THE NEXT WORKSHOP

It was decided to hold the Third Workshop on Plasma Focus in 1983 in Aachen, Federal Republic of Germany, after the Eleventh European Conference on Controlled Fusion and Plasma Physics. H. Herold will serve as the conference executive.

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Editor's Comment: *The Plasma Focus Workshop summarized here was held in conjunction with the Tenth European Conference on Controlled Fusion and Plasma Physics, Moscow, USSR, September 16-19, 1981. This summary was prepared by Professor O. Krokhin, executive for the workshop and Dr. N. Kalachev, scientific secretary. A significant effort in the elaboration of this summary was put forth by the chairman of the closing session, Dr. C. H. Maisonnier. A brief comment on the conference itself appeared earlier in* Nuclear Technology/Fusion, *2, 135 (1982).*

SUMMARY OF THE U.S.-JAPAN WORKSHOP ON DRIFT WAVE TURBULENCE, AUSTIN, TEXAS, JANUARY 11-15, 1982

This workshop was held at the University of Texas and was organized by the Institute for Fusion Studies (IFS) under the agreement between the United States and Japan for the exchange of information in theoretical plasma physics. There were approximately 30 invited scientific participants: 6 from Japan and 24 from the United States. There were six sessions with formal presentations and two sessions for informal discussions of key issues in the problem of drift wave turbulence and anomalous transport.

There were two major goals of the workshop. The first goal was the continuing effort to identify the more plausible anomalous transport mechanisms that take place in high temperature magnetic confinement systems. The second goal was the exchange of recent results between theorists, computer simulationists, and experimenters. Leading scientists representing these three approaches (theory, experiment, and simulation) made presentations reviewing the state-of-the-art in their respective areas. From these presentations, a general sense of understanding emerged as a primary product of the workshop. Some of the problems reported and issues discussed were the following.

The experimenters reported improved resolution in the $\boldsymbol{k},\omega$ space of the measured fluctuations, extension of the fluctuation measurements to new machines, and measurements of magnetic fluctuations in low temperature experiments. Theorists presented alternative explanations for the character of the fluctuation spectra based on renormalized drift wave turbulence theories and the solution of nonlinear dissipative systems exhibiting intrinsic chaotic behavior. In contrast to the weakly correlated turbulence theories, the Japanese emphasized the importance of large-scale correlated structures such as convective cells and solitons. An intermediate point of view of the turbulence was introduced by a theory containing a large number of randomly distributed solitons forming an ideal gas of strongly correlated objects. Simulations were presented by the Japanese of the collisions between drift wave solitons. A theoretical picture containing strong phase space correlations called "clumps" gave an alternative formula for the fluctuation spectrum.

Simulations of drift wave turbulence above (strong gradients) and below (weak gradients) the ion cyclotron frequency and the measured transport of particles and thermal energy were reported by Japan and the United States. A new simulation technique offering the possibility of greatly extended parameter variations and long time runs was also presented.

Discussions on the formulas for anomalous transport centered on the fact that, notwithstanding the importance of empirical scaling laws that synthesize large amounts of experimental data by a particular parameterization, the approach of characterizing the confinement by a formula for the global energy replacement time τ_E is an oversimplification of the issue since transport, atomic physics, and heating mechanisms are interrelated in power balance. The thermodynamic properties of anomalous transport were analyzed.

In a discussion session, the question was debated as to whether it is now timely to assemble the present differentiated areas of knowledge represented at this workshop into an integrated data base giving the present understanding in the field of anomalous transport. Although no consensus was apparent on this issue, there was a sentiment in the direction that the present understanding may well be stronger than generally realized. It is also clear, however, that many new and difficult problems continually emerge, and their solutions will change our understanding of the problem of anomalous transport.

The proceedings of the workshop are available as IFS Report #53.

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REPORT ON THE FOURTH SYMPOSIUM ON THE PHYSICS AND TECHNOLOGY OF COMPACT TOROIDS, LIVERMORE, CALIFORNIA, OCTOBER 27-29, 1981

The Fourth Symposium on the Physics and Technology of Compact Toroids was hosted by Lawrence Livermore National Laboratory (LLNL). Attendees, numbering 80, heard 10 review papers in three morning plenary sessions, and interacted in two afternoon poster sessions where some 45 contributions were presented. There were seven participants from overseas, including six scientists from Japan and one from the Federal Republic of Germany. Immediately following the symposium, a two-day joint U.S.-Japan workshop on compact toroid research was held.

