SUMMARY OF THE FIFTH CONFERENCE ON HIGH TEMPERATURE PLASMA DIAGNOSTICS, SEPTEMBER 16-20, 1984

The conference consisted of invited talks and contributed poster papers in the following areas: x-ray diagnostics, optical and ultraviolet diagnostics, infrared (IR) and far infrared (FIR) diagnostics, systems and applications, laser and particle probes, and particle diagnostics. A few selected results are described here [primarily of interest to reversed-field pinch (RFP) plasmas].

X-RAY DIAGNOSTICS

R. H. Day described applications of layered synthetic microstructures (LSMs), which consist of alternate layers of a high-Z metal (such as tungsten) and a low-Z material (such as carbon) with thicknesses of ~10 Å or greater. LSMs can reflect x rays in the 10- to 300-Å range, which falls in between the ranges of crystals (1 to 10 Å) and diffraction gratings (1000 to 20 000 Å). The layer thicknesses can be graduated in the vertical direction (perpendicular to the layers) to control reflectivity and energy resolution, and in the lateral direction to vary the wavelengths that are reflected at different locations. An 8-channel spectrometer has been made using an LSM with NE-111 scintillation detectors and photomultiplier (PM) tubes. A 1-deg beryllium mirror is used as a prefilter to reduce the heat load on the LSM.

N. Ceglio [Lawrence Livermore National Laboratory (LLNL)] reported progress on development of an x-ray laser. They use a 450-ps pulse of a 0.53-μm laser with a power density of 5×10^{13} W/cm^2 onto a neon-like selenium target, 1 cm long with a 0.02-cm^2 area. A gain at 206 and 209 Å is observed for ~200 ps and they are looking for a dramatic narrowing of the output angular distribution (from 10^4 to $>10^6$ W/sr) to indicate that lasing has occurred.

J. Kiraly et al. have developed an electron temperature measurement for the Tokamak Fusion Test Reactor (TFTR), using an array of 64 silicon surface barrier x-ray diodes looking along 10 to 30 chords, with various metallic foil filters in front of the diodes. Known x-ray spectra, including line emission, are used in a computer program that derives T_e from the diode data. The Be-Sc filters are used to avoid regions of prominent line emission. The results are in excellent agreement with electron cyclotron heating and Thomson scattering measurements. This technique is simpler and more reliable than Thomson scattering, and it yields T_e every 2 ms. It will also be attractive for the ohmically heated toroidal experiment (OHTE)/RFP plasmas. R. Decoste and P. Noel (Hydro-Quebec, Varennes, Canada) have studied the theory of x-ray tomography of plasma to yield two-dimensional contours, showing islands, etc. They plan to use six arrays with a total of 72 x-ray diodes to view the Varennes tokamak. Several other papers also described multichannel x-ray imaging systems using either scintillation detectors or charge-coupled devices (CCDs).

OPTICAL AND ULTRAVIOLET DIAGNOSTICS

David Register (Phillips Petroleum Company) described results of spectroscopic measurements on OHTE with a 512-channel diode array, and the design of his vacuum ultraviolet (VUV) monochromator. Benton Howell [Los Alamos National Laboratory (LANL)] reported Doppler broadening measurements of T_i in ZT-40M using a 7-channel VUV polychromator. They see T_i values rising steeply to a high peak (500 eV), decaying rapidly to an intermediate value (comparable to T_e), then rising briefly to a lower peak at the end of the discharge, which is similar in shape to some results from OHTE.

The Joint European Torus (JET) team reported Z_{eff} from absolute measurements of the continuum at 523.5 nm. The Z_{eff} decreases from ten at low currents to about four at high currents. They use optical fibers to transmit focused plasma light 100 m to their monochromators, filters, and detectors, so that these instruments can be located in a low-radiation zone.

An image-intensifier/CCD camera system has been developed for the Thomson scattering system on D-III (J. Smith et al.). A similar system may be useful for viewing the two-dimensional distribution of radiation emitted at a given wavelength, using an appropriate filter.

