PPPL--2860

DE93 002631

Summary of the Third Workshop on Alpha Particle Physics in TFTR

D. Sigmar*, K.M. Young, and S.J. Zweben

Abstract

This report summarizes the experimental, theoretical, and diagnostic talks presented at the Third Workshop on Alpha Particle Physics in TFTR, which was held at MIT May 28-29,1992.

* Plasma Fusion Center, MIT

1. Experimental Results and Plans

Two related topics were covered in the experimental session: alpha particle simulation experiments using existing DD plasmas (5 talks), and plans for the actual DT alpha particle experiments presently scheduled to start in 1993 (8 talks) .

I. Plans for the DT alpha experiments

K. McGuire from PPPL started the workshop with an overview of the TFTR DT plan. The physics goals of the DT run are: (1) to study the effects of collective alpha instabilities on alpha particle and plasma confinement, and (2) to study the heating and confinement properties of DT plasmas. The technological goals are: (1) a DT fusion power demonstration ($\approx$5-10 MW of fusion power), and (2) tests of various tritium-related hardware capabilities, e.g., tritium handling, diagnostics in a neutron environment and operation of an activated machine.

The DT run is presently scheduled to cover about 75 weeks, from 1993 to 1994, with an eight week maintenance period after the first 12 weeks of DT operation. This allows a total of $\approx$1000 DT shots, given the constraints of on-site tritium inventory (5 g.) and neutron production (10^{21} neutrons/calendar year). There can be about eight full-power DT shots per week (constrained by the tritium delivery system), but a larger number of DD set-up and comparison shots.

There are now three TFTR task forces which will continue through the DT run: Fusion Power (Strachan), DT Technology (Owens), and Transport and Advanced Tokamak Physics (Zarnstorff), with the leaders as indicated. The goals of these task forces for the 1992 DD run are to develop operating regimes for the highest Q_{DT} and β_{α}, develop and test actual run sequences for DT, and to continue studies in support of advanced tokamak physics and ITER. Each task force will develop specific experimental proposals for the DT run (DTXP's), and practice and debug them during the 1992 DD run. As usual, many collaborations with outside institutions are involved in this process., e.g., Columbia, MIT, Wisconsin, and various US and foreign national labs.

The next TFTR DT workshop in this series will be held at or near PPPL just before the Transport Task Force Meeting in February 1993. By then there should be a specific set of DTXP's for discussion and review.

J. Strachan from PPPL described the present status and plans for the Fusion Power Task Force. Their main goal is to provide the maximum possible DT fusion power from several TFTR operational regimes. The main activity has so far been to develop rough drafts of DTXP's. Several of these were outlined at the meeting:

"Trace Tritium Experiment to Determine DT Fusion Power" -- Jassby
"Fusion Power Production from Supershots" -- Strachan
"Heating of DT Supershots with ^{3}He Minority ICRF" -- Taylor
"Stabilization of (3,2) MHD Using ICRF" -- Fredrickson
"Tritium Pellet Fueled RF and NB Plasmas" -- Schmidt

Since it has been observed empirically that the maximum projected β_α is correlated with the maximum fusion power (i.e,. since the fusion power determines the alpha production rate, and the alpha slowing down time is roughly constant), the success of these DTXP's will provide a good opportunity to study alpha particle effects.

S. Zweben from PPPL reviewed three specific DTXP's concerning alpha particle confinement and loss in TFTR. These are being developed within the DT Technology task force, which will cover alpha diagnostics and some of the alpha physics.

The first proposed DTXP is a plasma current scan which aims to test the classical confinement models for actual alpha particles in DT. Previous experiments in DD with alpha-like 3 MeV protons have shown that their loss to the vessel bottom follows the first-orbit model, and their loss to the midplane is dominated by stochastic TF ripple loss, as expected. This DTXP will scan over 0.5-2.5 MA at moderate NBI power to avoid exciting background plasma MHD activity.

The second proposed DTXP concerns the effects of MHD activity, both plasma and alpha-driven, which can be examined using NBI powei scans at fixed current at full toroidal field. DD experiments have shown that large MHD activity often occurs at >25 MW at 1.8 MA, usually causing a severe MHD-induced loss of 3 MeV protons. In order to study collective alpha effects, regimes need to be identified which have high β_α without background plasma MHD activity.

The third proposed DTXP concerns the interaction between ICRH and alphas. Previous experiments with both H and ^3He minority heating have shown a large loss of MeV ions to the region ≤45º below the outer midplane, probably due to minority tail ions. However, there may also be a deconfinement of alphas due to ICRH which should be examined during DT. Effects of ICRH on the stability of the alpha distribution function (e.g., by a minority tail) should also be examined.

R. Budny from PPPL outlined the results of recent TRANSP simulations of the expected alpha behavior in TFTR DT discharges. Several new supershots were modeled (other than #55851, which was used in the Nucl. Fusion '91 paper). For three R=2.45 m shots (#55848, #51550, and #51553) the calculated alpha parameters were close to that for #55851, e.g., $\beta_\alpha(0)$ = 0.25%, 0.32%, and 0.25%, respectively. For a R=2.6 m supershot (#61862) and a high β_{pol} current ramp-down case (#55884) the result was $\beta_\alpha(0)$ = 0.11%. The effect of ICH added to #55851 was to increase the central electron temperature and the $\beta_\alpha(0)$ to ≥ 0.4%, but the Q_{DT} did not increase.

The alpha particle distribution functions in energy and μ vs time were obtained from a TRANSP run. Energy distributions near the plasma center were shown to be inverted up to about 0.5 sec after the start on NBI, with a pronounced hollowness of the pitch angle distribution near $v_{||}/v_\perp \approx -0.3$ (probably due to first-orbit loss).

The effect of alpha particle heating on electrons was simulated by assuming χ_e was the same as in the DD discharge. Near the end of NBI the central electron temperature increased from about 10 KeV to 11 KeV due to the effects of alpha heating. About 0.1 sec after NBI turn-off the central electron temperature was about 8 KeV with alpha heating and 7 KeV without, leading to a relatively larger difference effect than during the steady-state.

D. Mikkelsen from PPPL discussed a hot tritium target scenario designed to create a large alpha population with an inverted energy distribution function. In this scenario ICRH is used to heat a tritium-pellet-fueled discharge prior to NBI, so the initial alpha creation rate is increased due to the higher initial electron density. The injection of pure D beams into a pure T target plasma is also used in order to maximize the initial DT reaction rate.

