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MONTE CARLO ALPHA DEPOSITION

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Abstract: Prior work[1,2] demonstrated the importance of nuclear scattering to fusion product energy deposition in hot plasmas. This suggests careful examination of nuclear physics details in burning plasma simulations. An existing Monte Carlo fast ion transport code is being expanded to be a test bed for this examination. An initial extension, the energy deposition of fast alpha particles in a hot deuterium plasma, is reported. The deposition times and deposition ranges are modified by allowing nuclear scattering. Up to 10% of the initial alpha particle energy is carried to greater ranges and times by the more mobile recoil deuterons.

(Keywords: Monte Carlo, Fast Ion, Alpha Deposition)

Introduction

In the interest of brevity, the reader is referred to an earlier paper [1] for a more complete description of the approach and terminology. A brief summary follows.

Fast ions are assumed to lose energy continuously to plasma electrons and ions through Coulomb interactions along straight line paths until either a large angle ($\theta > \theta_0$) ion-ion scattering is statistically decreed or the ion is thermalized. Upon scattering, two fast ions emerge, the scattered ion and the recoil ion. Directions and energies of the scattered and recoil ions are randomly chosen by sampling angular distributions of the scattering process. Each fast ion is tracked by repeating this procedure until thermalization. With a sufficiently large number of initial fast ions, an average energy deposition in space and time is determined.

Previously[1] the deposition of fast deuterons in a deuterium plasma was reported. The next logical extension was to treat the important problem of fusion alpha deposition in a deuterium plasma.

Fast α Deposition in a Hot Deuterium Plasma

Data describing the d-α scattering including nuclear processes were obtained from D. C. Dodder some time ago.[3] These data were recently checked against a preliminary R-Matrix analysis[4] of the six-nucleon system and it was determined that the elastic scattering has been modified very little in the intervening time. When the six-nucleon analysis is more nearly complete, this will be reviewed again. The data were summed into cumulative probability tables and angular distributions for use by the Monte Carlo code, and the continuous energy loss functions,[1] $\phi.\psi$, and χ were evaluated for the Coulomb interactions of a fast alpha particle with a hot deuterium plasma. The simple Monte Carlo geometry[1] remained unchanged.

Alpha particle energies of 1.7, 3.6, 5.0, and 9.0 MeV were chosen to represent the products of a variety of fusion processes. The cutoff angle (θ_0) was set to 5° for the alpha particle and 10° for deuteron scattering. Plasma electron temperatures (kT_e) of 10, 25, 50, 75, 100, and 150 keV were selected to span conditions of interest. As before,[1] ion temperatures were arbitrarily set 50% greater than electron temperatures and thermalization was decreed for $E_{ion} \leq 3/2\ kT_{ion}$. 10,000 Monte Carlo alpha particles were started in each case. The deuteron number density was chosen to be $5.1 \times 10^{22} cm^{-3}$.

Results

The statistical quantities of the calculations are shown in Table 1. For example, each 5-MeV α in a 100-keV plasma made an average of 34.58 large angle (≥ 5°) collisions before thermalization. The average α energy following collisions was 1.6 MeV. The deuterons recoiled with an average energy of 41 keV so most were immediately thermalized. Recoils with energies above 225 keV $[(\frac{3}{2})^2 \times 100$ KeV] had enough collisions to give an average of 5.59 large angle (≥ 10°) collisions per recoil before thermalization. The average deuteron energy after scattering was 620 keV. The forward peaked cross section causes the low average recoil energy.

Figures 1 through 4 give $\frac{\Delta E}{E_0}$ vs R for a 3.6 MeV α particle in 10, 50, 100, 150 keV plasmas. The dotted line shows results for Rutherford continuous energy depositions. Data at other energies are available. Analogous deposition time data are also available; an example for 3.6 MeV at 50 KeV is shown in Fig. 5. Table 2 gives the fraction of energy deposited to ions by Monte Carlo (Rutherford only) for all cases treated. There is little change in the ion fraction.

An examination of all the calculations shows that up to 10% of the initial alpha particle energy is converted into recoil deuteron fluxes that extend factors of three in both space and time beyond the alpha deposition ranges and deposition times. Depending on the plasma devices being considered, this can either be ignored or included in the simulations if such perturbations are significant.

