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MED101: a laser-plasma simulation code. User guide

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MED101: a laser-plasma simulation code. User guide

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ABSTRACT

Complete details for running the 1-D laser-plasma simulation code MED101 are given including: an explanation of the input parameters, instructions for running on the Rutherford Appleton Laboratory IBM, Atlas Centre Cray X-MP and DEC VAX, and information on three new graphics packages. The code, based on the existing MEDUSA code, is capable of simulating a wide range of laser-produced plasma experiments including the calculation of X-ray laser gain.

Contents

1 Introduction

This document outlines recent modifications to the laser fusion code MEDUSA [1] (now renamed MED101). Like MEDUSA MED101 is a 1-D Lagrangian hydrodynamic code but is capable of modelling a wider range of experiments and has associated with it a suite of graphics programs.

Improvements to the physics in the program include
1) calculation of the ionisation stages of the plasma (as opposed to just the average ionisation)
2) calculation of X-ray laser gain in recombining laser-produced plasmas for H-like, Li-like and Na-like schemes
3) complete control over the design of a three-layer target
4) corrections to the energy exchange and heat conduction subroutines.

MEDUSA also needed to be overhauled as different source codes (requiring different input data files) existed for the Rutherford Appleton Laboratory IBM 3090 and the Atlas Centre Cray X-MP computers. This led to confusion as to which version was definitive. MED101 now runs transparently to the user from the same data file on either machine — this should be of benefit to users who don't have large amounts of Cray time at their disposal. MED101 should also run on all DEC VAXs without modification. You may find that results will differ slightly for identical runs on the Cray, IBM or VAX. This is because the machines have different standard numbers of significant figures and exponents.

There are three different graphics programs to post-process MED101 output:
1) FLIPPER — this plots the hydrodynamic variables (velocity, density, pressure, electron and ion temperatures, and average ionisation) vs. distance for different times, and also the hydrodynamic variables (cell edge and centre plus velocity etc.) vs. time for each cell
2) IONFLIP — this plots the ground state number density of the different ionisation stages vs. distance at different times during the interaction. IONFLIP also displays the zoning of the run. This can be useful to ensure that there are enough cells in the regions of interest
3) XRLFLIP — this plots the X-ray laser gain vs. distance at different times, and also the space-integrated gain for different lines (i. e. alpha, beta etc.) vs. time as would as measured by experiment.

Each graph has a panel at the top containing details of the input data used for that particular run.

The graphics packages have been written to run on the IBM and use NAG GKS routines. They produce GKS metafiles which can either be printed at Rutherford or transferred to the user's local site and printed there.

2 Getting started

In the following sections filenames are printed in CAPITAL LETTERS and commands that exist in batch files or commands that can be typed in by the user will be printed

```
IN THIS TYPEFACE
```

If you don't already have an account on the IBM contact the Theory and Computation group at the Central Laser Facility (telephone: 0235 21900 ext 6344/5678/6809). If you are not familiar with the CMS operating system on the IBM consult the brief guide in appendix C. However by following the instructions in the following sections and using the editor (XEDIT) it should be possible to obtain useful output.

To run MED101 you will need an input file, and an EXEC file to run on the IBM, or a JOB file to run on the Cray. Examples of all these files can be found on AR4's A-disk. To access this type

```
GIME AR4 Z
```

An example input file FPAP DATA can be obtained by typing

```
COPY FPAP DATA Z = = A
```

This will create a file called FPAP DATA in your filespace. If you had typed

```
COPY FPAP DATA Z INPUT DATA A
```

you would have created the same input file as before only this time it would be called INPUT DATA. The meanings of the various parameters in the data file are explained in section 4. It is now convenient to copy the example EXEC and JOB files as follows

```
COPY MED101 EXEC Z = = A
COPY MED101 JOB Z = = A
```

MED101 EXEC is the job file for the IBM and MED101 JOB is the job file for the Cray. You can now end your link with AR4's A-disk by typing

```
DROP Z
```

2.1 Running on the IBM

The batch system on the IBM is called SLAC-Batch and jobs are run using EXEC files. The file MED101 EXEC is listed below. EXEC files are normally written in REXX. To run MED101 EXEC type

```
BATCH SUBMIT MED101
```

Almost immediately you will be sent a message (note: this file was sent by user PR2).

```
File(s) being sent:
MED101   EXEC     A1
BMON     : PR2      PR2728   queued to run          @29Nov 10.45, cl M,
prty 09(09)
```

Your EXEC file will be sent to the batch monitor (BMON) which will assign it a priority (determined by the time and space limits set in the EXEC file) and send it to a batch worker machine. The batch job above has been classed M(edium). PR2728 is the job number. If for some reason you decide to cancel this job type

```
BATCH CANCEL PR2728
```

Full details of the different batch job classes can be found by typing

```
BR BATCH CLASSES R
```

When your job actually starts to run you will be sent a message like

```
PUN FILE 0048 SENT TO   BATCH09  RDR AS  0048 RECS 0041 CPY  001 A
NOHOLD NOKEEP
```

meaning your job has started on machine BATCH09. You can test the status of the job by typing

```
BATCH QUERY
```

Full details of this command can be obtained by typing

```
FIND BATCH QUERY
```

When the job has finished you will be sent a message such as

```
10.59:27  * MSG FROM BATCH09 : Job PR2 PR2728 ended at 10.59:27,
return code =0.
```

and any output files will be sent to your READER (see appendix C.8).

MED101 EXEC is listed below

```
/* This line is compulsory and should be used for comments*/
/*BATCH NOPROFILE */
/*BATCH SEND '= = =' */
/*BATCH NORETURN '* TEXT' */
/*BATCH NORETURN '* MAP' */
/*BATCH NORETURN '* LISTING' */
/*BATCH TIME 0:300 */
/*BATCH STORAGE 4M */
/*BATCH PRINT 16K */
TRACE R
'GLOBAL TXTLIB CMSLIB VSF2LINK VSF2FORT'
'EXEC GIME AR4'
'FILEDEF 5  DISK FPAP DATA A1'
'FILEDEF 6  DISK MED101 OUTPUT A1'
'FILEDEF 11 DISK XRL DATA A1'
'FILEDEF 12 DISK ION DATA A1'
'FILEDEF 13 DISK FLIPPER DATA A1'
'LOAD MED101(START'
Exit
```

Line 1 is compulsory and should be used for comments.
Line 2 instructs SLAC-Batch not to execute your PROFILE EXEC file.
Line 3 sends back all the files generated by the job except those covered by the NORETURN command
Lines 4-6 instruct SLAC-Batch not to send the TEXT, MAP and LISTING files to your READER.
Line 7 sets the time limit (in CPU seconds)
Line 8 sets the memory size
Line 9 sets the maximum size of the log file which can be produced
Line 10 links to AR4's space where the definitive version of MED101 is stored
Line 11 is optional. It records all the commands issued by the EXEC file in the log file.
Line 12 links the libraries needed to run the code
Lines 13-17 define the input and output streams for the run. MED101 reads its input from stream 5 (default FILE FT05F001). In this case the input file is FPAP DATA A1. MED101 produces a minimum of three and a maximum of five output files depending on the input. Data is always output on stream 6 (MED101 OUTPUT A1 in this case) and stream 13 (FLIPPER DATA A1). MED101 OUTPUT A1 will contain details of the input data and defaults set by the program plus all the output data in an easy-to-read form (see section 3 for some sample output). FLIPPER DATA A1 contains the hydrodynamic variables in a form suitable for the graphics package FLIPPER. Stream 11 (XRL DATA A1) contains the X-ray laser output in a form suitable for the graphic package XRLFLIP and stream 12 contains the ionisation data in a form suitable for IONFLIP. These two files are only created if the X-ray laser calculations are switched on in the input data file — see section 4. A log file will also be produced. For user ABC this file will be called ABC ABC001, ABC ABC002 etc. A file called FILE FT48F001 may also be created if MED101 crashes.

Line 18 runs the code
Line 19 is compulsory
If for some reason you have to re-compile MED101 on the IBM type

```
FORTVS2 MED101 (AUTODBL(DBLPAD)
```

This will compile the code in double precision to ensure it gives almost identical output to the Cray.

2.2 Running on the Cray

Jobs are run on the Cray using JOB files — there is only a limited interactive service on the Cray and it is not suitable for running jobs. MED101 is normally run on the Cray using the IBM 3090 as a front end. It is also possible to use the VAX front end to the Cray (RL.VMSFE) or submit jobs remotely over the FTP or JTMP networks. Although the same input data files should work for these methods the JOB files will require modifications and details are not included here. Using the IBM front end (in CMS) it is first necessary to link to the Cray by typing

```
GIME CRAY
```

To submit the job type

```
CRSUBMIT MED101
```

You can check on the job's progress by typing

```
CRSTAT
```

This supplies a constantly updating screen of information until you cancel out of it (press PF3 key). Your JOB will be listed according to the JN defined in line 1 of the JOB file rather than the JOB filename and will also have a Job Sequence Number (jsn) listed under Seq. If for some reason you have to cancel the job type

```
KILL jsn JN
```

from within CRSTAT. MED101 JOB is listed below

```
JOB,JN=MEDCOS1,US=USID,T=200,OLM=1600.
ACCOUNT,AC=CRAYAC,UPW=CRAYPW.
ACCESS,DN=MED,PDN=MED101,OWN=SJR.
FETCH,DN=DATA,TID=USID,TEXT='FN=FPAP,FT=DATA'.
ASSIGN,DN=DATA,A=FT05.
ASSIGN,DN=XRL,A=FT11.
ASSIGN,DN=ION,A=FT12.
ASSIGN,DN=FLIPPER,A=FT13.
SEGLDR,CMD='BIN=MED',GO.
DISPOSE,DN=XRL,DC=PU.
DISPOSE,DN=ION,DC=PU.
DISPOSE,DN=FLIPPER,DC=PU.
```

Note The first two lines (the JOB CARD and the ACCOUNT CARD) must be in upper case. For MED101 runs the lines should always end with a full stop though this is not true for all Cray JOB files. Comment lines begin with an asterisk and the continuation mark is $\wedge$ or $\neg$. DNs (Dataset Name) are files local to the job — their names must be seven characters or less. This might possibly

cause confusion as IBM filenames can be eight characters long. PDNs (Permanent Dataset Name) are files stored permanently on the Cray — their names can be up to 15 characters long.

Line 1 This is the JOB CARD. JN is the jobname — this may be up to seven characters long and can be different to the name of the JOB file. In this example the jobname is MEDCOS1. US is the Cray username — this is normally the same as your CMS username. In this example the username is USID. T is the time limit for the job in CPU seconds. The default is 8 seconds. OLM is the maximum octal size of the file output on stream 6. It is only compulsory to define JN and US in the JOB CARD but MED101 runs normally require more than 8 seconds to run and can produce lots of output so it is best to define T and OLM also.
Line 2 This is the ACCOUNT CARD. AC is the Cray account to which your job will be charged, CRAYAC in this example. UPW is your Cray password (CRAYPW is this example) — this will be different to your CMS password. To change your password modify line 2 as follows

```
ACCOUNT,AC=CRAYAC,UPW=CRAYPW,NUPW=NEWCRPW.
```

CRAYPW is the original password and NEWCRPW is the new password. Cray passwords must be between 6 and 8 characters.
Line 3 accesses the compiled version of MED101 permanently stored on the Cray and gives it a (local) Dataset Name of MED. **THIS LINE SHOULD NOT BE CHANGED**
Line 4 fetches the input data file for MED101. In this example it is FPAP DATA on your A-disk. If you want to fetch a file from a disk other than an A-disk, say your own 193 disk (where your username is USID), replace line 4 with

```
FETCH,DN=DATA,TID=USID,TEXT='FN=FPAP,FT=DATA,ADDR=193,PW=ALL'
```

Lines 5-8 define the output streams for the run. MED101 produces a minimum of two and a maximum of four output files depending on the input. Data is always output on stream 6 (MED101 OUTPUT A1 in this case) and stream 13 (FLIPPER CARDS A1). MED101 OUTPUT A1 will contain details of the input data and defaults set by the program plus all the output data in an easy-to-read form. MED101 OUTPUT will also contain run details and messages from the Cray. FLIPPER CARDS A1 contains the hydrodynamic variables in a form suitable for the graphics package FLIPPER. Stream 11 (XRL CARDS A1) contains the X-ray laser output in a form suitable for the graphic package XRLFLIP and stream 12 (ION CARDS) contains the ionisation data in a form suitable for IONFLIP. These two files are only created if the X-ray laser calculations are switched on in the input data file — see section 4.
Line 9 runs the code
Lines 10-12 sends the output files to your READER

2.3 Running on a VAX

On a VAX the equivalent command file would be:

```
$ SET DEFAULT DISC4:[AMR.DATAFILES]
!$ FORT MED101
!$ link med101
$ ASSIGN FPAP.DAT FOR005
$ ASSIGN MED101.LIS FOR006
$ ASSIGN XRL FOR011
$ ASSIGN IONSTA FOR012
$ ASSIGN FLIPPER FOR013
$ RUN MED101
$ exit
```

The first line sets the default working directory to the place where the authors use MED101 on a VAX. This will have to be changed to something sensible for the individual user. The next two lines are commented out but will have to be used the first time you use MED101 (remove the exclamation mark). The next 5 lines assign the streams to various file names, similar to the IBM and the CRAY. Finally the program is run. To run this command file you will have to enter something like

```
SUBMIT/NOTIFY/QUEUE=*****/CPU=**** MED101
```

You will have to find out the names of the requisite queues on your machine. If you type

```
SHOW QUEUE/FULL
```

this will list all the queues and also give you the maximum amount of CPU time you allowed on any one queue. The amount of CPU time used will appear on the LOG file that should be created.

3 Dealing with the output

When the job has finished on the Cray or IBM (or has failed due to lack of time or space, or because of an error) all the output files will be sent to your READER. This is a temporary filestore area on the IBM where files from other users, machines (e. g. the Cray) or processes (e. g. the SLAC-Batch machines) are sent. You can either
1)RECEIVE the files and then PRINT them, or process them with the graphics packages
2)PRINT them from your READER
3)PEEK them in your READER and DISCARD them.
See appendix C for more details on these commands.

The following pages show some typical MED101 output, obtained using the input data file below (FPAP DATA).

```
FLUORINE FIBRE (write-up #1)
8 MICRON DIAMETER
2.83E12 W/M/RAD   70PS    0.53MICRON IDEAL GAS
*********************************************
 $NEWRUN
 XAMDA1=0.53E-6, GAUSS=1.0,    ANPULS=1.0,  TOFF=1.0E-1,
 PLENTH=4.2E-11, PMAX=2.83E12, PMULT=2.381,
 NGEOM=2,        PIQ(55)=0.0,  TEINI=1.0E4, TIINI=1.0E4,
 MESH=60,   RINI=4.0E-6,    RHOGAS=2635.0, RF1=0.9000,
 XZ=9.0,    XMASS=19.0,     FNE=1.0,
 ZGLAS=0.0, DRGLAS=0.00E-0, ROGLAS=0.0,    RF2=0.0000,
 XZ2=0.0,   XMASS2=0.0,     FNE2=0.0,
 ZPLAS=0.0, DRPLAS=0.00E-0, ROPLAS=0.0,    RF3=0.0000,
 XZ1=0.0,   XMASS1=0.0,     HYDROG=0.0,
 NPRNT=-100,TSTOP=1.0E-09,  NRUN=80000,
 NP3=1,     NLEMP=F,
 NLBRMS=T,  FLIMIT=10.0,    SAHA=1.0,
 ANABS=0.2, FHOT=0.0,       FTHOT=-1.0,    RHOT=1.0,
 STATE=1.0, NLPFE=T,
 AK4=1.0E6,
 ICXRL=1,  IFRSTA=1, ILOSTA=0,   IHISTA=3,
 ISTAGE=1, IDFLG=0,  ROPMUL=0.0, ITBFLG=1, ISTFLG=0,
 IPUFLG=0, TPON=2.15E-10,        TPOFF=2.85E-10,
```

```
NLP=1,    NUP=3,    RMPD=0.002, DLAMDA=81.0E-10,
NLMAX=2,  FLSHORT=0.0001,       FLLONG=0.55,
$END
```

A similar input data file has been used to model an X-ray laser experiment performed at the Rutherford Appleton Laboratory [2] (note: in the published simulations the gain was sampled every 10ps). On some pages lines have been removed to save space.
Table 1.1: title page including first four lines of the input data file
Table 1.2 and 1.3: summary of input data — includes the quantities defined in the input data file and the defaults set by the code
Table 1.4 and 1.5: initial hydrodynamic conditions. All quantities are calculated at the cell centre except the velocity which is calculated at the cell edge. For mixtures Z is the average atomic number. When the X-ray laser calculations are switched off (ICXRL=0) the remainder of the output comprises frames similar to this at later times — in this case every 100ps (as defined by NPRNT) up to 1000ps (as defined by TSTOP).

