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TITLE: THE PROPOSED FRX-D EXPERIMENT

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THE PROPOSED FRX-D EXPERIMENT

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I. Introduction: The field-reversed-configuration (FRC) research program is poised for a significant step forward. Resolution of the critical FRC physics issues, which must now be addressed in order to advance the development of this concept, requires experimental studies in a plasma regime closer to reactor relevance than is possible with existing devices. The purpose of FRX-D[1,2] is to extrapolate the parameters of FRC's into the required regime of large plasma size relative to an ion gyroradius i.e., large $\bar{s}$. The critical issues that FRX-D will address are: 1) The FRC stability and confinement properties at large $\bar{s}$; 2) The demonstration of adiabatic compression as an efficient, technologically attractive FRC heating method; 3) The identification of the dominant electron energy-loss mechanism, and; 4) The determination of the dependence of poloidal flux loss on electron temperature. An additional, more technologically oriented purpose of FRX-D is to demonstrate the separation of FRC formation and heating functions using the reactor-like technique of sequential formation/translation/compression. A sketch of the FRX-D facility is shown in Fig. 1.

II. The $\bar{s}$ Parameter and Its Relation to Stability and Confinement: From experimental and theoretical studies,[3] $\bar{s}$ has emerged as an important parameter that characterizes the kinetic effects in an FRC and the impact of these effects on both stability and transport. The parameter, $\bar{s}$, which approximates the number of "local" ion gyroradii between the magnetic axis at $r = R$ and the separatrix at $r = r_s$ is defined as, $\bar{s} = \int r dr / r_s \rho_i$, where ρ_i is the local value of ion gyroradius.

In present experiments where $\bar{s} < 2$, the observed stability against the MHD-predicted tilt mode has been shown, by a recently-developed kinetic stability analysis,[4] to be associated with the large ion orbits characteristic of these plasmas. As $\bar{s}$ increases this stabilizing effect diminishes. Thus the tilt-mode growth rate from the kinetic analysis, normalized to the MHD growth rate, increases with $\bar{s}$ as shown in Fig. 2. According to this theory, the mode has not been detected experimentally simply because the finite duration of experiments is too short for the mode to develop. However, in FRX-D where $\bar{s}$ values between 4 and 7 are projected, the critical issue of FRC stability in a more MHD-like regime can be addressed. Transport models[3] that use a lower-hybrid-drift (LHD) resistivity predict a substantial enhancement of the FRC particle confinement properties with increasing $\bar{s}$, as demonstrated in Fig. 3. These models have been moderately successful in predicting particle transport losses in present small-$\bar{s}$ plasmas. The experimental investigation of confinement with larger $\bar{s}$ is essential for further development of the FRC concept.

III. Energy and Magnetic Flux Losses: In all FRC experiments T_e is observed to have relatively low values[5] (100 - 200 eV), nearly independent of T_i. This result, together with measurements showing negligible radiation losses,[6] suggest that electron thermal conduction is a significant energy-loss mechanism. Internal poloidal flux loss is thought to occur at the field null by resistive annihilation. However, no annihilation process has been identified that explains the experimentally inferred values[7] of the flux decay time τ_ϕ. Empirical scaling laws[7] for τ_ϕ show an R^2 dependence but only a weak dependence on T_e. In FRX-D the primary heating mechanism will be adiabatic compression. Because this method allows controlled heating of the electrons to higher temperatures than presently obtainable, it will permit for the first time in-depth studies of the electron loss channel and a determination of flux-loss scaling with T_e.

IV. <u>The FRX-D Facility</u>: In the FRX-D experiment, shown in Fig. 1, the FRC formation, heating, and final confinement functions are accomplished using three independent coil regions and the demonstrated technique of plasma translation.[8] The FRC is formed in a 1.3-m diameter, four-fed theta-pinch coil, using high-voltage to insure adequate flux trapping. The formation-bank energy (~ 1 MJ) and the peak-formation magnetic field (~ 4 kG) can be kept small because after formation the FRC is translated and heated by adiabatic compression. Heating is accomplished using a low-voltage (10-kV), ignition-switched capacitor bank. Translation improves the efficiency of adiabatic compression because the bias field and compression-coil dimensions are chosen so that the FRC nearly fills the entire coil before compression. After heating the FRC is translated into the confinement region which consists of a dc solenoid surrounding a metal vacuum chamber. This final translation also permits an increase of the FRC x_s (separatrix radius/coil radius, r_s/r_w) and consequently an increase in the confined plasma $\bar{s}$.