The review papers were chosen by the Program Committee with two objectives in mind. The first was to inform the attendees of the state of the compact torus art, in experiment and in theory, in the two mainline approaches to compact torus research—the field-reversed theta pinch (FRTP) and the Spheromak configuration. Second, to provide in-depth reviews by acknowledged experts of related fields (e.g., the reversed-field Z pinch) and/or common concerns (for example, particle transport) of interest to compact torus researchers.

In the first category, review papers by M. Tuszewski [Los Alamos National Laboratory (LANL)] and by D. Schnack (LANL) covered experiments and theory, respectively, in FRTP research. Of particular interest in these studies is the elucidation of the long duration grossly stable regimes there encountered, the existence of which is in apparent disagreement with the predictions of fluid magnetohydrodynamic (MHD) theory. The entities that we refer to here might be described as "elongated Hill's vortices," reversed-field configurations characterized by the total absence of toroidal field components. Finite-orbit effects may be able to explain both the existence of these grossly stable regimes and aspects of their behavior at termination when the plasma typically exhibits a rapidly growing elliptical ($m = 2$) rotational mode. Probably related also is the observation of nonclassical rates of cross field transport, apparently explainable in terms of the so-called "lower hybrid" mode, driven by steep field gradients near the separatrices, the steepness of the gradient being associated with the small size of the present experimental plasmas.

Again in the first category, the review papers by G. Goldenbaum (University of Maryland), J. Hammer (LLNL) and S. Jardin [Princeton Plasma Physics Laboratory (PPPL)] covered experimental (G. G.) and theoretical (J. H. and S. J.) work to date on the Spheromak plasmas. Here the good news is that the configurations achieved are seen to adhere closely to the (favorable) predictions of the theory of so-called "Taylor minimum-energy states," exhibiting remarkable and controllable grossly stable behavior, both in their formation and their subsequent gross behavior. The bad news is that in apparently every such experiment electron temperatures are low (10 to 20 eV), being dominated by impurity radiation losses. As a consequence, magnetic field energy decay lifetimes (some hundreds of microseconds) are severely limited. This conclusion was verified by direct measurement of radiation losses, and by correlations with preliminary measures (discharge cleaning) aimed at reducing the impurity levels.

A review paper was also given (T. Watanabe) covering compact torus research in Japan. It was evident from this paper that this field of fusion research is growing rapidly in Japan, with results already coming from new experiments. Of particular interest was the report of the merging of compact torus plasmas, a technique that could possibly lead to a means for continuously maintaining such entities.

In the second category of review papers, subjects of general interest, the four papers given included: a review of reversed-field Z-pinch work (J. DiMarco, LANL); a review of the application of particle beams to compact torus research (S. Robertson, Irvine); a general discussion of impurity radiation issues (D. Post, PPPL); and a review of the theory of anomalous transport in toroidal devices (N. Krall, Jaycor).

DiMarco: In that they seek a minimum-energy state, reversed-field Z pinches, such as the ZT-40 at LANL, share physics with Spheromaks; in that their plasmas are large aspect ratio entities of toroidal rather than spherical topology, they do not. Nevertheless, the transport processes involved in each may turn out to be similar. Determining whether or not this is the case, however, must await the impurity clean-up of Spheromak plasmas, a condition now adequately achieved in ZT-40, greatly aided by the circumstances that, relative to impurity radiation rates, heating levels are much higher than is presently the case in Spheromak plasmas.

Robertson: Particle beams have played a role in fusion research since its earliest days. Their earliest entry into the subject of field-reversed plasmas comes through work on the ASTRON concept of Christofilos. Since those early experiments, new techniques have appeared, in particular high current electron and ion diode generators, that benefit both the ASTRON concept and newer ones. In the Cornell experiment of Fleischmann and co-workers, field-reversing ASTRON-type electron rings, recently translated and magnetically compressed, have been studied. Most recently it has been found possible to embed these rings in a background plasma within which diamagnetic currents have been induced, leading to field-reversed entities that consist of a mixture of circulating high energy electrons and of currents carried in the background plasma. Attention is also being given to the possibility of creating such hybrid particle ring-plasma entities with energetic ions derived from pulsed diode generators. In work at Irvine, it has been shown that very high current ion beams can be transported across a magnetic field (and, presumably, into a field-reversed configuration). The technique, involving the presence of space-charge neutralizing electrons and the production of a transverse electric field by polarization, may become important for the creating and/or sustaining of field-reversed plasma entities.