In this example the X-ray laser calculations were switched on (ICXRL=1) so NLTE populations, LTE populations, X-ray laser information and ground state number densities are also produced in addition to the hydrodynamic variables. However only the hydrodynamic and NLTE details are output for the first time frame. Some typical data from the 400ps frame is shown.
Table 1.6: NLTE population in each cell (i. e. as a function of space) and the average degree of ionization, Z^*.
Table 1.7: LTE populations in each cell.
Table 1.8 and 1.9: X-ray laser information for each cell and gain on the different lines for comparison with experiment.
Table 1.10 Ground-state number fractions and densities in each cell — range of ionization stages defined by ILOSTA= 0 (i. e. stripped) and IHISTA= 3 (Lithium-like). The Helium and Lithium-like data is not shown.
Table 1.11 and 1.12: Hydrodynamic variables.
Table 2: This is some of the output on stream 13 for use by the graphics package FLIPPER. It contains all the hydrodynamic output from stream 6 in a compact (i. e. not-easy-to-read) form. This data was obtained using the input data file TARGET2 DATA — see section 4 and figures 9 and 10 in section 6.5.

```
 P R O G R A M   M E D U S A VS.101
 ++++++++++++++++++++++++++++++++++++++++++++++++++

FLUORINE FIBRE (write-up #1)

8 MICRON DIAMETER

2.83E12 W/M/RAD   70PS    0.53MICRON IDEAL GAS

**************************************************
```

Table 1.1: MED101 OUTPUT (written to stream 6 by MED101)

Table 1.2

SUMMARY OF THE INPUT DATA

MEDUSA VERSION 101 SUPPORTING XRL CALCULATIONS

THE ROSE-RODGERS-ROGOYSKI IMPLEMENTATION

GEOMETRY

NGEOM	CYLINDRICAL GEOMETRY PROBLEM		

LASER

GAUSS	THE LASER PULSE IS GAUSSIAN		
XAMDA1	THE LASER WAVELENGTH	=0.53000E-06	METERS
TOFF	TIME TO SWITCH OFF LASER	=0.10000E+00	SECONDS
ANPULS	NUMBER OF GAUSSIAN PULSES	=0.10000E+01	
PMAX	THE MAXIMUM LASER POWER	=0.28300E+13	WATTS/METERS/RAD
PEQUIV	EQUIVALENT SURFACE IRRADIANCE	=0.70750E+18	WATTS/SQUARE METER
PLENTH	THE HALF WIDTH OF THE PULSE IN TIME	=0.42000E-10	SECONDS
PMULT	INITIAL POWER LEVEL	=0.23810E+01	WATTS

IONS AND ELECTRONS

TEINI	INITIAL ELECTRONS TEMPERATURE	=0.10000E+05	DEGREE KELVIN
TIINI	INITIAL IONS TEMPERATURE	=0.10000E+05	DEGREE KELVIN
FHOT	FRACTION OF ANOMALOUS ABSORPTION INTO HOT ELECTRONS	= 0.00	
STATE	ELECTRON EQUATION OF STATE IS THOMAS FERMI		

TARGET

XZ	CHARGE NUMBER OF EXTRA ELEMENT	= 9.00	
XMASS	MASS NUMBER OF EXTRA ELEMENT	= 19.00	
RINI	RADIUS OF THE SHELL FILLED WITH THE GAS	=0.40000E-05	METERS
FNE	THE COMPOSITION OF GAS IS PURE XZ		
RHOGAS	THE GAS DENSITY	=0.26350E+04	KG/CUBIC METERS
RF1	GAS FILL GRID FACTOR	=0.90000000	
XZ2	CHARGE NUMBER OF GLASS SHELL ELEMENT	= 8.00	
XMASS2	MASS NUMBER OF GLASS SHELL ELEMENT	= 16.00	
DRGLAS	THICKNESS OF GLASS	=0.00000E+00	METERS
ROGLAS	DENSITY OF GLASS	=0.00000E+00	KG/CUBIC METERS
RF2	GLASS SHELL GRID FACTOR	=0.00000000	
FNE2	FRACTION OF XZ2	= 0.000000	%
	FRACTION OF SILICON	=100.000000	%
XZ1	CHARGE NUMBER OF PLASTIC SHELL ELEMENT	= 6.00	
XMASS1	MASS NUMBER OF PLASTIC SHELL ELEMENT	= 12.01	
DRPLAS	THICKNESS OF PLASTIC COATING	=0.00000E+00	METERS
ROPLAS	DENSITY OF PLASTIC	=0.00000E+00	KG/CUBIC METERS
RF3	PLASTIC SHELL GRID FACTOR	=0.00000000	
HYDROG	FRACTIONAL NUMBER DENSITY OF HYDROGEN IN THE TARGET	= 0.00	

RADIATION

NLBRMS	BREMSSTRAHLUNG RADIATION IS INCLUDED		

Table 1.3

```
ANABS  :  FRACTIONAL ANOMALOUS ABSORPTION AT CRITICAL          =   0.20
SAHA   :  THE IONISATION EQUILIBRIUM IS CALCULATED

                                                  NUMERICAL

MESH   :  THE TOTAL NUMBER OF MESH POINTS                      =    60
ZPLAS  :  NUMBER OF MESH POINTS IN PLASTIC                     =     0.
ZGLAS  :  NUMBER OF MESH POINTS IN GLASS                       =     0.
TSTOP  :  MAXIMUM VALUE OF TIME PERMITED                       =0.10000E-08        SECONDS

X-RAY LASER CALCULATIONS ARE ON

ISTAGE :  IONISATION STAGE : H-LIKE
IDFLG  :  NO OPTICAL DEPTH CORRECTION
ITBFLG :  POPULATION OF HIGHEST LEVEL FORCED INTO LTE
ISTFLG :  MOTIONAL STARK BROADENING NOT INCLUDED
IPUFLG :  PHOTOPUMPING OFF
DLAMDA :  X-RAY LASER WAVELENGTH                               =   8.10000E+01     ANGSTROMS
NLMAX  :  NO OF LENGTHS USED IN INTENSITY CALCULATION          = 2
FL(1)  :  LENGTH                                               =   1.00000E-06     METERS
FL(2)  :  LENGTH                                               =   5.50000E-03     METERS
```

Table 1.4

TIMESTEP NUMBER 0 TIME = 0.0000000E+00 TIME R-TO-P = -9.9978494E-11 DELTA T = 1.0000000E-18

BOUNDARY : R (CM) = 4.0000E-04 U (CM/SEC) = 0.0000E+00

ENERGIES (J/CM) : THERMAL 8.6320SE-02 KINETIC 0.00000E+00 NUCLEAR 0.00000E+00 ERROR 0.00000E+00

LASER POWER (W/CM) 1.49603E-01 TOTAL ENERGY INPUT FROM LASER (J/CM) 0.00000E+00

ABSORPTION AT R (CM) = 3.9996E-04

COLUMN 1 : CELL NUMBER
COLUMN 2 : CELL EDGE (CM)
COLUMN 3 : HYDRODYNAMIC VELOCITIES (CM/SEC)
COLUMN 4 : CELL CENTRE (CM)
COLUMN 5 : DENSITY (G/CM**3)
COLUMN 6 : HYDRODYNAMIC PRESSURE (MB)
COLUMN 7 : ELECTRON TEMPERATURE (EV)
COLUMN 8 : ION TEMPERATURE (EV)
COLUMN 9 : AVERAGE Z

CELL	CELL EDGE	VELOCITY	CELL CENTRE	DENSITY	PRESSURE	ELEC TEMP	ION TEMP	Z*	Z
1	0.0000E+00	0.0000E+00	2.0036E-05	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
2	4.0072E-05	0.0000E+00	5.8104E-05	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
3	7.6137E-05	0.0000E+00	9.2366E-05	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
4	1.0860E-04	0.0000E+00	1.2320E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
5	1.3781E-04	0.0000E+00	1.5095E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
6	1.6410E-04	0.0000E+00	1.7593E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
7	1.8776E-04	0.0000E+00	1.9841E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
8	2.0906E-04	0.0000E+00	2.1864E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
9	2.2822E-04	0.0000E+00	2.3685E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
10	2.4547E-04	0.0000E+00	2.5324E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
11	2.6100E-04	0.0000E+00	2.6798E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
12	2.7497E-04	0.0000E+00	2.8126E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
13	2.8754E-04	0.0000E+00	2.9320E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
14	2.9886E-04	0.0000E+00	3.0396E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
15	3.0905E-04	0.0000E+00	3.1363E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
16	3.1822E-04	0.0000E+00	3.2234E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
17	3.2647E-04	0.0000E+00	3.3018E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
18	3.3389E-04	0.0000E+00	3.3723E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
19	3.4057E-04	0.0000E+00	3.4358E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
20	3.4659E-04	0.0000E+00	3.4930E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
21	3.5200E-04	0.0000E+00	3.5444E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
22	3.5687E-04	0.0000E+00	3.5907E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
23	3.6126E-04	0.0000E+00	3.6323E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
24	3.6520E-04	0.0000E+00	3.6698E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
25	3.6876E-04	0.0000E+00	3.7035E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
26	3.7195E-04	0.0000E+00	3.7339E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
27	3.7483E-04	0.0000E+00	3.7612E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
28	3.7742E-04	0.0000E+00	3.7858E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
29	3.7975E-04	0.0000E+00	3.8080E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
30	3.8185E-04	0.0000E+00	3.8279E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
31	3.8373E-04	0.0000E+00	3.8458E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
32	3.8543E-04	0.0000E+00	3.8620E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
33	3.8696E-04	0.0000E+00	3.8765E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000

Table 1.5

34	3.8834E-04	0.0000E+00	3.8896E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
35	3.8957E-04	0.0000E+00	3.9013E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
36	3.9069E-04	0.0000E+00	3.9119E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
37	3.9169E-04	0.0000E+00	3.9214E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
38	3.9260E-04	0.0000E+00	3.9300E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
39	3.9341E-04	0.0000E+00	3.9377E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
40	3.9414E-04	0.0000E+00	3.9447E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
41	3.9480E-04	0.0000E+00	3.9509E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
42	3.9539E-04	0.0000E+00	3.9566E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
43	3.9592E-04	0.0000E+00	3.9616E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
44	3.9640E-04	0.0000E+00	3.9662E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
45	3.9683E-04	0.0000E+00	3.9703E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
46	3.9722E-04	0.0000E+00	3.9740E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
47	3.9757E-04	0.0000E+00	3.9773E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
48	3.9789E-04	0.0000E+00	3.9803E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
49	3.9817E-04	0.0000E+00	3.9830E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
50	3.9843E-04	0.0000E+00	3.9854E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
51	3.9865E-04	0.0000E+00	3.9876E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
52	3.9886E-04	0.0000E+00	3.9895E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
53	3.9905E-04	0.0000E+00	3.9913E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
54	3.9921E-04	0.0000E+00	3.9929E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
55	3.9937E-04	0.0000E+00	3.9943E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
56	3.9950E-04	0.0000E+00	3.9956E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
57	3.9962E-04	0.0000E+00	3.9968E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
58	3.9973E-04	0.0000E+00	3.9978E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
59	3.9983E-04	0.0000E+00	3.9988E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
60	3.9992E-04	0.0000E+00	3.9996E-04	2.6350E+00	1.1449E+00	8.6173E-01	8.6173E-01	1.0000E+00	9.000
61	4.0000E-04	0.0000E+00							

TIMESTEP NUMBER 990 TIME = 4.0139529E-10 TIME R-TO-P = 3.0139329E-10 DELTA T = 8.9747953E-12

NLTE POPULATIONS

CN	K-SHELL	L-SHELL	M-SHELL	N-SHELL	O-SHELL	P-SHELL	Z*
1	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
2	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
3	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
4	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
5	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
6	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
7	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
8	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
9	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
10	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
21	2.00000	4.83460	0.33052	0.31698	0.32078	0.19712	1.00000
22	2.00000	4.98536	0.22326	0.21993	0.26210	0.30935	1.00000
23	2.00000	4.99706	0.16745	0.17358	0.22808	0.30578	1.12806
24	2.00000	4.49607	0.13258	0.12019	0.14705	0.18978	1.91433
25	2.00000	3.60313	0.10935	0.08283	0.09187	0.11216	3.00065
26	2.00000	2.62777	0.09116	0.05917	0.06001	0.06942	4.09247
27	2.00000	1.74039	0.07388	0.04382	0.04180	0.04644	5.05367
28	2.00000	1.00700	0.05445	0.03180	0.02954	0.03211	5.84509
29	2.00000	0.50461	0.03441	0.02106	0.01969	0.02135	6.39888
30	1.99911	0.17811	0.02045	0.01396	0.01341	0.01465	6.76031
31	1.74232	0.01026	0.01291	0.01059	0.01048	0.01146	7.20199
32	1.42121	0.00347	0.00928	0.00870	0.00878	0.00961	7.53896
33	1.19746	0.00196	0.00701	0.00738	0.00759	0.00833	7.77027
34	1.03170	0.00128	0.00534	0.00627	0.00657	0.00724	7.94159
35	0.90752	0.00092	0.00418	0.00540	0.00576	0.00637	8.06984
36	0.81784	0.00069	0.00332	0.00469	0.00508	0.00564	8.16274
37	0.75135	0.00054	0.00264	0.00405	0.00446	0.00498	8.23200
38	0.70493	0.00043	0.00213	0.00351	0.00394	0.00441	8.28066
39	0.67660	0.00034	0.00172	0.00303	0.00345	0.00389	8.31096
40	0.66419	0.00028	0.00140	0.00262	0.00303	0.00344	8.32503
41	0.66676	0.00023	0.00114	0.00226	0.00265	0.00302	8.32394
42	0.68302	0.00019	0.00093	0.00193	0.00231	0.00265	8.30898
43	0.71219	0.00016	0.00076	0.00165	0.00201	0.00232	8.28091
44	0.75285	0.00014	0.00062	0.00140	0.00173	0.00201	8.24127
45	0.80489	0.00012	0.00051	0.00119	0.00149	0.00174	8.19007
46	0.86708	0.00010	0.00042	0.00100	0.00128	0.00150	8.12863
47	0.93810	0.00009	0.00034	0.00084	0.00108	0.00129	8.05827
48	1.01620	0.00007	0.00028	0.00070	0.00092	0.00110	7.98073
49	1.10074	0.00007	0.00023	0.00058	0.00077	0.00093	7.89668
50	1.18977	0.00006	0.00019	0.00048	0.00065	0.00079	7.80806
51	1.28162	0.00005	0.00016	0.00040	0.00054	0.00066	7.71657
52	1.37449	0.00005	0.00013	0.00032	0.00045	0.00055	7.62402
53	1.46674	0.00004	0.00010	0.00025	0.00036	0.00045	7.53206
54	1.55675	0.00004	0.00008	0.00020	0.00029	0.00036	7.44229
55	1.64308	0.00004	0.00006	0.00015	0.00022	0.00028	7.35618
56	1.72458	0.00003	0.00004	0.00011	0.00017	0.00021	7.27486
57	1.80019	0.00003	0.00003	0.00008	0.00012	0.00015	7.19941
58	1.86934	0.00003	0.00002	0.00005	0.00008	0.00010	7.13039
59	1.93126	0.00003	0.00001	0.00002	0.00004	0.00006	7.06859
60	1.98449	0.00006	0.00000	0.00000	0.00001	0.00002	7.01542

Table 1.6

Table 1.7

LTE POPULATIONS

CN	K-SHELL	L-SHELL	M-SHELL	N-SHELL	O-SHELL	P-SHELL	Z*
1	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
2	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
3	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
4	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
5	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
6	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
7	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
8	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
9	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
10	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
21	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
22	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
23	2.00000	6.00000	0.00000	0.00000	0.00000	0.00000	1.00000
24	2.00000	4.56172	0.12929	0.11706	0.14319	0.18480	1.86394
25	2.00000	3.75663	0.10512	0.07916	0.08772	0.10707	2.86431
26	2.00000	2.91027	0.08746	0.05560	0.05615	0.06490	3.82563
27	2.00000	2.13318	0.07310	0.04113	0.03875	0.04292	4.67092
28	2.00000	1.39619	0.05785	0.03063	0.02776	0.02998	5.45759
29	2.00000	0.75775	0.03973	0.02116	0.01908	0.02049	6.14179
30	2.00000	0.40864	0.02644	0.01445	0.01313	0.01414	6.52319
31	2.00000	0.32283	0.02090	0.01107	0.00989	0.01054	6.62478
32	2.00000	0.28795	0.01767	0.00911	0.00804	0.00850	6.66874
33	2.00000	0.25623	0.01532	0.00779	0.00683	0.00719	6.70664
34	2.00000	0.22546	0.01329	0.00670	0.00585	0.00615	6.74254
35	2.00000	0.19842	0.01164	0.00585	0.00510	0.00535	6.77364
36	2.00000	0.17439	0.01025	0.00514	0.00448	0.00470	6.80104
37	2.00000	0.15196	0.00898	0.00451	0.00393	0.00413	6.82649
38	2.00000	0.13207	0.00789	0.00398	0.00347	0.00365	6.84894
39	2.00000	0.11343	0.00689	0.00350	0.00306	0.00322	6.86990
40	2.00000	0.09671	0.00601	0.00307	0.00270	0.00284	6.88866
41	2.00000	0.08137	0.00520	0.00269	0.00237	0.00251	6.90585
42	2.00000	0.06752	0.00447	0.00234	0.00208	0.00220	6.92138
43	2.00000	0.05557	0.00384	0.00204	0.00182	0.00194	6.93479
44	2.00000	0.04481	0.00324	0.00175	0.00158	0.00169	6.94692
45	2.00000	0.03592	0.00274	0.00151	0.00138	0.00148	6.95697
46	2.00000	0.02845	0.00230	0.00130	0.00119	0.00129	6.96546
47	2.00000	0.02220	0.00191	0.00110	0.00103	0.00111	6.97265
48	2.00000	0.01717	0.00158	0.00094	0.00088	0.00096	6.97847
49	2.00000	0.01318	0.00130	0.00079	0.00075	0.00082	6.98316
50	2.00000	0.01010	0.00107	0.00067	0.00064	0.00071	6.98682
51	2.00000	0.00764	0.00087	0.00055	0.00054	0.00060	6.98981
52	2.00000	0.00571	0.00069	0.00046	0.00045	0.00050	6.99219
53	1.99999	0.00422	0.00055	0.00037	0.00037	0.00041	6.99409
54	1.99999	0.00309	0.00043	0.00029	0.00030	0.00034	6.99557
55	1.99999	0.00221	0.00033	0.00023	0.00023	0.00027	6.99674
56	1.99998	0.00154	0.00024	0.00017	0.00018	0.00020	6.99769
57	1.99997	0.00104	0.00017	0.00013	0.00013	0.00015	6.99841
58	1.99995	0.00065	0.00011	0.00008	0.00009	0.00010	6.99902
59	1.99990	0.00034	0.00006	0.00005	0.00005	0.00006	6.99956
60	1.99960	0.00009	0.00002	0.00001	0.00001	0.00002	7.00024