Projected parameters for the three-stage FRX-D experiment are given in TABLE I, where ℓ_s is the separatrix length, n_M is the density at the field null, and E_p is the plasma energy. The fully formed FRC source-plasma parameters are estimated using Steinhauer's formation model,[9] and the plasma

TABLE I: REPRESENTATIVE FRX-D PARAMETERS

	Formation	Compression	Confinement
r_w (cm)	64	37	17.5
x_s	0.55	$0.8 \rightarrow 0.52$	0.8
ℓ_s (m)	2.6	$5.7 \rightarrow 1.9$	4.2
$n_M (10^{15} cm^{-3})$	1.0	$0.8 \rightarrow 4.7$	5.0
$T_e = T_i$ (eV)	188	$150 \rightarrow 521$	500
B (kG)	4.0	$3.2 \rightarrow 14.1$	14.1
$\bar{s}$	4.2	$5.6 \rightarrow 4.6$	6.5
E_p (kJ)	80	$64 \rightarrow 221$	212
λ_{ii}/r_s	1.7	$2.0 \rightarrow 5.2$	7.9

parameters of the three stages are related by the FRC adiabatic laws.[10] In all stages the FRC is maintained in a relevant regime of collisionality (ion mean free path/separatrix radius, $\lambda_{ii}/r_s > 1$). The design point represented by TABLE I is a minor revision of previous parameters[1,2] that takes into account the temperature drop[11] required when translating into the compression coil and confinement chamber. Finite losses that result from transport during the three-stage translation and compression have also been considered. Particle diffusion based on the LHD model, classical-like flux dissipation that scales as $T_e^{3/2}$, and electron thermal conductivity based on the LHD model would not appreciably alter the values in TABLE I. However, other assumptions, such as the empirical scaling for flux loss[7], or the micro-tearing model[12] for electron thermal conductivity would result in measurable departures from these values. Based on present understanding, the energy containment time, τ_E, of the FRC in the confinement region would be on the order of several hundred microseconds with an $n\tau_E$ greater than 1×10^{12} $cm^{-3}s$.

In summary, the proposed FRX-D experiment represents a flexible facility for continued exploration of the FRC concept. The parameter variations achieved by the combination of translation and compression will allow study of the critical FRC issues.

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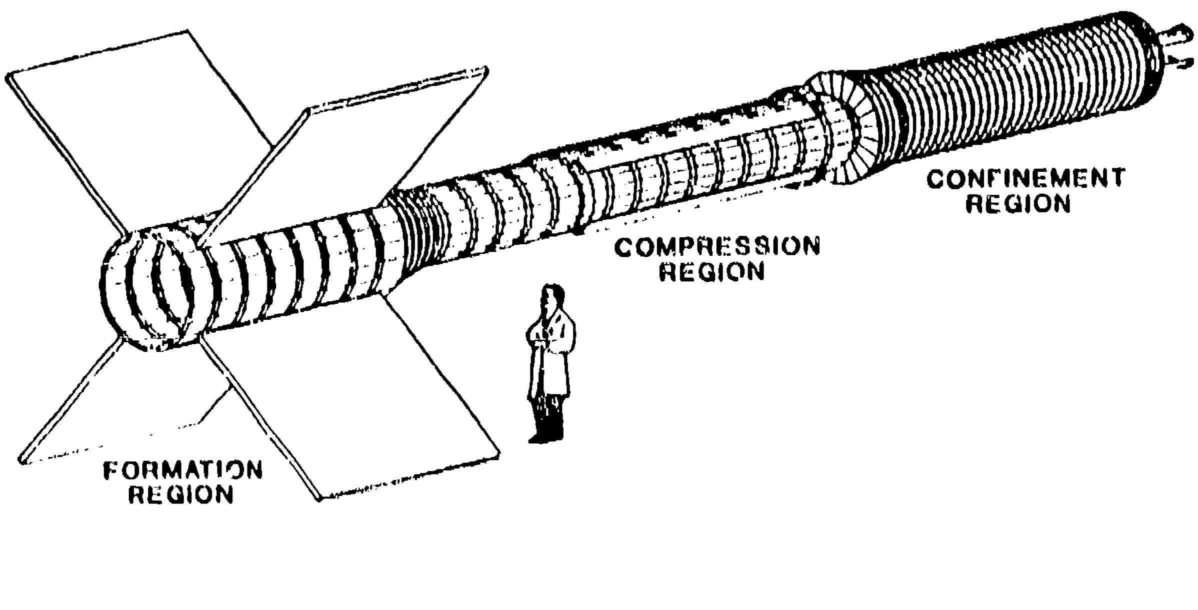

Figure 1. Coil system of the proposed FRX-D experiment.

