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NONTHERMAL EFFECTS IN TWO COMPONENT DT FUSION REACTORS

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NONTHERMAL EFFECTS IN TWO COMPONENT DT FUSION REACTORS*

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ABSTRACT

Net energy generation rates and f-factors are calculated for a variety of two component DT reactor configurations using a computer code[1,2] that follows the energy distributions of the reactants and products explicitly, utilizing the Fokker-Planck approximation for low-angle Coulomb scattering and a transfer matrix for high-angle Coulomb, nuclear, and radiative processes. The relative importance of such non-thermal effects as alpha particle deposition, non-Maxwellian energy distributions for the target tritons and electrons, and the influence of high-angle Coulomb and nuclear scattering on the energy loss rate of the injected deuterons is explicitly assessed.

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Introduction

Nonthermal effects play a central role in two component DT fusion reactors,[1,2] in which a beam of energetic deuterons is injected into a relatively cold, magnetically-confined triton plasma. The principal effect is, of course, the nonthermal nature of the deuteron energy distribution as it evolves from a relatively monochromatic beam to a Maxwell-Boltzmann distribution at the same temperature as the tritons. In addition, however, other nonthermal effects have been suggested to be of some significance,[1,5] including alpha particle deposition, non-Maxwellian energy distributions for the electrons and tritons, and the influence of high-angle Coulomb and nuclear scattering on the energy loss rate of the injected deuterons.

To quantitatively assess the relative importance of such effects, a modified form of the FOKN nonthermal nuclear burn code[1,2] was employed. This code follows the energy distributions of the reactants and products explicitly, utilizing the Fokker-Planck approximation for low-angle Coulomb scattering, and transfer matrices for high-angle Coulomb, nuclear, and radiative processes. The treatment of both the distribution functions and the radiative emission rates is relativistically correct, and an infinite isotropic, homogeneous system is assumed. The effects of an injected beam are approximated by adding particles at a specified rate to a given energy group. Exponential <u>number</u> loss rates of one or more particle species can also be specified. In this manner, the nature of the nuclear burn occuring in simple two-component reactor systems can be explicitly investigated.

Nuclear Cross-Sections

In generating the transfer matrices needed for FOKN, differential cross-sections for nuclear reactions and scattering between the various plasma species are required. For the processes $^3H(d,n)^4He$, $^2H(d,d)^2H$, $^4He(d,d)^4He$, and $^4He(t,t)^4He$, sufficient measurements[6, 7, 8] exist to approximately specify these cross-sections over the ranges of interest (specifically, the scattering cross-sections are believed accurate to $\lesssim$ 50% and the DT reaction cross-section to $\lesssim$ 5%). For $^3H(d,d)^3H$, the most important scattering reaction, however, the only reported measurements below a deuteron lab energy, E_d, of 200 keV are due to Balashko and Barit[9] and only concern scattering of 90° in the center-of-mass frame. On the assumption that the nuclear component of this scattering was due primarily to the s-wave resonance at E_d = 107 keV, the energy dependent nuclear widths, level shift, and channel radius of this resonance were determined by fitting the measured scattering and $^3H(d,n)^4He$ reaction cross-sections to a single level dispersion formula[10] in which the interference between Coulomb and nuclear scattering is taken into account. The resulting parameterized resonance formula was then used to extrapolate the scattering cross-section to other angles. (The details of this fit which is accurate to ~20% are available upon request.) At high scattering angles ($\gtrsim$ 60°), the combined cross-section drops below the Rutherford value by up to a factor of 2 due to destructive interference between the nuclear and Coulomb terms on the low energy side of the 107 keV resonance. At lower angles, however, Coulomb scattering predominates as expected.

