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TIME DEPENDENT MODELING OF NON-LTE PLASMAS

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I. INTRODUCTION

During the period of performance of this contract Science Applications International Corporation (SAIC) has aided Lawrence Livermore National Laboratory (LLNL) in the development of an unclassified modeling tool for studying time evolution of high temperature ionizing and recombining plasmas. The numerical code developed, (D)ynamic (D)etailed (C)onfiguration (A)ccounting (DDCA), was written to run on the National Magnetic Fusion Energy Computing Center (NMFEC) network as well as the classified Livermore Computer Center (OCTOPUS) network. DDCA is a One-Dimensional (1D) time dependent hydrodynamic model which makes use of the non-LTE detailed atomic physics ionization model DCA.

The DDCA model is aimed at treating general problems of hot optically thin dynamically evolving non-LTE laser heated plasmas in 1D (either planar, cylindrical, or spherical) including the effects of laser light absorption, shock formation, thermal conduction, radiative cooling, and non-equal electron and ion temperatures. The modeling of high temperature, dense, time dependent plasmas is a complex task. Conditions of interest, such as those found in soft X-ray lasers^[1-3] or in astrophysics, often involve time varying non-equilibrium ionization and excitation states with many level couplings, differing electron and ion temperatures, spatial gradients, and dynamic motion. Numerical treatments of such highly non-linear systems must be capable of accurate and efficient modeling of the physical interactions involved. What makes this task difficult is the complexity of each aspect of the modeling, and the great care which must be taken to couple the many physical interaction which may simultaneously be taking place. In addition, even if the physics is accurately done, the resulting code may be of little practical use if it is too slow.

In DDCA the time dependent rate equations for the atomic ionization and excitation level structure are solved simultaneously with the equations of motion for density,

velocity, and electron and ion temperatures. Detailed atomic physics level structure and rates can be used through the coupling with the DCA model. Alternately, the model can use either the simplified hydrogenic DCA model or a constant ionization ideal gas model. The level of physics which is planned to be incorporating in the model will provide for both analysis of target design parameters for laser plasma experiments, and for physical insight into general questions involving non-LTE ionization processes. By developing and maintaining the model on the unclassified NMFECC network it will be readily accessible to users both at LLNL and in the scientific community in general. This easy access should lead to greatly improved collaborative efforts between LLNL and other groups such as KMS. The unclassified nature of the model will also provide an ideal tool for involving LLNL staff members awaiting clearance approval in research programs involving laser modeling and non-LTE ionization physics.

II. TIME DEPENDENT NON-LTE MODEL

As a starting point in the modeling, use was made of a 1D hydrodynamic model developed by Peter Giles of LLNL, which treats shocks, electron and ion thermal conduction with a flux limiter, electron-ion thermal coupling, Bremsstrahlung emission, and other processes involved in the evolution of a plasma irradiated by an intense laser beam. The model solves directly for r , u , T_e , and T_i using a moving Lagrangian mesh in either a slab, cylindrical, or spherical geometry. The variables r , u , T_e and T_i respectively give the grid boundary position, the grid boundary velocity, the electron temperature and the ion temperature. Constant ionization was assumed in the original model. The code was modified to run on the NMFECC network, and was then coupled to DCA to provide for changing electron density and potential energy due to changes in the plasma ionization structure.

To accurately solve for the ionization along with the 1D equations of motion we time-split (solved successively) the equations of motion and the equations governing the excitation and ionization structure. In our time-splitting algorithm we first use the explicit Lagrangian grid algorithm with the hydrodynamic equations

$$\frac{dr}{dt} = u, \quad (1)$$

$$\rho \frac{du}{dt} = -\nabla(P_e + P_i + Q), \quad (2)$$

to calculate the changes in matter density and velocity. The variables P_e , P_i and Q , which respectively give the electron pressure, the ion pressure, and the artificial viscosity are defined as

$$P_e = \rho \bar{n}_e k T_e, \quad (3)$$

$$P_i = \rho \bar{n}_i k T_i, \quad (4)$$

$$Q = 1.2\rho(\Delta u)^2. \quad (5)$$

The variables $\bar{n}_e$ and $\bar{n}_i$ are the electron and ion densities respectively in units of mole per gram, and ρ is the matter density in units of gm cm^{-3} . In equation (5) the notation Δu is used to signify the spatial finite difference of u . The units currently used in DDCA are those inherited from Peter Giles. The units of length, time, mass, and temperature are respectively cm, ns, gm, and keV. The unit of energy is therefore $\text{gm cm}^2 \text{ns}^{-2}$ and is designated as a nerg. Conversion to cgs units will be made in a future version of the code.