Table 1.8

L	RADIUS(CM)	NE(CM**-3)	TE(KEV)	GAIN(CM**-1)	VOIGT A	REFRACTION TOL	
1	3.3231E-05	3.0366E+22	3.6370E-03	-3.5690E-29	1.7250E+01	0.0000E-79	0.0000E+00
2	9.5488E-05	3.1578E+22	3.4072E-03	-9.5863E-30	1.7746E+01	-7.4372E-14	-2.2498E-06
3	1.5002E-04	3.2721E+22	3.1447E-03	-1.0339E-29	1.8065E+01	-6.9872E-14	-2.1136E-06
4	1.9815E-04	3.3541E+22	2.9214E-03	-1.0995E-29	1.8135E+01	-7.4894E-14	-2.2656E-06
5	2.4070E-04	3.4549E+22	2.7190E-03	-1.1739E-29	1.8221E+01	-1.0668E-13	-3.2271E-06
6	2.7808E-04	3.5832E+22	2.5491E-03	-1.2574E-29	1.8406E+01	-1.0475E-13	-3.1688E-06
7	3.1104E-04	3.6578E+22	2.4064E-03	-1.3212E-29	1.8292E+01	-3.9039E-15	-1.1809E-07
8	3.4083E-04	3.5967E+22	2.2465E-03	-1.3445E-29	1.7339E+01	-8.6588E-14	-2.6193E-06
9	3.6740E-04	3.7764E+22	2.1935E-03	-1.4287E-29	1.7956E+01	1.1057E-13	3.3449E-06
10	3.9180E-04	3.4648E+22	1.9708E-03	-1.3827E-29	1.5356E+01	1.6847E-13	5.0964E-06
11	4.1453E-04	3.5469E+22	2.0894E-03	-1.3744E-29	1.6357E+01	6.4035E-13	1.9371E-05
12	4.3790E-04	2.6487E+22	2.3797E-03	-9.6181E-30	1.3168E+01	1.2230E-12	3.6996E-05
13	4.6680E-04	1.8377E+22	3.2453E-03	-5.1427E-29	1.0219E+01	7.7384E-13	2.3409E-05
14	5.0213E-04	1.3427E+22	4.2490E-03	-3.2837E-29	7.7303E+00	4.0558E-13	1.2269E-05
15	5.4314E-04	1.0128E+22	5.0918E-03	-2.5133E-30	5.8122E+00	2.2223E-13	6.7226E-06
16	5.8766E-04	8.3301E+21	6.0009E-03	-1.9045E-30	4.6961E+00	1.3548E-13	4.0983E-06
17	6.3416E-04	6.7821E+21	6.7177E-03	-1.4650E-30	3.4644E+00	1.0169E-13	3.0761E-06
18	6.8206E-04	5.7282E+21	7.4452E-03	-1.7368E-30	2.7437E+00	7.3889E-14	2.2351E-06
19	7.3053E-04	4.8473E+21	8.2482E-03	-1.9485E-30	1.8284E+00	6.5724E-14	1.9881E-06
20	7.8038E-04	3.9718E+21	8.9076E-03	-2.2660E-30	1.1743E+00	5.3632E-14	1.6224E-06
21	8.3153E-04	3.3785E+21	1.0447E-02	-3.4819E-30	5.1577E-01	6.8419E-14	2.0697E-06
22	9.0956E-04	1.3807E+21	9.2088E-03	-1.3754E-30	2.6823E-01	5.6171E-14	1.6992E-06
23	1.0666E-03	6.0504E+20	8.6579E-03	-6.1032E-31	1.1051E-01	1.0318E-14	3.1213E-07
24	1.3586E-03	4.0927E+20	9.7349E-03	-8.0560E-31	3.6618E-02	1.7088E-15	5.1691E-08
25	1.8281E-03	2.8776E+20	1.1994E-02	-1.5471E-30	1.0034E-02	6.9807E-16	2.1117E-08
26	2.4632E-03	2.1108E+20	1.4753E-02	-2.4925E-30	3.3074E-03	3.3438E-16	1.0115E-08
27	3.2032E-03	1.6588E+20	1.7693E-02	-3.0014E-30	1.4569E-03	1.8154E-16	5.4915E-09
28	3.9861E-03	1.3642E+20	2.0818E-02	-2.3446E-29	8.1696E-04	1.3101E-16	3.9631E-09
29	4.7894E-03	1.0942E+20	2.3951E-02	-6.9795E-18	5.3388E-04	1.0999E-16	3.3273E-09
30	5.6102E-03	8.7918E+19	2.6619E-02	-8.5073E-06	3.8990E-04	7.4883E-17	2.2652E-09
31	6.4258E-03	7.6079E+19	2.8984E-02	-1.7380E-02	4.4694E-04	4.3547E-17	1.3173E-09
32	7.2020E-03	6.8967E+19	3.0905E-02	1.0764E-02	5.8549E-04	3.0907E-17	9.3495E-10
33	7.9206E-03	6.3474E+19	3.2363E-02	3.2132E-02	6.8624E-04	2.9752E-17	8.9999E-10
34	8.5869E-03	5.7788E+19	3.3511E-02	3.9019E-02	7.6027E-04	3.0324E-17	9.1730E-10
35	9.2100E-03	5.2831E+19	3.4443E-02	3.7948E-02	8.1401E-04	2.9242E-17	8.8457E-10
36	9.7947E-03	4.8186E+19	3.5172E-02	3.3161E-02	8.5241E-04	2.9874E-17	9.0368E-10
37	1.0348E-02	4.3595E+19	3.5771E-02	2.6983E-02	8.8043E-04	2.9472E-17	8.9152E-10
38	1.0875E-02	3.9526E+19	3.6271E-02	2.1299E-02	8.9834E-04	2.8632E-17	8.6610E-10
39	1.1378E-02	3.5575E+19	3.6684E-02	1.6138E-02	9.0942E-04	2.7923E-17	8.4468E-10
40	1.1863E-02	3.2017E+19	3.7035E-02	1.1994E-02	9.1300E-04	2.6666E-17	8.0664E-10
41	1.2331E-02	2.8669E+19	3.7334E-02	8.6667E-03	9.1084E-04	2.5850E-17	7.8196E-10
42	1.2785E-02	2.5535E+19	3.7591E-02	6.0960E-03	9.0370E-04	2.4213E-17	7.3245E-10
43	1.3228E-02	2.2761E+19	3.7813E-02	4.2396E-03	8.9078E-04	2.3020E-17	6.9636E-10
44	1.3661E-02	2.0052E+19	3.8009E-02	2.8255E-03	8.7534E-04	2.1506E-17	6.5056E-10
45	1.4088E-02	1.7730E+19	3.8184E-02	1.8695E-03	8.5361E-04	1.9317E-17	5.8433E-10
46	1.4507E-02	1.5607E+19	3.8337E-02	1.2020E-03	8.2810E-04	1.8138E-17	5.4869E-10
47	1.4923E-02	1.3609E+19	3.8471E-02	7.3941E-04	8.0016E-04	1.6718E-17	5.0573E-10
48	1.5338E-02	1.1832E+19	3.8594E-02	4.3814E-04	7.6804E-04	1.4949E-17	4.5221E-10
49	1.5753E-02	1.0238E+19	3.8702E-02	2.4677E-04	7.3218E-04	1.3154E-17	3.9791E-10
50	1.6169E-02	8.8616E+18	3.8799E-02	1.3110E-04	6.9166E-04	1.1806E-17	3.5712E-10
51	1.6588E-02	7.5564E+18	3.8883E-02	6.0867E-05	6.4963E-04	1.0805E-17	3.2686E-10
52	1.7018E-02	6.3676E+18	3.8960E-02	2.2364E-05	6.0523E-04	9.6110E-18	2.9073E-10
53	1.7464E-02	5.2707E+18	3.9029E-02	3.6130E-06	5.5943E-04	8.2991E-18	2.5105E-10
54	1.7934E-02	4.3050E+18	3.9093E-02	-3.5457E-06	5.1139E-04	6.9858E-18	2.1132E-10

55	1.8440E-02	3.4231E+18	3.9148E-02	-4.8729E-06	4.6288E-04	5.8477E-18	1.7689E-10
56	1.9001E-02	2.6181E+18	3.9199E-02	-3.7229E-06	4.1466E-04	4.5895E-18	1.3883E-10
57	1.9646E-02	1.9342E+18	3.9244E-02	-2.1479E-06	3.6521E-04	3.4280E-18	1.0370E-10
58	2.0435E-02	1.2997E+18	3.9287E-02	-8.7188E-07	3.1895E-04	2.4267E-18	7.3409E-11
59	2.1551E-02	7.2377E+17	3.9328E-02	-1.9477E-07	2.8079E-04	1.3255E-18	4.0097E-11
60	2.4041E-02	2.1466E+17	3.9375E-02	-1.2471E-08	2.8989E-04	0.0000E+00	0.0000E+00

Table 1.9

MAXIMUM GAIN POINT AT:

L	RADIUS(CM)	NE(CM**-3)	TE(KEV)	GAIN(CM**-1)	VOIGT A	REFRACTION TOL	
34	8.5869E-03	5.7788E+19	3.3511E-02	3.9019E-02	7.6027E-04	3.0324E-17	9.1730E-10

FIBRE LENGTH (CM) = 1.00E-04

WIDE PH S**-1 ST**-1	ALPHA	BETA	GAMMA
	2.47E+18	1.30E+18	4.26E+17
NARR PH S**-1 ST**-1	ALPHA	BETA	GAMMA
	2.47E+18	1.30E+18	4.26E+17
SATURATION FACTOR	ALPHA	BETA	GAMMA
	1.53E-09	3.26E-10	7.60E-11

FIBRE LENGTH (CM) = 5.50E-01

WIDE PH S**-1 ST**-1	ALPHA	BETA	GAMMA
	3.18E+22	7.72E+21	2.33E+21
NARR PH S**-1 ST**-1	ALPHA	BETA	GAMMA
	2.49E+22	7.54E+21	2.33E+21
SATURATION FACTOR	ALPHA	BETA	GAMMA
	1.96E-05	1.93E-06	4.16E-07

EFFECTIVE GAIN CALCULATED FROM NARROW LINE
INTENSITIES USING LENGTHS :5.50000E-01 / 1.00000E-04 CM
ALPHA : 2.01880E+00 BETA : 1.93441E-01 GAMMA : -1.34116E-02

GROUND-STATE NUMBER FRACTIONS AND DENSITIES

Table 1.10

CELL NO	C-OF-C COORDINATE	STRIPPED NO FRACTION	STRIPPED NO.DENSITY	H-LIKE NO FRACTION	H-LIKE NO.DENSITY
1	3.32313E-05	7.52316E-37	2.28446E-14	6.77626E-21	2.05765E+02
2	9.54880E-05	1.88079E-37	5.93922E-15	3.38813E-21	1.06991E+02
3	1.50022E-04	1.88079E-37	6.15420E-15	3.38813E-21	1.10864E+02
4	1.98147E-04	1.88079E-37	6.30836E-15	3.38813E-21	1.13641E+02
5	2.40698E-04	1.88079E-37	6.49796E-15	3.38813E-21	1.17057E+02
6	2.78080E-04	1.88079E-37	6.73923E-15	3.38813E-21	1.21403E+02
7	3.11040E-04	1.88079E-37	6.87959E-15	3.38813E-21	1.23932E+02
8	3.40829E-04	1.88079E-37	6.76463E-15	3.38813E-21	1.21861E+02
9	3.67405E-04	1.88079E-37	7.10253E-15	3.38813E-21	1.27948E+02
10	3.91799E-04	1.88079E-37	6.51652E-15	3.38813E-21	1.17391E+02
21	8.31529E-04	2.29518E-36	7.75423E-15	4.13462E-20	1.39688E+02
22	9.09561E-04	1.81053E-36	2.49981E-15	3.26156E-20	4.50325E+01
23	1.06657E-03	2.02052E-36	1.08372E-15	3.63985E-20	1.95226E+01
24	1.35863E-03	9.24635E-36	1.97680E-15	1.66567E-19	3.56108E+01
25	1.82807E-03	6.90092E-35	6.61800E-15	1.24316E-18	1.19219E+02
26	2.46322E-03	3.85200E-34	1.98675E-14	6.93915E-18	3.57901E+02
27	3.20319E-03	1.40911E-33	4.62521E-14	2.53843E-17	8.33204E+02
28	3.98608E-03	3.26112E-32	7.61122E-13	1.95824E-16	4.57039E+03
29	4.78937E-03	3.06659E-20	5.24403E-01	2.57163E-10	4.39763E+09
30	5.61021E-03	1.56375E-07	2.03365E+12	7.00225E-04	9.10641E+15
31	6.42577E-03	1.57003E-02	1.65852E+17	2.12317E-01	2.24283E+18
32	7.20203E-03	8.04781E-02	7.36217E+17	3.95227E-01	3.61555E+18
33	7.92063E-03	1.55904E-01	1.27355E+18	4.65243E-01	3.80049E+18
34	8.58689E-03	2.28223E-01	1.66071E+18	4.86330E-01	3.53886E+18
35	9.21003E-03	2.91698E-01	1.90968E+18	4.84629E-01	3.17276E+18
36	9.79466E-03	3.42655E-01	2.02277E+18	4.74112E-01	2.79878E+18
37	1.03479E-02	3.83344E-01	2.03013E+18	4.61335E-01	2.44316E+18
38	1.08746E-02	4.13302E-01	1.97279E+18	4.49931E-01	2.14762E+18
39	1.13785E-02	4.32432E-01	1.85100E+18	4.42170E-01	1.89268E+18
40	1.18631E-02	4.41314E-01	1.69724E+18	4.38862E-01	1.68781E+18
41	1.23308E-02	4.40269E-01	1.51635E+18	4.40358E-01	1.51665E+18
42	1.27852E-02	4.30155E-01	1.32194E+18	4.46175E-01	1.37117E+18
43	1.32277E-02	4.11764E-01	1.13179E+18	4.55427E-01	1.25180E+18
44	1.36612E-02	3.86564E-01	9.40555E+17	4.66706E-01	1.13555E+18
45	1.40877E-02	3.55278E-01	7.69110E+17	4.78549E-01	1.03597E+18
46	1.45074E-02	3.19503E-01	6.13436E+17	4.89058E-01	9.38978E+17
47	1.49233E-02	2.80886E-01	4.74365E+17	4.96275E-01	8.38118E+17
48	1.53379E-02	2.41223E-01	3.57621E+17	4.98336E-01	7.38802E+17
49	1.57527E-02	2.01645E-01	2.61438E+17	4.93649E-01	6.40030E+17
50	1.61685E-02	1.63762E-01	1.85858E+17	4.80946E-01	5.45838E+17
51	1.65884E-02	1.28785E-01	1.26111E+17	4.59513E-01	4.49974E+17
52	1.70180E-02	9.76703E-02	8.15739E+16	4.29240E-01	3.58500E+17
53	1.74641E-02	7.10049E-02	4.96869E+16	3.90605E-01	2.73332E+17
54	1.79343E-02	4.90706E-02	2.83850E+16	3.44684E-01	1.99383E+17
55	1.84398E-02	3.18247E-02	1.48091E+16	2.93007E-01	1.36346E+17
56	1.90009E-02	1.89537E-02	6.82104E+15	2.37360E-01	8.54210E+16
57	1.96456E-02	9.97732E-03	2.68054E+15	1.79778E-01	4.82997E+16
58	2.04355E-02	4.26685E-03	7.77765E+14	1.22091E-01	2.22548E+16
59	2.15511E-02	1.18117E-03	1.20943E+14	6.63685E-02	6.79567E+15
60	2.40409E-02	6.01097E-05	1.83925E+12	1.53852E-02	4.70758E+14

Table 1.11

TIMESTEP NUMBER 990 TIME = 4.0139529E-10 TIME R-TO-P = 3.0619326E-10 DELTA T = 9.5999261E-12

DELTA T DETERMINED BY CONDITION 1 AT MESHPOINT 11

BOUNDARY : R (CM) = 2.6594E-02 U (CM/SEC) = 8.2054E+07

ENERGIES (J/CM) : THERMAL 3.84087E-01 KINETIC 9.38681E+00 NUCLEAR 0.00000E+00 ERROR 1.01208E+00

LASER POWER.(W/CM) 0.00000E+00 TOTAL ENERGY INPUT FROM LASER (J/CM) 1.31867E+01

ABSORPTION AT R (CM) = 7.6271E-04

RADIATION LOSS -1.94190E-01

HOT ELECTRON TEMPERATURE 0.00000E+00 EV
FRACTIONAL ENERGY LOSS IN EACH GROUP
0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00
0.000E+00 0.000E+00 0.000E+00 0.000E+00 0.000E+00