Numerical simulations for the plasma and alpha parameters vs time were presented and compared to those for a standard DT supershot. The central DT reaction rate in the new scenario increases within 0.1 sec to $>10^{12}/m^3$, compared to a slower increase over 0.5 sec to $<10^{12}/m^3$ for the standard supershot, while after 0.5 sec the central fast alpha beta reaches 0.8% in the new scenario, compared with 0.3% in the standard supershot. The alpha particle distribution function remains inverted above 1 MeV for about 0.4 sec in both scenarios, but the central alpha density at 0.4 sec is about four times larger in the new scenario.

These results open up new possibilities for collective alpha experiments which can make use of these, (presumably), more unstable inverted alpha distribution functions. Plans are being made to develop a DTXP based on this scenario and to test it with DD during the 1992 run. Theoretical candidates for alpha instabilities in this scenario are needed to help define this DTXP.

II. DD Alpha Particle Simulation Experiments

K.-L. Wong from PPPL described recent toroidal Alfvén eigenmode (TAE) experiments using lithium pellet injection during NBI on TFTR. With Li pellet injection during NBI (B=15 kG, I=630 kA, P=15 MW) the line averaged density increased from 4.5×10^{13} cm^{-3} before to $>8 \times 10^{13}$ cm^{-3} at 20 msec after pellet injection, and then decreased back to the pre-pellet density over ≈ 0.2 sec. The Mirnov fluctuation spectrum showed a distinct peak at ≈ 90 kHz at 40-50 msec after pellet injection, the frequency of which increased to ≈ 110 kHz at 100-110 msec after pellet injection and to ≈ 120-130 kHz at 160-170 msec after pellet injection. The appearance of this TAE feature during the pellet-induced increase in V_b/V_A (and its increase in frequency with reduced density) are qualitatively consistent with TAE theory; further comparisons between this experiment and theory are planned. Bursts of RF probe emission (5-50 MHz) were also observed to be correlated with TAE fluctuations.

Fu's recent theoretical analysis implies that finite orbit effects increase the TAE growth rate for $V_b/V_A<1$. Evidence for this behavior was observed in TFTR, in that when B was fixed at 15 kG with 10 MW of NBI, the TAE feature appeared at I=420 kA and not at 504 kA or 630 kA, in qualitative agreement with the theory.

For the DT experiment (e.g,. shot #55851) the ion Landau damping at the center should be about three times larger than the collisional damping, but for modes with amplitudes peaked at $r/a>0.2$ the ion beta becomes low enough so that collisional damping is larger than Landau damping. It seems difficult to excite TAE modes at the projected levels of $\beta_{\alpha}(0)\approx0.3\%$ and $<\beta_{\alpha}>\approx0.04\%$, although higher I will tend to help the excitation through the finite orbit effect (at $V_b/V_A>1$). Continuum damping can be varied by ramping the plasma current up or down, possibly causing the TAE to come and go.

D. Darrow from PPPL discussed MHD-induced beam ion loss measurements made in TFTR using the midplane scintillator probe. Beam ion losses were observed coincident with ≈ 100 kHz Mirnov bursts during TAE mode experiments (B=15 kG, I=500 kA). Lower amplitude bursts incur smaller beam loss, but the beam ion losses persist well after the end of the Mirnov bursts, and sometimes do not peak until after the end of the burst. The (E,μ) location of the loss is not altered by the bursts ($E\approx 100$ keV, $\chi\approx 60^{\circ}$), and corresponds to a trapped orbit with its banana tip below the plasma center. The loss mechanism could be MHD-induced "ripple" loss, or else increased diffusion of passing ions across the passing-trapped boundary into the stochastic TF ripple loss region.

Other, non-TAE beam ion losses were observed at a lower density and lower beam power (B=12 kG, I=420 kA, $n_e(0)\approx 2.2\times10^{13}$ cm^{-3}). The time history shows sharp bursts of beam ion losses coincident with Mirnov activity, but at a lower Mirnov frequency than TAE modes ($\approx$25 kHz). Beam ion losses in this mode can include a passing ion feature at $\chi\approx 40^{\circ}$, qualitatively similar to recent theory (H. Mynick, PPPL) which predicts a stochastic threshold above which MHD activity can cause passing particle loss.

Future experiments for DT should attempt to change V_{α}/V_A at high β_{α}, both to decrease it to $V_{\alpha}/V_A\approx 1$ to increase TAE instability, and to increase it to $V_{\alpha}/V_A\approx 2.5$ to simulate ITER. A database study of 1990 supershots showed discharges at 40 kG had a range $V_{\alpha}/V_A\approx 1.1$-$1.6$, compared to $V_{\alpha}/V_A\approx 1.2$-$1.4$ for discharges with 50 kG. Further exploration of low-B parameter space is warranted.

R. Boivin from MIT (formerly from PPPL) discussed ripple loss experiments on DD fusion products in TFTR and possible ripple experiments in DT. The global stochastic TF ripple losses for R=2.6 m plasmas in TFTR were calculated using the MAPLOS code to be $\approx 3\%$ in the range 1.4-1.8 MA. Previous measurements on TFTR using the midplane scintillator probe showed a peak at $\chi \approx 60^{\circ}$-65° (distinct from the first-orbit loss peak), with a magnitude close to that predicted by the code. These experiments could be extended by installing simple detectors at the locations expected for TF ripple trapping, 40°-50° below the outer midplane. Such detectors (e.g., a 1-channel scintillator or Faraday cup) would need to be able to measure orbits near $\chi \approx 90^{\circ}$, which the present detectors cannot.

Further experiments can also be done on TF ripple stochastic diffusion in DT discharges, although the basic loss mechanism is expected to be the same for alphas as it is for DD fusion products. Thermocouples in the RF limiter could potentially measure the alpha ripple loss, which is estimated to be up to ≈ 1 kW/cm^2 for a 5% ripple loss near Q=1. Calorimetric measurements could be made using a movable midplane probe (although probe overheating is possible). Investigation of the poloidal and toroidal location of alpha wall heat loads would be valuable for the ITER wall design.

Other possible DT experiments involved concern the interaction between alpha ripple loss and the observed loss of MeV ions during MHD activity and ICRH heating. The synergistic effects among these mechanisms are not yet understood experimentally or theoretically.

