# MEETING REPORT

## SUMMARY OF WORKSHOP ON ESTABLISHING THE PHYSICS BASIS NEEDED TO ACCESS THE POTENTIAL OF COMPACT TOROIDAL REACTORS, OAK RIDGE, TENNESSEE, JULY 19-22, 1994

### INTRODUCTION

A workshop on establishing the physics basis needed to access the potential of compact toroidal reactors was held July 19-21, 1994, at Oak Ridge National Laboratory, Oak Ridge, Tennessee. The presentations and discussions at the workshop covered the low-aspect-ratio ($A$) tokamak and the spheromak. The findings of the workshop, summarized here, covered

1. reactor and pathway
2. plasma confinement
3. magnetohydrodynamic (MHD) equilibrium and global stability
4. MHD beta-limit studies
5. plasma heating and current drive
6. divertor power and particle handling
7. present device experimental plans
8. action items.

The workshop benefited from advice from R. A. Blanken and S. A. Eckstrand of the Office of Fusion Energy of the U.S. Department of Energy (DOE).

### REACTOR AND PATHWAY

#### Tokamak

The low-$A$ tokamak provides the following reactor advantages relative to the standard and high-$A$ tokamaks:

1. better access for remote maintenance of blanket, shield, and divertor
2. simpler system requiring no inboard blanket, no ohmic, and possibly no poloidal divertor coils
3. potential for stronger vertical stability and fewer or no disruptions, easing design of first wall, blanket, and shield structure
4. possible cost advantages due to smaller core size and lower magnetic fields
5. physics that permits, if desirable, higher wall loading in smaller unit size
6. possibly the only configuration that permits viable advanced fuel reactors.

Major issues for this configuration are

1. unshielded single-turn normal-conducting center leg for the toroidal field coil (TFC), which requires regular replacement (at fluences $\leq$10 MW$\cdot$yr/m$^2$) and generates added radioactive waste
2. divertor design and power handling, which are yet to be developed for any $A$ and may be more challenging for low $A$
3. recirculating power associated with normal-conducting center leg and current drive, which must be minimized.

Systems code calculations for deuterium-tritium and advanced-fuel low-$A$ reactors using the presented physics assumptions were recommended by the workshop.

The low-$A$ tokamak offers the possibility of a steady-state high-volume plasma neutron source (HVPNS) that produces neutron wall loading of 1 to 2 MW/m$^2$ in small, driven, high-current plasmas ($R_0 \approx 0.8$ to 1.0 m, $I_p \approx 6$ to 9 MA). Such a device provides a reduced-cost approach for testing full-function power blankets if high neutron fluence ($\approx$6 MW$\cdot$yr/m$^2$) can be obtained. It would complement the capability of the International Thermonuclear Experimental Reactor (ITER) in testing full-size blankets to a limited fluence ($\approx$1 MW$\cdot$yr/m$^2$). Reliable power blankets are needed to achieve high duty factors in a fusion demonstration power plant.

#### Spheromak

The potential advantages for the spheromak are

1. no need for TFCs, leading to a simplified torus geometry

2. helicity injection current drive, which is projected to be efficient in reactor level devices, assuming development of steady-state helicity injection with small energy losses due to the induced magnetic turbulence
3. the possibility of combining the divertor, helicity injector for current drive, and fueling system and positioning them near the machine axis (small $R$) for vertical access.

The issues facing the spheromak are

1. lack of data on core energy confinement and high beta limit during sustainment
2. unresolved mechanisms and scaling for confinement and beta limits
3. feedback or other stabilization required for global instabilities for discharges lasting beyond the flux conserver timescales.

The normal-conductor TFC center leg introduces an added complexity to the low-$A$ tokamak relative to the spheromak. The external toroidal field, however, produces the high-$q$ tokamak magnetic field geometry with the attending promises of tokamak-like confinement, high beta stability, current drive, and impurity control. The spheromak progress in these areas has been relatively modest in comparison.

## PLASMA CONFINEMENT

### Tokamak

The Small Tight Aspect Ratio Tokamak (START) (Culham Laboratory, United Kingdom) experiment and initial kinetic instability analysis using modeled equilibria and profiles have provided enticing results on plasma confinement in the low-$A$ tokamak.

