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ENERGETIC ALPHA TRANSPORT IN A MAGNETIZED FUSION TARGET

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ABSTRACT

Magnetized target fusion (MTF) promises to ease the power and intensity requirements for a fusion driver. High gain MTF targets require fusion ignition to occur in the magnetized fuel. Ignition requires the energy deposited by the charged fusion reaction products to exceed that lost from the plasma by a variety of loss mechanisms. We have used single particle tracking through a magnetized plasma to obtain preliminary results on the DT alpha particle deposition as a function of the plasma ρR and BR for a uniform spherically symmetric volume with a uniform B_θ magnetic field. More complicated plasma density, temperature, and field distributions can be handled by the code, including 2-D distributions, but the efficiency of this approach makes extensive calculations impractical. A more efficient approach is needed, particularly for use in dynamic calculations. However, particle tracking is useful for obtaining information for building more accurate models of the deposition for use in survey codes.

I. INTRODUCTION

In some 1945 Los Alamos lectures Enrico Fermi cited the work done by Landshoff [1] concerning a method of reducing thermal conduction in a deuterium plasma. By imposing a sufficiently strong magnetic field parallel to a wall, thermal transport to the wall could be impeded. At low density the energy loss from the deuterium-tritium (DT) plasma in an inertial confinement fusion (ICF) target is dominated by electron thermal conduction[2], so that magneto-thermal insulation can greatly facilitate fusion in a low density DT plasma. Since then Widner reported electron beam experiments at Sandia National Laboratory using micro-balloons mounted on the anode [3], and Lindemuth and Widner made a detailed analysis with the computational tools available at that time [4]. Sweeny and Farnsworth proposed using magnetized DT as a central igniter for a cold fuel layer in an electron- or ion-beam target to achieve high gain [5]. More recently researchers at the All-Russian Scientific Institute for Experimental Physics (VNIIEF) reported on a pulsed power experiment (which they refer to as MAGO) that created a magnetized DT plasma [6]. It consistently provides significant neutron yields in the process of heating and magnetizing the plasma. No compression experiments have been done.

The above experiments are all examples of what we now call magnetized target fusion (MTF) [7]. Magnetized target fusion (MTF) relies on a magnetic field to reduce the electron thermal conductivity of a DT plasma and to partially trap the DT fusion alphas, so that ignition may occur at greatly reduced values of ρR, but only when the value of the field times radius parameter BR is greater than about 0.3 MGcm.

While much of the physics for MTF is available in existing ICF codes, some additional physics is needed and some of the existing physics capabilities need to be re-formulated numerically to improve the efficiency for calculating MTF targets. The particle tracking presented in this paper is a first attempt to treat DT alpha particle transport more accurately, but not more efficiently.

II. ANALYTIC RESULTS

For the case of energy deposited to electrons only ($dE/ds = -b_e E^{1/2}$) De Peretti obtained an analytic result for the x excursion of a DT alpha particle in a homogeneous magnetized plasma [8]. We have extended De Peretti's work to the case of energy deposited to both electrons and ions. Although incomplete, the analytic results connecting time t, distance traveled s, and particle energy E are very useful for integrating the equations that describe the DT alpha trajectories. For the case of a B_θ field, displacement along the field direction changes the direction of the field, leading to very complicated motion or trajectory. While the trajectory of a single DT alpha in a prescribed field is interesting, we need the net DT alpha energy deposition due to the compendium of all DT alpha trajectories through the DT plasma. Because the analytic task seemed very daunting, we resorted to a numerical approach.

III. ALPHA DEPOSITION CODE

A few years ago we wrote a simple code to study DT alpha energy deposition in a magnetized plasma. It was based on some work by Loveberg for electron slowing only [9]. The early cylindrical version for $B = B_z$ was extensively modified to generalize it for more complex targets. This code tracks the very complex trajectories of the alphas, tabulating the energy deposited along the path.

Each trajectory is followed by doing a fourth order Runge-Kutta integration of the equations of motion. Relativistic effects are ignored. Also, we have not attempted to address the nuclear scattering component [10]. After each step along the trajectory a check is made to see if the alpha has reached thermal velocity or left the DT plasma. If so the trajectory is terminated. For the case of B=0 the results with this code are in reasonable agreement with Evans' earlier results for alpha ranges in an ummagnetized DT plasma [11]. For the case of vanishingly small plasma density the Larmor (or gyro-) radius is what it should be: 0.27 cm in a 1 MG field.

Here, only an integrated result, the fractional deposition in the DT plasma due to all particles born in that volume is presented, but the same code suffices to get distributions of the energy deposition for any specified plasma and magnetic field distribution.

IV. MAIN RESULT

DT alpha energy deposition is enhanced by a strong magnetic field due to the increased path length that it must follow to escape the target plasma. Figures 1 and 2 show the fractional deposition (averaged over volume and angle) in a homogeneous magnetized plasma with an azimuthal field B_θ, with $B_\theta/dr = B_\theta/dz = 0$. The important parameter for enhancement is the field times radius product BR for the target, where R is the target radius. For BR = 0.3 MGcm, noticeable enhancement is evident, for BR > 0.6 MGcm, significant enhancement occurs, and BR > 5.0 MGcm greatly increases energy deposition.