After calculating the change in r and u , DCA can be run in each spatial zone with the density and temperatures are held fixed. DCA returns the changes over the time-step in the electron excitation potential energy U and in the electron density $\bar{n}_e$. Next the equations for the electron and ion temperatures are solved

$$\begin{aligned} \frac{3}{2} \bar{n}_e k \frac{dT_e}{dt} = & -P_e \frac{d1/\rho}{dt} + \Gamma - \frac{3}{2} k T_e \frac{d\bar{n}_e}{dt} - \frac{dU}{dt} + \frac{1}{\rho r^{\delta-1}} \frac{\partial}{\partial r} \left(r^{\delta-1} C_e \frac{\partial T_e}{\partial r} \right) \\ & + \omega^{ei} (T_i - T_e) - \beta^{er} (T_e - T_r), \end{aligned} \quad (6)$$

$$\frac{3}{2} \bar{n}_i k \frac{dT_i}{dt} = -(P_i + Q) \frac{d1/\rho}{dt} + \frac{1}{\rho r^{\delta-1}} \frac{\partial}{\partial r} \left(r^{\delta-1} C_i \frac{\partial T_i}{\partial r} \right) - \omega^{ei} (T_i - T_e), \quad (7)$$

using an implicit scheme. The variables Γ , C_e , C_i , ω^{ei} , and β^{er} represent the laser absorption source term, the electron conduction coefficient, the ion conduction coefficient, electron-ion coupling coefficient, and Bremsstrahlung emission coupling coefficient. The geometry is given by the variable δ which equals one, two, or three for planar, cylindrical, or spherical modeling. The electron-ion and Bremsstrahlung coupling coefficients are given by^[4]

$$\omega^{ie} = 8.79 \times 10^{-2} \frac{\bar{n}_e \rho Z^2 \ln(\Lambda_e)}{a^2 (T_e + T_i/1836a)^{3/2}}, \quad \text{nerg ns}^{-1} \text{ keV}^{-1} \quad (8)$$

and

$$\beta^{er} = 1.76 \times 10^{-3} \frac{\bar{n}_e \rho Z^2}{a T_e^{1/2}}, \quad \text{nerg ns}^{-1} \text{ keV}^{-1} \quad (9)$$

where a is the average atomic weight in grams per mole and Z is the average atomic charge. The electron and ion conduction coefficients without the flux limiters are⁽⁴⁾

$$C_e^0 = 4.01 \times 10^{-7} \frac{T_e^{3/2}}{f(Z) \ln(\Lambda_e)} \quad \text{nerg ns}^{-1} \text{ gm cm keV}^{-1} \quad (10)$$

$$C_i^0 = 3.95 \times 10^{-9} \frac{T_i^{5/2}}{Z^4 a^{1/2} \ln(\Lambda_i)} \quad \text{nerg ns}^{-1} \text{ gm cm keV}^{-1} \quad (11)$$

where $f(Z) = Z + 3.44 + 0.26 \ln(Z)$. The Coulomb logarithms are⁽⁴⁾

$$\Lambda_e = \max \left(1, \frac{1}{2} \ln (1.4 \times 10^4 T_e^2 / \rho \bar{n}_e) \right) \quad (12)$$

$$\Lambda_i = \max \left(1, \frac{1}{2} \ln (1.0 \times 10^5 T_e T_i^2 / Z^4 \rho \bar{n}_e) \right). \quad (13)$$

The form of the flux limited conduction used is

$$C_e = \frac{C_e^0}{1 + C_e^0 F_i^e} \quad (14)$$

$$C_i = \frac{C_i^0}{1 + C_i^0 F_i^i} \quad (15)$$

with

$$F_i^e = 9.0 \times 10^2 a \frac{\left| \frac{\partial T_e}{\partial r} \right|}{\rho Z T_e^{3/2}}, \quad (16)$$

$$F_i^i = 4.0 \times 10^4 a^{3/2} \frac{\left| \frac{\partial T_i}{\partial r} \right|}{\rho Z T_e^{3/2}}. \quad (17)$$