G. E. Busch (KMS Fusion) described a novel technique for recording four holograms taken at different times (20-ps exposures, taken every 75 ps) on the same film. The scene beam goes through the plasma, and the four reference beams impinge on the film from different angles. Viewing the film from those various angles reconstructs the four different fringe patterns.

LASER AND PARTICLE PROBES

R. J. Fonck [Princeton Plasma Physics Laboratory (PPPL)] reviewed charge-exchange (CX) recombination spectroscopy. The CX recombination reactions occur when fast neutral atom beams interact with plasma ions. The beams may be for plasma heating (such as D^0), or especially for diagnostics [lithium beams on ASDEX, TEXT, and Nagoya Bumpy Torus (NBT)].

Attenuation of the beam is determined primarily by the local electron density. The Doppler spread of the spectral lines gives a measure of the ion distribution function (temperature and rotational velocity). The crossed beam experiment (neutral beam and line of sight of the monochromator) provides good spatial resolution, without the need for Abel inversion. The main disadvantage of the technique is that very high-energy beams are needed for penetration into large, high-density plasmas. In those cases, lower energy beams are still useful for probing edge regions and divertors.

Internal magnetic fields can be determined from the Zeeman shift. K. Kadota et al. described measurements of the internal magnetic field in NBT determined by Fabry-Perot measurement of the Zeeman splitting of an injected lithium beam. In some cases, a probing laser beam is used to excite the injected beam atoms. Such work is under way on ZT-40 (P. G. Weber and G. A. Wurden) and on TEXT (W. P. West and D. M. Thomas), but results are not yet available. Weber and Wurden use intracavity absorption of a dye laser that is rapidly scanned across the Zeeman lines to attain very high sensitivity (near laser threshold) and immunity to mechanical vibrations. From comparison of vapor cell measurements with ^{6}Li and ^{7}Li lines, they determined that the intracavity absorption technique can measure lithium atom concentrations 1000 times lower than ordinary fluorescence.

M. Wickham and N. Lazar (TRW, Inc.) described internal magnetic field measurements on the STM device using dye laser fluorescence of an injected 10-μA barium ion beam and Zeeman splitting. They were also able to measure electrostatic field fluctuations.

K. G. Moses et al. discussed the injection of a heavy atom beam into a plasma. From detection of K-shell x rays, the local electron temperature can be determined, and if absolute intensity calibration is achieved, the electron density can also be determined.

J. A. Gelbwachs (Aerospace Corp.) reviewed the use of laser-induced fluorescence for measuring impurity atom concentrations. The saturation photon emission rate is roughly the reciprocal of the excited state lifetime, or $\sim 10^8$ photon/atom·s. Using a dye laser to excite sodium atoms in a background of argon gas, concentrations of sodium as low as 200 atom/cm^3 were detected, which is a time average of only 0.2 sodium atoms in the laser beam volume! Laser fluxes of ~ 10 kW/cm^2 are desirable for attaining good signal-to-noise ratios. However, long counting times (seconds) may be needed at low concentrations.

D. A. Evans et al. reported measurements of neutral deuterium atom concentrations in HBTX-1A using laser-induced fluorescence of D-alpha and D-beta lines (6561 and 4861 Å), and observed that D beta had a much better signal-to-noise ratio (factor of 3). The measured densities ranged from 10^{12} cm^{-3} at the edge to $< 10^9$ near the plasma center.

R. A. Stern (University of Colorado) explained how beam motion reduces the effective Doppler broadening, permitting more accurate Zeeman measurements than with thermal ions. He pointed out that E and B fields can have overlapping effects, in view of the relativity relations $E(v) = E(0) + vxB/c$, $B(v) = B(0) - vxE/c$, and compared the magnitudes of the Stark and Zeeman effects. He described a time-of-flight (TOF) technique where one laser beam excites a metastable state, the excited atom flies to another location, and then a second laser beam excites a higher state, from which fluorescence radiation is observed. From the number of photons observed at various times after the first laser pulse, the velocity distribution $f(v)$ of the atoms can be calculated. He also discussed the application of two-photon spectroscopy to the measurement of internal magnetic fields. If the two exciting photons come from opposite directions with equal wavelengths, then no Doppler shift is observed on the resulting emitted photons, so small Zeeman shifts can be detected.