References

1. F. Evans, Phys. Fluids 16, 1011 (1973).
2. A. Andrade and G. M. Hale, Phys. Rev. A 30, 1940 (1984).
3. D. C. Dodder, private communication, March 1973.
4. G. M. Hale, private communication, May 1988.

Table 1. Average Collisions and Energies Per Initial Alpha Particle

	PLASMA TEMPERATURES (keV)					
	10	25	50	75	100	150
1.7 MeV α						
α-d Collisions	10.86	18.16	23.19	24.88	25.49	26.40
d-d Collisions	0.15	0.31	0.51	0.57	0.63	0.39
E_α scattered (MeV)	0.76	0.84	0.87	0.89	0.90	0.90
E_d recoil (MeV)	0.012	0.011	0.012	0.012	0.012	0.012
E_d scattered (MeV)	0.32	0.37	0.39	0.40	0.41	0.51
3.6 MeV α						
α-d Collisions	11.25	21.82	27.69	29.54	31.96	36.24
d-d Collisions	0.22	1.02	2.04	2.66	3.29	2.74
E_α scattered (MeV)	0.99	1.12	1.28	1.37	1.39	1.35
E_d recoil (MeV)	0.017	0.022	0.026	0.029	0.029	0.029
E_d scattered (MeV)	0.42	0.47	0.53	0.56	0.56	0.69
5.0 MeV α						
α-d Collisions	12.57	21.81	28.51	31.90	34.58	39.19
d-d Collisions	0.34	1.34	3.07	4.23	5.59	5.03
E_α scattered (MeV)	1.02	1.27	1.47	1.57	1.60	1.57
E_d recoil (MeV)	0.022	0.028	0.036	0.040	0.041	0.044
E_d scattered (MeV)	0.41	0.52	0.58	0.63	0.62	0.78
9.0 MeV α						
α-d Collisions	12.14	20.76	29.31	33.41	36.70	41.32
d-d Collisions	0.45	2.27	6.41	10.30	14.54	14.61
E_α scattered (MeV)	1.17	1.52	1.73	1.85	1.87	1.84
E_d recoil (MeV)	0.035	0.052	0.073	0.084	0.088	0.100
E_d scattered (MeV)	0.50	0.62	0.74	0.79	0.79	1.00

Table 2. Fractional Energy Deposited to Ions.
The numbers in the parentheses are the corresponding values for Rutherford only continuous deposition.

E_α / T_e	1.7	3.6	5.0	9.0
10	.40 (.41)	.23 (.24)	.18 (.19)	.11 (.11)
25	.65 (.66)	.44 (.45)	.36 (.36)	.24 (.23)
50	.82 (.82)	.64 (.64)	.55 (.54)	.41 (.38)
75	.89 (.89)	.75 (.74)	.67 (.66)	.53 (.49)
100	.92 (.92)	.81 (.81)	.74 (.73)	.62 (.57)
150	.95 (.95)	.88 (.88)	.83 (.82)	.73 (.68)