To calculate the laser energy deposition rate Γ we solve the radiation transfer equation

$$\left(\frac{1}{c} \frac{\partial}{\partial t} + \mu \frac{\partial}{\partial r} + \alpha \right) \Phi = 0, \quad (18)$$

where μ is an assumed cosine of the reflected laser beam, α is the absorption coefficient, and Φ is the laser beam intensity. The absorption coefficient is given by⁽⁵⁾

$$\alpha = \frac{\phi^2 \alpha_{cr}}{(1 - \phi)^{1/2}}, \quad (19)$$

where

$$\alpha_{cr} = 1.85 \times 10^3 \bar{n}_{cr} \frac{Z^2}{\bar{n}_e T_e^{3/2}} [\ln (3.22 \times 10^3 \lambda T_e) - .577] \quad (19)$$

$$\bar{n}_{cr} = \frac{1.85 \times 10^{-3}}{\lambda^2} \quad (20)$$

$$\phi = \frac{\bar{n}_e \rho}{\bar{n}_{cr}} \quad (21)$$

Equation (18) is broken up into an inward laser beam, Φ_i , and an outward reflected beam, Φ_o , and then is solved implicitly. The laser energy absorption rate is calculated from

$$\Gamma = (\Phi_i + \Phi_o) \alpha / \rho \quad (22)$$

The use of implicit schemes is necessary in the numerical modeling for the temperature and the DCA rate equations to avoid problems with the potentially "stiff" coupling terms such as the ion-electron collision terms in equations (6-7). An interaction becomes "stiff" whenever the time-step is larger than the interaction timescale. An implicit treatment of the thermal conduction terms also is best in that it removes the mesh size restriction on the size of the time-step. Three separate implicit algorithms are used, one for the temperature equations, a second for the laser radiation transport equation, and a third for the rate equations.

The time-step used to solve the dynamic equations is governed primarily by two constraints which insure stability and accuracy. The dominant constraint is that of the Courant-Friedrich-Lewy (CFL) condition which limits the time-step to less than the local sound propagation time across any spatial zone. The second criterion used is that any change in the temperatures be resolved in time.

To improve the usage of the current model it is being modified to run under the BASIS operating system. BASIS is a system for interactive calculations and program development which is available on the CRAY computers at NMFECC and at the Livermore Computer Center. Using BASIS one can create a program that has a sophisticated

programming language as its user interface so that the user can set, plot, and calculate all the major variables in the program. The program author provides the scientific part of the program and BASIS supplies an environment which includes an interactive language interpreter, graphics, error recovery, macros, formatted I/O, and online documentation. Use of BASIS will allow both for very flexible usage of the model, and for the immediate transfer of improvements in DCA to LASNEX.

III. REFERENCES

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IV. CODE GLOSSARY

This section contains the glossary for the (D)ynamic (D)etailed (C)onfiguration (A)ccounting code. Variables which are read at the start up of the code are marked as input. The parameters given below are used to set the array lengths of the code variables. Currently only one isotope should be used ($MI = 1$). The values of the DCA array lengths are specified by DCA and use the values $MA = 200$, $MP = 1000$, and $MPI = 100$.

The variables described as multipliers can be used to vary the coefficients of the physical processes treated by the code. Generally the multipliers should be set to 1 for the proper treatment of a process and set to a very small number ($\approx 1.0 \times 10^{-10}$) to neglect the process. Three multipliers however are used differently. The radiation pressure multiplier (PRX) should always be a small number as the radiation field is assumed to be optically thin in the current version of the code and the radiation pressure is not correctly modeled. Conversely the radiation energy density multiplier (ERX) should be set to a very large number. This increases the radiation field heat capacity and keeps the radiation temperature low. A very small radiation temperature is necessary for the current model as absorption is not consistently modeled. The low radiation temperature keeps the radiative absorption low. Because of the usage of the laser reflection multiplier (REFX), to stop reflection one should set REFX to a very large number ($\approx 1.0 \times 10^{10}$) instead of using a small multiplier.

The variables described as being difference factors are used to determine the time and space centering scheme. As a difference factor varies from 0-1, the centering varies from being first order explicit to first order implicit. Values of 1/2 generate second order differencing which is the average of the explicit and implicit differencing. If the difference factor is set to exactly zero on input, then the code dynamically will try to

choose a difference value at each time step. This is not recommended for this version of the code as this feature has not been tested extensively.