J. A. Cobble reported extension of Thomson scattering measurements down to densities of 2×10^{11} cm^{-3} in EBT-S. M. Bassan et al. described the Eta-Beta II system for seven-point Thomson measurements, but no RFPs have reported any profile results yet. W. A. Peebles et al. [University of California, Los Angeles (UCLA)] described collective Thomson scattering of IR laser beams at small angles to measure T_i and fluctuations.

IR AND FIR DIAGNOSTICS

P. E. Young (UCLA) described the use of microbolometer arrays for chord-averaged plasma measurements. They are useful in the FIR and millimetre regions. Thin strips of conductor are deposited on silicon and tapered to tiny dots of bismuth, which form resistive junctions 2×3 μm. The conducting strips are spaced half a wavelength apart and function as antennas, picking up incident radiation from the plasma. The induced currents heat the bismuth junctions, and the change in temperature causes a change in resistance, which is detected with a resistance bridge. A 20-channel detector array was used with a heterodyne interferometer to measure line density profiles in the Microtor tokamak, and the results Abel inverted to give $n_e(r)$. For comparison, every other channel was ignored and ten channels were also Abel inverted. The distortion and loss of accuracy caused by going from 20 to 10 channels are dramatic. Most of the large experiments are developing FIR interferometers, because the wavelength is long enough for high sensitivity, yet short enough to avoid cutoff, and insensitive to mechanical vibrations. Such interferometers can also provide useful information about fluctuations.

A five-channel Faraday rotation measurement has been performed by C. H. Ma et al. on the Impurity Studies Experiment, and a multichannel system is under development by R. M. Erickson et al. on ZT-40. Unless the number of channels is very large, however, the errors resulting from the Abel inversion will nullify the value of the measurements for discriminating between rival theoretical field profiles.

PARTICLE DIAGNOSTICS

R. K. Smither et al. (Argonne National Laboratory) described a foil activation method for measuring T_i via neutron emissions from deuterium-tritium plasmas. The ratio of yields from ^{54}Fe$(n,2n)$ and ^{27}Al$(n,2n)$ reactions is very sensitive to T_i, because these reactions both have threshold energies near 14 MeV.

H. W. Hendel et al. (PPPL) described the use of Bicron 720 ZnS detectors for obtaining neutron count rates on TFTR. Recoil protons from a thin plastic sheet excite the ZnS screen, and a curved light pipe leads the photons to a PM tube. A 90-deg bend shields the PM tube and electronics from the high neutron flux. The detectors have a short decay time (200 ns), so high count rates can be measured.

Several experiments use ^{235}U fission detector systems for measuring neutron emission rates. M. S. Derzon et al. (LLNL) are developing a high-pressure (200-atm) ^3He scintillation detector, which is expected to provide very good neutron energy resolution (<5% at 2.5 MeV).

M. T. Swinhoe (JET) described neutron measurements on JET. In addition to fission counters, they have a detector filled with 3 atm of ^3He and 6 atm of argon. It is located over a hole in a concrete floor 20 m above the torus, and it can attain an energy resolution of 60 keV, which is adequate to measure the observed 120-keV width of the deuterium-deuterium neutron peak ($T_i = 2.7$ keV).

C. A. Bunting et al. reported ion temperature measurements on HBTX-1A using a CX neutral atom energy analyzer. They measured T_i up to 120 eV, for plasma currents up to 250 kA, and noted 10-kHz fluctuations on the detector signals, which appear to correlate with magnetic field fluctuations.