Confinement results from a mega-ampere, low-$A$ tokamak are needed to develop a more broadly based empirical confinement scaling. Only very limited data are available from START for comparison with scalings; additional information is hoped for from the Current Drive Experiment-Upgrade (CDX-U) [Princeton Plasma Physics Laboratory (PPPL)], the Helicity Injected Tokamak (HIT) (University of Washington), and START with neutral beam injection (NBI) heating. Auxiliary heating with $P_{aux} \gg P_{oh}$ will be needed to develop scalings with confidence.

The experiment will investigate the suppression of trapped particle modes and related turbulence and transport. The initial analysis indicated the following:

1. Increased good curvature at low $A$ reduces the drive for this instability.

2. Strong dependence on $A$ is expected in the range of 1.2 to 1.6 and on $\nu_{*,e}$ at low collisionality.

3. Fluctuation diagnostics in such plasmas will be necessary to evaluate these effects directly.

The experiment will permit study of H-mode physics at low $A$. The present ohmic plasma data provide no information on the L or H mode. Effects of divertor configuration, wall conditioning, and threshold powers on L- and H-mode transitions need to be measured.

### Spheromak

For the spheromak, the most important need is to determine core energy confinement in a steadily sustained, stable discharge. Spheromak experimental physics made significant progress during the decade in which the United States conducted the research; an electron temperature of 400 eV was reached in the final tests on the Compact Torus Experiment (CTX) (Los Alamos National Laboratory).

A strong relationship was recently observed in the reversed-field pinch (RFP) experiment of the Madison Symmetric Torus (University of Wisconsin) between magnetic fluctuations and plasma heat and particle fluxes $Q_r$ and $\Gamma_r$ near the plasma edge.

Magnetic fluctuations and radial transport losses are observed to decrease as the profile of $\lambda = j_{\parallel}(r)/B(r)$ is flattened in spheromaks and in RFPs. As the helicity lifetime increases with electron temperature, this observation leads to the prediction that energy losses will decrease as the spheromak core becomes hotter and, in some simple modeling, that the confinement would be adequate when extrapolated to a reactor. A model of spheromak core confinement based on this mechanism has been developed and indicates favorable extrapolation to a reactor.

The timescale for plasma buildup in this experiment can be shorter than the soak-through time of the flux conserver, so that no externally applied vertical field is required to maintain plasma edge position. No auxiliary heating power $P_{aux}$ would be required for this purpose.

Wall conditioning will be important as in tokamaks; progress in the CTX experiments will be obtained only when discharge cleaning and wall conditioning are done.

## MHD EQUILIBRIUM AND GLOBAL STABILITY

### Tokamak

The following properties characterize the low-$A$ tokamak:

1. Given a simple vertical field (decay index $\geq 0$), the limiter plasma elongation ($\kappa \equiv b/a$) increases to $\geq 2$ and triangularity to $\geq 0.6$ naturally without using plasma-shaping coils as $A$ approaches the ultralow $A$ range of 1.1 to 1.2.

2. This plasma is vertically stable without external control.

3. Strong elongation, triangularity, and toroidicity lead to strong plasma shaping, producing $(I_p q_\psi / a B_{t0})$, which approaches 200 MA/m·T at ultralow $A$. START has produced $(I_p q_\psi / a B_{t0}) \approx 20$ MA/m·T for $A \approx 1.4$ and $\kappa \approx 1.6$.

4. The START plasma has not experienced major disruptions for $A \leq 1.8$, whereas CDX-U plasmas did recently. The causes for the difference need to be investigated.

5. The scrape-off layer (SOL) flux tube connected to the plasma inboard diminishes as $A$ decreases, leaving the SOL mostly diverted without using divertor coils.

6. The PPPL calculations and Tokyo Spheromak-3 (TS-3) (University of Tokyo, Japan) experimental results suggest that plasma tilt can be prevented for the low-$A$ tokamak when $I_p/I_{tf} \leq 2$ and/or $q_\psi \geq 1$. The dependence of this limit on plasma shaping and profiles needs to be clarified.

### Spheromak

Major spheromak plasma stability properties are (a) tilt, shift, and low-$n$ external kinks that can be stabilized by a close-fitting flux-conserver over a resistive wall time and (b) feedback stabilization of these modes on longer timescales. Rotation may provide stability against some modes.

## MHD BETA-LIMIT STUDIES

### Tokamak

Tremendous progress was reported at this workshop in quantitative theoretical analysis of tokamak beta limits at low $A$.