The three input switch control variables IH, IV, and IQ are used to specify different variations in the hydrodynamic model. IH equal 1, 2, or 3 sets the spatial difference algorithm for equation (2), $\rho\Delta r$. For IH = 1, the average of $\rho\Delta r$ on either side of each grid boundary is used. For IH = 2, the smaller values of $\rho\Delta r$ on either side of each grid boundary is used. For IH = 3, $\rho\Delta r$ is evaluated from the average mass associated with each grid boundary divided by the grid surface area. The switch variable IV determines the left boundary condition behavior. For IV = 0 the left boundary is taken to be fixed in space, with reflection of all left moving waves. For IV = 1 and planar geometry ($\delta = 1$), the left boundary is free to move and no reflection takes place. The switch variable IQ allows the choice between the artificial viscosity given in equation (5), which is used for IQ = 1, and an alternate artificial viscosity defined as $\rho^2(\Delta r/dt)^2\Delta(1/\rho)$, which is used for IQ = 2.

PARAMETERS

MR	- maximum number of radial points + 1	(input)
MI	- maximum number of isotopes	(input)
MA	- maximum number of DCA radiation bins	(input)
MP	- maximum number of DCA level populations	(input)
MPI	- maximum number of DCA level population indices	(input)
MR	- maximum number of laser power profile points	(input)
QX	- artificial viscosity multiplier	(input)
PEX	- electron pressure multiplier	(input)
PIX	- ion pressure multiplier	(input)
PRX	- radiation pressure multiplier	(input)

BRX	- bremsstrahlung cooling multiplier	(input)
EIX	- electron/ion coupling multiplier	(input)
ABSX	- laser absorption multiplier	(input)
REFX	- laser reflection multiplier	(input)
EMX	- electron thermal conduction multiplier	(input)
OMX	- ion thermal conduction multiplier	(input)
ELIX	- electron thermal conduction flux limiter multiplier	(input)
OLIX	- ion thermal conduction flux limiter multiplier	(input)
ERX	- radiation energy density multiplier	(input)

CONTROL VARIABLES

FDNX	- electron thermal conduction temporal difference factor	(input)
FEIX	- electron/ion coupling temporal difference factor	(input)
FBX	- bremsstrahlung cooling temporal difference factor	(input)
FRX	- laser absorption spatial difference factor	(input)
FTX	- laser absorption temporal difference factor	(input)
ID	- geometry switch, ID = 1, 2, 3 for plane, cylinder, sphere	(input)
JM	- total number of spatial zones used	(input)
JMP1	- total number of spatial zones + 1	(input)
JEMIN	- inner zone limit for output	(input)
JEMAX	- outer zone limit for output	(input)
ISO	- number of isotopes	(input)
IH	- hydrodynamic difference switch	(input)
IV	- left boundary condition switch	(input)
IQ	- artificial viscosity switch	(input)
MAXCY	- maximum number of time steps	(input)
ICYCLE	- current time step	(input)
IECY	- maximum number of time steps between print output	(input)
ICY	- number of time steps since last print output	(input)
IO	- i/o switch, IO = 0, 1 for limited output, full output	(input)
IOINIT	- starting time step for print output	(input)
LEXIT	- LEXIT = 1 means stop	
IRMSNT	- spatial zoning switch, IRMSNT = 0, 1, 2 $\Rightarrow$ equal spacing, equal mass, or linearly decreasing spacing	(input)
NITER	- maximum number of energy equation iterations	(input)

TMAX	- maximum time [ns]	(input)
DTED	- maximum time between print outputs [ns]	(input)
TED	- time [ns] since last print output	(input)
ZION	- ion charge for ideal gas model with DCA turned off	(input)
	- or nuclear charge with DCA turned on	(input)
VACWAV	- laser vacuum wavelength [microns]	(input)
BARMU	- cosine of angle of laser reflection	(input)
DELTAR	- initial spatial size [cm]	(input)
IDEAL	- ideal gas switch 0, 1 for DCA, ideal gas EOS	(input)
GAMMA	- ideal gas adiabatic index	(input)
RHO(MR)	- initial density [gm cm ⁻³]	(input)
F(MI)	- mole fraction of isotopes	(input)
AK(MI)	- atomic weight of isotopes [gm mole ⁻¹]	(input)
ZK(MI)	- nuclear charge of isotopes	(input)
M(MI,MR)	- isotope indices for each spatial zone	(input)
I PRO	- number of laser input profile entries	(input)
T PRO(20)	- laser profile times [ns]	(input)
P PRO(20)	- laser input power at profile times [watts cm ⁻²]	(input)