Results and Discussion

Figure 1 shows the f-factors that result when deuteron beams with mean energies of 145, 209, and 302 keV are injected into a triton plasma with a density, n_t, of 10^{14} cm^{-3}; an initial triton temperature, T_t, of 1 keV; and an initial electron temperature, T_e, of 25 keV. 8.6×10^{10} deuterons/cm^3 are injected into the plasma in 30 milliseconds, and there are no plasma losses. The f-factor is defined as usual as the ratio of the thermonuclear energy generated to the energy originally in the deuteron beam. The low deuteron density was chosen to study f-factor behavior in the linear regime, where the beam does not significantly change the state of the background plasma, while the high electron temperature assures that most of the deuteron energy loss is due to collisions with ions rather than electrons, thus resulting in a slowing down time that is both temperature independent and the maximum possible. Under these idealized conditions, f-factors in the range 2.6 to 3.3 are obtained, with the lower energy beams producing somewhat higher f-factors at substantially shorter times, and thus being clearly preferable. This behavior is due to the combination of the $E_d^{-1/2}$ dependence of the energy loss rate and the E_d^{-1} dependence of the thermonuclear energy generation rate in the range 150 keV $\lesssim E_d \lesssim$ 1000 keV.

The f-factors for the cases where high-angle transfer matrices for all the scattering reactions indicated above were included (solid curves), are typically 5-10% below those for the cases where all Coulomb scattering was done using the Fokker-Planck approximation and no nuclear scattering was included (dashed lines). This difference is due almost entirely to the increased dt scattering cross-section in the former case, and by scattering events in which a deuteron's energy is changed from well above to well below the dtnα reaction resonance, thus missing its chance to react.

Figure 2 shows the f-factors for reactor configurations in which 8.6×10^{12} and 8.6×10^{13} deuterons/cm^3 (n_d) respectively are injected into a triton plasma with $n_t = 7\times10^{13}$ cm^{-3} and $T_e = T_t = 6$ keV. Here $E_d = 145$ keV; the injection time, τ_I, is 0.03 sec; and the reactants escape with an e-folding time, τ_c, of 1 sec. The deuteron beams cause significant plasma heating with peak triton temperatures of 48 keV and 14 keV being reached in the high and low flux cases respectively. A substantial amount of thermal burn thus takes place in the high flux case, and this is reflected in the continued increase of its f-factor at late times. At early times, the low-flux f-factor dominates because interactions between deuterons in the injected beam cause less energy loss than in the high flux case. The difference between the runs done with and without transfer matrices ($\sim$ 2%) is less here than in the linear case, due to the increased importance of electron-deuteron scattering at lower electron temperature, and to the effects of alpha-deposition due to nuclear scattering which tend to increase the f-factor. A high flux run made without scattering transfer matrices and alpha deposition (double-dashed line) in fact falls below the run with all effects included.

Figure 3 shows f-factors for the same case as Figure 2 except that $\tau_c = 0.2$ sec instead of 1 sec. Under these conditions the amount of thermal burn is greatly diminished, and low-flux case ends up with the higher f-factor. The electron temperature and thus the importance of high angle scattering is also diminished. The low-flux case here corresponds to Scenario I of the two-component reactor calculations of Killeen et al,[11] except that they considered energy rather than number density losses. While the two calculations are in reasonable agreement at early times ($\lesssim$ 0.05 sec), the present final f-factors (.8) are somewhat more pessimistic than those of Killeen, et al. (∿1.1), perhaps due to the fact that their energy loss mechanism served to sweep deuterons though the reaction resonance that would otherwise have been lost at high energy.

Examination of the electron and triton energy distributions during the above runs show deviations from a Maxwell-Boltzmann distribution of up to ∿10%, with the deviations being greatest in the runs of highest flux. Typically, the low energy tail of the electron distribution is depressed, while the high energy tail of the triton distribution is slightly augmented, apparently due in both cases to deuteron upscattering.

In conclusion, we find that secondary nonthermal effects in two component DT fusion reactors, while interesting and diverse, are unlikely to diminish attainable f-factors by more than 10%.