CELL	CELL EDGE	VELOCITY	CELL CENTRE	DENSITY	PRESSURE	ELEC TEMP	ION TEMP	Z*	Z
1	0.0000E+00	0.0000E+00	3.4889E-05	8.6902E-01	2.9696E-01	3.3904E+00	3.3870E+00	1.0000E+00	9.000
2	6.9778E-05	3.7036E+05	1.0016E-04	9.0738E-01	2.9119E-01	3.1839E+00	3.1808E+00	1.0000E+00	9.000
3	1.3054E-04	6.7298E+05	1.5716E-04	9.4400E-01	2.8027E-01	2.9456E+00	2.9429E+00	1.0000E+00	9.000
4	1.8378E-04	9.2201E+05	2.0732E-04	9.7153E-01	2.6863E-01	2.7432E+00	2.7407E+00	1.0000E+00	9.000
5	2.3087E-04	1.1276E+06	2.5157E-04	1.0038E+00	2.5878E-01	2.5577E+00	2.5554E+00	1.0000E+00	9.000
6	2.7228E-04	1.2992E+06	2.9038E-04	1.0433E+00	2.5241E-01	2.4003E+00	2.3983E+00	1.0000E+00	9.000
7	3.0849E-04	1.4467E+06	3.2468E-04	1.0591E+00	2.4089E-01	2.2567E+00	2.2545E+00	1.0000E+00	9.000
8	3.4087E-04	1.5995E+06	3.5563E-04	1.0512E+00	2.2466E-01	2.1201E+00	2.1185E+00	1.0000E+00	9.000
9	3.7040E-04	1.7037E+06	3.8327E-04	1.0917E+00	2.2598E-01	2.0540E+00	2.0516E+00	1.0000E+00	9.000
10	3.9613E-04	1.8434E+06	4.0869E-04	1.0092E+00	1.8878E-01	1.8551E+00	1.8549E+00	1.0000E+00	9.000
11	4.2125E-04	1.9270E+06	4.3229E-04	1.0336E+00	2.0508E-01	1.9694E+00	1.9659E+00	1.0000E+00	9.000
12	4.4333E-04	2.0381E+06	4.5672E-04	7.6209E-01	1.7114E-01	2.2253E+00	2.2287E+00	1.0000E+00	9.000
13	4.7010E-04	2.1714E+06	4.8687E-04	5.3548E-01	1.6574E-01	3.0701E+00	3.0686E+00	1.0000E+00	9.000
14	5.0364E-04	2.3105E+06	5.2372E-04	3.8787E-01	1.5641E-01	3.9993E+00	3.9987E+00	1.0000E+00	9.000
15	5.4380E-04	2.5149E+06	5.6653E-04	2.9424E-01	1.4292E-01	4.8158E+00	4.8177E+00	1.0000E+00	9.000
16	5.8925E-04	2.7101E+06	6.1306E-04	2.4003E-01	1.3661E-01	5.6443E+00	5.6439E+00	1.0000E+00	9.000
17	6.3687E-04	2.9644E+06	6.6168E-04	1.9677E-01	1.2607E-01	6.3511E+00	6.3563E+00	1.0000E+00	9.000
18	6.8649E-04	3.1887E+06	7.1189E-04	1.6425E-01	1.1570E-01	6.9900E+00	6.9807E+00	1.0000E+00	9.000
19	7.3728E-04	3.4746E+06	7.6271E-04	1.4035E-01	1.1034E-01	7.7880E+00	7.8045E+00	1.0000E+00	9.000
20	7.8815E-04	3.7271E+06	8.1527E-04	1.1266E-01	9.4121E-02	8.3790E+00	8.1904E+00	1.0000E+00	9.000
21	8.4239E-04	4.0516E+06	8.6809E-04	1.0197E-01	1.0562E-01	9.9696E+00	1.0575E+01	1.0000E+00	9.000
22	8.9379E-04	4.2054E+06	9.4518E-04	4.2702E-02	3.8418E-02	9.1078E+00	8.7359E+00	1.0000E+00	9.000
23	9.9658E-04	3.9179E+06	1.1037E-03	1.5968E-02	1.4213E-02	8.3766E+00	8.2034E+00	1.1281E+00	9.000
24	1.2109E-03	4.4357E+06	1.4045E-03	6.3162E-03	8.6417E-03	9.3390E+00	9.2580E+00	1.9143E+00	9.000
25	1.5980E-03	5.8020E+06	1.8897E-03	2.8295E-03	6.5487E-03	1.1491E+01	1.1424E+01	3.0007E+00	9.000
26	2.1814E-03	7.9531E+06	2.5468E-03	1.5210E-03	5.5115E-03	1.4129E+01	1.4045E+01	4.0925E+00	9.000
27	2.9121E-03	1.0673E+07	3.3124E-03	9.6755E-04	4.9984E-03	1.6947E+01	1.6814E+01	5.0537E+00	9.000
28	3.7127E-03	1.3676E+07	4.1223E-03	6.8842E-04	4.7337E-03	1.9950E+01	1.9772E+01	5.8451E+00	9.000
29	4.5319E-03	1.6691E+07	4.9517E-03	5.0605E-04	4.3339E-03	2.2977E+01	2.2833E+01	6.3989E+00	9.000
30	5.3716E-03	1.9510E+07	5.7978E-03	3.8525E-04	3.8476E-03	2.5557E+01	2.5309E+01	6.7603E+00	9.000
31	6.2239E-03	2.2309E+07	6.6377E-03	3.1339E-04	3.6047E-03	2.7838E+01	2.7644E+01	7.2020E+00	9.000
32	7.0515E-03	2.4935E+07	7.4365E-03	2.7170E-04	3.4716E-03	2.9685E+01	2.9623E+01	7.5390E+00	9.000
33	7.8215E-03	2.7322E+07	8.1757E-03	2.4263E-04	3.3353E-03	3.1087E+01	3.1090E+01	7.7703E+00	9.000
34	8.5300E-03	2.9545E+07	8.8612E-03	2.1620E-04	3.1375E-03	3.2193E+01	3.2166E+01	7.9416E+00	9.000
35	9.1925E-03	3.1616E+07	9.5021E-03	1.9469E-04	2.9465E-03	3.3090E+01	3.3131E+01	8.0698E+00	9.000
36	9.8118E-03	3.3508E+07	1.0103E-02	1.7552E-04	2.7398E-03	3.3793E+01	3.3751E+01	8.1627E+00	9.000
37	1.0395E-02	3.5315E+07	1.0672E-02	1.5749E-04	2.5178E-03	3.4370E+01	3.4138E+01	8.2320E+00	9.000

Table 1.12

38	1.0950E-02	3.7028E+07	1.1214E-02	1.4202E-04	2.3132E-03	3.4851E+01	3.4452E+01	8.2807E+00	9.000
39	1.1478E-02	3.8643E+07	1.1732E-02	1.2736E-04	2.1025E-03	3.5250E+01	3.4459E+01	8.3110E+00	9.000
40	1.1986E-02	4.0198E+07	1.2230E-02	1.1446E-04	1.9081E-03	3.5588E+01	3.4344E+01	8.3250E+00	9.000
41	1.2475E-02	4.1688E+07	1.2711E-02	1.0253E-04	1.7194E-03	3.5876E+01	3.3979E+01	8.3239E+00	9.000
42	1.2948E-02	4.3125E+07	1.3178E-02	9.1508E-05	1.5387E-03	3.6124E+01	3.3358E+01	8.3090E+00	9.000
43	1.3409E-02	4.4515E+07	1.3633E-02	8.1844E-05	1.3761E-03	3.6337E+01	3.2572E+01	8.2809E+00	9.000
44	1.3857E-02	4.5878E+07	1.4079E-02	7.2464E-05	1.2146E-03	3.6527E+01	3.1414E+01	8.2413E+00	9.000
45	1.4300E-02	4.7210E+07	1.4517E-02	6.4507E-05	1.0757E-03	3.6696E+01	3.0187E+01	8.1901E+00	9.000
46	1.4734E-02	4.8499E+07	1.4948E-02	5.7235E-05	9.4714E-04	3.6844E+01	2.8722E+01	8.1286E+00	9.000
47	1.5162E-02	4.9757E+07	1.5375E-02	5.0310E-05	8.2410E-04	3.6973E+01	2.6945E+01	8.0583E+00	9.000
48	1.5588E-02	5.1042E+07	1.5801E-02	4.4209E-05	7.1580E-04	3.7092E+01	2.5105E+01	7.9807E+00	9.000
49	1.6014E-02	5.2282E+07	1.6227E-02	3.8659E-05	6.1762E-04	3.7197E+01	2.3130E+01	7.8967E+00	9.000
50	1.6440E-02	5.3531E+07	1.6654E-02	3.3863E-05	5.3330E-04	3.7291E+01	2.1181E+01	7.8081E+00	9.000
51	1.6868E-02	5.4760E+07	1.7085E-02	2.9201E-05	4.5268E-04	3.7373E+01	1.9064E+01	7.7166E+00	9.000
52	1.7303E-02	5.6039E+07	1.7526E-02	2.4911E-05	3.7986E-04	3.7448E+01	1.6933E+01	7.6240E+00	9.000
53	1.7750E-02	5.7349E+07	1.7984E-02	2.0878E-05	3.1300E-04	3.7516E+01	1.4773E+01	7.5321E+00	9.000
54	1.8219E-02	5.8706E+07	1.8467E-02	1.7271E-05	2.5459E-04	3.7578E+01	1.2696E+01	7.4423E+00	9.000
55	1.8715E-02	6.0112E+07	1.8986E-02	1.3889E-05	2.0131E-04	3.7632E+01	1.0636E+01	7.3562E+00	9.000
56	1.9256E-02	6.1668E+07	1.9562E-02	1.0745E-05	1.5318E-04	3.7682E+01	8.6152E+00	7.2749E+00	9.000
57	1.9867E-02	6.3406E+07	2.0223E-02	8.0200E-06	1.1256E-04	3.7726E+01	6.7426E+00	7.1994E+00	9.000
58	2.0580E-02	6.5462E+07	2.1034E-02	5.4437E-06	7.5252E-05	3.7768E+01	4.8690E+00	7.1304E+00	9.000
59	2.1488E-02	6.8051E+07	2.2178E-02	3.0605E-06	4.1701E-05	3.7809E+01	2.9915E+00	7.0686E+00	9.000
60	2.2868E-02	7.1881E+07	2.4731E-02	9.1520E-07	1.2304E-05	3.7856E+01	1.0594E+00	7.0154E+00	9.000
61	2.6594E-02	8.2054E+07							

```
TAR213   DATA     A1   VM/XA CMS 5.5 Atlas Centre 201.07   05/12/89   Page 00001

Two-layer target (write-up #2)                    NGEOM:   2       PMAX: 7.075E+09
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 6.00
XMASS:12.00 RINI: 9.900E-05 XZ2: 6.00 XMASS2:12.00 FNE2: 1.00 DRGLAS: 1.000E-06
XZ1: 6.00 XMASS1:12.00 DRPLAS: 0.000E+00 MESH:  40 ZGLAS:20.00 ZPLAS: 0.00
RF1: 7.200E-01 RF2: 1.000E+00 RF3: 1.000E+00 XRL OFF DLAMDA: 8.100E-07
PEQUIV: 7.075E+13 W/M**2 OPACITY CORRECTIONS OFF
   40
 0.0000E+00-9.8607E-11
 0.0000E+00 0.0000E+00 1.3879E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 2.7759E-03 0.0000E+00 3.7752E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 4.7745E-03 0.0000E+00 5.4940E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 6.2136E-03 0.0000E+00 6.7316E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 7.2496E-03 0.0000E+00 7.6226E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 7.9956E-03 0.0000E+00 8.2642E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 8.5328E-03 0.0000E+00 8.7261E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 8.9195E-03 0.0000E+00 9.0587E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.1979E-03 0.0000E+00 9.2981E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.3984E-03 0.0000E+00 9.4706E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.5427E-03 0.0000E+00 9.5947E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.6467E-03 0.0000E+00 9.6841E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.7215E-03 0.0000E+00 9.7484E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.7754E-03 0.0000E+00 9.7948E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8141E-03 0.0000E+00 9.8281E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8421E-03 0.0000E+00 9.8521E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8622E-03 0.0000E+00 9.8694E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8767E-03 0.0000E+00 9.8819E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8871E-03 0.0000E+00 9.8908E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.8946E-03 0.0000E+00 9.8973E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9000E-03 0.0000E+00 9.9025E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9050E-03 0.0000E+00 9.9075E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9100E-03 0.0000E+00 9.9125E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9150E-03 0.0000E+00 9.9175E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9200E-03 0.0000E+00 9.9225E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9250E-03 0.0000E+00 9.9275E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9300E-03 0.0000E+00 9.9325E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9350E-03 0.0000E+00 9.9375E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9400E-03 0.0000E+00 9.9425E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9450E-03 0.0000E+00 9.9475E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9500E-03 0.0000E+00 9.9525E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9550E-03 0.0000E+00 9.9575E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9600E-03 0.0000E+00 9.9625E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9650E-03 0.0000E+00 9.9675E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9700E-03 0.0000E+00 9.9725E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9750E-03 0.0000E+00 9.9775E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9800E-03 0.0000E+00 9.9825E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9850E-03 0.0000E+00 9.9875E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9900E-03 0.0000E+00 9.9925E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 9.9950E-03 0.0000E+00 9.9975E-03 2.635E+00 1.269E+00 8.62E-01 8.62E-01 1.67E+00
 1.0000E-02 0.0000E+00
 1.0140E-10 2.5278E-12
 0.0000E+00 0.0000E+00 1.3879E-03 2.635E+00 4.834E-01 8.62E-01 8.62E-01 1.67E+00
```

Table 2: TAR213 DATA (written to stream 13 by MED101)

4 Changing the Input Data File

This is the most important part of the process by which you may edit the data input file in order to create the conditions you desire. MED101 reads in data using NAMELIST. The NAMELIST is a non-standard FORTRAN extension that works on the IBM, the CRAY and other machines such as DEC VAXs (although the control character may change from a dollar to something else. The CRAY, IBM and VAX all use $). A typical data file may look like this (TARGET2 DATA — some graphs resulting from this input data are included in section 6.5).

```
Two-layer target (write-up #2)
Carbon sphere 100mu radius
7.075E9 W/m*m      0.53micron Ideal gas
***********************************************
 $NEWRUN
 XAMDA1=0.53E-6, GAUSS=1.0,     ANPULS=1.0,  TOFF=1.0E-1,
 PLENTH=4.2E-11, PMAX=7.075E9, PMULT=2.381,
 NGEOM=2,         PIQ(55)=0.0,  TEINI=1.0E4, TIINI=1.0E4,
 MESH=40,    RINI=99.0E-6,    RHOGAS=2635.0, RF1=0.72000,
 XZ=6.0,     XMASS=12.0,      FNE=1.0,
 ZGLAS=20.0,DRGLAS=1.00E-6, ROGLAS=2635.0, RF2=1.0,
 XZ2=6.0,    XMASS2=12.0,     FNE2=1.0,
 ZPLAS=0.0, DRPLAS=0.00E-0, ROPLAS=0.00,   RF3=0.0,
 XZ1=0.0,    XMASS1=0.00,     HYDROG=0.0,
 NPRNT=-100,TSTOP=1.0E-09,  NRUN=80000,
 NP3=1,      NLEMP=F,
 NLBRMS=T,  FLIMIT=10.0,     SAHA=1.0,
 ANABS=0.2, FHOT=0.0,        FTHOT=-1.0,     RHOT=1.0,
 STATE=1.0, NLPFE=T,
 AK4=1.0E6,
 $END
```

This may look a little messy (it is) but apart from changing the source code it is the only way of controlling the run. There is a space in the first column of this file, this is necessary so don't remove it. The four lines written before the $ have no effect and are thus like a comment space. These lines do, however, get printed out by the code so they may be used to identify any particular run (assuming you change them). These lines are necessary as the code expects four lines of something before it starts to read the NAMELIST file. The first of these four lines is also included in the titles given to the graphics output packages so if each run is sensibly labelled it should be easier to reconcile all the MED101 output you will inevitably generate. Going through this NAMELIST file will provide a user with just about all they need to know about controlling MED101. The order in which the data appears in the NAMELIST is not significant. Also if a constant is not declared in the NAMELIST then it should default to some reasonably sensible value. This is why most input data files do not have all the control variables shown in the following list.

Note When editing this file make sure all lines except the last have a comma at the end.

Below the letters C,I,R and L refer to character, integer, real and logical constants respectively. D denotes the default value. The default value may stop the code from falling over but it will not necessarily give sensible results for your problem.

4.1 Explanation of the input parameters

Geometry

- **NGEOM (I) D=3** This variable sets the geometry of the problem; 1 is planar, 2 is cylindrical and 3 is spherical. Note: the X-ray laser calculations will at present only work in cylindrical and planar geometries.

Laser

- **XAMDA1 (R) D=10.0E-6** laser wavelength (m).
- **GAUSS (R) D=0.0** This sets the laser pulse shape. GAUSS=1.0 gives a gaussian pulse, GAUSS=0.0 gives an isentropic pulse and GAUSS=−1.0 gives a triangular pulse. For a specification of the isentropic pulse see [1].
- **TOFF (R) D=0.0** This defines the turn-off time of the laser (in s). This is normally set to a large value such as 1.0. This does not mean that you will run for a simulation time of 1 second as other control factors will stop the run well before this.
- **PMAX (R) D=0.0** This is the peak power of the laser in units of W m^{-2} for planar targets, W m^{-1} rad^{-1} for cylindrical targets and W $ster^{-1}$ for spherical targets. Note: The print-out also includes a factor called PEQUIV which shows the equivalent surface irradiance in W cm^{-2} for any of the three geometries. In this way one can check that, for example, a planar experiment modelled in cylindrical geometry has the right surface irradiance.
- **PLENTH (R) D=0.0** This is the time from the peak of the laser pulse to the value at which the laser is only e^{-1} of its maximum value (in s). This may be approximated to PLENTH=0.6×FWHM.
- **PMULT (R) D=0.0** This is the number of PLENTH times at which the run starts before the peak of the pulse. The larger the number the slower the turn-on of the laser, this helps avoid shocks at the beginning. However, the larger the number, the longer the code will have to run and the more AUs it will use.
- **ANPULS (R) D=0.0** Set this variable to 1.0 when using a Gaussian pulse.