D. Post: Owing in large part to interest in the subject stimulated by impurity problems in tokamaks, the physics of impurity radiation is by now well understood. Computer codes are now available to model almost any situation of interest in fusion research. These codes, applied to compact torus experiments, provide additional confirmation that their present performance is limited by power losses to impurity radiation, which is clamping the electron temperature and thereby shortening the magnetic field decay time through attendant ohmic losses in the plasma.

N. Krall: A central issue for all toroidal confinement systems is that of cross-field transport, known to be anomalous in virtually all such systems. A starting point for the theoretical treatment of anomalous transport is the quasilinear theory. In the context of field-reversed systems, this formalism has been applied with success to the case of the FRTP. Here the unstable wave during the transport is taken to be the lower hybrid wave. As shown by Linford and Hamasaki, the analysis yields a scaling for confinement times varying as R^2/a_i, plasma radius (to maximum density) squared, divided by mean ion gyroradius. This scaling seems to fit the experimental results well, over a range of $40 \leqslant R^2/a_i \leqslant 120$ cm ($25 \leqslant \tau \leqslant 65$ μs). Whether this scaling will continue to larger values of the scaling parameters, thereby allowing much larger τ values, is of course not yet known.

In these regimes, one expects other sources of anomalous transport, such as resistive interchanges, and trapped electron modes. These have, of course, been studied extensively in connection with tokamak theory. How they will apply to compact toruses is not clear at this time. What is clear, however, is that one cannot *a priori* assume that anomalous transport will necessarily be negligible in such systems. It is, therefore, fortunate that one need not achieve anything approaching classical transport rates to achieve adequate confinement for fusion purposes in a compact torus system: There is a "margin of safety."

In the poster sessions, the papers submitted spanned the spectrum of compact torus research. A random selection includes:

1. studies of the onset time of rotational instabilities in a field-reversed configuration (FRC) plasma; T. Nogi et al. (Nihon University, Japan)
2. initial operation of FRX-C (the new LANL compact torus facility); W. T. Armstrong et al. (LANL)
3. analytic model of radiation-dominated decay of a compact toroid; S. Auerbach (LLNL)
4. Spheromak experiments in Proto S-1C; M. Yamada et al. (PPPL)
5. particle transport in FRCs, M. Tuszewski (LANL).

Considering the totality of the poster papers, and comparing them broadly with the work reported in the previous (third) symposium, some evident advances can be seen, both in experiment and in theory. In Spheromak experiments, a much better understanding of the tilting and shifting instabilities and their control has been gained. At the same time, the essential role played by impurity radiation losses in limiting lifetimes has been made clear, and has been confirmed by theory and by computer code calculations. In FRTP research, new facilities have been brought into operation, and a better experimental understanding has been gained of the limits on lifetime of the plasma entities, including plausible theoretical scaling laws. More generally, it appears that the groundwork has now been laid for the next round of improvements in the performance of compact torus systems, improvements that could include a major increase in the electron temperature and, presumably therefore, the lifetime of Spheromak plasmas.

As noted earlier, the symposium was followed by a joint U.S./Japan workshop on compact torus research. The mode of the workshop was, by definition, less structured, leaving more time for detailed discussion. Highlights from the workshop included:

1. a discussion of the very interesting Japanese work on the merging of two Spheromak configurations
2. recent Cornell work on hybrid electron ring-plasma FRCs, including experiments on inducing circulating currents in the plasma.

Summarizing the week's activities, it can be fairly said that compact torus research has, in its newer areas, graduated from a purely exploratory phase to one of more clearly defined goals, with progress toward those goals already being made. In the older approaches, such as those of particle rings and the FRTP, new facilities are appearing, and with them, improved understanding of the physics issues involved. Specifically, the stability of particle ring-plasma hybrids is being explored both theoretically and experimentally (Cornell); the radial transport and rotational instability of FRTPs is being explored, both in the United States (LANL and Math Sciences N.W.) and in Japan (Nihon University). Perhaps of greatest significance is the fact that it is now being widely recognized that MHD stable FRCs of a variety of forms can exist and that these configurations could have a very important role to play in the development of fusion power, particularly with respect to their intrinsic size advantage and their potential with respect to fusion systems employing advanced fuels.

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Editor's Comment: *This summary will be used as part of the proceedings from the symposium and workshop. The proceedings will have a limited distribution although some copies may be obtained by contacting Dr. Richard Post, LLNL.*

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