References

1. G. Lee, G. Zimmerman, and L. Wood, Bull. APS, 17, 989 (1972) and UCRL-74192.
2. G. Zimmerman and E.T. Scharlemann, private communication.
3. J.M. Dawson, H.P. Furth, and F.H. Tenney, Phys. Rev. Letters, 26, 1156 (1971).
4. H.P. Furth and D.L. Jassby, Phys. Rev. Letters 32, 1176 (1974).
5. M. Gryzinski, Phys. Rev. 115, 1087 (1959).
6. N. Jarmie and R. Seagrave, eds. LA-2014 (LASL, 1957), and references cited therein.
7. T. Lauritsen and F. Ajzenberg-Selove, Nucl. Phys. 78, 1 (1966) and references cited therein.
8. S. L. Greene, UCRL-70522 (LLL, 1967).
9. I.G. Balashko and I.I. Barit, in Nuclear Forces and the Few Nucleon Problem, p. 615 (Pergamon, 1960).
10. J.M. Blatt and V.F. Weisskopf, Theoretical Nuclear Physics, (Wiley, New York, 1952).
11. J. Killeen, T.H. Johnson, A.A. Mirin, and M.E. Rensink, UCID-16530 (LLL, 1974).

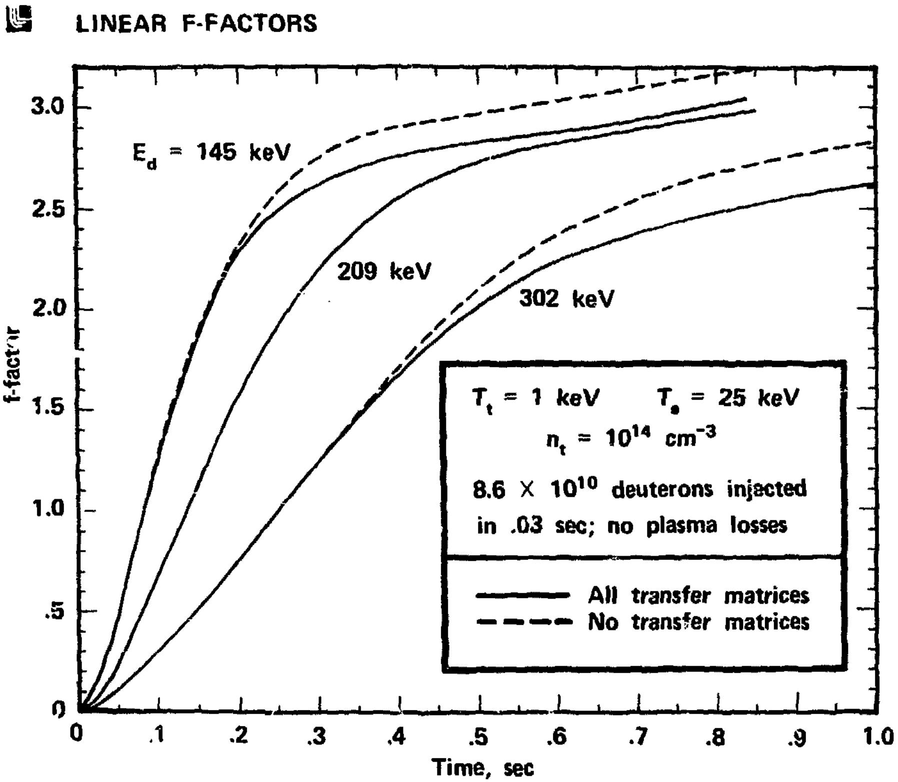
LINEAR F-FACTORS
E_d = 145 keV
209 keV
302 keV
T_t = 1 keV T_e = 25 keV
$n_t = 10^{14}$ cm^{-3}
8.6 × 10^{10} deuterons injected in .03 sec; no plasma losses
All transfer matrices
No transfer matrices
f-factor
3.0
2.5
2.0
1.5
1.0
.5
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Time, sec