CONSTANTS

- GCON - gas constant ($gcon = 9.64845 \times 10^{-4} \text{ nerg keV}^{-1} \text{ mole}^{-1}$)
- RCON - radiation energy density constant ($rcon = 1.37194 \times 10^{-4}$
- $\text{nerg keV}^{-4} \text{ cm}^{-3}$)
- ELCRDE - critical electron density constant [$\text{moles micros}^{+2} \text{ cm}^{-3}$]
- ABSC - critical electron density laser absorption constant [$\text{cm}^{+2} \text{ keV}^{3/2} \text{ mole}^{-1}$]
- XLNC - laser absorption Coulomb logarithm constant [$\text{microns}^{-1} \text{ keV}^{-1}$]
- PICON - volume constant, equals 1, π , $4\pi/3$ for planar, cylindrical,
- or spherical models

DCA VARIABLES

- INDEXG(MPI,MI,MR) - spatial storage for DCA variable INDXP
- LPG(MI, MR) - spatial storage for DCA variable LENPOP
- GENPOP(MP, MI,MR) - spatial storage for DCA variable POP
- J1G(MI,MR) - spatial storage for DCA variable J1
- J2G(MI,MR) - spatial storage for DCA variable J2
- IDATG(10,MI,MR) - spatial storage for DCA variable INDTL
- ADATG(20,MI,MR) - spatial storage for DCA variable ADATL
- IDATT(10,MI,MR) - spatial storage for DCA variable IDAT
- ADATT(10,MI,MR) - spatial storage for DCA variable ADAT
- INDXP(MPI) - DCA index population index variable
- POP(MP) - DCA atomic level populations
- IDATL(10) - DCA data array,
- IDATL(1) - highest Rydberg level used
 - IDATL(2) - width of hydrogenic ion stages above and below the ion stages with excited states
 - IDATL(3) - number of ion stages with excited states on either side of the average ion state
 - IDATL(4) - lowest ion stage with excited states allowed
 - IDATL(5) - 1 for hydrogenic mode, 2 for detailed model
- ADATL(20) - DCA data array
- ADATL(1) - dielectric recombination multiplier
 - ADATL(2) - radiation temperature [eV]
 - ADATL(3) - ion temperature [eV]
 - ADATL(4) - atomic weight
 - ADATL(5) - ion density

	- ADATL(6) - spatial zone size
	- ADATL(7) - velocity gradient
ADAT(10)	- DCA data array
IDAT(10)	- DCA data array
NNU	- number of radiation groups for DCA
TTR	- radiation temperature for DCA [eV]
AHNU(MA)	- radiation energy density for DCA [eV ⁺⁴]
AUNU(MA)	- radiation group spacing for DCA [eV]
AKAP(MA)	- radiation opacity from DCA [cm ⁺² atom ⁻¹]
EKAP(MA)	- radiation emissivity from DCA [cm ⁺² atom ⁻¹]

DIAGNOSTIC AND OUTPUT VARIABLES

POWTS	- entering laser energy rate [nerg ns ⁻¹]
REFLEC	- entering laser reflectivity at critical surface
TPOWX	- entering laser energy during current time step [nerg]
POWRX	- laser energy reflected during current time step [nerg]
POWLX	- laser energy leaving left surface during current - time step [nerg]
TPOW	- total entering laser energy [nerg]
POWR	- total laser energy reflected [nerg]
POWL	- total laser energy leaving through left surface [nerg]
SRP1	- total laser energy absorbed [nerg]
ENINIT	- total initial matter energy [nerg]
EKMH	- total matter kinetic energy [nerg] (icycle-1/2)
EKPH	- total matter kinetic energy [nerg] (icycle+1/2)
EKP1	- total matter kinetic energy [nerg] (icycle+1)
EBR	- total bremsstrahlung emission [nerg]
ENP1	- total matter energy [nerg] (icycle+1)
EU	- total electron excitation energy [nerg] (icycle)
TEE	- total electron internal energy [nerg] (icycle+1)
TEI	- total ion internal energy [nerg] (icycle+1)
TER	- total radiation internal energy [nerg] (icycle+1)
EETRM1(MR)	- $3*GCON*FREE*(TEP1-TE)/2$, change in electron thermal - energy [nerg gm ⁻¹]
EETRM2(MR)	- $PEPH*(VP1-VP)$ [nerg gm ⁻¹]
EETRM3(MR)	- electron-ion coupling frequency*TEPH*DTPH [nerg gm ⁻¹]
EETRM4(MR)	- electron thermal conduction energy change [nerg gm ⁻¹]

