**Final Technical Report: Development of a Positronium Atom
Diagnostic Beam to Study Transport in Tokamaks**

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I. Introduction

Anomalous transport is probably *the* key physics issue in magnetic confinement fusion. It severely limits our ability to create and maintain a dense, hot, fusion plasma. There is also good evidence that there is a fundamental lack of understanding in this area, namely the transport of particles and energy induced by waves and fluctuations in magnetically confined plasmas.

The positronium atom beam diagnostic, if successful, can provide a qualitatively new and different way of studying transport in tokamak fusion plasmas. The use of the positron as a thermalized, electron-mass test particle will allow important new tests of current theories of plasma transport. In particular, it could provide unique insights into the potential role of magnetic fluctuations in producing anomalous transport. This is particularly significant in that, at present, there is essentially no in situ probe of these fluctuations or the transport which they produce.

To our knowledge this was the only project, proposing to use positrons to study plasma transport, being conducted anywhere in the world. This work was closely related to the DoE Transport Initiative, in that this diagnostic was complimentary to other tokamak diagnostics currently installed on tokamak plasmas and/or under development. This project, if it were carried to completion, could be expected to test current theories of plasma transport in new and well-defined ways.

II. Project History

This project was initiated at the beginning of the Transport Initiative in the fall of 1989. It is the principal investigator's understanding that it was *the* top-rated, experimental proposal funded under the Initiative. The one year grant in FY90 was augmented by a three-year grant intended to be funded from FY91 through FY93. A favorable technical review of the project was conducted in May 1991. However, in August 1991, it was decided that, given other budgetary priorities, there are insufficient funds to continue the project; the project was scheduled to end at the end of FY92, with close-out funds for FY92 in the amount of \$150,000. In order to complete some aspects of the work, a no-cost extension was obtained which extended the grant to December 31, 1992.

The DoE funding (in \$) over the history of the project is as follows:

FY	Total DoE	=	research funding	+ overhead	UCSD Matching Funds
1990	203,884		153,314	50,570	6,276
1991	244,896		189,406	55,490	10,288
1992	150,000		113,559	36,441	5,006

III. Specific Objectives of the Project

The objective of the project was to develop a new technique to study transport in tokamak plasmas, using the positron as a thermalized, electron-mass test particle. The work included optimization of the accumulation and storage of positrons from a radioactive source to match the cycle of tokamak operation. It also involved developing techniques to convert positrons to neutral positronium atoms at energies appropriate for injection into tokamak plasmas, so that the positrons will be efficiently ionized by the plasma and thereby be deposited in the hot plasma. Finally, the work involved the optimization of a detection scheme for the annihilation gamma-rays produced when the positrons are transported out of the plasma and strike a limiter or divertor plate.

IV. Accomplishments During the Grant

Accomplishments were made in several areas, including development of a reliable and efficient positron source, optimization of the ability to accumulate and store large numbers of low energy positrons, production of an energetic, neutral positronium atom beam (from a slow positron source) suitable for the tokamak experiment, and design of a detector/limiter assembly optimized for the experiment.

With regard to a positron source, we purchased and installed a new ^{22}Na radioactive source from DuPont Corporation. We evaluated the fast-positron production efficiency of the source, relative to the source strength. We concluded that such a source is acceptable for the positron diagnostic, yielding a usable, fast-positron output equivalent to 20% of the total number of radioactive decays. Measurement of the absolute efficiency of the source also allowed us to measure the absolute efficiency of our tungsten moderators (which are used to slow the fast positrons, with energies up to 540 keV, down to an energy of 2eV). We have now shown that these moderators, produced by Aarhus University in Denmark at near cost, are adequate for the tokamak experiment.

One of the major achievements, which was done with both ONR and DoE support, was to optimize our ability to accumulate and store positrons in the modified Penning trap. Presently, we are able to accumulate and store greater than 30% of the slow positrons incident on the trap. This is a higher efficiency than we had anticipated, and a one order of magnitude improvement over the maximum efficiency obtainable at the beginning of the project. The trapping scheme has now progressed to the stage where we are confident that we can trap a sufficient number of positrons to be able to conduct the tokamak experiment.