Several papers described neutral atom energy analyzers, using *E*-parallel-to-*B* geometry and surface barrier detectors or microchannel plate detectors. For high-density pinches, however, such detectors view only the plasma edge region.

J. D. Strachan (PPPL) reviewed methods for measuring fusion products in tokamaks. The 3-MeV protons emitted by the D(d,p)T reaction and the 14.7-MeV protons from the ^{3}He(d,p)^{4}He reaction have been detected. The energy distribution of these reaction products is a good measure of T_i.

DIAGNOSTIC SYSTEMS AND APPLICATIONS

Franz Jahoda (LANL) described the peculiar properties of barium titanate ($BiTiO_3$), which make it useful as a "phase conjugate mirror." Laser beams reflected from it produce the phase conjugate of the incident beam, which means that phase aberrations produced by going through refractive media (glass, plasma) are nullified, so that a Michelson interferometer with such a mirror would measure nothing at equilibrium. The response time of the mirror is slow, however, so rapid changes of refractivity do produce fringes. Hence, the interferometer is sensitive not to refractive index, but to the rate of change of the refractive index. Such a mirror might also be useful with an intracavity absorption experiment to get rid of unwanted phase sensitivity.

Sid Medley et al. (PPPL) and M. J. Moran (LLNL) described potential measurements of gamma rays emitted during fusion reactions. Although the branching ratios for gamma emission are very small (10^{-7} in some cases), the resultant gammas can provide useful information about the plasma.

G. A. Cottrell et al. (GA Technologies, Inc.) described a technique for determining plasma profiles from a few chord measurements. Instead of assuming an approximate shape or doing a matrix inversion, an iterative process that proceeds toward the profile having the "maximum entropy" is performed; hence, it is deemed to be the most probable, given the limited data available.

The conference proceedings will be published in the *Review of Scientific Instruments*. The Sixth Topical Conference on High Temperature Plasma Diagnostics will be held in the spring of 1986. The chairmen for that conference will be John Soures, Laboratory for Laser Energetics, University of Rochester, and Ken Young, PPPL.

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SUMMARY OF THE FUSION POWER ASSOCIATES' SYMPOSIUM ON NEW DIRECTIONS IN MAGNETIC FUSION, ROCKVILLE, MARYLAND, OCTOBER 3, 1984

THE SYMPOSIUM

Congressional action on the FY 1985 fusion budget resulted in funding cutbacks and called for the preparation by the U.S. Department of Energy (DOE) of a new fusion program plan. This symposium was convened for the purpose of receiving a presentation from John F. Clarke, head of the U.S. magnetic fusion program, on the first draft of the new policy plan and to conduct panel discussions on several important topics related to the policy plan. The panel discussions covered four areas: the role of industry, the role of tokamak ignition device options, the role of improved fusion concepts, and the role of technology research and development (R&D).

PLANNING

In his opening remarks, Fusion Power Associates' president Steve Dean stated that "there is a continuing need to develop a spirit of cooperation among all the organizations that are working on the program because we are a small community in a country that has got a lot of fish to fry.... We have a lot of work to do to get people to understand what it is we do and why it is important." Dean pointed out that, since 1976, we have not been getting the funding, nor making facility commitments, that would allow us to claim we are on a path to a scheduled endpoint of operating a power plant. "It is the burden of a plan or planning activity to explain, as best one can, how one is going to get from where one is to where one wants to go," he said. "A real plan must contain milestones, activities needed, schedules and costs." Dean noted that in addition to basic physics and technology programs, proof-of-principle experiments, and major scaleups of those experiments, it is necessary "to do some other things, like make some energy and study some engineering issues and learn what to do with fusion, if eventually we are to get to commerical fusion power.... This will require building some energy-producing experimental reactors."

NEW DIRECTIONS

In his keynote address, describing the new draft policy plan, John Clarke said that, technically, the fusion program is ready to carry out an ignited burning plasma experiment but that, politically, there is little perceived requirement for