Physics

- **TEINI (R) D=5.0E3** This is the initial temperature of the electrons, normally set to a value of, typically, 10^4K.
- **TIINI (R) D=5.0E3** This is the initial temperature of the ions, normally set to the same value as TEINI, typically, 10^4K.
- **ANABS (R) D=0.0** This is the amount of laser energy that having reached critical density (i. e. having been to some extent depleted by inverse bremsstrahlung absorption) is deposited in the plasma by resonance absorption. Typically 10%-20% (e. g. ANABS=0.2). Note: this only works if NLCRI1=.TRUE.
- **FHOT (R) D=0.0** This is the fraction of laser energy absorbed by resonance absorption that gets converted to hot electrons, typically 0.1. This is not the same as setting the amount of laser energy deposited by resonance absorption.

- **FTHOT (R) D=0.0** This determines the way in which the code calculates the hot electron temperature T_H. If FHOT>0.0 then T_H =FTHOT$\times T_{ec}$ where T_{ec} is the electron temperature at critical density. If FHOT<0.0 then T_H = −FTHOT$\times f(I\lambda^2)$ where $f(I\lambda^2)$ is the LASL compilations of T_H versus $I\lambda^2$.

- **RHOT (R) D=0.0** This controls the transport of hot electron energy after the electrons have made a single pass through the target. If RHOT=1.0 the energy remaining at this time is deposited throughout the target uniformly. If RHOT=0.0 then the remaining energy is lost. Typical value of RHOT is 1.0.

- **FLIMIT (R) D=0.0** This is the control of the flux limiter where

$$\text{FLIMIT} = \frac{\text{classical free streaming limit}}{\text{desired flux limit}}$$

  A typical value of FLIMIT is 10.0 (i. e. the desired flux limit is 0.1)

- **PIQ(27) (R) D=0.0** It is possible to vary the thermal conductivity of the electrons, K_e, using

$$K_e = K(Spitzer) \times (1.0 + \text{PIQ}(27))$$

  As all elements of the PIQ array default to zero the conductivity will be the Spitzer value by default.

- **STATE (R) D=0.0** The ions always have a perfect gas equation of state regardless of the value of NLPFI (see next section). If NLPFE=T then the electrons also use the perfect gas equation of state. If NLPFE=F then the equation of state is decided by the value given to STATE. Typically, STATE=3.0 is reasonable, if NLPFE=T, this will save CPU time but the physics may not be strictly applicable to your specific situation. The values of STATE are
  * 0.0 Fermi Dirac
  * 1.0 Thomas Fermi
  * 2.0 Thomas Fermi with quantum corrections
  * 3.0 Thomas Fermi with modified corrections to give correct solid density.

- **SAHA (R) D=0.0** SAHA determines whether or not to calculate ionization equilibrium. If SAHA=0.0, the material is assumed to be fully ionised, if SAHA=1.0 then the ionization equilibrium is calculated. A value of SAHA=0.0 is the more realistic option if the perfect electron gas equation of state is used. Note: If the X-ray laser calculations are turned on then the ionization balance is calculated using a routine in the X-ray laser code.

- **PONDF (R) D=0.0** This controls whether or not the pondermotive force of the laser is included in the momentum equation. PONDF=1.0 includes the pondermotive force.

Physics: Logical Switches

This section details the logical switches that control whether certain pieces of physics are to be included in the calculation. If **switch**=.TRUE. (or T) the part is included, if **switch**=.FALSE. (or F) it is not.

- **NLABS (L) D=T** This controls whether the absorption of laser radiation by inverse bremsstrahlung is included in the calculation.

- **NLBRMS (L) D=T** This controls whether radiation from bremsstrahlung in the plasma is included in the calculation.

- **NLBURN (L) D=T** This controls whether burning of fusion fuel is included in the calculation.
- **NLCRI1 (L) D=T** This controls whether any laser energy is dumped at critical density in the calculation.
- **NLDEPO (L) D=T** This controls whether any energy from fusion products is included in the calculation.
- **NLECON (L) D=T** This controls whether electron heat conduction is included in the calculation.
- **NLICON (L) D=T** This controls whether ion heat conduction is included in the calculation.
- **NLFUSE (L) D=T** This controls whether fusion from D-D, D-T and D-He3 (if present) is included in the calculation.
- **NLMOVE (L) D=T** This controls whether fluid motion is included in the calculation.
- **NLPFE (L) D=T** This controls whether the equation of state for electrons is the perfect gas EOS.
- **NLPFI (L) D=T** This controls whether the equation of state for ions is the perfect gas EOS.
- **NLX (L) D=T** This controls whether ion-electron collisional relaxation is included in the calculation.

Numerical and Target Design

MED101 was previously designed to model three layer ICF targets comprising the inner gas fill, the middle glass shell and an outer plastic shell. The code was modified to allow the user to control the contents of the inner gas fill (referenced as neon). In practise this meant that one could decide that the proportion of 'neon' was, say, 100% and that the 'neon' should have an atomic charge number of, for example, 79.0 (i. e. gold). This meant that the inner fill was solid gold. The code has now been modified to allow the user to alter not only the inner gas fill but to overwrite the 'glass' and 'plastic' constituents of the second and third shell. In this way MED101 now allows the user complete control over a three layer target. Some of the names given to the desired quantities will seem odd. This is because the modifications to MED101 have been made with the intent of making the code upwardly compatible with older versions (i. e. MED101 should run with an old data file with no modifications and produce the same results, except perhaps where a correction or modification to the physics has been made. Note however that the wavelength is now called XAMDA1, not LAMDA1).

- **MESH (I) D=40** This controls the total number of cells used in ALL THREE layers. This number should not exceed 90. The larger this number is, the more accurately the layer will be modelled but the longer the code will take to run. A typical value for MESH is 60.
- **ZGLAS (R) D=0.0** This controls the number of cells in the second layer or 'glass' layer. Note: this number is a real. If no second layer is desired then set ZGLAS=0.0
- **ZPLAS (R) D=0.0** This controls the number of cells in the third layer or 'plastic' layer. Note: this number is a real. If no third layer is desired then set ZPLAS=0.0

- **RINI (R) D=4.8E-4** This sets the thickness of the inner layer or 'gas' fill(m). Each cell will then be RINI/(MESH-ZGLAS-ZPLAS) thick, e. g. if RINI=10.0E-6 and MESH=60, ZGLAS=20.0 and ZPLAS=20.0 then the cell thickness in the inner layer will be 0.5E-6 meters. The setting of this value becomes more complicated with the use of the arithmetic gridding factors (see later parameters and appendix A).
- **DRGLAS (R) D=0.0** This sets the thickness of the second layer(m). The thickness of the individual zones is then DRGLAS/ZGLAS. If no second layer is desired then specify DRGLAS=0.0. (Note: if ZGLAS=0.0 then DRGLAS is set to 0.0)
- **DRPLAS (R) D=0.0** This sets the thickness of the third layer(m). The thickness of the individual zones is then DRPLAS/ZPLAS. If no third layer is desired then specify DRPLAS=0.0. (Note: if ZPLAS=0.0 then DRPLAS is set to 0.0)
- **RHOGAS (R) D=124.0** This is the density of the inner layer or 'gas fill'. Units are kgm^{-3}.
- **ROGLAS (R) D=0.0** This is the density of the middle layer or 'glass shell'. Units are kgm^{-3}.
- **ROPLAS (R) D=0.0** This is the density of the outer layer or 'plastic shell'. Units are kgm^{-3}.
- **XZ (R) D=10.0** This is the atomic number of the inner layer or 'gas fill' material.
- **XZ2 (R) D=14.0** This is the atomic number of the middle layer or 'glass shell' material.
- **XZ1 (R) D=6.0** This is the atomic number of the outer layer or 'plastic shell' material.
- **XMASS (R) D=20.183** This is the atomic mass number of the inner layer or 'gas fill' material.
- **XMASS2 (R) D=28.086** This is the atomic mass number of the middle layer or 'glass shell' material.
- **XMASS1 (R) D=12.011** This is the atomic mass number of the outer layer or 'plastic shell' material.
- **FNE (R) D=0.0** This is the fraction of the material specified by XZ, XMASS and RHOGAS that is used in the inner layer. The remaining fraction is divided equally between deuterium and tritium. This is really only useful for modelling ICF targets, to fill the inner layer entirely with a specified material set FNE=1.0.
- **FNE2 (R) D=0.0** This is the fraction of the material specified by XZ2, XMASS2 and ROGLAS that is used in the middle layer. The remaining fraction is set to be silicon. Again, this is left-over from modelling ICF targets. To get control specify FNE2=1.0.
- **HYDROG (R) D=0.0** This controls the fraction of hydrogen in the plastic or outer shell. If HYDROG=0.0 then the outer layer is composed entirely of the material specified by XZ1, XMASS1 and ROPLAS. Anything greater than 0.0 will result in a plastic of some form. For example, to obtain CH_2 use HYDROG=0.67.

  As stated earlier MED101 has been altered to allow the user control over the constituent materials in all three layers. If a mixed layer is desired then the atomic numbers and mass numbers should be averaged. From the point of view of modelling the hydrodynamics, averaging the atomic and mass numbers is acceptable, providing the real density is used for the material. For example, to have a plastic layer as the inner target layer corresponding to CH

then the charge number would be 3.5 and the mass number would be 6.5 with a density of 1000 kgm^{-3}. Note: this does not make sense for X-ray laser calculations (see below).

- **RF1 (R) D=0.99999** This controls the arithmetic gridding in the 'gas fill' or inner layer. For a definition of RF1, RF2 and RF3 see appendix A.
- **RF2 (R) D=0.99999** This controls the arithmetic gridding in the 'glass' or middle layer.
- **RF3 (R) D=0.99999** This controls the arithmetic gridding in the 'plastic' or outer layer.

  When using planar geometries it is possible to specify whether the left and right boundaries of the mesh are fixed or free. This is controlled by the variable PIQ(55). Bear in mind that MED101 treats the laser as travelling from right to left (from a high cell number towards cell number 1)
- **PIQ(55) (R) D=0.0** PIQ(55) is set to 0.0 by default and if NGEOM≠1 then the left boundary is fixed with PIQ(55) controlling the right boundary. A thin foil, for example, would be best modelled with PIQ(55)=2.0. The various combinations are:
  - 0.0 Left boundary fixed. Right boundary free.
  - 1.0 Left boundary fixed. Right boundary fixed.
  - 2.0 Left boundary free. Right boundary free.
  - 3.0 Left boundary free. Right boundary fixed.

Run Control

- **TSTOP (R) D=1.0E-6** This is the time in the simulation at which the calculation stops (units are seconds).
- **NRUN (I) D=100** This is the maximum number of time steps that the code is allowed to run for. Set this to something large (e. g. 80000) so that the code will always terminate because of TSTOP rather than NRUN — this makes it easier to terminate the run exactly when you want.
- **NPRNT (I) D=100** This is the number of time steps between printer (and graphics files) dumps. If NPRNT is negative then this number becomes the number of picoseconds between successive printer (and graphics files) output.
- **NLEMP (L) D=T** This controls whether you receive reams of diagnostic print-out when the code falls over. Probably best set to .FALSE.
- **NP3 (I) D=(MESH/20)** This how often the range of cells is sampled in order to provide output for the printer and graphics dumps, i. e. it is part of a construct

```
      DO 10 I=1,MESH,NP3
        WRITE ...
   10 CONTINUE
```

  Set NP3=1.

X-Ray Laser Calculations

One of the major new additions in MED101 is a subroutine for calculating X-ray laser gain in recombining plasmas [3]. This is suitable for the three main single electron atom/ion lasing schemes (i. e. H-like, Li-like and Na-like). This is now an integral part of MED101 but is switched off by default so that users only interested in modelling hydrodynamics may do so.

When X-ray laser gain is calculated a different routine is used to calculate the ionization of the species within the plasma. An option for modelling photo-pumping is included. The X-ray laser data output includes gain as a function of radius for every time frame dumped, refraction of the X-ray beam (based upon the width and length of the X-ray laser target which is supplied by the user) and a spatially integrated measure of gain that may be compared directly with the experimental results of X-ray laser experiments [2,3,4]. All of this data is printed out on the standard MED101 printout but is also written to data files for interpretation by the graphics packages. The X-ray laser code will run in cylindrical and planar geometries.

There is also an option to add a scaling factor to the opacity part of the code. This is by default set to zero (i. e. no absorption of the resonance line is included), if the scaling factor flag is set equal to 1 then a variable scaling factor may be used (this has been included to investigate the best agreement with experimental results).

As a sub-set of the X-ray laser calculations the spatially dependent ion densities of selected ionic species may also be output. Only the ground state number densities are calculated (typically 90–99% of the ions are in their ground state). An option is supplied to calculate exactly what percentage of all of the ion states is in the ground state.

All of these options are controlled by various switches and variables now included in the NAMELIST file. For the Integer type switch set the variable equal to 1 for the particular calculation to be carried out.

Note: in X-ray laser calculations pure atomic numbers and atomic mass numbers (XZ and XMASS etc.) must be used. However the real densities of the target materials should be used. For example, to model the carbon in a plastic target in an X-ray laser calculation use a density of 1000 kgm^{-3} (if it uses a plastic target) rather than using the higher density appropriate for pure carbon, but with a charge number of 6 and a mass number 12.

- **ICXRL (I) D=0** This is a switch that controls whether the X-ray laser calculations are to be included.
- **IFRSTA (I) D=0** This is a switch that controls whether the spatially dependent ion densities are included in the calculation. This cannot be carried out at present without the X-ray laser calculation being turned on.
- **ISTAGE (I) D=1** This controls the scheme used in the calculation:

1 H-like

2 Li-like

3 Na-like

- **IDFLG (I) D=0** This is a switch that controls whether trapping of the resonance line is included in the calculation.
- **ROPMUL (R) D=0.0** This is the scaling factor that alters the escape factor of the resonance line in the calculation. Set equal to 0.0 if no trapping is desired (or set IDFLG=0), set =1.0 if full trapping is to be included. Any other value chosen for this variable is up to you.
- **ITBFLG (I) D=1**

0 No thermal band.

1 Forces the population of the highest level to be in LTE.

- **ISTFLG (I) D=0** This controls whether motional Stark broadening is to be included in the calculation (NB: Only data for carbon is at present included).

0 Motional Stark broadening is not included.

1 Motional Stark broadening is included on the Balmer alpha line.

- **IPUFLG (I) D=0** This controls whether photo-pumping is to be included in the calculation.
- **TPON (R) D=0.0** This is the time at which the photo-pumping is switched on (units are seconds).
- **TPOFF (R) D=0.0** This is the time at which the photo-pumping is switched off (units are in seconds).
- **NLP (I) D=0** This is the lower level (corresponding to the principal quantum number of the state in question) with which a coincidence photo-pumping line is to be included.
- **NUP (I) D=0** This is the upper level (corresponding to the principal quantum number of the state in question) with which a coincidence photo-pumping line is to be included.
- **RMPD (R) D=0.0** This is the modal photon density of the pumping radiation.
- **DLAMDA (R) D=81.0E-8** This is the wavelength of the X-ray lasing transition (units are meters).
- **FLSHORT (R) D=0.1** This is the short length of the X-ray laser gain medium (i. e. the width of the gain region), units are in cm.
- **FLLONG (R) D=1.0** This is the long length of the X-ray laser gain medium, units are in cm.

  The sub-set of the X-ray laser calculations that allows the spatially dependent ion densities of selected ion species in ground state to be calculated are controlled by ILOSTA and IHISTA. These specify the range of ionization stages that the calculation will use.
- **ILOSTA (I) D=1** This is the number of electrons in the most ionised ion to be considered (the ion with the least bound electrons). For example, if ILOSTA=0 then the code will supply data on completely stripped ion densities, if ILOSTA=1, H-like ions, and so on.
- **IHISTA (I) D=2** This is the number of electrons in the least ionised ion to be considered (the ion with the most bound electrons). For example, if ILOSTA=1 and IHISTA=3 then the code will supply the spatially dependent ion densities of H-like, He-like and Li-like ions.
- **IGSTAT (I) D=0** This is a switch that controls whether the total number of ions in all ionisation stages in the ground state, is calculated. This can be used to check whether the data supplied by the routines controlled by ILOSTA and IHISTA is reasonably valid. A high percentage of ions in the ground state means that this data is good. Note: Because this call calculates all of the possible ground state ions, it tends to eat up CPU time, so allow extra time if you include this.

Code Control

This section lists some of the parameters available to the user for altering some of the numerical parameters in the code. Generally, these values should not be altered unless a specific problem is encountered, it is best to seek advice.

- **DELTAT (R) D=1.0E-18** This is the initial timestep, the code will automatically choose its own value for this after a few time steps. Something small, typically 10^{-18}s (the default) is recommended.
- **AK0 (R) D=5.0** The is the maximum allowable ratio of successive time steps. Set AK0 to something large (e. g. 100.0) if message 'time centering is damaged' appears.

- **AK1, AK2, AK3, AK4, AK5 (R) D=0.25,0.25,0.25,0.25,0.0** These numbers control the choice of timestep by the code. Refer to routine TIMSTP. AK1 controls the CFL condition:$\Delta t < \Delta r/c_s$. AK2–4 control the range of density, ion temperature and electron temperature respectively, AK5 is not used at present.

- **NLITE (L) D=T** This is a logical switch that controls iterations on T_i, T_e and U (the internal energy). Since the thermal conductivity is non-linear it is best to iterate. Calculations which have electron thermal conduction switched off could set NLITE=F.

- **DUMAX, DTEMAX, DTIMAX (R) D=0.1,0.1,0.1** The maximum fractional change in U, T_e and T_i which represent acceptable convergence.

- **NITMAX (I) D=5** The maximum number of iterations before code stops due to the iterations failing to converge.

5 General Hints

The following section outlines briefly the steps that a user should go through in order to set up data for a run.