E. Strait from GA described comparisons between experiment and theory concerning the stability of beam-driven TAE modes in the DIII-D tokamak. In L-mode limiter discharges (typically with B=0.8T, I=0.6 MA, and 5 MW NBI) the Fourier spectrum of high frequency MHD with n=1-5 within f=50-150 kHz is consistent with TAE modes, as is its frequency scaling with B. The TAE fluctuation amplitude and the fast ion loss level (inferred from the neutron emission) increase rapidly for $V_{||}/V_A \geq 0.6$, with the latter rising to 20% at $V_{||}/V_A = 1.1$. The TAE mode amplitude also increases rapidly above about $\beta_f \approx 1\%$, and the fast ion beta saturates at $\beta_f \approx 1.3\%$.

Theoretical driving and damping rates are becoming increasingly consistent with experimentally observed mode numbers and stability thresholds (for the simplified analyses presently available), with continuum damping ($\propto m^{-3/2} s^2$) being important for low-m mode numbers, and electron kinetic effects ($\propto m^{2/3} s^{2/3}$) dominating at high mode numbers (s is the shear). Intermediate mode numbers n=3-9 are least stable, consistent with experiment. The theory predicts that increased shear should stabilize TAE modes, particularly for low mode numbers, which appears to be consistent with the delayed onset and time-variation of the n-spectrum of TAE mode activity during current ramp-down experiments (see further discussion in the alpha theory section of this report).

The ratio of fast ion drive for TAE modes in the DIII-D beam experiment to alpha drive in the standard TFTR DT supershot case (#55851) was estimated to be $\approx$0.1-0.2, whereas the ratio of damping rates was $\approx$1 for continuum damping and $\approx$0.4 for electron kinetic damping. This suggests that normal supershots would be TAE unstable at $\langle\beta_\alpha\rangle \approx 0.05$-$0.1\%$, which is slightly larger than the expected 0.04% in #55851. The most favorable conditions for observation of TAE modes in TFTR DT should be in low-shear discharges, at moderate-to-low q, and with a positive current ramp.

H. Duong of GA described the confinement of fusion-produced MeV ions in the DIII-D tokamak. Both triton burnup (measured by the 14 MeV/2.5 MeV neutron ratio) and ^{3}He burnup (measured by the 15 MeV proton flux to a silicon detector) were consistent with the classical prediction over 0.5<I<3 MA (within a factor of 2-3 uncertainty) in high field and VH-mode discharges. The time dependence and electron temperature dependences were also nicely consistent with classical modeling (first-orbit loss only, without ripple loss).

Anomalously low triton and ^{3}He burnup were clearly observed during both TAE and fishbone instabilities, which occur above about $\beta \approx 5\%$ in DIII-D. During these MHD-active periods the burnup rates were a factor of 3 to >10 lower than expected, suggesting a large loss of fusion products. However, burnup during an MHD-quiescent plasmas with β=11% was classical, and burnup during sawtoothing discharges was also nearly classical.

The most likely mechanism responsible for the anomalous loss was said to be orbit stochasticity in the helically distorted fields, which can reach $\tilde{B}/B \approx 10^{-3}$ during TAE activity. The important implication for TFTR DT is the possiblity of having fluctuation-driven alpha losses without having collective alpha instability, and that if the goal is to maximize β_α then strong background plasma MHD activity should be avoided.

S. Sesnic from PPPL discussed high frequency modes observed during high β_{pol} plasmas on PBX-M (I=0.3-0.4 MA, B=1.3 T, P=4-6 MW NBI, κ=1.8). Two modes are present, a strong low frequency (7 kHz) n=1 mode, and a weak high frequency (100 kHz) high-n mode which appears only near the "crest" of the low frequency mode. There are several high frequency peaks separated by the fundamental and harmonics of the low frequency mode, probably due to non-linear coupling. The high frequency mode has 4<m<10 with n=m-1 just outside the q=1 surface.

An attempt was made to determine whether the high frequency fluctuations were TAE or KBM modes, or something else. The measurements show $V_{\parallel}/V_A \approx 0.8$, i.e., high enough to satisfy the $V_A/3$ resonance of TAE modes, and β_f of the beam ions is also high enough to excite TAE modes. The region outside q=1 is also close to the ideal ballooning limit, as required for the KBM. The measured frequency of the m=8/n=7 mode was 59 kHz (in the plasma frame), while the predicted TAE frequency was 84 kHz and the predicted KBM frequency was 68 kHz. The predicted growth rates for the TAE and KBM were 2.3×10^4 sec^{-1} and 4.3×10^3 sec^{-1}, respectively. The indications are that the observed behavior could be due to either a TAE or KBM.

A. Gondhalekar from JET described measurements of neutral H and ^3He minority ions at MeV energies in JET made using a high energy particle analyzer developed at the Ioffe Institute. This instrument can resolve escaping neutral emission of various species (H, D, T, ^3He, and ^4He) between 0.5<E<3.5 MeV. The analyzer was installed to view a He^0 NB injector vertically, over an area of 8x7 cm at the midplane. With H minority heating the analyzer saw both passive flux (without NBI) and a 3-4 times higher active flux (with He^0 NBI), both of which had an effective neutral emission temperature of about 0.5-1 MeV. Detailed calculations are in progress to explain these fluxes based on known H^+ neutralization cross-sections. With ^3He minority heating in a ^4He background plasma with ^4He NBI there was only active flux due to double CX on the ^4He beam, with an inferred ^3He temperature apparently >1 MeV.

Experiments were performed to measure the width of the ICRH resonance layer by sweeping the TF field. The FWHM of the H^+ emission region was 0.17 m, compared to 0.3 expected from ICRH theory. The effects of TF ripple were measured by operating with 16 coils (instead of 32), which caused a decrease in the H^+ tail temperature and a decrease in the high energy neutral flux (1.8 MeV) by a factor of 35, indicating large ion losses which increase with energy as expected from TF ripple trapping. Other experiments showed that the apparent H^+ tail temperature with ICRH saturated at 0.4-0.6 MeV at low-to-medium density [$n(0)<3\times10^{13}$], where the Stix temperature was >1 MeV; however, at higher density the apparent H^+ tail temperature followed the expected Stix spectrum. This may be due to high energy CX with carbon and beryllium at low density. At high density the decay time after ICRH turn-off also follows the classical Stix theory. This technique is proving to be a valuable diagnostic for high energy ions, and should be attempted, if possible, during DT alpha experiments on TFTR.