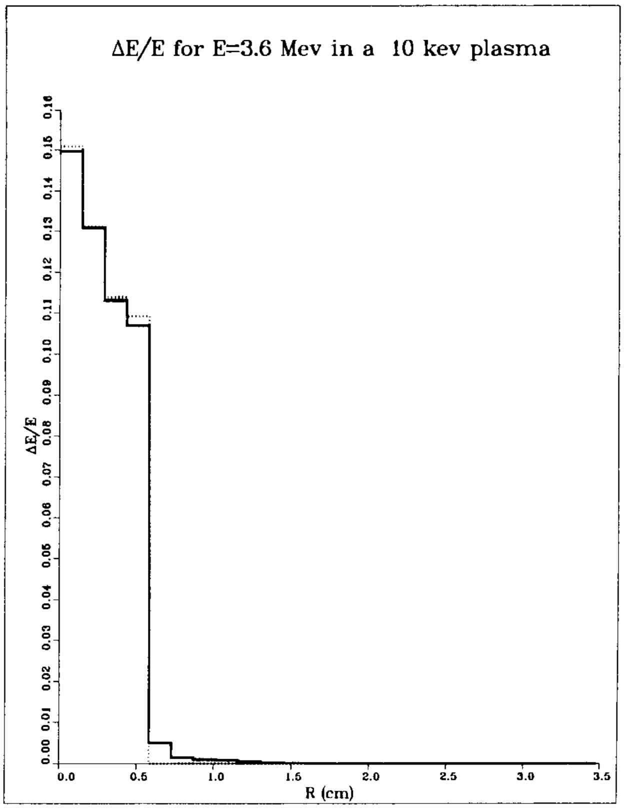

Fig. 1. Radial distribution of $\Delta E/E$ for E=3.6 MeV and kT_e=10 keV. The dotted line is Rutherford continuous energy loss results.

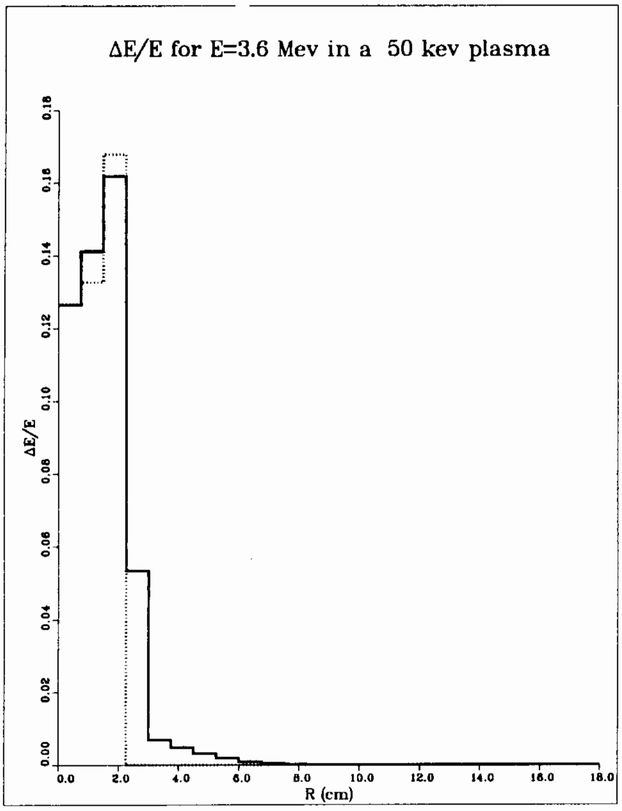

Fig. 2. Radial distribution of ΔE/E for E=3.6 MeV and kT_e=50 keV. The dotted line is Rutherford continuous energy loss results.

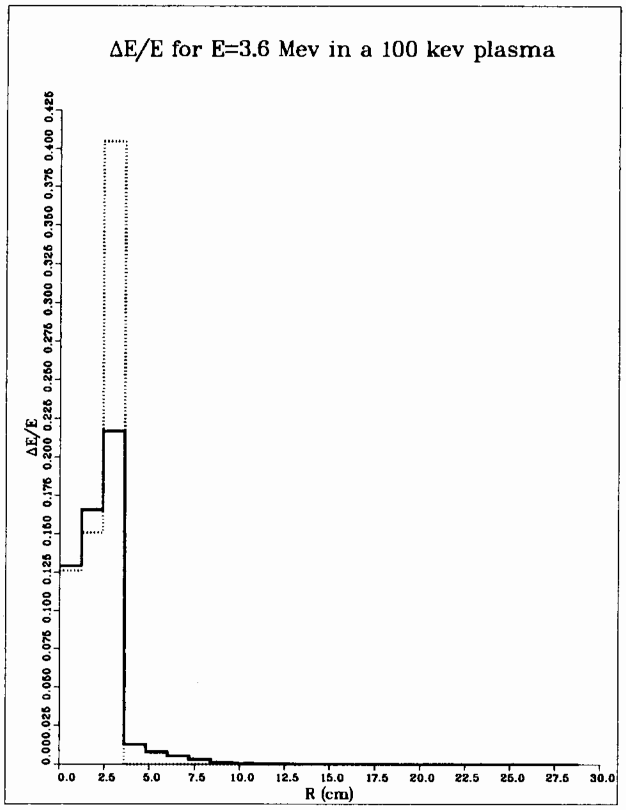

Fig. 3. Radial distribution of ΔE/E for E=3.6 MeV and kT_e=100 keV. The dotted line is Rutherford continuous energy loss results.