1. For current profiles with $q_0 \sim 1$ and $A$ down to 1.3, the Troyon scaling remains roughly unchanged ($\beta_{Nt}$ rises slightly in some analyses and falls in others), giving $\langle\beta_t\rangle$ up to ~20% without a conducting wall. A standard version of Troyon scaling is used here: $\langle\beta_t\rangle \equiv 2\mu\langle p\rangle/B_{t0}^2 \equiv \beta_{Nt} I_p/aB_{t0}$; $B_{t0} \equiv$ vacuum field at center of plasma midplane.

2. For current profiles with higher $q_0$ ($\geq 2$ and reverse shear in some cases) and nearby conducting walls, higher values of $\beta_{Nt}$ have been found, which results in $\langle\beta_t\rangle$ as high as 25 to 35%. Stable plasmas with a high pressure-driven current fraction and good alignment of plasma current, however, have not been identified for these cases.

3. For ballooning stability alone and for current profiles with high $q_0$ ($\geq 3$ to 5), order-unity values in $\langle\beta_t\rangle$ ($\approx 1.0$) have been found in limiter equilibria with $R_0/a = 1.2$, $\kappa = 2.3$, $\beta_1 \approx 0.6$ to 1.1, $q_\psi \approx 11$ to 22, and aligned current profiles with the pressure-driven currents. Kink mode calculations for these equilibria are in progress.

These results are promising enough that further work should be undertaken to determine if at these values of $\langle\beta_t\rangle$, MHD stable high pressure-driven current fraction modes can be found, with good alignment of plasma current.

### Spheromak

Major results for spheromak beta-limit calculations are as follows:

1. Stability for Mercier modes theoretically limits $\langle\beta\rangle$ [$\equiv 2\mu_0\langle p\rangle/(B_t^2 + B_p^2)$] to ~1 to 3% in standard configurations, whereas $\langle\beta\rangle \sim 5\%$ has been observed experimentally. Peak (core) electron $\langle\beta\rangle \sim 20\%$ was observed in CTX before the profile relaxed, presumably because of instability.

2. Configurations have been designed (e.g., bow tie) that are projected to provide stability against Mercier modes to $\langle\beta\rangle \sim 10\%$.

3. The gradient for $(\mu_0 j_\parallel/B)$, $\nabla\lambda$, drives resistive-tearing modes, which are believed to cause the magnetic reconnection that allows the plasma to approach the Taylor-relaxed state.

4. Spheromak plasmas are calculated to be unstable to resistive interchange modes at all betas. However, the effects of high magnetic Reynolds number $S$ and high drift frequency ($\omega^*$) may contribute to stabilizing these modes or minimizing their consequences at high temperatures and reactor-relevant parameters.

## PLASMA HEATING AND CURRENT DRIVE

### Tokamak

In low-$A$ tokamaks, NBI, ion cyclotron resonance frequency wave, ion Bernstein wave, Alfvén wave, electron cyclotron wave, and lower-hybrid wave are being considered for heating, and NBI and helicity injection are being considered for current drive.

1. Many radio-frequency schemes are expected to present special challenges for high beta studies at low $A$ because of the low field ($\leq 1$ T) and high density expected. (Initial calculations of electron Landau damping, performed after the workshop, look very favorable for fast-wave electron heating at the frequency range of the high ion cyclotron harmonics.)

2. For the next-step mega-ampere experiments, NBI is a straightforward method for heating and current drive. Steady-state cases have been calculated for HVPNS ($I_p \sim 6$ to 9 MA and $Q \sim 1$) using 0.5- to 1-MeV NBI, consistent with the beta limit, energy confinement $\tau_E$, external driven current $I_{CD}$, and significant pressure-driven current ($I_{bs} + I_{dia} + I_{PS}$).

3. The scenarios for noninductive startup and steady-state current maintenance in the presence of high pressure-driven currents need to be developed for future reactor applications.

4. The reduced $R_0$ tends to compensate for the impact of high current and density on current drive efficiency.

5. Helicity injection, as demonstrated by HIT, is an attractive method for tokamak startup. But, its ability to sustain the current has not been demonstrated. Its utility for current maintenance in future large devices will depend on the required power, the impurity generation, and enhanced losses due to magnetic relaxation.

### Spheromak

The spheromak results are as follows:

1. Helicity injection startup and current drive have been demonstrated in several experiments, with (gun-driven) CTX achieving $B > 1$ T due to plasma current alone.

2. The transfer of power and current from the gun to the confinement region in a low-temperature spheromak, such as in SPHEX (University of Manchester, Institute of Science and Technology, United Kingdom), has been shown to be related to an $m = 1$ mode of the central plasma column.