G. Sadler from JET reviewed various neutron measurements, including those from the preliminary tritium experiment (PTE). During the PTE an NE213 liquid scintillator successfully measured the 14 MeV neutron spectrum in DT, and the 14 MeV neutron flux was measured with fission chambers, a silicon diode, and the activation system. The 14 MeV neutron profile was also measured with the neutron profile monitor, and had the same shape as the 2.5 MeV neutron profile, showing that the beam deposition properties of 78 KeV T and 135 KeV D are similar. The measured DD and DT neutron rates and radial profiles vs time agreed with the TRANSP simulations for the PTE (and also for the 1% tritium shots). The gamma ray detectors in their (non-optimized) configuration for the PTE were overwhelmed by background radiation, even in the roof laboratory.

Triton burnup during DD discharges has generally been consistent with classical, i.e. with little or no anomalous triton loss. However, discharges which had a particularly long slowing down time indicate a non-classical loss time of about 1 sec, which can be explained by a $D \approx 0.1$ m^2/sec or possibly by CX losses. The latest triton burnup profile data also show that tritons are displaced by sawteeth and then stay in their displaced positions during thermalization.

In the PTE discharges the central neutron emission peaked well before the total neutron emission, perhaps correlated with increasing MHD activity before the "X-event" which ended the rise in neutron emission. The maximum neutron rate was 7.2×10^{17} n/sec. The triton burnup was monitored after the PTE to evaluate the tritium cleanup process; after about 150 discharges with 2 MW of deuterium beams the DT neutron rate reached the level expected from triton burnup alone. This indicates that little T remained locked up in the walls (<10 Ci).

The ion cyclotron emission measured near the outer midplane in the PTE followed the DT neutron emission with a time lag of 0.2-0.4 sec, consistent with the growth time of the fusion product population, and dropped rapidly within 0.1 sec of the X-event. Increased TF ripple (with 16 instead of 32 coils) caused a 40% deficit in the triton burnup, roughly consistent with the expected TF ripple losses. Increased minority tail ion loss were also seen in the TF ripple experiment (see Sadler, et al., EPS '92).

2. Alpha Particle Theory

I. Introduction

The theory talks given at the Third Workshop on Alpha Physics in TFTR showed a certain consolidation of linear stability work, compared to the earlier mood of excitement about new instabilities and first calculations of linear damping mechanisms. However, at least two new driving terms of the TAE [namely a hitherto neglected term $\propto$ $(\omega/\Omega\alpha)$ ε_{gap}^{-2} and a kinetic TAE due to finite $k_{\perp}^2$ ρ_s^2] and several new evaluations of damping terms combined with an increasing number of interactions between such effects still leave us with no definite answer to two main questions: Will TFTR at $Q < 0.5$ and high T_i be able to enter the unstable TAE regime in order to explore it, and will ITER be able to avoid the (more unstable) EAE regime. Concerning JET, no experimental data exist yet on simulating the TAE/EAE with super-Alfvénic fast parallel ions, nor has the international theory community turned its attention to evaluating JET parameters in this regard. Nevertheless, the two major talks from the JET team on minority ion losses and ICE-neutron- and gamma- measurements were highly relevant and led to stimulating discussions.

Because of the rather small number of theoretical α-specialists present (there were only about 14 contributors to this meeting) it is not surprising that topics other than toroidal Alfvén wave stability and consequences for fast α-confinement were only briefly covered this time. Some emphasis was given to low n MHD modes interacting with alphas, such as the n = m = 1 mode and higher n kinetic ballooning modes (KBM) destabilized by alphas, helium ash transport considerations, alternate high $\varepsilon\beta p$ burning plasma scenarios for TFTR and χ_e-χ_i transport models for D-T. In the next 12-15 months before D-T in TFTR one would like to see more TFTR specific theory work on α-fishbones, α-sawtooth oscillations, α-KBM's, and in the nonlinear domain, a first fully toroidal self-consistent gyrokinetic simulation of the α-TAE saturation for a TFTR-like plasma. Further progress with the TAE initial value code TAE-FL, the stochastic α-codes ORBIT and H. Mynick's related code can be expected.

With this wish list notwithstanding it must be emphasized that the spirit of collaboration between α-experimentalists, α-diagnosticians, D-T discharge modelers, and α-theoreticians evident at this meeting was outstanding, perhaps exceeding a similar spirit of cooperation at the most recent Transport Task Force meeting on confinement in Oak Ridge in March 1992.

II. Brief Discussion of Individual Contributors -- Highlights

G. Fu and C. Z. Cheng from PPPL gave a detailed assessment for high n ($n\varepsilon > 1$) TAE mode stability including FLR and finite α-orbit effects, continuum damping, ILD (with the $v_{||} = v_A/3$ resonance), ELD, plus collisional trapped electron damping and the stabilizing effect of $|\nabla p_i| > 0$ (which provides ILD for increasing β_i). Addressing specifically the TAE for NB and D-T shots in TFTR it is found that the n = 2,3 unstable regime may be accessible (although the theory is beginning to break down for such low n) and that the following choices favor instability: $2q^2R (dp_i/dr)/B^2$ not too large; low n_e; high T_e , T_i to maximize β_α and minimize ELD, low $d/dr(k_{||}{}^2 v_A{}^2)$ (i.e., low shear) to minimize continuum damping. For the low n = 2,3 values, Nova-K should be used to verify this work after all of the above damping mechanisms have been incorporated. The paper contains many valuable parametric dependences of the growth rate.

The paper of **H. Berk** et al. (IFS) shows further progress on the linear damping theory of TAE (for moderately high n) in general and aiming at TFTR-like plasmas. After revisiting the underlying theory of the continuum damping (published recently by Berk et al. [and closely related to work by L. Chen and F. Zonca]) details are given for specific v_A-profiles, q-profiles and mode numbers resulting in continuum damping rates typically of the order of a few percent of the Alfvén frequency $v_A(0)/R_0$. Then, using an approximate analytic Lorentzian form for the radial TAE eigenfunction, the resonant wave-particle power transfer is worked out leading to the n-dependence of the TAE growth rate. Continuum damping increases as n^2 (n-toroidal mode number). Next, the results of important work (recently submitted) by Berk et al. on the effect of finite α-orbit width Δ_b over radial mode width Δ_m are reviewed and the toroidal mode number n-dependence of the growth rate is given. In the relevant $\Delta_b > \Delta_m$ limit the TAE growth rate decreases with increasing n.

The recent appearance of collisional trapped electron damping by Gorelenkov and Sharapov is traced back to early work by Rosenbluth. It scales as $|\gamma_e| \propto n_e \beta_p [(\beta_\alpha/\beta_e) T^{7/4}]^{-1}$ which is interesting with respect to TFTR run scenarios in D-T.

