MEETING REPORT

SUMMARY OF THE SIXTH TOPICAL CONFERENCE ON PLASMA DIAGNOSTICS, HILTON HEAD ISLAND, SOUTH CAROLINA, MARCH 9–13, 1986

The Sixth Topical Conference on Plasma Diagnostics was jointly sponsored by the American Physical Society, the Department of Energy/Applied Plasma Physics Division, the Princeton University Plasma Physics Laboratory, and the University of Rochester, Laboratory for Laser Energetics. The meeting provided a forum for presentation and discussion of developments in diagnostic techniques for high-temperature plasmas, with the emphasis on those used in the study of magnetically and inertially confined fusion research plasmas.

The meeting had 183 registered participants, the majority of whom were from national and university laboratories in the United States and Europe. The meeting was held in seven sessions. Each session consisted of three invited talks, each of which summarized the author's work in the area under discussion, and 15 to 30 contributed poster presentations. In order of their presentation, the sessions were: particle diagnostics; laser- and particle-probe-based diagnostics; computer support for diagnostics; infrared and far-infrared diagnostics; optical, ultraviolet, and extreme ultraviolet diagnostics; diagnostic systems and other applications; and x-ray diagnostics.

Several themes ran through the presentations:

1. Diagnostics for previously unmeasured plasma parameters are becoming available, for example, the Faraday rotation measurements of the current density profile in the TEXTOR tokamak {H. Soltwisch [Institut für Plasmaphysik (IPP), Jülich]}.
2. Established diagnostic methods are being refined to provide more detailed information by such techniques as two-dimensional spatial imaging and tomographic data analysis.
3. The diagnostic needs of reactor-like plasmas are beginning to be addressed, for example, alpha-particle diagnostics are being developed.

The latter subject was addressed in a workshop on diagnostics for the compact ignition tokamak, which followed the conference. Following is a summary of each session.

In the first session, particle diagnostics, O. N. Jarvis [Joint European Torus (JET)] described work on detailed neutron spectrometry on JET in preparation for the deuterium-tritium phase of JET operation. In addition to determining whether or not the neutrons produced are of thermonuclear origin, neutron spectrometry allows high-energy tails in particle distribution functions, such as those produced by auxiliary heating, to be measured, and should provide measurements of deuteron and triton densities in reactor plasmas. S. J. Zweben [Princeton Plasma Physics Laboratory (PPPL)] spoke on approaches to the diagnostics of alpha particles. A simple scintillation detector for the measurement of fast (energy > 0.5 MeV) escaping alphas is being tested on the Tokamak Fusion Test Reactor (TFTR), and it should be possible to measure the density of slow (0.01 to 0.5 MeV) confined alphas using charge-exchange recombination spectroscopy (CXRS). However, techniques for the observation of the important fast (0.5 MeV < energy < 3.5 MeV) confined alphas have not yet been developed. In space plasmas, very detailed measurements of particle densities, energies, flow velocities, and magnetic fields are possible, as described by S. J. Bame (Los Alamos National Laboratory).

The posters of the first session were devoted primarily to neutron diagnostics of inertial confinement fusion plasmas, neutron and alpha-particle diagnostics for TFTR, and neutral particle diagnostics for tokamaks and tandem mirror endloss measurements.

The second session dealt with laser- and particle-probe-based diagnostics. The majority of the presentations dealt with Thomson scattering measurements or heavy ion beam probes for plasma potential measurements. D. W. Johnson (PPPL) spoke on multichannel Thomson scattering systems with high spatial resolution. Such systems are now used on all the large tokamaks. Several posters described variations on the traditional Thomson scattering measurements: an edge Thomson scattering system for TFTR [B. Grek et al. (PPPL)], the possibility of using the TFTR Thomson scattering system for q-profile measurements [A. Brizard et al. (PPPL)], a two-dimensional Thomson scattering system for the Advanced Toroidal Facility {R. Kindsfather et al. [Oak Ridge National Laboratory (ORNL)]}, the use of Thomson scattering to measure alpha-particle densities [R. K. Richards and D. P. Hutchinson (ORNL)], and a laser scattering system for $S(\omega,\boldsymbol{k})$ measurements [R. E. Kirk et al. (Culham)]. In the area of heavy ion beam probes, the use of such a probe to make edge density, temperature, and space potential measurements was presented by W. C. Jennings et al. [Rensselaer Polytechnic Institute (RPI)], and a method for making simultaneous measurements of radial and poloidal wave numbers using a heavy ion beam probe was discussed

by K. A. Conner and T. P. Crowley (RPI). C. M. Surko (AT&T Bell Laboratories) spoke on a technique for studying particle transport in tokamak plasmas in which neutral positronium atoms are injected into the plasma, are ionized, and the flux of annihilation radiation produced as the positrons strike a limiter is measured. Also of interest were the probe-based measurements of magnetic field reconnection and wave and particle interactions in a low density and temperature laboratory plasma reported by W. Gekelman [University of California, Los Angeles (UCLA)].