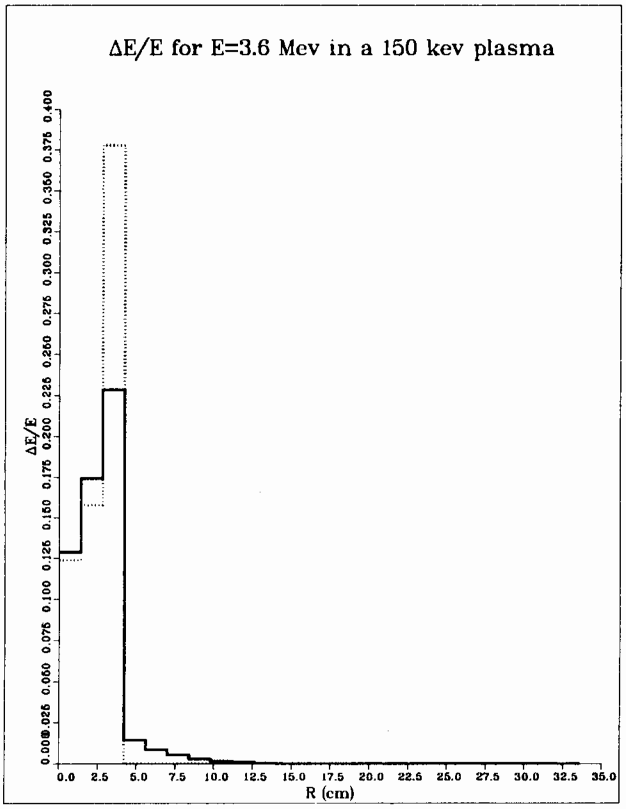

Fig. 4. Radial distribution of ΔE/E for E=3.6 MeV and kT_e=150 keV. The dotted line is Rutherford continuous energy loss results.

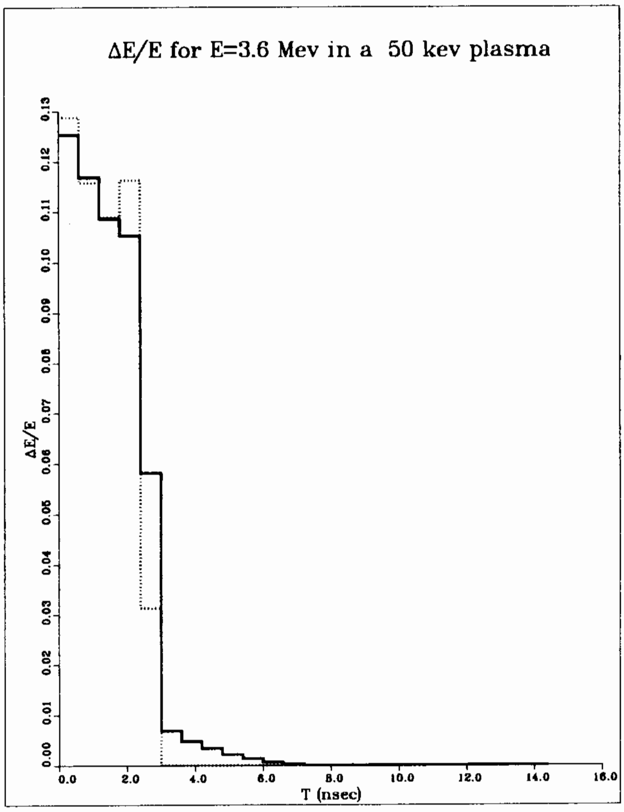

Fig. 5. Distribution in time of ΔE/E for E=3.6 MeV and kT_e=50 keV. The dotted line is Rutherford continuous energy loss results.