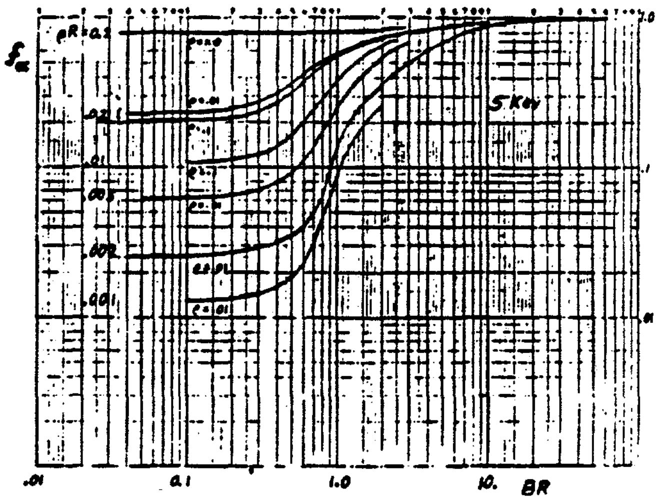

Figure 1. Fractional deposition in a homogeneous 5-Kev magnetized plasma with an azimuthal field for various values of ρR.

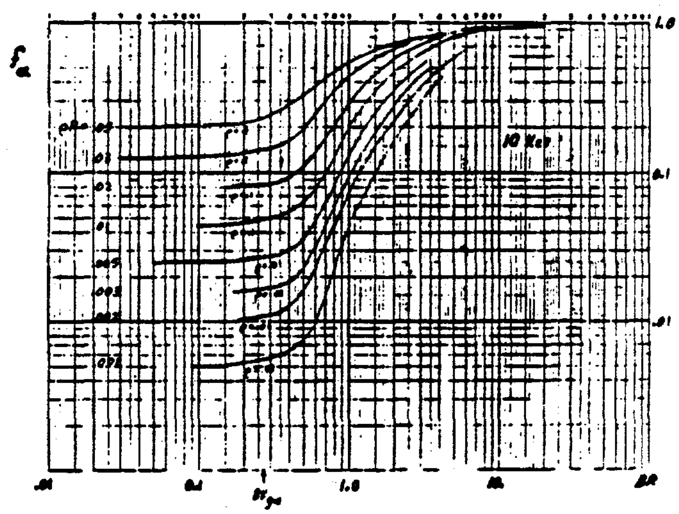

Figure 2. Fractional deposition in a homogeneous 10 Kev magnetized plasma with an azimuthal field for various values of ρR.

Figures 1 and 2 are samples of integrated results, the mean fractional deposition integrated over angle and volume. These results are presented as sets of curves of fractional deposition as a function of BR, each curve for a different target ρR, and each set is for a different plasma electron temperature. We have assumed that the electron and ion temperatures are equal. Computations become tedious for small ρR and large BR, so that another approach is needed.

The results obtained here are not subject to statistics, as would be the case for Monte Carlo. They are obtained by applying angular and volume weights to a regular set of starting directions and positions. Therefore, while deterministic, there are questions of accuracy and sensitivity to the set of angles and positions chosen. We used a 6 x 6 grid and 216 directions. Admittedly, the grid is crude, but successive grid refinements did not yield any significant differences in results.

REFERENCES

1. R. Landshoff, Los Alamos National Lab. Report LA-466 ``Electric and Thermal Behavior of ---Completely Ionized Deuterium in the Presence of a Magnetic Field" (1945); Phys. Rev 79 (1949) 904; Phys. Rev. 82 (1951) 442.

2. J. D. Lindl, ``Physics of Ignition for ICF Capsules" in ``Inertial Confinement Fusion," Proc. of Int. School of Plasma Physics, Varenna, Italy (1988).

3. M. M. Widner, ``Neutron Production from Relativistic Electron Beam Targets," Bull. Am. Phys. Soc. 22 (1977) 1139.

4. I.R. Lindemuth and M. M. Widner, ``Magnetohydrodynamic Behavior of Thermonuclear Fuel in a Preconditioned Electron Beam Imploded Target," Phys. of Fluids 24 (1981) 753.

5. M.A. Sweeny and A.V. Farnsworth, Jr., ``High-Gain, Low-Intensity ICF Targets for a Charged-Particle Beam Fusion Driver," Nucl. Fusion 21 (1981) 41.

6. A.M. Buyko, V.K. Chernyshev, V.A. Demidov, et al.. ``Investigations Poster paper P1-9, Eighth IEEE Pulsed Power Conference, San Diego,em MAGO," California, June 17-19, (1991).

7. R.C. Kirkpatrick, I.R. Lindemuth, and M.S. Ward, ``Magnetized Target Fusion: an Overview", Fusion Tech. 27 (1995) 201.

8. M. de Peretti, private communication (1994).

9. R.H. Loveberg, ``Retention of DT Alpha Particles in the High Density Z-Pinch", unpublished (1989).

10. T. L. Tally and F. Evans, ``Monte Carlo Alpha Deposition", Nuclear Data for Science and Technology (1988, MITO), JAERI.

11. F. Evans, ``Note on the Calculation of Energy Deposition of Alpha Particles in a DT plasma by Rutherford Scattering", LA-5448-MS (1973).

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