- Specify laser wavelength, power (check units and geometry), pulse shape and duration. For Gaussian pulses set ANPULS=1.0

- Specify the target material/s. Build the target from the inner layer outwards, i. e. if only one layer is desired then use the inner or 'gas' fill layer. Check MESH is greater than (ZPLAS+ZGLAS). Check values of arithmetic gridding factor, if used. Check adjacent layers do not have a difference of more than a factor of 2 in mass (this applies when different target materials are used in different layers). For example, if layer 1 has a material with a density of x kgm^{-3} then if layer 2 has a material with density $2x$ kgm^{-3} then the cell size of layer 2 should be half that of layer 1.

  In specifying the physics the following applies to most normal situations:

- Always set STATE=3.0 then chose between perfect gas and corrected Thomas Fermi by NLPFE=T or F.

- If NLPFE=F set SAHA=1.0, if NLPFE=T set SAHA=0.0

- Always set RHOT=1.0 and FTHOT=-1.0

- If you know the absorption in a particular experiment that you are simulating, set NLABS=F and ANABS=*actual absorption*. If you have no information on the amount of hot electrons generated, set FHOT=0.5.

- The most useful way to get output over your run is to set it to print out data between 10-20 times over the duration of the run. This is most accurately controlled by using NPRNT with a negative value so that it prints at specific times rather than using a positive value that prints out after a specific number of timesteps (the difference between print-outs then varies), i. e. NPRNT=INT[(TSTOP*10^{12})/10.0.]

- Give TIINI and TEINI identical values of at least 10^4.

- When modelling X-ray lasers, generally speaking, use cylindrical geometry. If the aim is to model a planar experiment then the code may be used provided the radius of the target is made large enough to model the plasma expansion as approximately planar. A general

rule of thumb is to have the radius the same size as the width of the planar target to be modelled. This may, however, produce a plasma that cools too quickly and incorrectly model the resulting gain. If a larger radius is used the expansion will be more similar to a planar expansion. If in doubt, set at least one run to use real planar expansion and use this as the lower limit of the observed gain.

5.1 Common Error Messages

There are two fairly common error messages:

- TIME CENTERING DAMAGED means that the ratio of successive time steps is less than AK0^{-1}. The remedy for this is to make AK0 larger, for example, set AK0=100.0. There is no penalty in run time and only a small likelihood of a serious numerical error.
- ITERATIONS FAIL TO CONVERGE VARIABLE n IN CELL l. This is self-explanatory, the variable n corresponds to the quantities: 1=velocity, 2=density (specific volume), 3=T_i and 4=T_e. The approach should be to reduce the value of AKn (e. g. AK4 if T_e fails to converge) to a smaller value. There will be an increase in run time as the values of AKn are reduced but the exact amount is unpredictable.
- POPULATIONS FAILED TO CONVERGE IN CELL n. This will only be seen in the X-ray laser part of the code. This normally happens only at the very beginning of a code run. At the start of the run the system will try to ionize very rapidly; if the timestep is too large (the timestep is determined by the hydrodynamics) then the calculation determining the ionization will fail to converge. If this only occurs at the start of the code (within 100ps) then ignore it — the system will settle down after a short time. If the message occurs late in the run then there may be something wrong with the way the run has been set up.
- There are messages DENSITIES/TEMPERATURES TOO LOW. These will only normally be seen if the code has been allowed to run for extremely long times (e. g. greater than 10^{-6}).

6 Using the Graphics Packages

The packages FLIPPER, XRLFLIP and IONFLIP are all available for interpretation of the files output by MED101.
1) FLIPPER — this plots the hydrodynamic variables (velocity, density, pressure, electron and ion temperatures, and average ionisation) vs. distance for different times, and also the hydrodynamic variables (cell edge and centre plus velocity etc.) vs. time for each cell
2) IONFLIP — this plots the ground state number density of the different ionisation stages vs. distance at different times during the interaction. IONFLIP also displays the zoning of the run. This can be useful to ensure that there are enough cells in the regions of interest.
3) XRLFLIP — this plots the X-ray laser gain vs. distance at different times, and also the space-integrated gain for different lines (i. e. alpha, beta etc.) vs. time as would as measured by experiment.

To obtain the compiled versions of these files link to AR4 as described in section 2 and type

```
COPY FLIPPER TEXT Z = = A
COPY XRLFLIP TEXT Z = = A
COPY IONFLIP TEXT Z = = A
```

All the graphs produced include six lines of data, (including a run name) compiled from the input data file recording, detailing most of the parameters used in that MED101 run.

6.1 FLIPPER

FLIPPER reads data from stream 13 (default FILE FT13F001 A1) and writes to stream 16. Therefore if your input data is in FLIPPER DATA (as it would be if you used the EXEC in section 2.1) and you want to call your output graphics file FLIPPER CGM (CGM means Computer Generated Metafile — this is the GKS default) type

```
FILEDEF 13 DISK FLIPPER DATA A
FILEDEF 16 DISK FLIPPER CGM A
RUN FLIPPER
```

First you will be asked

```
 Execution begins...
 RAL GKS 1.11 IBM
 ENTER WORKSTATION ID
    50   GKS METAFILE
    201  TEKTRONIX 4010
    203  TEKTRONIX 4014
 ?
```

Most times you should enter 50. Then you will be asked

```
 DO YOU WANT TO
  S  Plot quantities vs SPACE
  T  Plot quantities vs TIME
  X  EXIT
```

Enter S to plot quantities vs. space and T to plot quantities vs. time. When plotting vs. space you will be asked

```
 WHAT DO YOU WANT TO PLOT
    1. HYDRODYNAMIC VELOCITIES
    2. DENSITY
    3. PRESSURE
    4. ION TEMPERATURE
    5. ELECTRON TEMPERATURE
    6. AVERAGE IONISATION
    0. RETURN TO SPACE-TIME-EXIT OPTION

       Enter choice (0 - 6)
 ?
```

if you enter 1, 2, 3, 4, 5 or 6 you will be asked

```
 DO YOU WANT TO PLOT ALL TIME FRAMES? Y/N
```

If you answer Y you will be asked

```
 DO YOU WANT LOGS ON THE Y-AXIS WHERE POSSIBLE? Y/N

 DO YOU WANT THE OVERALL MAXIMA FOR EVERY TIME FRAME? Y/N
```

Plotting the frames with the overall maxima allows comparisons to be made between the different time frames. If you answer N to this prompt each time frame will have local X and Y maxima (which will be different for every frame).

If you had entered N to the PLOT ALL TIME FRAME question you would be asked several questions about each time frame. These prompts are self-explanatory, if somewhat tiresome.

If you had opted to plot against time you will be prompted

```
WHAT DO YOU WANT TO PLOT?
   1. CELL EDGES
   2. HYDRODYNAMIC VELOCITIES
   3. CELL CENTRES
   4. DENSITY
   5. PRESSURE
   6. ION TEMPERATURE
   7. ELECTRON TEMPERATURE
   8. AVERAGE IONISATION
   0. RETURN TO SPACE-TIME-EXIT OPTION

      ENTER CHOICE (0 - 8)
?
```

You are then given the option of only plotting part of the range on the X(time) or Y axis. You are then asked

```
DO YOU WANT TO PLOT ALL CELLS? Y/N
```

Any of the following types of responses are valid

```
ALL
1 to 10
1,3,12 to 25,45
```

Except for the cell edges, velocities and cell centres it is not advisable to plot all the cells are the results are usually totally confusing.

If you are logged on in line-mode to a Tektronix 4010 terminal you can obtain plots interactively on the screen by answering 201 to the ENTER WORKSTATION ID prompt. You will be asked the same questions as before (you are advised not to opt to plot all the time-frames in this case) and can experiment by restricting the X and Y-axes. After each screen plot you are given the option to make a HARDCOPY. This will send the graphs to stream 16 for printing.

See section 6.4 for details on how to plot graphics files and section 6.5 for sample plots.

6.2 XRLFLIP

XRLFLIP reads data from stream 11 and writes to stream 14. Therefore if your input data is in XRL CARDS (as it would be if you used the JOB file in section 2.2) and you want to call your output graphics file XRL CGM type

```
FILEDEF 11 DISK XRL CARDS A
FILEDEF 14 DISK XRL CGM A
RUN XRLFLIP
```

First you will be asked

```
Execution begins...
DO YOU WANT TO USE ABSOLUTE TIME OR TIME RELATIVE
TO THE PEAK OF THE LASER PULSE? A/R
```

Enter A or R. You will then be asked Y/N questions.

```
RAL GKS 1.11 IBM
DO YOU WANT TO PLOT GAIN VS RADIUS? Y/N
```

You will also be given the option of plotting the alpha, beta etc. gain vs.time on separate plots and then of plotting all the gains on one plot.

See section 6.4 for details on how to plot graphics files and section 6.5 for sample plots.

6.3 IONFLIP

IONFLIP reads data from stream 12 and writes to stream 15. Therefore if your input data is in ION CARDS (as it would be if you used the EXEC in section 2.1) and you want to call your output graphics file ION PIC type

```
FILEDEF 12 DISK ION DATA A
FILEDEF 15 DISK ION PIC A
RUN IONFLIP
```

First you will be asked

```
Execution begins...
RAL GKS 1.11 IBM
Enter minimum value of Y::(Default=1.40000E+01):
```

All the prompts in IONFLIP have sensible defaults and if you hit <ENTER> after each query you should obtain useful output.

See section 6.4 for details on how to plot graphics files and section 6.5 for sample plots.

6.4 Printing and previewing graphical output

To print any of the files generated above, say ION PIC, type

```
GKSMCOPY ION PIC A X
```

or

```
GKSMCOPY ION PIC A VA4
```

Your graphs will then be printed on the Atlas Centre Xerox printer XER4050A or the Atlas Centre Versatec plotter. Alternatively type

```
GKSMCOPY ION PIC A
```

and follow the prompts. Depending on your distribution code these will either be delivered to R1 or sent to your remote site by post. You can check your distribution code by typing

```
USERINFO
```

or

```
DIRM REV
```

It can be changed by typing

```
DIRM DIST
```

and answering the prompts (see appendix C.6).

GKS metafiles can also be previewed on some graphics terminals using the

```
GKSMVIEW fn ft
```

command.

Alternatively you can try to print the GKS Metafiles at your own site, or transfer the graphics programs to your local site and generate graphs there.

Appendix B shows simple FORTRAN constructs that can be used to read in the data files XRL CARDS, FLIPPER DATA and ION DATA. The user can then write their own graphics packages to make use of these files.

6.5 Examples of graphical output

In this section we show plots of the MED101 output obtained in sections 2 and 3 (using FPAP DATA and TARGET2 DATA as input data files) obtained with the graphics packages FLIPPER, XRLFLIP and IONFLIP. The top panel of figures 1–8 are the same as they are all plots of the same MED101 run. Similarly for figures 9 and 10. In both runs data was output at approximately 100ps intervals up to 1000ps. All plots were printed on the Atlas Centre XEROX 4050 (XER4050A) laser printer.

FLIPPER and FPAP DATA

Figure 1 shows some of the plots obtained by opting to plot log density vs. space for all times not using the overall maxima for every frame. Figure 2 shows the same data plotted with the overall maxima. Figure 3 shows the position of all the cell edges plotted vs. time. Figure 4 shows the same data with the X-axis (time) and Y-axis (cell edge) expanded. Note that the discontinuity at 100 ps is an artefact — if the variables had been sampled with shorter intervals (say 10ps by setting NPRNT=-10) this artefact would disappear. More frequent sampling will not increase the CPU time needed to run the program but will produce much larger output files.

XRLFLIP and FPAP DATA

Figure 5 shows some of the graphs obtained by plotting X-ray laser gain vs. radius. Figure 6 shows the gain on the Alpha line plotted vs. time (the lower graph is an expanded version of the top graph). The plots for the Beta and Gamma lines are not shown. Figure 7 shows all three gains plotted on one pair of axes.

IONFLIP and FPAP DATA

Figure 8 shows one of the plots of ion density vs. radius (for four ion stages and time = 400ps in this case) obtained by using the defaults in IONFLIP. The position of the cell edges are shown below the X-axis, allowing the zoning of the run to be monitored. Equivalent plots are obtained up to 1000ps.

FLIPPER and TARGET2 DATA

Figure 9 shows cell edge vs. time for all cells for the input data file TARGET2 DATA listed in section 4. This is a spherical carbon target (100μ m radius) modelled with two layers — an outer layer, 1μm thick, of 30 evenly spaced cells, most of which will be burned off, and the inner region (99μm) containing 20 cells. We have chosen the arithmetic gridding factor for the inner region (RF1) such that the outermost cell of the inner region has almost the same thickness as the innermost cell of the outer region to avoid discontinuities. Figure 10 shows the same data with the Y-axis (cell edge) expanded.

Figure 1: Sample FLIPPER output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

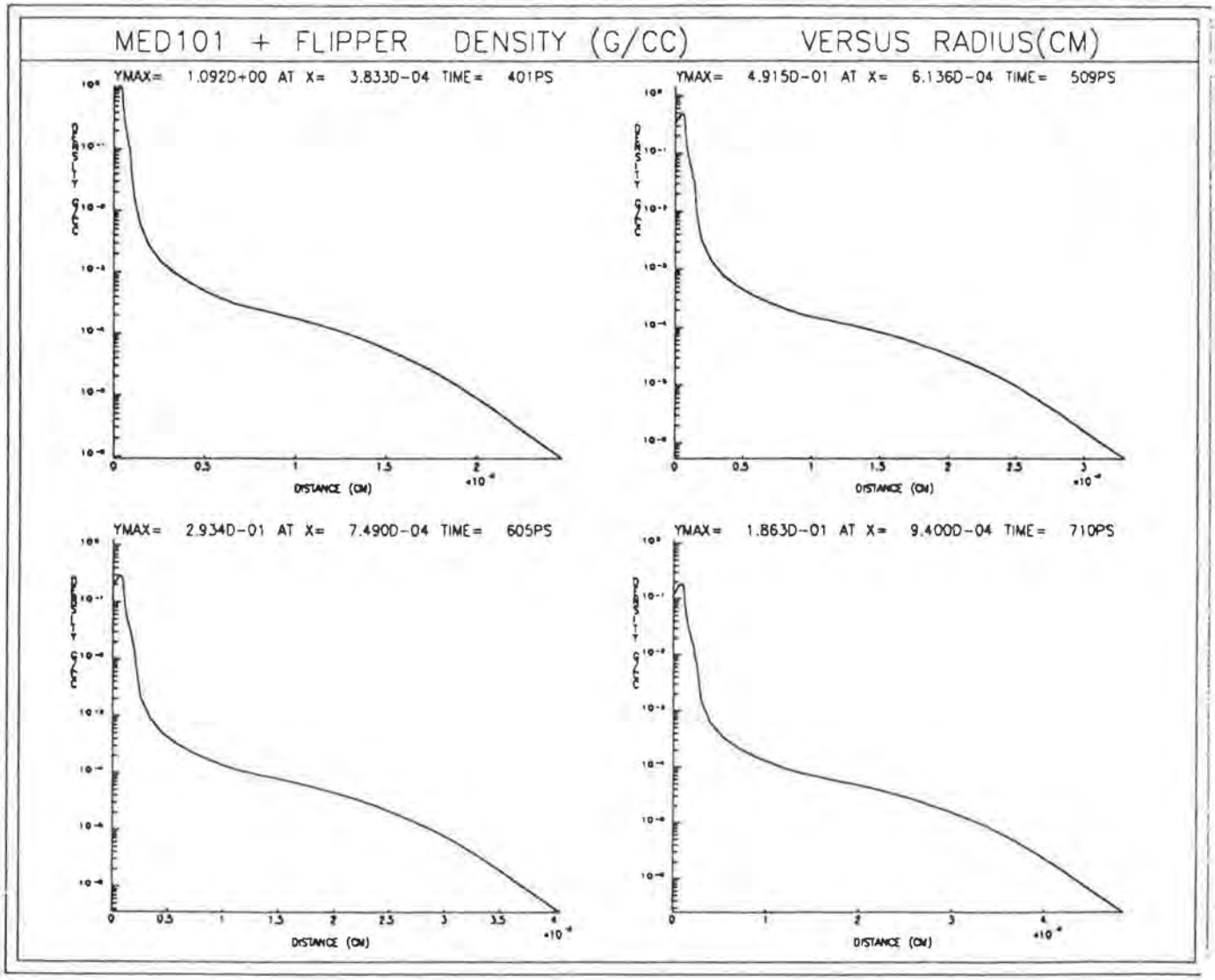


Figure 2: Sample FLIPPER output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