FIGURE 1

F-FACTORS: $\tau_C = 1$ SEC

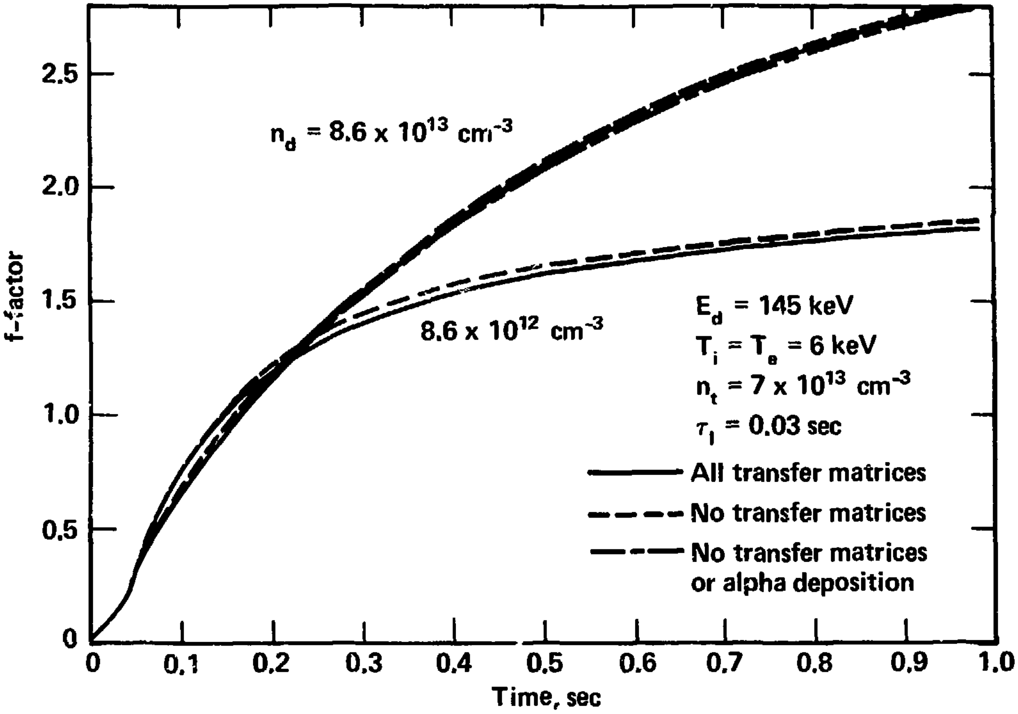

FIGURE 2

F-FACTORS: τ_c = 0.2 SEC

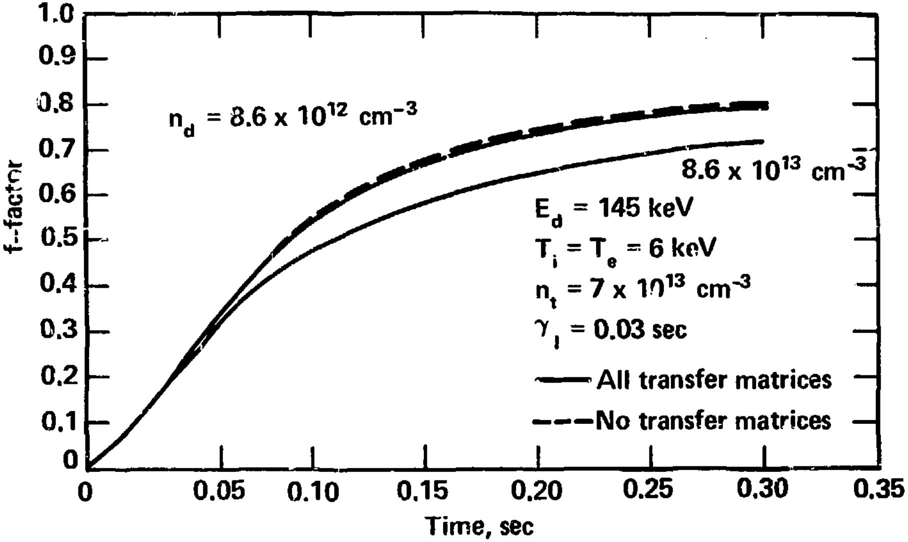

FIGURE 3