PREPRINT UCRL-80169

CONF-780202-9

Lawrence Livermore Laboratory

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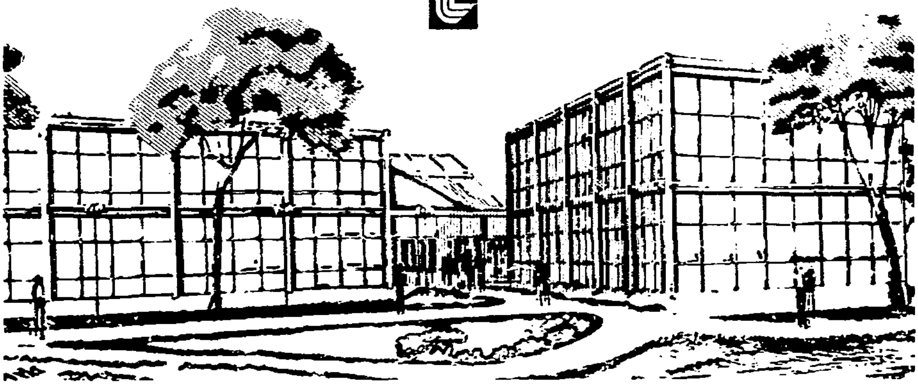
October 6, 1977

This paper was prepared for presentation at the Inertial Confinement Fusion Conference, February 7-9, 1978 in San Diego, California.



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ABSTRACT

A brief description is presented of the physical processes, models and numerical methods employed in the LASNEX code for calculating inertial confinement fusion.

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*Work performed under the auspices of the U.S. Department of Energy under contract No. W-7405-Eng-48.

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The LASNEX code[1] has been developed to study the physical processes and design targets for inertial confinement fusion. It has been used to calculate the results of many laser plasma experiments and to design targets and determine the desirable pulse characteristics for future laser, electron and ion beam experiments. LASNEX is used to determine the effects of various assumptions on experimentally measured quantities and to design fusion pellets that are insensitive to the uncertainties. Here we give a brief review of the physical models and numerical methods incorporated in this computer code.

LASNEX evolves in time a two dimensional axially-symmetric plasma composed of thermal electrons and ions, suprathermal electrons, x-rays, thermonuclear reaction products and the associated electric and magnetic fields generated in such a plasma. All spatially dependent plasma quantities are described on a grid composed of arbitrarily shaped quadrilaterals. When solving partial differential equations which involve spatial derivatives it is necessary to include terms which account for the elongation, rotation and skewness of the quadrilateral grid. For example, the Laplacian operator requires a minimum of a nine point module. The resulting sparse matrix is solved by the ICCG[2] iterative linear system solver. Typically the grid moves with the plasma material as in Lagrange hydrodynamics. If this would result in severe mesh distortion, however, material is allowed to flow through the mesh leading to a semi-Eulerian formulation.

Generally the numerical methods are designed to be reasonably accurate without being unreasonably expensive. This often means that several different numerical models must be developed for a single physical process. In order of importance for our purposes we choose numerical schemes that (1) solve the differential equation, (2) provide a reasonable steady-state answer in the limit at large time steps and (3) conserve certain desirable physical quantities. Very accurate, high order difference schemes are generally not warranted because the differential equations to be solved are themselves only approximations to the true physics.

Energy can be supplied to the target by a laser, electron or ion beam. The deposition profile for relativistic electron beams is taken from separate Monte-Carlo calculations in a similar geometry. Ion beam deposition is treated in LASNEX by calculating the slow down and straggling caused by Coulomb collisions with the background plasma electrons and ions. Laser light propagation and deposition is handled in the geometric optics approximation. The laser beam is broken up into several hundred rays which travel through the code's spatial mesh, bend according to the laws

*Research performed under the auspices of the U.S. Energy Research and Development Administration under contract No. W7405-Eng-48.

of refraction and lose energy to absorption by inverse bremsstrahlung and the resonant excitation of plasma waves. Resonant absorption is treated by absorbing a certain fraction of the ray's energy when the ray reaches its peak electron density. The amount of light absorbed depends on the peak density in a manner consistent with plasma simulation calculations and experimental absorption measurements.[3] Resonant absorption produces a high energy non-thermal tail to the electron distribution function. In LASNEX this tail is approximated by a Maxwell distribution at an elevated temperature. This temperature has been determined by plasma simulation code runs[4] and is parameterized in terms of the local background thermal electron temperature, the laser intensity and wavelength.