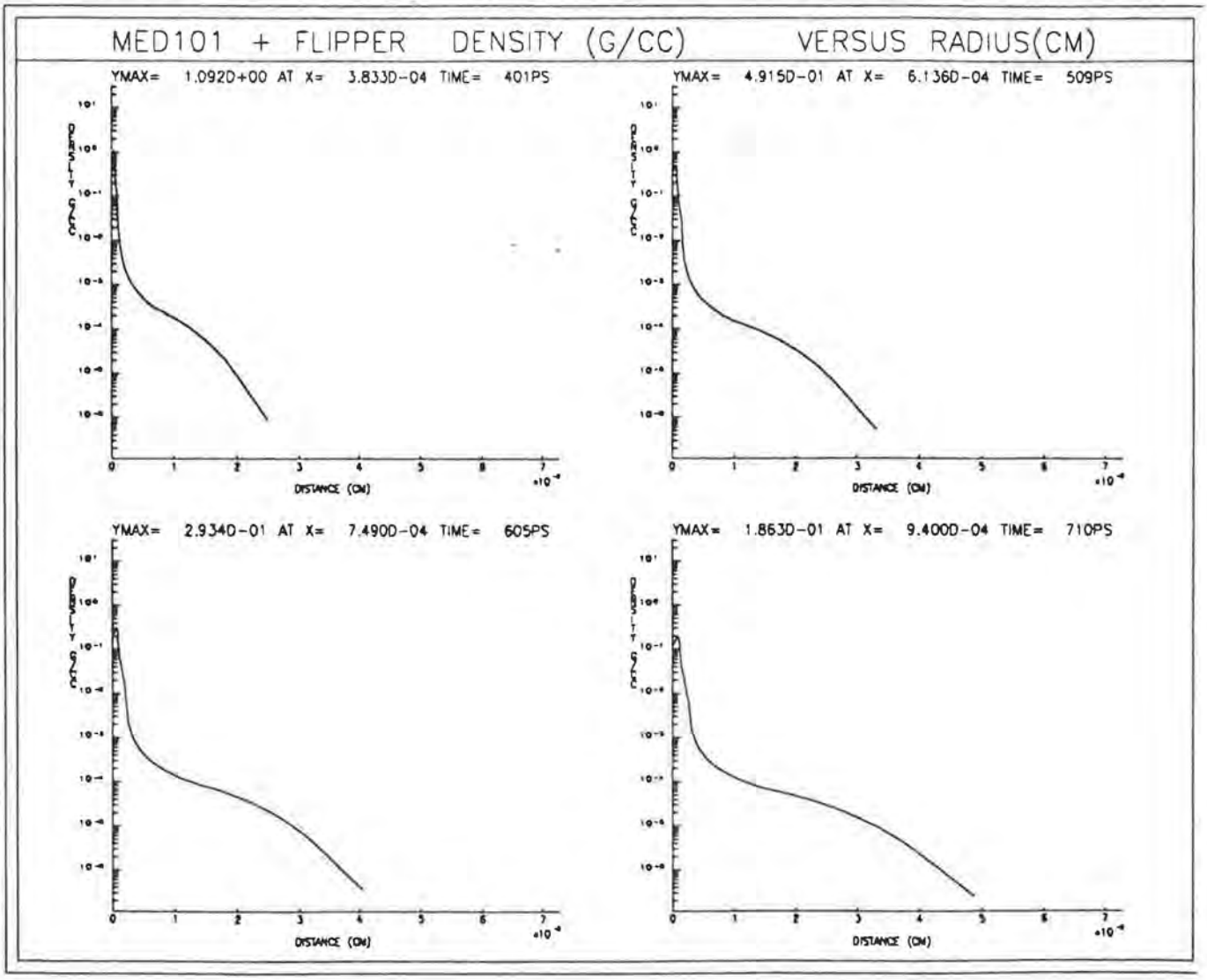


Figure 3: Sample FLIPPER output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

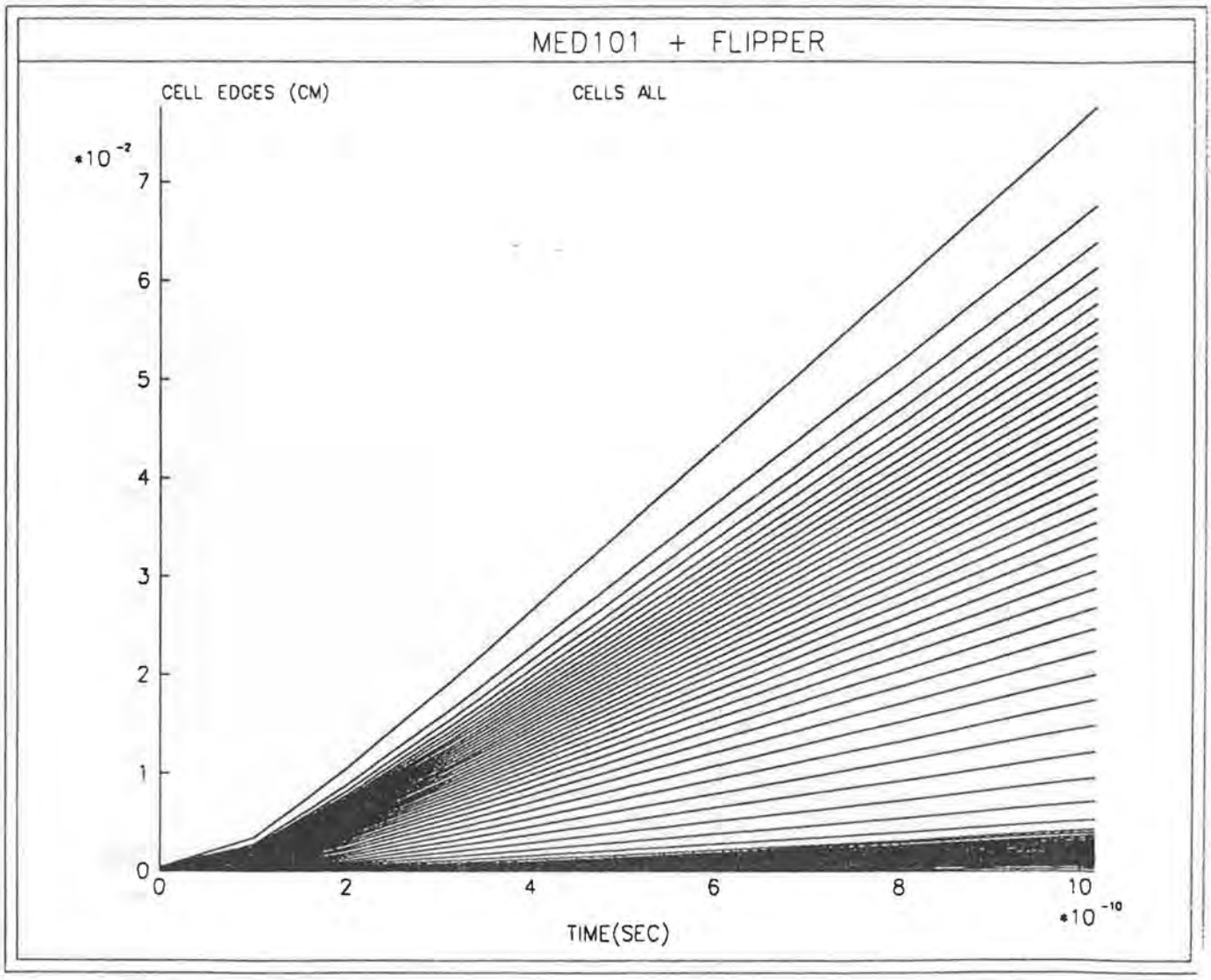


Figure 4: Sample FLIPPER output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

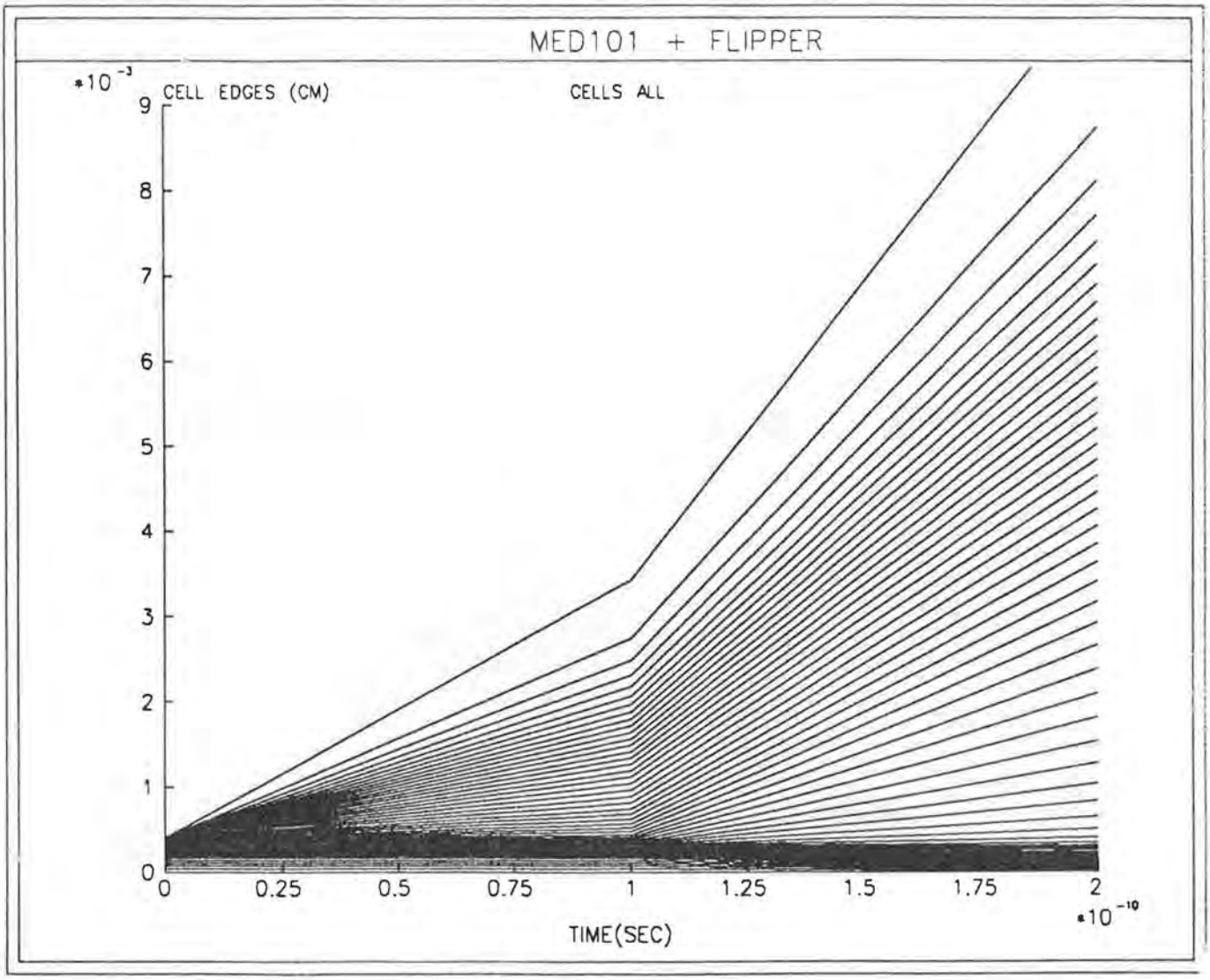


Figure 5: Sample XRLFLIP output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

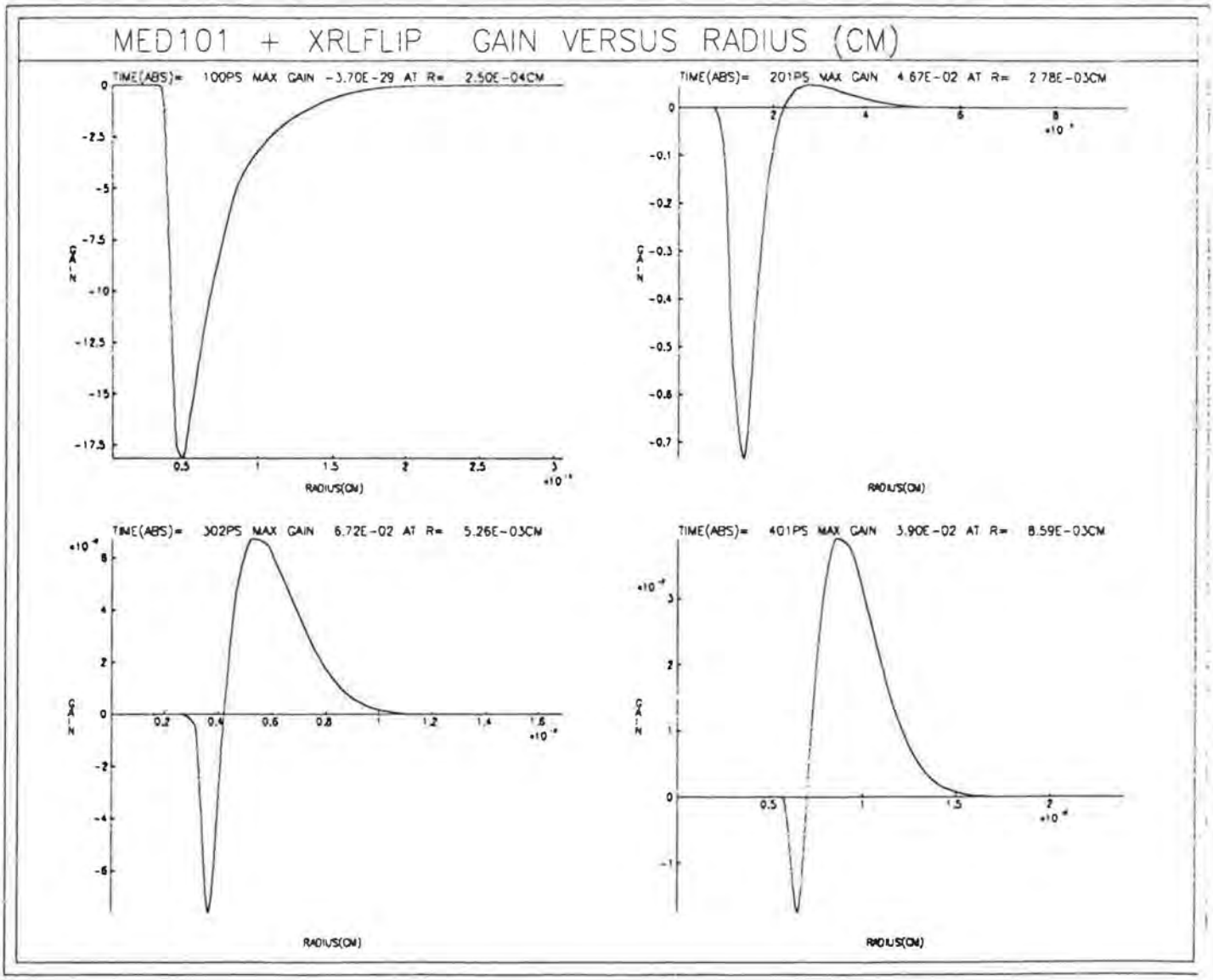


Figure 6: Sample XRLFLIP output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

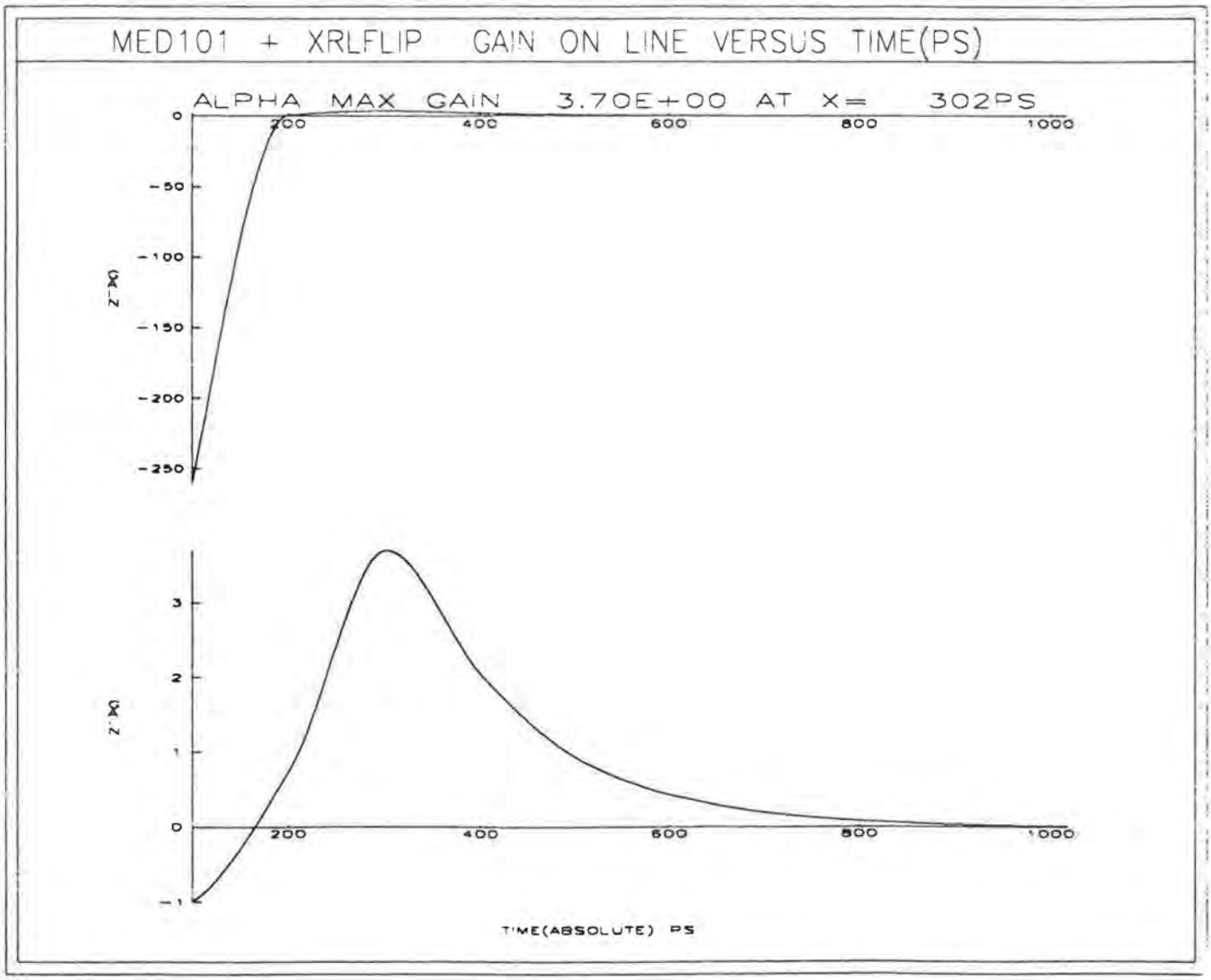


Figure 7: Sample XRLFLIP output

FLUORINE FIBRE (write-up #1) NGEOM: 2 PMAX: 2.830E+12
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 9.00
XMASS:19.00 RINI: 4.000E-06 XZ2: 8.00 XMASS2:16.00 FNE2: 0.00 DRGLAS: 0.000E+00
XZ1: 6.00 XMASS1:12.01 DRPLAS: 0.000E+00 MESH: 60 ZGLAS: 0.00 ZPLAS: 0.00
RF1: 9.000E-01 RF2: 0.000E+00 RF3: 0.000E+00 XRL ON DLAMDA: 8.100E-09
PEQUIV: 7.075E+17 W/M**2 OPACITY CORRECTIONS OFF