The additional TAE damping arising from finite $k_\perp^2(\rho_e^2, \rho_i^2)$ kinetic effects i.e., finite parallel fluctuating electric field, is mentioned (also see the discussions of Mett's work, below).

Overall, while it is still difficult to obtain results for low toroidal mode numbers and allowing a number of contributing damping effects, ITER may be TAE-stable for $T_e < 15$ keV (with no results yet for EAE's), and TFTR-TAE stability needs further attention to details such as the radial variation of the $v_{||} = v_A$ and $v_A/3$ resonance and kinetic damping effects.

R. Mett and **S. Mahajan** from IFS took a fresh look at the usually neglected ($k_\perp^2\rho_s^2$, $k_\perp^2 \rho_i^2$) corrections to the ideal MHD description of the TAE. This kinetic theory step reintroduces the parallel component of the fluctuating electric field into "kinetic" Alfvén wave (whose simplified cylindrical tokamak dispersion relation is $\omega^2 = v_A^2 k_{||}^2[1+ (k_\perp \rho_s)^2]$. The KAW not only increases damping but also leads to the existence of a kinetic toroidicity induced Alfvén eigenmode (KTAE) with a frequency just above the gap. This mode is produced by the coupling of two kinetic Alfvén waves. While due to $n_\alpha/n_e << 1$ the α-growth rate can be calculated perturbatively the parallel kinetic electron dynamics of the KAW and KTAE is intrinsically a non-perturbative effect. The KAW carries wave energy away from the Alfvén singularity at the gap thereby exceeding continuum damping. The KTAE has just been discovered and its net growth rate in TFTR is not yet clear.

C. Z. Cheng and **G. Y. Fu** from PPPL reconsidered important properties of the low n TAE and EAE modes. Using the Nova-K code the effects of the profiles of the current density, pressure, ion density, flux surface geometry and wall boundary can be quantitatively explored. The realistic gap structure is produced numerically allowing insight into continuum damping possibility at very low n (where the Zonca-Chen and Berk-Rosenbluth high n theory fails).

Collisional trapped electron damping is now included in Nova-K, finite α-orbit width effects are not yet.

H. Mynick (PPPL) showed extensive studies of α-losses due to low n MHD fluctuations including frequencies far below the Alfvén (gap) frequency range. Resistive MHD effects and thus magnetic islands are included in addition to possible α-orbit islands and orbit stochasticity. Working closely with the TFTR experimental group different kinds of fast ion loss processes and ensuing poloidal loss patterns are theoretically identified (e.g., well passing ions spiraling radially outward). Theoretical possibilities for helium ash transport due to multiple harmonics are suggested but not yet fully worked out. The observed ratio of anomalous to prompt ion losses in TFTR plasmas with low MHD activity is compared with orbit loss simulations below the stochastic threshold.

H. Biglari from PPPL strongly emphasized the transition from high n TAE's at low β to α-driven kinetic ballooning modes KBM at higher β. As noted in Fu's talk and other talks at this conference, an increasing background pressure gradient tends to stabilize the TAE but destabilize the KBM as the mode frequency shifts downward. [However, it is useful to recall related work by G. Rewoldt -- presented at a previous TFTR a-physics workshop and in Nucl. Fusion **31** (1991), 2333 showing the existence of more than one branch of α-driven KBM's, also at higher frequencies, as first pointed out by Spong et al]. Depending on $v_A/v_{\|}$(hot), β, (and the unstable mode numbers appearing in the drift resonance $\omega - k_{\perp} v_D(\text{hot}) \approx 0$) trapped fast ions can also destabilize the TAE and KBM. Numerical work by Sabbagh for specific TFTR shots were shown as evidence that at $\beta < \beta_{crit}$ (ideal) in the steep gradient region the TAE dominates over the KBM and, conversely, in supershots with $\beta \approx \beta_{crit}$ (ideal), in the steep gradient region, strong continuum damping should suppress the TAE and drive the KBM.

B. Coppi from MIT presented an overview of transport models for DT and various other published results by his group. In beam heated plasmas a modified Coppi-Mazzucatto-Gruber diffusivity D_{CMG} is augmented by adding the ubiquitous mode diffusivity D_{UB}. Combined, this yields an L-mode type scaling whose first principles derivation describes a coupling of the collisionless trapped electron mode and the impurity gradient driven mode near the plasma edge.

The scaling for the energy confinement time is

$$\tau_E \sim 1.75 \times 10^{-13} (n_e \kappa / P_{aux})\ 0.6\ (I_p/\alpha_T)\ 0.8\ (aR_0{}^{1.2}/Z_{eff}{}^{0.2})\ \ (q_\psi A_i)^{0.4}$$

where I_p is in MA, P_{aux} in MW, R_0 in m, and τ_E in seconds. The profile parameter α_T comes from Te ~ exp $(-\alpha_T r^2/a^2)$. Using this theory, G. Lapenta (1992) worked out the consequences in a transport modeling code, predicting $T_e(r)$ for various P_{aux} profiles.

M. Mauel from Columbia Univ. proposed an alternative operating scenario, namely high $\varepsilon\beta p$, high q(a), for the DT phase of TFTR. Recent experience with rapid current rampdown shots leading to quite different much broader pressure profiles (and highly peaked current profiles) show a substantial relative increase in confinement time and a $Q_{DD} \sim 1.3 \times 10^{-3}$ at betas approaching second stability. A first glance at the TAE continuum boundaries for these nonstandard profiles show some changes, but basically similar features. This needs to be pursued since q-profile changes are one way to control continuum damping of the TAE.

W. Hui from U. Illinois, Urbana showed a survey of an analysis aimed to extract helium transport coefficients (diffusion D and radial pinch velocity V) from existing machines (PDX, TFTR, JT-60). In TFTR, D ranges from 0.2 to 10 m^2/s and V from 0 to 36 m/s. Empirical fits for D and V of the form $n^a T_i^b (dn_e/dr)^c q^d$ were presented. More work is needed on the changes of these scalings in L-mode vs supershots, with and without sawtooth oscillations, effects (if any) of the injected He-source strength on the observed D and V and ultimately, on the difference between D-D and future D-T plasmas.