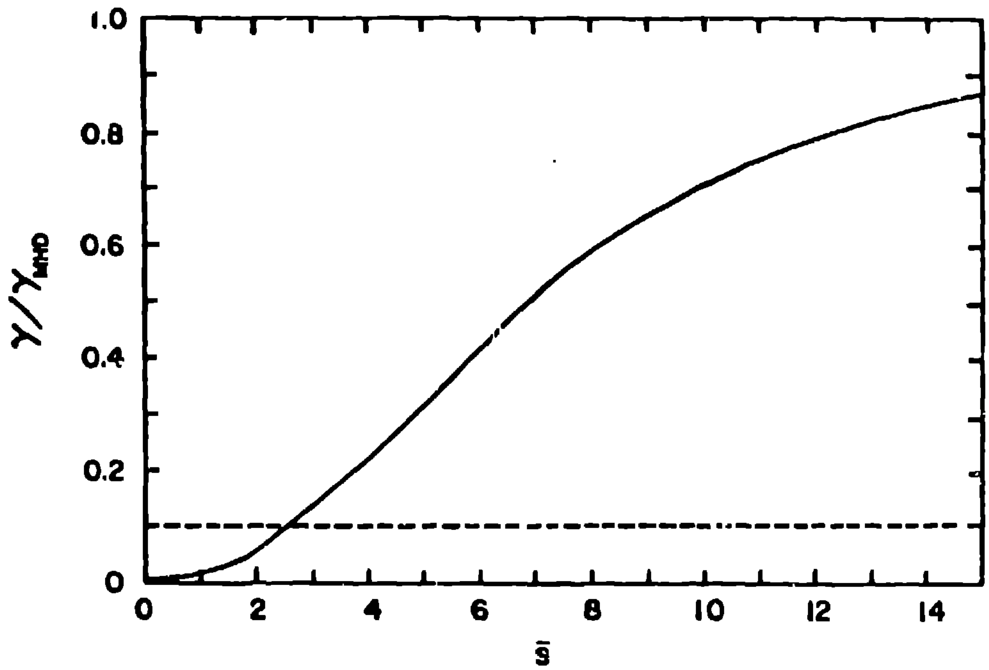

Figure 2. Growth rate of the internal tilt mode, normalized to the MHD growth rate, vs. $\bar{s}$. The dashed line is the approximate threshold for the mode to be observable.

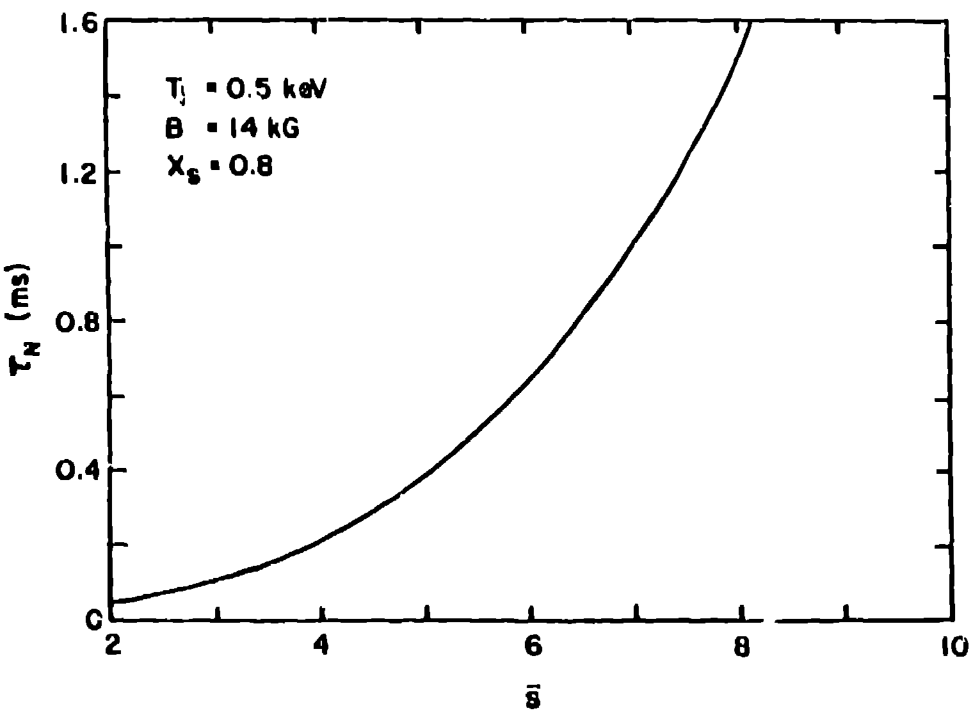

Figure 3. Particle containment time vs. $\bar{s}$ predicted from transport model[3] that uses lower-hybrid-drift resistivity.