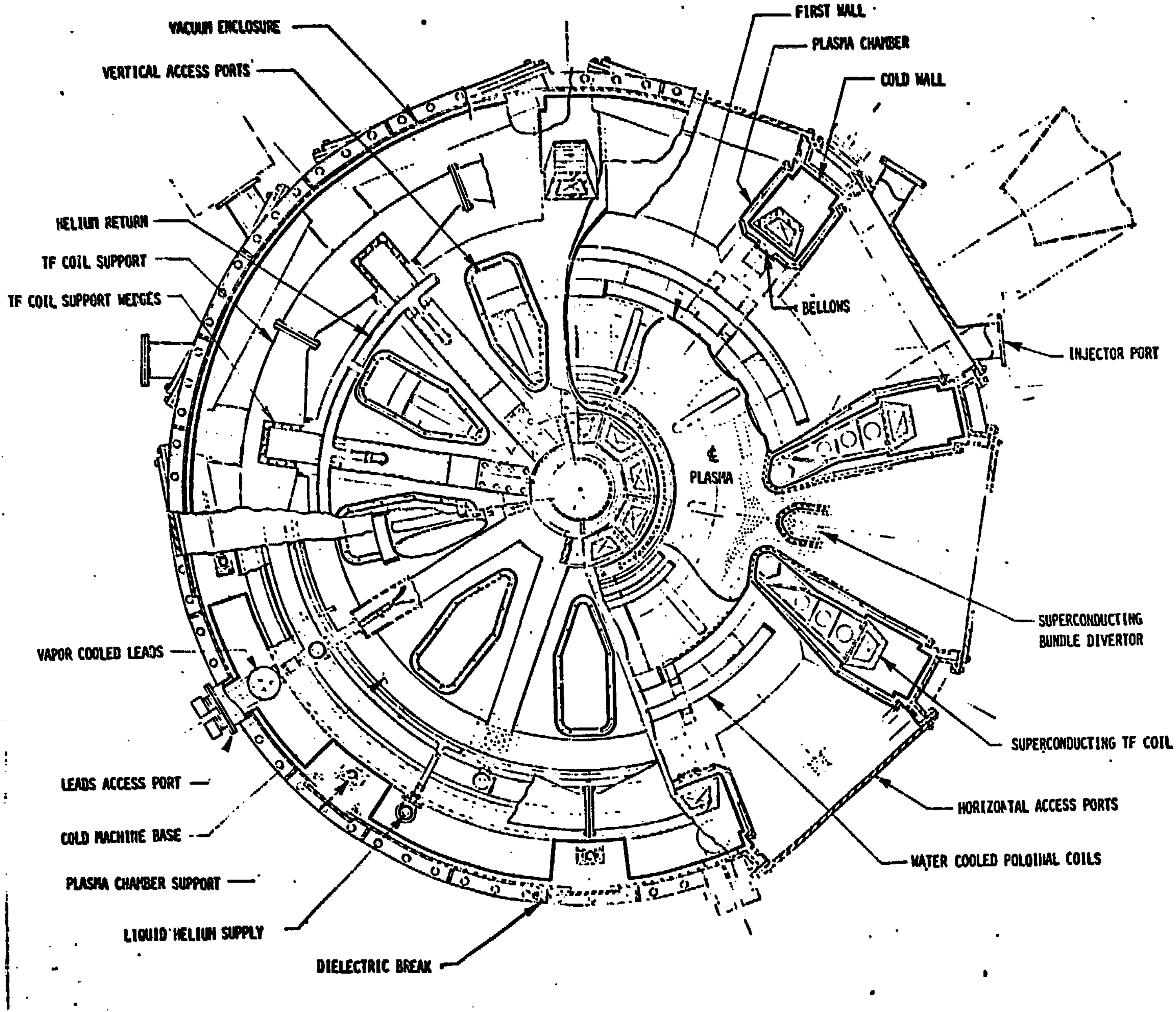

FIG. 2 LPTT plan view