Since the high energy electrons generated by laser light absorption are not collisionally dominated, it is necessary to treat the non-equilibrium aspects of the transport and thermalization of these electrons in some detail. LASNEX accomplishes this by allowing the electron distribution to be described in terms of a speed coordinate as well as a temporal and two spatial coordinates. This model is actually quite a simple one compared to a full transport model that would allow two angular coordinates as well. The validity of the simpler model rests upon the assumption that the electrons will always be nearly isotropic even if they are far from equilibrium in their energy distribution. In high Z plasmas this situation can arise simply from classical Coulomb collisions, since the isotropization rate is proportional to Z^2 while the thermalization rate is proportional to Z. In low Z plasmas the electrons can be rendered isotropic by magnetic fields which always seem to be produced in laser plasmas and by ion density fluctuations caused by collective effects in the plasma.

With the assumption that the suprathermal electrons are nearly isotropic, their transport and thermalization can be handled by a combined multi-group, flux-limited diffusion and simplified Fokker-Planck treatment.[5] In this model a self-consistent electric field is set up by using a generalized Ohm's law and the condition of no net current.

Thermal electrons receive energy from Coulomb collisions with the suprathermal electrons and from Ohmic heating caused by the previously mentioned electric field. The thermal electrons are assumed to have a Maxwellian distribution which simplifies the calculation of their interactions with the other plasma components. The transport of the thermal electron energy is accomplished by using tensorial plasma conductivities in a magnetic field somewhat modified by a flux-limiter, variable degree of ionization and an optional inhibition due to plasma turbulence. The hydrodynamic pressure and specific heat of the thermal electrons are taken from a Thomas-Fermi-Dirac model which includes both partial-ionization and electron degeneracy.

The thermal ions are heated by Coulomb collisions with thermal electrons and by hydrodynamic compression. At ion temperatures above 1 keV thermonuclear reactions begin. LASNEX uses Maxwellian averaged cross-sections for most interesting thermonuclear reactions and transports the reaction products using a multi-group diffusion model.[6] Nonthermal charged particles can also be produced as a result of "knock-on" reactions between neutrons and thermal ions. While in flight the charged particles can undergo nuclear reactions with background ions, but their transport is dominated by the Coulomb drag against background electrons and ions. Energy lost is deposited separately into the electron and ion thermal fields. A transfer matrix formed from neutron cross section data is used to calculate the neutron transport and redistribution of neutrons among energy groups.

The photons in the plasma are handled by a multi-group, flux-limited diffusion model similar to that used for suprathermal electrons. Frequency dependent opacities due to bound-bound, bound-free and free-free processes are taken from an average atom model. Atomic populations can be generated either by assuming local thermodynamic equilibrium or by solving the rate equations for radiative and collisional transitions.[7] The redistribution of photon energy due to Compton scattering is treated in the Fokker-Planck approximation. In addition the frequency distribution of photons produced by bremsstrahlung from suprathermal electrons is included.

In an axially symmetric laser produced plasma (r, z coordinates in LASNEX) magnetic fields perpendicular to the plane of calculation can be generated spontaneously by non-parallel electron pressure and density gradients. Such a magnetic field then influences the plasma hydrodynamically through the $\underset{\sim}{J} \times \underset{\sim}{B}$ force and, most importantly, by altering transport coefficients for all charged particles. The transport coefficients used in LASNEX are essentially those derived by Braginskii.[8] However, because of plasma turbulence, these transport coefficients may not be valid in high $\omega\tau$ situations. In the absence of a better estimate, Bohm diffusion is sometimes used to test the sensitivity of the calculations to turbulent diffusion.

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