Another area in which we have made significant progress was the development of a suitable technique to convert positrons to fast positronium atoms. We measured the efficiency for production of positronium atoms at energies optimum for the first experiment on TEXT (i.e., ~ 100 eV), and recently, we

measured the angular dependence of the positronium-atom production efficiency. This latter quantity, while crucial to the application of the charge-exchange technique to the positron diagnostic, had not been measured previous to our work. We have shown that charge-exchange in a hydrogen gas cell is an acceptable method to produce positronium atoms for the tokamak experiment.

We identified a new and more suitable gamma-ray detector for use in the tokamak experiment. It uses a CsI detector in combination with a photodiode. This detector package provides excellent quantum efficiency and a more compact detector array which can be housed just behind the plasma limiter.

During the grant, we also improved the reliability and repeatability of our positron trap, and we developed better methods of monitoring and controlling the positron trap.

Finally, we made a preliminary design for the layout of the positron experiment at the TEXT tokamak; since, at the time, it was planned to first install the diagnostic on TEXT.

V. Next Steps Toward a Positronium Atom Diagnostic of Plasma Transport

The next important task regarding the production of a positronium atom beam would be to design a differential pumping scheme which would provide suitable isolation between the pressure in the charge-exchange gas cell (i.e., at about 1×10^{-3} torr) and the edge of the tokamak plasma (1×10^{-8} torr). We made progress on this topic, but more work remains to be done. In this regard, the fact that we have been able to develop the method of charge exchange in H_2 gas as an acceptable positron-to-positronium converter is significant in that there will be no non-hydrogenic contaminants coming from the positronium beam.

Future work would also include design and construction of a positron trap optimized for installation on a tokamak; construction of a positron beam line from the trap to the edge of the tokamak; construction and installation of the charge-exchange gas cell located at approximately the radius of a toroidal field coil of the tokamak; and design, construction, and

installation of a specially-designed limiter with a built-in gamma-ray detector. During the course of the presently funded work, we made some progress on the design of the apparatus to achieve these goals, but more work needs to be done.

VI. Concluding Remarks

We have now established that we can provide a positronium atom diagnostic beam suitable for measurement of transport in a TEXT-sized tokamak plasma. The data rate is presently estimated to be sufficiently high that the global, positron diffusion coefficient could be measured in approximately one single plasma discharge.

In rough terms, an experiment on TEXT or a similar tokamak would take about two to two and one half years to build and install. If one included an additional two years of run time (the final year at full operation), we estimate that the total cost of the four-year project would be about \$2M. Our view has been, and continues to be that the qualitatively new measure of plasma transport that this diagnostic would provide is well worth the cost. Unfortunately, this view was not shared by the OFE.

VII. Publications and Reports

A. Published Work

1. C. M. Surko and T. J. Murphy "Use of the Positron as a Plasma Particle," *Phys. Fluids B2*, 1372 (1990).
2. S. Tang and C. M. Surko, "Angular Dependence of Positronium Formation in Molecular Hydrogen," *Phys. Rev. A*, February 1993.
3. The following are abstracts of APS talks and poster papers describing various aspects of the work:
 - a. T. J. Murphy, C. M. Surko, M. Leventhal and W. L. Rowan, *Bull Am. Phys. Soc.* 34, 2108 (1989).

b. M. J. Penn, T. J. Murphy, S. Tang and C. M. Surko, *ibid.*, 35, 3044 (1990).

c. S. Tang, C. M. Surko and T. J. Murphy, *ibid.*, 36, 753 (1991).

d. S. Tang, T. J. Murphy, and C. M. Surko, *ibid.*, 36, 2492 (1991).

e. S. Tang and C. M. Surko *ibid.*, 37 1148 (1992).

B. Unpublished Reports

1. Yearly progress report, April 27, 1990 (Appendix A).
 2. Yearly progress report, May 2, 1991 (Appendix B).
- } *cycled separately*

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