EETRM5(MR) - bremsstrahlung cooling [nerg gm⁻¹]
 EETRM6(MR) - laser absorption heating [nerg gm⁻¹]
 EETRM7(MR) - 3*GCON*TEPH*(FREEP1-FREE) [nerg gm⁻¹]
 EETRM8(MR) - ULP1-UL [nerg gm⁻¹]
 EITRM1(MR) - 3*GCON*(TIP1-TI)/2A, change in ion thermal energy [nerg gm⁻¹]
 EITRM2(MR) - PIPH*(VP1-VP) [nerg gm⁻¹]
 EITRM3(MR) - electron-ion coupling frequency*TIPH*DTPH*VPH [nerg gm⁻¹]
 EITRM4(MR) - ion thermal conduction energy change [nerg gm⁻¹]

FIRST SET OF MODEL VARIABLES

DTPH	- current time step [ns]
DTMH	- previous time step [ns]
T	- time [ns] (icycle)
TPH	- time [ns] (icycle+1/2)
TP1	- time [ns] (icycle+1)
R(MR)	- boundaries of spatial zones [cm] (icycle)
RPH(MR)	- boundaries of spatial zones [cm] (icycle+1/2)
RP1(MR)	- boundaries of spatial zones [cm] (icycle+1)
DR(MR)	- zone thickness [cm]
V(MR)	- specific volume [cm ⁺³ gm ⁻¹] (icycle)
VPH(MR)	- specific volume [cm ⁺³ gm ⁻¹] (icycle+1/2)
VP1(MR)	- specific volume [cm ⁺³ gm ⁻¹] (icycle+1)
DM(MR)	- mass per zone [gm]
U(MR)	- velocity of zone boundary [cm ns ⁻¹] (icycle+1/2)
UX(MR)	- intermediate velocity value [cm ns ⁻¹]
UDOT(MR)	- acceleration of zone boundary [cm ns ⁻²]
TE(MR)	- electron temperature [keV] (icycle)
TEPH(MR)	- electron temperature [keV] (icycle+1/2)
TEP1(MR)	- electron temperature [keV] (icycle+1)
TETS(MR)	- electron temperature guess [keV] (icycle+1/2)
TI(MR)	- ion temperature [keV] (icycle)
TIPH(MR)	- ion temperature [keV] (icycle+1/2)
TIP1(MR)	- ion temperature [keV] (icycle+1)
TITS(MR)	- ion temperature guess [keV] (icycle+1/2)
TR(MR)	- radiation temperature [keV] (icycle)

TRPH(MR)	- radiation temperature [keV] (icycle+1/2)
TRP1(MR)	- radiation temperature [keV] (icycle+1)
TRTS(MR)	- radiation temperature guess [keV] (icycle+1/2)
PR(MR)	- radiation pressure [nerg cm ⁻³] (icycle)
PE(MR)	- electron pressure [nerg cm ⁻³] (icycle)
PI(MR)	- ion pressure [nerg cm ⁻³] (icycle)
P(MR)	- total pressure [nerg cm ⁻³] (icycle)
Q(MR)	- artificial viscosity pressure [nerg cm ⁻³] (icycle)
QTS(MR)	- intermediate artificial viscosity value [nerg cm ⁻³]
ER(MR)	- radiation energy density [nerg gm ⁻¹] (icycle)
EE(MR)	- electron energy density [nerg gm ⁻¹] (icycle)
EI(MR)	- ion energy density [nerg gm ⁻¹] (icycle)
UL(MR)	- electron excitation energy [nerg gm ⁻¹] (icycle)
ULPH(MR)	- electron excitation energy [nerg gm ⁻¹] (icycle+1/2)
ULP1(MR)	- electron excitation energy [nerg gm ⁻¹] (icycle+1)
FREE(MR)	- electron number density [mole gm ⁻¹] (icycle)
FREEPH(MR)	- electron number density [mole gm ⁻¹] (icycle+1/2)
FREEP1(MR)	- electron number density [mole gm ⁻¹] (icycle+1)
AE(MR)	- electron conduction outer coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
BE(MR)	- electron conduction central coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
CE(MR)	- electron conduction inner coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
DFFE(MR)	- electron conduction coupling coeff. [nerg cm keV ⁻¹]
AI(MR)	- ion conduction outer coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
BI(MR)	- ion conduction central coupling coeff [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
CI(MR)	- ion conduction inner coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
DFFI(MR)	- ion electron conduction coupling coeff. [nerg cm keV ⁻¹]
ELIM(MR)	- electron flux limiter