As plasma experiments become better diagnosed and individual diagnostics produce more data, data acquisition systems are faced with the problems of acquiring, processing, and displaying large amounts of data in relatively short periods of time. These issues were the subject of the third session, computer support for diagnostics. D. J. Williams [Johns Hopkins University (JHU), Applied Physics Laboratory] spoke on data acquisition and display in space plasma physics. Because the magnetic and electric field and particle distribution function data obtained by space probes span large ranges in frequency, intensity, and energy and cover long time periods, compact data displays are needed for physicists to be able to identify interesting data subsets for detailed analysis. Color plots of the compressed data are effectively used for this purpose. A number of presentations described the structure of data acquisition systems for entire plasma experiments. The trend in the larger experiments is to use different computers for machine control, data acquisition, and data analysis. The use of computers dedicated to individual diagnostics and coupled to a larger data analysis system appears likely to become common in the future. Plans for implementation of this concept on the ASDEX-Upgrade experiment were presented by F. Hertweck (IPP, Garching). The MDS/MIT data system, described by T. W. Fredian and J. A. Stillerman [Massachusetts Institute of Technology (MIT)], is a general purpose VAX-based data acquisition and analysis system that can be easily applied to a variety of diagnostics. Another trend seen in many of the presentations is the use of relational data bases for discerning trends in data.

Infrared (IR) and far infrared (FIR) diagnostics, which were the subjects of the fourth session, have been traditionally used mainly for measurement of electron temperature from electron cyclotron emission (ECE) and electron density via FIR interferometry. However, a number of the presentations showed that IR and FIR diagnostics have applications in the measurement of other plasma parameters. In addition to the previously mentioned Faraday rotation measurements of the current density profile on TEXTOR, observation of Faraday rotation of FIR laser light on TFTR was reported [C. H. Ma et al. (ORNL)]. Thus, it appears possible to make detailed measurements of the current density profile on tokamaks, an important parameter that has not been routinely measured in the past.

A significant development in FIR interferometry was reported by E. J. Doyle (UCLA) in his invited talk on measurement of two-dimensional density distributions on the Microtor tokamak using phase-imaging interferometry. Two probe beams, expanded to completely fill orthogonal views of the plasma cross section, were imaged onto two 20-channel detector arrays. Tomographic techniques were used to reconstruct the two-dimensional density profiles without *a priori* assumptions as to their shape. The profiles were found to be asymmetric in some cases. Another application of FIR diagnostics is the measurement high-energy tail of the electron distribution function during lower hybrid current drive on the Alcator C tokamak described by I. H. Hutchinson (MIT). The ECE measurements were combined with x-ray bremsstrahlung data to reconstruct the distribution function. In the area of FIR scattering, homodyne spectroscopy has been applied to the measurement of the frequency spectra and wave propagation direction of low-frequency density fluctuations in TEXT tokamak plasmas [D. L. Brower (UCLA)]. Several of the poster presentations addressed the uses of optically thin ECE for plasma diagnostics: It appears to be possible to use the extraordinary mode third harmonic or the ordinary mode second harmonic of the ECE from TFTR to measure the electron density {F. J. Stauffer and D. A. Boyd [University of Maryland (UM)]}, and perpendicular ECE from hot (100- to 400-keV) electrons in the thermal barrier region of the TMX-U tandem mirror experiment has been used to measure the hot electron density and temperature {R. A. James [Lawrence Livermore National Laboratory (LLNL)]}. The temperature and loss-cone-angle of the distribution function of the hot electrons in the axisymmetric plug plasma of the TARA tandem mirror device have been measured using ECE [S. K. Guhuray (UM)].

The fifth session was devoted to optical, ultraviolet, and extreme ultraviolet diagnostics. Charge-exchange (CX) recombination spectroscopy has become a mature diagnostic technique; it is routinely used on several tokamaks to measure the ion temperature and plasma rotation velocities. R. P. Seraydarian and K. H. Burell [GA Technologies, Inc. (GA)] described a multichannel CXRS system for the DIII-D tokamak that will measure radial profiles of ion temperature and both toroidal and poloidal rotation velocity profiles. Detailed measurements of impurity densities, radiative losses, and sources are being made on JET, as discussed in the invited talk by K. Behringer (JET). He also reported CXRS measurements of the central ion temperature in JET using deuterium line emissions excited by CX recombination with a heating neutral beam. Measurements of the outer half of the ion temperature profile on the TEXT tokamak using the far wings of the H_α line were presented in a poster by R. D. Bengston et al. (University of Texas); it should be possible to extend these measurements to the plasma center when the TEXT diagnostic neutral beam is operational. W. P. West (GA) spoke on plasma density and poloidal magnetic field measurements in TEXT using spectroscopy of an injected lithium beam. The possibility of making measurements of the poloidal magnetic field in tokamaks using the Zeeman effect in CX excited lines was discussed in the poster by D. Wroblewski and H. W. Moos (JHU). Multichannel spectrographs that allow a wide region of the spectrum to be observed in one discharge are now widely used in plasma spectroscopy. Of interest in this area was a space and time resolving extreme ultraviolet spectrograph described by D. Content et al. (JHU).