3. This experiment directly measured the dynamo electric fields resulting from $m = 1$ oscillation and turbulence, which transport current to the plasma core. These fields are consistent with the plasma current observed.

## DIVERTOR POWER AND PARTICLE HANDLING

### Tokamak

Divertor effects and questions relating to the low-$A$ tokamak were discussed during the workshop.

1. High heating power $P$ and low $R$ at the divertor strike point in future low-$A$ tokamaks lead to high $P/R$. Here $R$

could be significantly smaller than $R_0$. Near-term devices have $P/R$ in the same range as present large tokamaks.

2. Divertor considerations for low $A$ are similar to those for high $A$. They include space for divertor plates, baffles to confine neutrals in the divertor chamber, strong pumping in the divertor chamber, and impurity entrainment by plasma flow in the SOL.

3. The same divertor solutions will probably apply, but the divertor must provide strong pumping to hold the plasma density below the Greenwald limit to make noninductive sustainment of the plasma current attractive for 90% pressure-driven currents.

4. Large SOL flux expansion for low-$A$ plasmas, seen so far in START, may be useful for controlling heat fluxes; this is a worthwhile test objective for near-term devices.

5. The double-null configuration may be favored for minimizing power exhaust on the inboard side; this needs to be proven.

6. A ballooning limit to the SOL thickness (pressure gradient) is interesting. This needs to be investigated more widely.

7. Can the electrodes for coaxial helicity injection (either for tokamak or for spheromak) do double duty as divertor plates? In this case, can a "detached" plasma be obtained? These potentially attractive techniques need to be investigated.

#### Spheromak

Spheromak configurations appear compatible with a divertor, subject to the foregoing discussion and the absence of a significant toroidal field at the plasma edge.

### PRESENT DEVICE EXPERIMENTAL PLANS

#### Tokamak

At present, there are two ohmic low-$A$ tokamaks in the world: START and CDX-U. HIT is a helicity-injection-driven low-$A$ tokamak. There are three spheromak or near-spheromak low-$A$ devices: TS-3, SPHEX, and the Flux Amplified Compact Toroid (FACT) (Himeji University, Japan).

Regarding near-term improvement plans of present devices, START plans to add an NBI capability to test auxiliary heating, confinement, and beta limit in the 200- to 300-kA range. The CDX-U will increase electron cyclotron heating (ECH) power to 100 kW at 8 GHz in addition to upgrading the ohmic solenoid power supply capability. The HIT plans to add ohmic current drive capability.

An ohmic low-$A$ tokamak is being built and should become operational in late 1994 at the University of Tokyo. The Magnetic Reconnection Experiment (MRX) facility is being readied at PPPL, which can also investigate the near-spheromak low-$A$ regime. The Instituto de Pesquisas Espaciais (Brazil) is building a small spherical tokamak experiment ETE to be ready in 3 yr.

There are several important areas in which the present and near-term devices can contribute toward future experiments at the 1-MA level.

1. One area is in testing of the $q$ limit. As the $q(a)$ is pushed down toward 4 for $A \sim 1.4$, the CDX-U discharges often end in hard disruptions, whereas the START discharges exhibit reconnection events without hard disruptions.

2. In TS-3, the global MHD stability of the ultralow-$A$ ($\geq 1.05$) configuration formed from a spheromak with $q(a) \sim 1$ is another area that has been explored.

3. Strong stabilization of the microturbulence behavior has been calculated for plasmas with $A \leq 1.5$. Transport measurements of microturbulence and confinement for $A \leq 1.5$ can be pursued in the collisionless regimes in CDX-U and START.

4. With auxiliary-heated CDX-U (ECH, 8 GHz) and START (NBI) plasmas, MHD stability behavior at increased beta can be explored.

5. To move toward the ultralow-$A$ regime, one must initiate and form tokamak plasmas without induction. Several promising options such as helicity injection, ECH pressure-driven currents, and compression can be explored in CDX-U, START, HIT, TS-3, SPHEX, and MRX.

6. It is important to develop efficient current maintenance options. Similar to the startup problem, helicity injection and pressure-drive currents are promising options that can be explored on CDX-U, HIT, and SPHEX.

7. The spheromak low-$A$ tokamak continuum can be investigated in the ultralow-$A$ and low-$q$ regimes in the TS-3, FACT, SPHEX, and MRX. In TS-3, the addition of a modest toroidal field has resulted in stabilization of the tilt-like MHD mode. Various spheromak issues can also be pursued, if needed, with possible new experiments on HIT and CDX-U.