OLIM(MR)	- ion flux limiter
FLI(MR)	- ratio of diffusion to free-stream electron flux
FLE(MR)	- ratio of diffusion to free-stream ion flux
AR(MR)	- radiation conduction outer coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
BR(MR)	- radiation conduction central coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]
CR(MR)	- radiation conduction inner coupling coeff. [nerg gm ⁻¹ keV ⁻¹ ns ⁻¹]

SECOND SET OF MODEL VARIABLES

DRDT(MR)	- radiation specific heat [$\text{nerg gm}^{-1} \text{keV}^{-1}$]
DIDT(MR)	- ion specific heat [$\text{nerg gm}^{-1} \text{keV}^{-1}$]
DEDT(MR)	- electron specific heat (with $dUL/dTE=0$) [$\text{nerg gm}^{-1} \text{keV}^{-1}$]
DRDV(MR)	- radiation isothermal specific heat [nerg cm^{-3}]
FDN(MR)	- electron thermal conduction sliding difference parameter
FEI(MR)	- electron-ion coupling sliding difference parameter
FB(MR)	- bremsstrahlung sliding difference parameter
FLR(MR)	- laser spatial sliding difference parameter
FLT(MR)	- laser temporal sliding difference parameter
DTCS	- time step constraint from Courant condition [ns]
DVM	- time step constraint from volume change [ns]
DTM	- time step constraint from temperature change [ns]
DTI	- time step constraint from ion conduction [ns]
O(MR)	- electron-ion coupling coefficient [$\text{nerg gm}^{-1} \text{keV}^{-1} \text{ns}^{-1}$]
BEE(MR)	- electron temperature, ion temperature coupling coeff.
BRE(MR)	- bremsstrahlung coupling coefficient [$\text{nerg gm}^{-1} \text{keV}^{-1} \text{ns}^{-1}$]
BRR(MR)	- electron temperature, radiation temperature coupling coeff.
ABSB(MR)	- laser energy absorption coefficient [cm^{-1}]
COULE(MR)	- electron Coulomb logarithm
COULI(MR)	- ion Coulomb logarithm
SRCE(MR)	- electron source term [$\text{nerg gm}^{-1} \text{ns}^{-1}$]
SR(MR)	- radiation generalized source term [$\text{nerg gm}^{-1} \text{ns}^{-1}$]
SE(MR)	- electron generalized source term [$\text{nerg gm}^{-1} \text{ns}^{-1}$]
SI(MR)	- ion generalized source term [$\text{nerg gm}^{-1} \text{ns}^{-1}$]
PHI(MR)	- ratio of electron density to critical density

POWIN(MR)	- time centered in bound laser flux [nerg ns ⁻¹ cm ⁻²]
POWON(MR)	- time centered outbound laser flux [nerg ns ⁻¹ cm ⁻²]
POWJO(MR)	- spatial centered laser outbound flux [nerg ns ⁻¹ cm ⁻²]
POWJ(MR)	- spatial centered in bound laser flux [nerg ns ⁻¹ cm ⁻²]
D(MR)	- electron conduction back substitution coefficient
E(MR)	- electron conduction back substitution coefficient
FE(MR)	- electron conduction back substitution coefficient
A(MR)	- average atomic weight [gm mole ⁻¹]
Z(MR)	- average ion charge
Z2A(MR)	- average Z^2/A
C(MI,MR)	- amount of isotopic species [moles]
DULDT(MR)	- change in UL from DCA code [nerg gm ⁻¹]
DFREEDT(MR)	- change in free from DCA code [mole gm ⁻¹]