The presentations of the sixth session, diagnostic systems and other applications, covered a variety of diagnostics and plasma experiments. The Nova facility is now operating; the early experimental results were summarized by E. M. Campbell et al. (LLNL). The important edge region of tokamak plasmas is becoming better diagnosed: In his invited talk, D. Manos (PPPL) described several types of probes used on TFTR for the study of plasma/surface interactions and particle and energy transport in the plasma edge. Microwave and FIR diagnostics will benefit from the development of gyrotrons that can operate in wavelength ranges where microwave tubes and lasers are impractical [P. Woskoboinikow (MIT)]. Gyrotrons have been operated at frequencies up to 650 GHz

and have been made continuously tunable over the 100- to 330-GHz range. New diagnostics, such as three-dimensional plasma imaging with many detector arrays, should become possible using these gyrotrons. A gyrotron scattering diagnostic will be used on TARA to study instabilities such as the drift cyclotron loss cone. Several posters presented aspects of the diagnostic neutral beam [G. Schilling et al. (PPPL)], which is beginning operation on TFTR. It will be used in conjunction with several other diagnostics, in particular a CXRS system and the CX neutral particle analyzers.

The trend toward tomography was seen in the analysis of asymmetric radiation profiles on TFTR based on data from two perpendicular bolometer arrays [J. E. Schivell (PPPL) and C. E. Bush (ORNL)]. On the PBX tokamak, comparison of radiated power profiles from a tangentially viewing bolometer array and a poloidal array provided information on poloidal asymmetries in the profiles [S. F. Paul et al. (PPPL)].

X-ray diagnostics were the subject of the seventh session. X-ray measurements are particularly important for diagnosing laser-imploded targets; B. Yaakobi (University of Rochester) presented work in this area. Absorption lines are formed in the target tamper out of the continuum emitted by the hotter core plasma. The tamper $\rho\Delta R$ is derived from the area between these lines, and the tamper temperature is obtained from the relative intensities of the lines. Doubly diffracting crystals are used to do two-dimensional imaging of emissions from signature layers in spherical targets. Several presentations dealt with x-ray imaging of laser-produced plasmas. J. H. Underwood (Lawrence Berkeley Laboratory) discussed high-energy x-ray microscopy of these plasmas. The spatial distribution of the x rays emitted by the hot plasma can be measured with reasonable resolution by using multilayer reflectors to extend the energy response of x-ray microscopes to 10 keV, while retaining good spectral sensitivity. X-ray diagnostics also play an important role in magnetically confined fusion plasmas. E. H. Silver (LLNL) reviewed the x-ray diagnostics used on the TMX-U tandem mirror. Tomographic analysis of data from two-dimensional x-ray imaging has been used on JET to study magnetohydrodynamic activity, particularly sawteeth, with good spatial and temporal resolution [H. U. Fahrbach et al. (JET)]. An x-ray imaging system for performing similar measurements will be used on TFTR [L. C. Johnson et al. (PPPL)]. Another application of x-ray imaging on tokamaks was the observation of centrally peaked impurity profiles following pellet injection in Alcator C [R. D. Petrasso et al. (MIT)]. X-ray detector arrays with different filters were used to measure central carbon and molybdenum profiles; the carbon profile was close to the neoclassical prediction. Also on Alcator C, radial profiles of the Rydberg series of lines emitted by helium-like argon were measured and used to deduce the thermal neutral density profile [J. E. Rice et al. (MIT)]. High resolution spectra of the K_α lines of metallic impurities have been used to obtain the central ion temperature and plasma rotation velocity in TFTR [M. Bitter et al. (PPPL)]. Measurements of the x-ray bremsstrahlung emission during lower hybrid current drive on the Princeton Large Torus tokamak have been used to measure non-Maxwellian tails in the electron distribution function [S. Von Goeler et al. (PPPL)].

In summary, the presentations of the conference dealt with either the refinement of an established diagnostic method, for example, the trend toward two-dimensional measurements, or with the development of techniques for the measurement of previously unmeasured plasma parameters.

The proceedings of the conference will be published in a dedicated issue of *Review of Scientific Instruments*.

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