B. Breizman from IFS described a mechanism for the nonlinear evolution of α-particle instabilities using the O'Neil paradigm of saturation of a single mode by particle trapping with frequency ω_b and phase mixing. A finite wave amplitude can be maintained if there is a (fusion) source rate υ_{eff} of resonant particles and a plasma background damping rate γ_d. The steady state amplitude is given by $\omega_b{}^3 = \gamma_l\ \upsilon_s\ \omega^2/\gamma_d$ where γ_l is the linear growth rate and $\upsilon_s = (v/\Delta v)^{-2}\ \upsilon_{eff}$ is the simple scattering frequency into the trapping region and $v/\Delta v = \omega/\omega_b$. This model can be applied to the α-Alfvén wave problem provided the wave amplitude Φ is such that $\omega_b \equiv (ek^2\Phi/m)^{1/2} > \gamma_d$. First, the amplitude grows linearly until $\omega_b \sim \gamma_l$ whereupon f_α flattens in the resonant region in a time $\sim \omega_b^{-1}$. The wave damps at the background damping rate γ_d after which the α-source restructures f_α and another cycle begins. This picture can be generalized to many (say N) discrete modes. If $N < \omega/\gamma_l$ the resonance regions will not overlap. For $N > \omega/\gamma_l$ they will quickly flatten a large region of $f_\alpha(v)$. In this case, if the wave amplitude is large enough to produce α-orbit stochasticity a large loss of alphas occurs. (This theory is in IFS report 542).

D. Spong from ORNL presented new results on nonlinear TAE simulations for TFTR, obtained with the initial value "gyrofluid" code TAE-FL which evolves the non-ideal MHD equations (in the so-called FAR code of ORNL) coupled to a gyrokinetic fluid description of the α-response. This α-fluid model has evolution equations for n_α and $V_{\parallel\alpha}$ such that the destabilizing α-Alfvén wave Landau resonance is described by the Hammett-Perkins n-pole approximation to the plasma dispersion function. Furthermore, the background ion FLR effects are included via a Padé approximation of the Bessel function of argument $k_\perp \rho_i > 0$ which facilitates the inclusion of finite parallel fluctuating electric field effects and magnetic island formation (non-ideal MHD). Continuum damping is self-consistently appearing provided the radial grid is taken sufficiently small. (It is in the runs presented.) The equilibrium geometry of both the MHD wave and the α-particles is fully 2-D toroidal, allowing for shaped plasma cross sections. Background ILD and ELD is included. Simultaneous toroidal mode numbers n = 1 , ... 8 are feasible, including a large number of poloidal harmonics. Finite α-orbit width effects and trapped α-effects are not yet included. A third fluid moment, namely the $m_\alpha v_\parallel{}^2/2$ energy moment, will be included soon, thereby, intensifying the toroidal mode coupling in the nonlinear evolution. Quasilinear modification of n_α (r,t) are contained in the equations through the convective terms $V_\perp \cdot \nabla n_\alpha$, $V_\perp \cdot \nabla V_{\parallel\alpha}$.

Results. I. For the TFTR DT study Budny's equilibrium and α-parameters for β_α,

v_α/v_A , etc. are used. At first, running the TAE-FL code with the nonlinearities switched off, the $n = 2$-4 modes appear unstable over a range of accessible v_α/v_A and β_α. II. A second simulation for TFTR was done on the super-Alfvénic NBI plasma of recent DD discharges whose parameters were taken from Wong's PRL **66** (1991) 1874. Near saturation the dominant toroidal harmonic is $n = 2$ resulting in a rather global mode structure and $\tilde{B}_r/B_0 \sim 2 \times 10^{-3}$. Since this is a nonideal MHD system ($k_{||}\ \phi - \omega A_{||} \neq 0$) magnetic islands and fieldline stochastization are observed, followed by self-healing when the perturbed magnetic field collapses. For a given n, nonlinear mode coupling produces an $m = 0$ poloidal harmonic. An $n = 0$ component is also observed to appear, i.e., a change in equilibrium of n_{hot} (r) which is clearly visible in the simulation. A very interesting diagnostic in the code permits the display of the computed fluctuating B_θ frequency spectrum at the plasma edge. Its peak around 90 kHz and its width agrees excellently with Wong's PRL spectrum data for the $B = 10$ kG plasma. Furthermore, the simulation shows a time delay of about 40 poloidal Alfvén times between the peaking at $r/a = 0.6$ (where the "Mirnov" oscillations are observed). These edge fluctuations are also smaller by a factor of ~ 10.

These quantitative features of the TAE-FL simulation should be very useful for interpretation of the upcoming DT experimental observations in TFTR.

C. T. Hsu from MIT Plasma Fusion Center reported first results of stochastic α-transport due to multiple toroidal mode numbers n of the TAE. [Previous single mode $n = 1$ results have appears in Phys. Fluids **B4**, 1492 (1992)]. For more than one toroidal mode, there is no one dimensional Poincaré plot P_φ versus (n_φ - ωt) but the onset of stochastic diffusion of the type $<(\Delta P_\varphi)2> \propto D_{pp}\ \Delta t$ is clearly observable as the perturbed field amplitudes are increased. In this study the radial mode structures for all essential n and m components are taken from D. Spong's nonlinear TAE simulation for TFTR discussed above. Given this structure of the perturbation, 512 alphas are launched with fixed $v_{\alpha 0}$ at $r/a = 0.2$ but random θ, φ and $\mu B_0/E$ (thus including large α-orbit sizes interacting with more than one gap mode simultaneously. The run lasts 500 transit times. As expected, for a single mode $n = 2$ there is no diffusion below $\tilde{B}_r/B_0 \sim 10^{-3}$ but with ($n = 2$, $n = 4$) simultaneously at equal amplitude the diffusion threshold is at $\tilde{B}_r/B_0 \sim$

10^{-4}. For twice this value the observed radial diffusion rate ~ 1 m^2/s. A third case occurring during Spong's modelling of the time evolution is [$(\tilde{B}_r/B_0)$ for n = 4 divided by $(\tilde{B}_r/B_0)$ for n = 2] = 10^{-1}. In this case the subdominant mode n = 4 does not lower the diffusion threshold from the value for the single n = 2 mode. Thus, overall, the addition of one additional ~ equal amplitude low n-TAE eigenmode lowers the stochastic a-orbit threshold by a factor of ~ 5. In a fully self-consistent simulation this would suggest a relaxation oscillation process of α-particle ejection sufficient to lower β_α below the linear instability threshold, with the maximum amplitude $\tilde{B}_r/B_0$ set by orbit stochasticity much below the saturation amplitude occurring in the absence of a-particle ejection.