#### Spheromak

Device experimental plans for the spheromak were not presented at the workshop.

### ACTION ITEMS

The workshop participants agreed to take actions to bring forth nationally based low-$A$ toroidal experiments at the mega-ampere level in the United States. These critical action items for the low-$A$ tokamak were determined as follows:

1. agree on desirable mission elements for a next-step low-$A$ tokamak
2. determine if there is a role for more than one device (in different scales, presently existing or new)
3. determine device characteristics that follow from each mission element for the large-scale and perhaps smaller scale devices
4. determine the sites that can provide these characteristics and the required costs
5. ask DOE to select site(s) so that a national design effort can be carried out.

*Action Item 1: Desirable Mission Elements for Next-Step Low-A Tokamak Experiment*

Action item 1 was accomplished at this workshop and is presented in Table I in accumulative progression.

*Action Item 2: Mission Elements for Smaller Low-A Tokamak Devices*

For action item 2, it was agreed that there are very important physics activities for ongoing low-$A$ tokamak experiments (HIT, CDX-U) and other possible device upgrades. However, a consensus was not obtained at the workshop regarding when these activities would be completed and whether their continuation or other similarly scaled devices would be needed during operation of the next-step low-$A$ tokamak experiment. Some of the possible mission elements for ongoing or future smaller scale low-$A$ tokamak experiments were agreed to as follows:

1. testing of $q$ limits
2. investigating transport physics mechanisms (turbulences) at low $A$
3. investigating innovative divertor geometries
4. studying disruption characteristics and beta limits under moderate heating
5. developing innovative startup schemes extrapolatable to a next-step low-$A$ tokamak
6. developing innovative current drive concepts extrapolatable to a next-step low-$A$ tokamak
7. studying spheromak configurations and the spheromak low-$A$ tokamak continuum.

These missions roughly correspond to the first three phases of Table I with an emphasis on exploratory studies.

*Action Item 3: Provisional Mission-Driven Device Characteristics for a Next-Step Low-A Tokamak*

Action item 3 was completed at this workshop, and the device characteristics as driven by the mission are provided in Table I.

*Action Item 4: Determination of the Sites that Can Provide These Characteristics and the Required Costs*

It is proposed that each institution interested in hosting the next-step low-$A$ tokamak be asked to evaluate the credits provided by their existing facility to support these device characteristics. In addition, each group should provide rough costs associated with site upgrades needed to support the full set of desired device characteristics. Each institution has the freedom to choose a subset of the device characteristics that effectively uses the existing facility.

*Action Item 5: Request for DOE Selection of Site(s) for Execution of National Design Effort*

The host-site summaries should be brought together for the purpose of calibration by the working group before the end of September, 1994. The results will be forwarded to DOE to facilitate the Department's decision-making process.

No action items were defined for the spheromak research at the workshop. The following material was included after the workshop as an addendum.

A two-step approach is recommended for developing spheromaks, wherein the critical issues are addressed progressively. In the first step, core energy confinement would be investigated in a low-cost short-pulse experiment. The

TABLE I

Desirable Progressive Mission Elements and Required Device Characteristics for Midsize Low-$A$ Tokamaks

| Phase | Proposed Mission Elements | Required Device Characteristics |
|---|---|---|
| Ohmic | Determine the range in $q$ (or $I_p/aB_{t_0}$) for well-confined, stable tokamak plasmas for $A = 1.3$ to $1.8$ | $I_p \sim 1$ MA, $\tau_{flattop} \sim 1$ s |
| Noninductive startup | Develop techniques for plasma startup to full operating current, in the absence of a central transformer | Helicity injection or other noninductive startup system (additional systems can be considered as upgrades)<br>Noninductive current drive system (considered as upgrade) |
| $P_{aux} > P_{OH}$ | Determine energy confinement scaling at low $A$ ($= 1.15$ to $1.8$)<br>Investigate beta and disruption limits in limited parameter range<br>Investigate scrape-off characteristics of low-$A$ plasmas | $P_{aux} \sim 4$ MW, $\tau_{flattop} \sim$ I s, $D^0 \rightarrow D^+$ NBI<br>Inertial-power-handling hardware |
| $P_{aux} \gg P_{OH}$ | Determine beta-limit scaling at low $A$; test effect of nearby conducting wall<br>Investigate disruption behavior of high-$\langle\beta_t\rangle$, low-$A$ plasmas | $P_{aux} \sim 10$ MW, $\tau_{flattop} \sim 1$ s (upgrade requirement depends on $\beta_t$ limits and $\tau_E$ achieved) |
| Long pulse | Investigate high pressure-driven current fraction, high-$\langle\beta_t\rangle$ operating regimes, and approach to steady state at low $A$<br>Test external current drive schemes<br>Steady-state operation in advanced regimes | $P_{aux}$ for $\tau_{flattop} \sim 10$ s, inertial plasma-facing components (PFCs)<br>$P_{aux}$ for $\tau_{flattop} \sim 10^2$ s, actively cooled PFCs |

TABLE II

Mission Elements and Required Device Characteristics for Near-Term Spheromak Experiments

| Phase | Proposed Mission Element | Required Device Characteristics |
|---|---|---|
| Core energy confinement | Demonstrate core energy confinement by quiescent ohmic electron heating to $T_e \sim 0.4$ keV in a sustained, short-pulsed spheromak<br>Evaluate core energy confinement (effective thermal conductivity) and correlate with level of magnetic turbulence<br>Determine beta limits and their relationship with transport<br>Optimize operation of a sustained spheromak (e.g., particle control and helicity match to the plasma)<br>Obtain initial data on long-pulse operation | Plasma equilibrium established by spheromak injection into a conducting flux conserver<br>Plasma formation and sustainment by helicity and power injection from a coaxial gun<br>Helicity injector matched to the plasma to minimize magnetic turbulence<br>Clean vacuum and wall conditions<br>$\tau_{pulse} \geq 2$ ms, $I_p \sim 1$ MA, $P_{aux} \sim 0$<br>Magnetic fluctuation diagnostics |
| Long-pulse experiment | Transfer the equilibrium maintenance from the flux conserver to external poloidal field coils<br>Stabilize the tilt and shift modes on timescales long compared with the soak-through time of the flux conserver<br>Achieve $T_e < 1$ keV<br>Evaluate ohmic heating extrapolation to a reactor<br>Is auxiliary heating required?<br>Study the physics of multi-kilo-electron-volt spheromak plasmas | Vertical field coils to support the plasma<br>Feedback or other stabilization (e.g., via plasma rotation) for the tilt and shift modes<br>Quiescent ohmic heating by the helicity-driven current<br>Divertor to handle particle and power losses<br>Extensive diagnostics set:<br>Density (Thomson scattering, interferometer)<br>Temperature (Thomson scattering, impurity Doppler broadening)<br>Magnetic (pickup loops, motional Stark effect, O-to-$X$ mode conversion)<br>$\tau_{pulse} \geq 100$ ms, $I_p > 1$ MA |

plasma pulse in this experiment would be long compared with the energy confinement time (at a few hundred electron-volts) but short compared with the magnetic field soak-through time of the confining and stabilizing flux conserver. Good confinement results would encourage the second step, wherein a long-pulse experiment would address the confinement physics of high-temperature (>1-keV) spheromaks and stability of equilibria maintained by external poloidal coils. This could be conducted in a mega-ampere low-$A$ tokamak experiment, saving cost and permitting the common use of diagnostics. However, the design of such a facility to address both configurations requires resolution.

The mission elements and device characteristics for the spheromak experiments are provided in Table II.

*Y.-K. M. Peng*

Oak Ridge National Laboratory
P.O. Box 2009
Oak Ridge, Tennessee 37831-8071

*R. J. Goldston*

Princeton Plasma Physics Laboratory
Princeton University
P.O. Box 451
Princeton, New Jersey 08544

*R. J. Colchin*

Oak Ridge National Laboratory
P.O. Box 2009
Oak Ridge, Tennessee 37831-8072

*E. B. Hooper*

Lawrence Livermore National Laboratory
P.O. Box 808
Livermore, California 94550

*S. M. Kaye*
*M. Ono*

Princeton Plasma Physics Laboratory
Princeton University
P.O. Box 451
Princeton, New Jersey 08544

*R. E. Siemon*

Los Alamos National Laboratory
P.O. Box 1663
Los Alamos, New Mexico 87545

*R. Stambaugh*

General Atomics, Fusion Group
P.O. Box 85608
San Diego, California 92186-9784

*A. J. Wootton*

University of Texas at Austin
Austin, Texas 78712

June 2, 1995