R. Betti from U. Rochester ended the theory papers at this meeting with important new results on two kinetic effects on low n MHD modes, namely a destabilizing term to the TAE/EAE mode proportional to $(\omega/\Omega_\alpha)\ \varepsilon_{gap}^{-2}$ and a stabilizing term for the internal kink due to $\omega_{*\alpha}$. Previously Betti et al. had pointed out [Phys. Fluids **B4**, 1465 (1992)] that the $v_{||} = v_A/3$ ion resonance contributes crucial ILD to the TAE which because $(\omega/k_{||}\ v_{thi})^2 \sim (v_A/v_{thi})^2 = \beta_i^{-1}$ increases strongly with β_i. This result was obtained readily from the exact Vlasov equation, first integrating it analytically along the full α-gyro orbits, simplifying the a-response by integrating by parts and reusing the equation of motion without ordering $\omega < \Omega_{c\alpha}$, and finally performing the remaining resonant orbit integral in the drift kinetic approximation. This gives rise to a term $(\omega/\Omega_{c\alpha})/(r_{gap}/R_0)^2$ and noting that this $(\varepsilon_{gap})^{-2}$ factor is large in the gap region where the low n mode structure of the TAE is steep, this term is retained. It is shown to be proportional to the poloidal mode number and always destabilizes the α-response and only affects the $v_{||} = v_A$ but not the $v_{||} = v_A/3$ resonance. Thus, it does not affect ILD (or ELD for which ω/Ω_{ce} is too small). Betti works out the growth rate also for an α-slowing down distribution and when evaluating the new theory result for the growth rate in the standard n-T diagram finds the unstable TAE region substantially enlarged for $n \geq 3$ toroidal modes.

Revisiting the kinetic derivation of the internal kink mode including fast ion effects, he finds an additional damping from α-FLR comparable to the trapped α-stabilization and an additional α-term in the real real frequency of the ω_{*i} fishbone branch, of the form $\omega_r = \omega_{*i} + (r_a/ri)\omega_{*\alpha}$. The $\omega_{*\alpha}$ term should decrease upon ejection of fast ions and this trend is actually observed in fishbone oscillations.

(For completeness it should be added that C. Z. Cheng -- using Nova-K -- finds a destabilizing term from the α-precesion drift reversal at higher β values of the background plasma. More quantitative work on the α-fishbone interaction needs to be done in preparation of DT operation in TFTR.)

3. Alpha Particle Diagnostics

The Diagnostics session concentrated totally on the progress being made in constructing α-particle diagnostics to be installed on TFTR for DT operation. All of these instruments are to be operational in the upcoming DD campaign so that their performance can be assessed using the fast ions from neutral beam or ICRF heating. All of the measurement techniques are untested so some experimental demonstration prior to the very short DT Program was considered essential.

Two papers on the collective scattering measurement of high energy α-particles were presented by members of the collaborating groups from PPPL and MIT. **H. Park** from PPPL et al. presented the hardware design for the X-mode 60 GHz Gyrotron Scattering System, pulsed at 200 kW for half a second. This frequency is below the fundamental electron cyclotron frequency. The goals of the experiment are to test collective scattering theory on fast ions and then measurement of the confined α-particles. He showed an example of the ray tracing necessary to locate the scattering volume in the plasma. He discussed the hardware design for the beam optics and propagation and described the dumps needed to constrain the scattering of the incoming beam off the walls into the receiver. **P. Woskov** (MIT) et al. described the analytical basis for the method and showed a number of calculated spectra assuming different α-particle distributions. Considering the receiver properties, he showed detailed signal-to-noise calculations for assumptions of different α-particle densities and α-particle distributions.

N. Bretz from PPPL summarized the status of the wide variety of fluctuation-measuring diagnostics on TFTR with reference to the measured parameter and to the frequency bandwidth. The relevance of each technique with respect to the different theoretically-predicted instabilities can thus be assessed.

B. Stratton from PPPL described the progress of the charge-exchange recombination spectrometer for measuring low energy confined α-particles being developed jointly with R. Fonck (U. Wisconsin). This instrument, referred to as α-CHERS, makes use of the visible 468.6 nm He radiation emitted following charge exchange of an α-particle with a neutral D° atom from a heating neutral beam. Since the cross-section for charge-exchange is only significant over a narrow range of relative velocities between the α-particles and the beam atoms, only α-particles with velocities near the beam velocity produce significant emission. Even so, the signal level will be small compared to the visible bremstrahlung for the anticipated α-particle densities. Stratton described two viewing geometries, each with five spatial channels, the high-throughput optics and requirements for a low-noise, stable detector system. 1 mm quartz fibers carry the light from the plasma through the wall of the TFTR Test Cell to the spectrometers and low noise CCD cameras located in an readily accessible area. This technique should work best where the electron density is modest such as in supershots or after the main heating beams have been turned off and the density decays.

R. Fisher from General Atomics described the possibility of using the He° atoms arising from double charge exchange of the α-particles with the ions in the ablating cloud of an impurity pellet. This development is a collaboration between groups at General Atomics, MIT, Ioffe Physico-Technical Institute, and PPPL. Fisher showed the results of calculations indicating that there will be a region of the pellet cloud many centimeters long, along the magnetic field direction, which is in the helium-like ionization state. The optimum impurity is lithium, which is already introduced into TFTR for poloidal field measurement. Fisher has already done a simplified feasibility study on TFTR with a simple magnetic analyzer observing neutralized high energy deuterons. It is now proposed to install a 1-3.5 MeV a-particle energy analyzer, previously used by the Ioffe Group at JET, close to the line-of-fire of the 1 km/sec Li-pellet injector.

The last series of talks was on the escaping-α-particle detectors. **Darrow** from PPPL described efforts to ensure calibration quality throughout the DT run. He described the equipment being added and additional precautions being taken to monitor potential degradation of components and to assure continuity of measurement through redundancy of essential equipment. **Tuszewski** from LANL described his calibration of scintillators for use in these escaping-α detectors using the Los Alamos three-stage Van de Graff facility. He showed that the ZnS scintillators now in use for the TFTR D-D experiments (P11) show saturation in their light output at a particle flux $\leq 4 \times 10^{10}$ $cm^{-2}s^{-1}$. He found that P46 scintillators, which are relatively less sensitive but have good thermal properties, reached their linearity limit at about 6×10^{13} $cm^{-2}s^{-1}$, which is easily sufficient for TFTR DT operation (but marginal for ITER). **Zweben** from PPPL dealt with some practical issues of making these detectors operate in the hostile environment. He described the carbon-carbon composite thermal shielding needed to protect the detectors from plasma heating. The detectors must be a relatively short distance behind the local limiter surface, so that the particle orbits are not obstructed. He also pointed out the difficulties of evaluating the effects of the neutron and gamma backgrounds, not only on the scintillators and their substrates but also on the optical components between the vacuum vessel wall and the cameras in the basement.

Acknowledgment This work was in part supported by U.S.Department of Energy contract
DE-AE02-76-CHO3073.

EXTERNAL DISTRIBUTION IN ADDITION TO UC-420

Dr. F. Paoloni, Univ. of Wollongong, AUSTRALIA
Prof. M.H. Brennan, Univ. of Sydney, AUSTRALIA
Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
Prof. I.R. Jones, Flinders Univ, AUSTRALIA
Prof. F. Cap, Inst. for Theoretical Physics, AUSTRIA
Prof. M. Heindler, Institut für Theoretische Physik, AUSTRIA
Prof. M. Goossens, Astronomisch Instituut, BELGIUM
Ecole Royale Militaire, Lab. de Phy. Plasmas, BELGIUM
Commission-European, DG. XII-Fusion Prog., BELGIUM
Prof. R. Boucique, Rijksuniversiteit Gent, BELGIUM
Dr. P.H. Sakanaka, Instituto Fisica, BRAZIL
Instituto Nacional De Pesquisas Espaciais-INPE, BRAZIL
Documents Office, Atomic Energy of Canada Ltd., CANADA
Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
Dr. H.M. Skarsgard, Univ. of Saskatchewan, CANADA
Prof. J. Teichmann, Univ. of Montreal, CANADA
Prof. S.R. Sreenivasan, Univ. of Calgary, CANADA
Prof. T.W. Johnston, INRS-Energie, CANADA
Dr. R. Bolton, Centre canadien de fusion magnétique, CANADA
Dr. C.R. James,, Univ. of Alberta, CANADA
Dr. P. Lukác, Komenského Universzita, CZECHO-SLOVAKIA
The Librarian, Culham Laboratory, ENGLAND
Library, R61, Rutherford Appleton Laboratory, ENGLAND
Mrs. S.A. Hutchinson, JET Library, ENGLAND
Dr. S.C. Sharma, Univ. of South Pacific, FIJI ISLANDS
P. Mähönen, Univ. of Helsinki, FINLAND
Prof. M.N. Bussac, Ecole Polytechnique,, FRANCE
C. Mouttet, Lab. de Physique des Milieux Ionisés, FRANCE
J. Radet, CEN/CADARACHE - Bat 506, FRANCE
Prof. E. Economou, Univ. of Crete, GREECE
Ms. C. Rinni, Univ. of Ioannina, GREECE
Dr. T. Mual, Academy Bibliographic Ser., HONG KONG
Preprint Library, Hungarian Academy of Sci., HUNGARY
Dr. B. DasGupta, Saha Inst. of Nuclear Physics, INDIA
Dr. P. Kaw, Inst. for Plasma Research, INDIA
Dr. P. Rosenau, Israel Inst. of Technology, ISRAEL
Librarian, International Center for Theo Physics, ITALY
Miss C. De Palo, Associazione EURATOM-ENEA , ITALY
Dr. G. Grosso, Istituto di Fisica del Plasma, ITALY
Prof. G. Rostangni, Istituto Gas Ionizzati Del Cnr, ITALY
Dr. H. Yamato, Toshiba Res & Devel Center, JAPAN
Prof. I. Kawakami, Hiroshima Univ., JAPAN
Prof. K. Nishikawa, Hiroshima Univ., JAPAN
Director, Japan Atomic Energy Research Inst., JAPAN
Prof. S. Itoh, Kyushu Univ., JAPAN
Research Info. Ctr., National Instit. for Fusion Science, JAPAN
Prof. S. Tanaka, Kyoto Univ., JAPAN
Library, Kyoto Univ., JAPAN
Prof. N. Inoue, Univ. of Tokyo, JAPAN
Secretary, Plasma Section, Electrotechnical Lab., JAPAN
S. Mori, Technical Advisor, JAERI, JAPAN
Dr. O. Mitarai, Kumamoto Inst. of Technology, JAPAN
J. Hyeon-Sook, Korea Atomic Energy Research Inst., KOREA
D.I. Choi, The Korea Adv. Inst. of Sci. & Tech., KOREA
Prof. B.S. Liley, Univ. of Waikato, NEW ZEALAND
Inst of Physics, Chinese Acad Sci PEOPLE'S REP. OF CHINA
Library, Inst. of Plasma Physics, PEOPLE'S REP. OF CHINA
Tsinghua Univ. Library, PEOPLE'S REPUBLIC OF CHINA
Z. Li, S.W. Inst Physics, PEOPLE'S REPUBLIC OF CHINA
Prof. J.A.C. Cabral, Instituto Superior Tecnico, PORTUGAL
Dr. O. Petrus, AL I CUZA Univ., ROMANIA
Dr. J. de Villiers, Fusion Studies, AEC, S. AFRICA
Prof. M.A. Hellberg, Univ. of Natal, S. AFRICA
Prof. D.E. Kim, Pohang Inst. of Sci. & Tech., SO. KOREA
Prof. C.I.E.M.A.T, Fusion Division Library, SPAIN
Dr. L. Stenflo, Univ. of UMEA, SWEDEN
Library, Royal Inst. of Technology, SWEDEN
Prof. H. Wilhelmson, Chalmers Univ. of Tech., SWEDEN
Centre Phys. Des Plasmas, Ecole Polytech, SWITZERLAND
Bibliotheek, Inst. Voor Plasma-Fysica, THE NETHERLANDS
Asst. Prof. Dr. S. Cakir, Middle East Tech. Univ., TURKEY
Dr. V.A. Glukhikh,Sci. Res. Inst. Electrophys.I Apparatus, USSR
Dr. D.D. Ryutov, Siberian Branch of Academy of Sci., USSR
Dr. G.A. Eliseev, I.V. Kurchatov Inst., USSR
Librarian, The Ukr.SSR Academy of Sciences, USSR
Dr. L.M. Kovrizhnykh, Inst. of General Physics, USSR
Kernforschungsanlage GmbH, Zentralbibliothek, W. GERMANY
Bibliothek, Inst. Für Plasmaforschung, W. GERMANY
Prof. K. Schindler, Ruhr-Universität Bochum, W. GERMANY
Dr. F. Wagner, (ASDEX), Max-Planck-Institut, W. GERMANY
Librarian, Max-Planck-Institut, W. GERMANY
Prof. R.K. Janev, Inst. of Physics, YUGOSLAVIA

END

DATE
FILMED
12/4/92