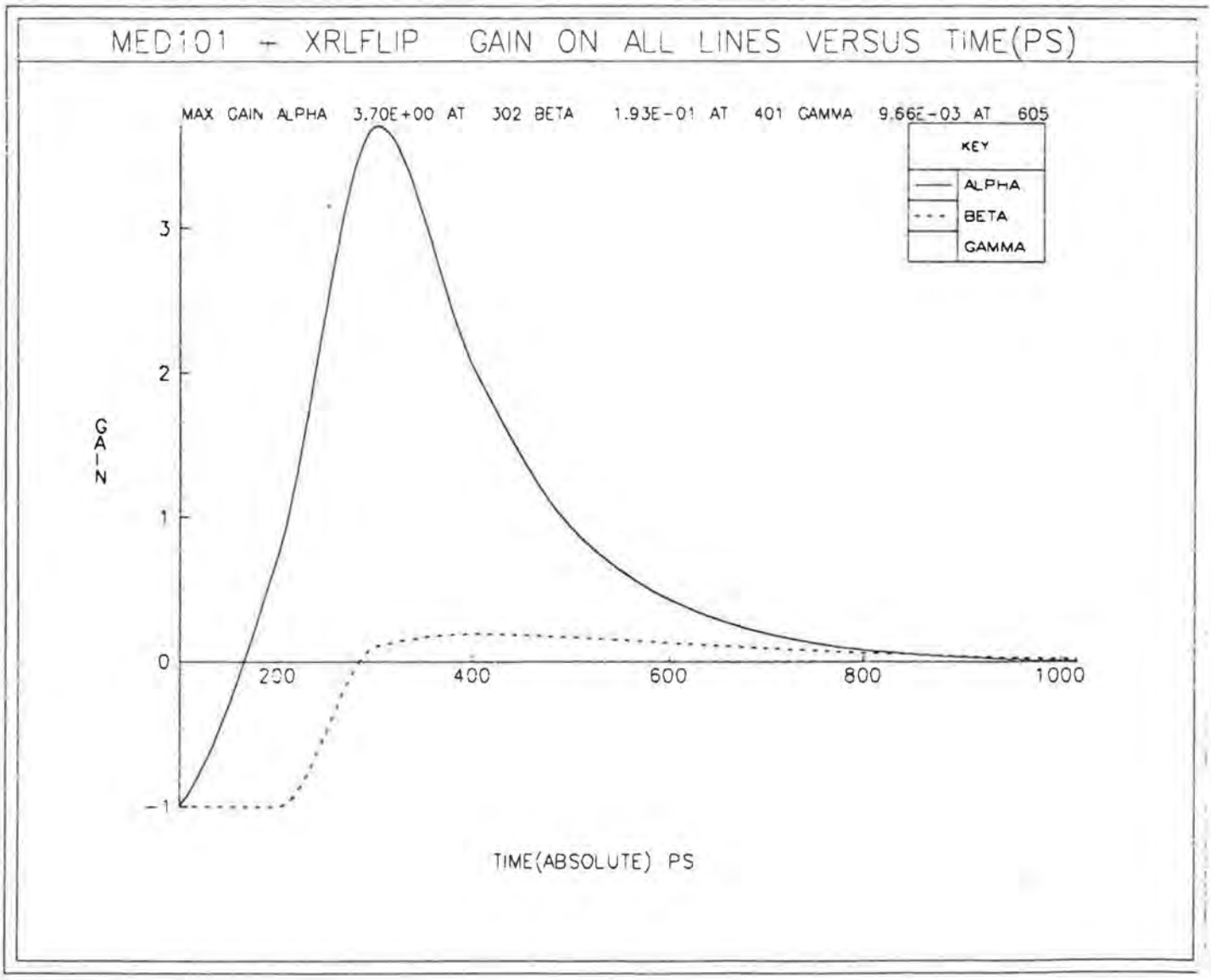


Figure 8: Sample IONFLIP output

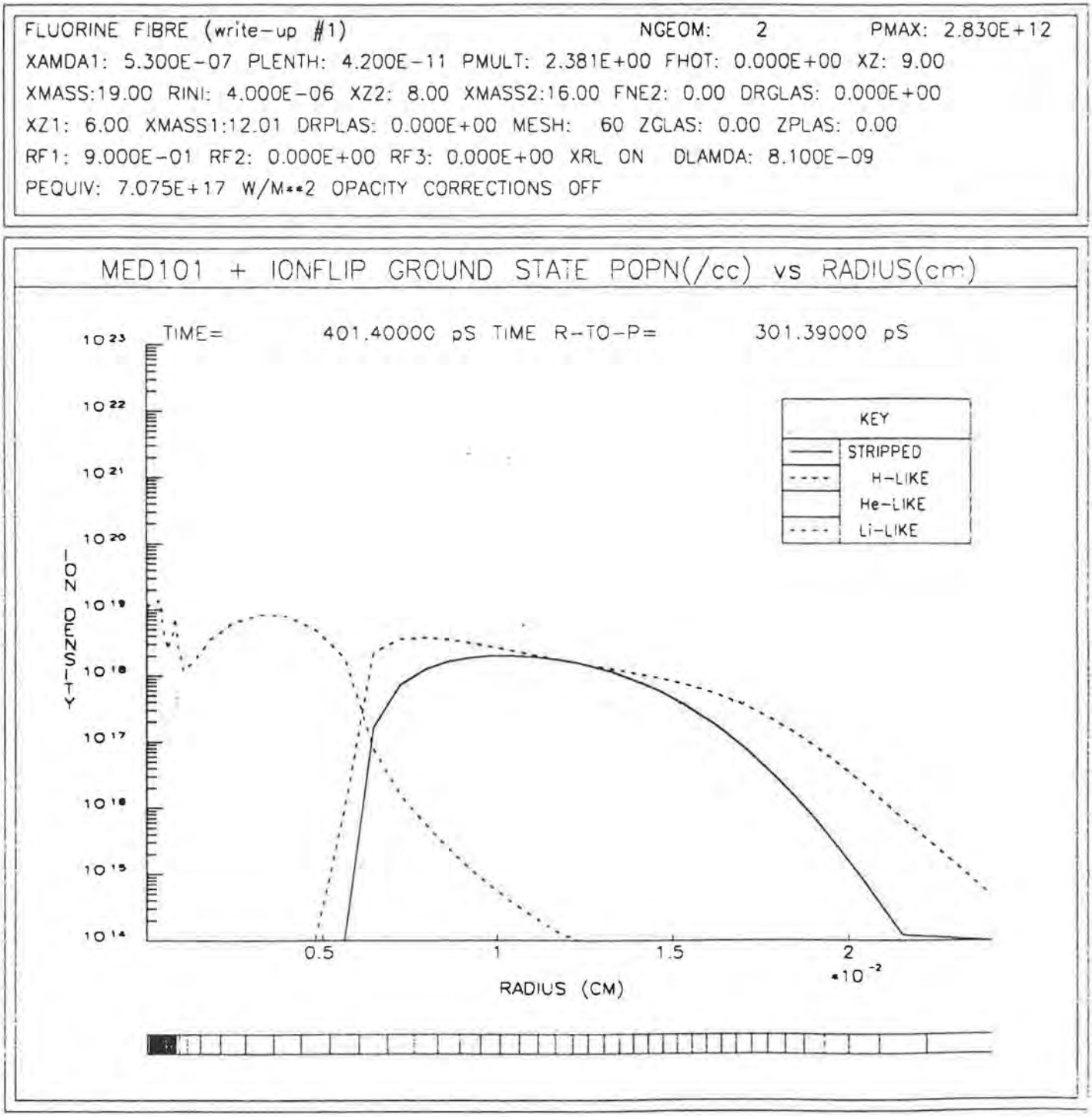


Figure 9: Sample FLIPPER output

Two-layer target (write-up #2) NGEOM: 2 PMAX: 7.075E+09
XAMDA1: 5.300E-07 PLENTH: 4.200E-11 PMULT: 2.381E+00 FHOT: 0.000E+00 XZ: 6.00
XMASS:12.00 RINI: 9.900E-05 XZ2: 6.00 XMASS2:12.00 FNE2: 1.00 DRGLAS: 1.000E-06
XZ1: 6.00 XMASS1:12.00 DRPLAS: 0.000E+00 MESH: 40 ZGLAS:20.00 ZPLAS: 0.00
RF1: 7.200E-01 RF2: 1.000E+00 RF3: 1.000E+00 XRL OFF DLAMDA: 8.100E-07
PEQUIV: 7.075E+13 W/M**2 OPACITY CORRECTIONS OFF

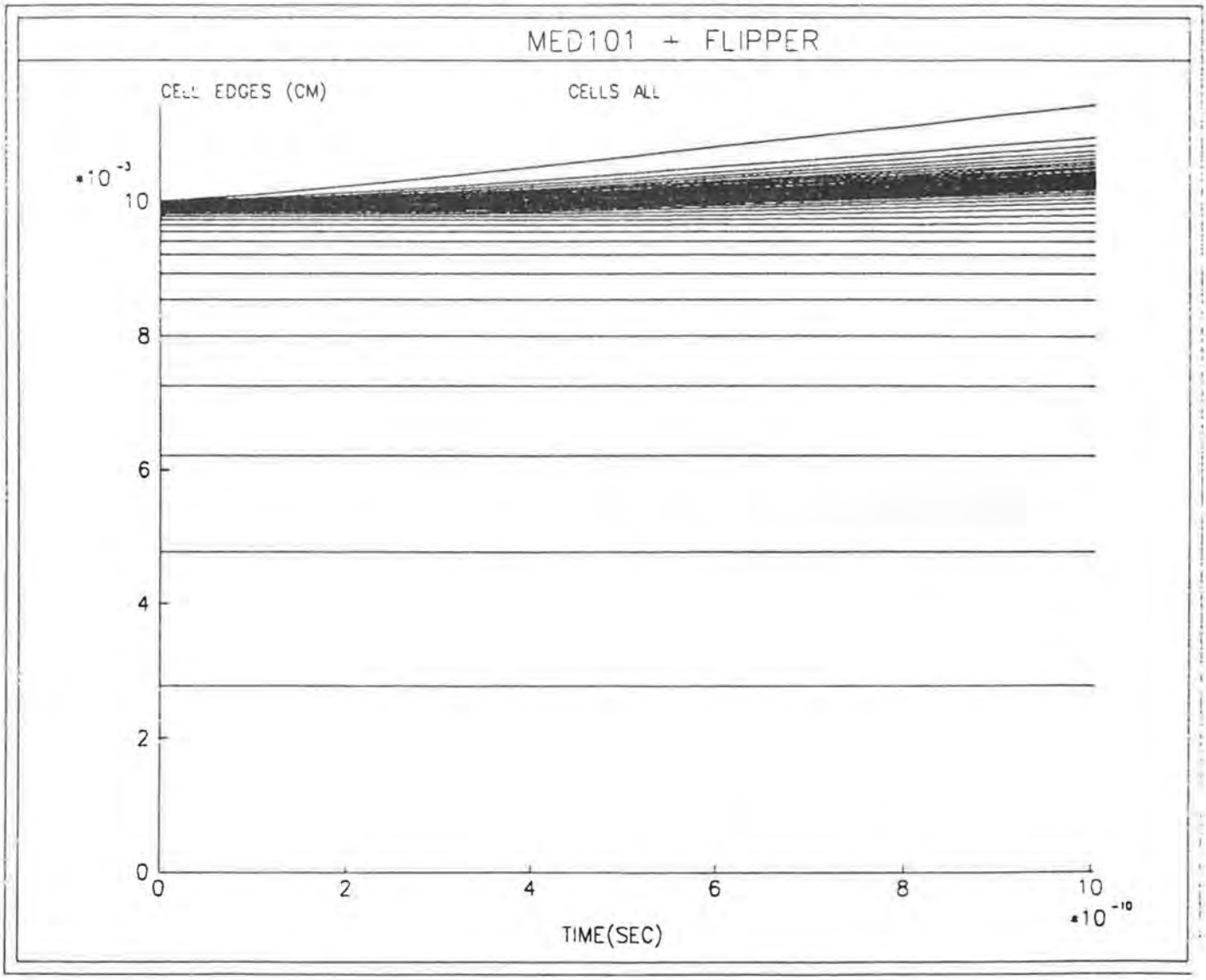
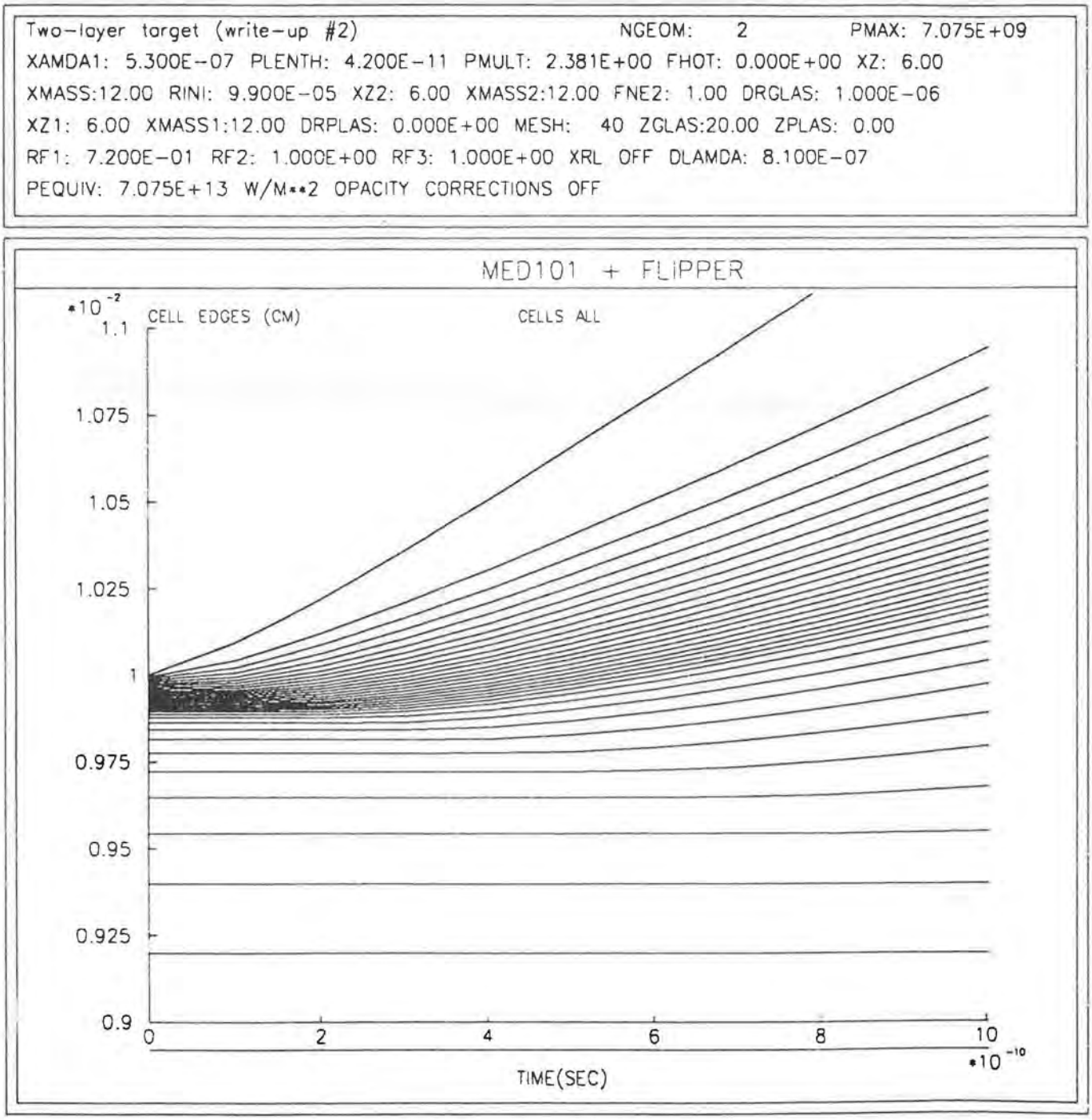


Figure 10: Sample FLIPPER output



7 Summary

It is hoped that this guide will provide enough detail for any user to run MED101. If you have any problems contact Steven Rose (userid : SJR) or Peter Rodgers (userid : PR2). It would be helpful if users refrained from making alterations to the code but instead sent details of gripes, bugs, etc. to the above users. It would also be useful to know if people are actively engaged in writing some piece of code that changes the physics. This may be for interest but if some piece of physics is lacking then of course, it would be our aim to include this in future versions of MED101. Details of modifications, etc. will be kept in AR4's file space titled NEWS SCRIPT.

References

[1] JP Christiansen, DETF Ashby and KV Roberts *MEDUSA A one-dimensional laser fusion code* Computer Phys Comm **7** 271-287 (1974)

[2] M Grande et al. *Measurement and detailed analysis of single pass gain at 81Å in a recombining laser-produced fluorine plasma* Opt Comm (to be published)

[3] GJ Pert and SJ Rose *Simulations of gain in experiments* Applied Physics B (to be published)

[4] C Chenais-Popovics et al. *Laser amplification at 18.2nm in recombining plasma from a laser-irradiated carbon fiber* Phys Rev Lett **59** 2161-2164 (1987)

APPENDICES

A Arithmetic gridding

A further modification made in MED101 is the option of arithmetic gridding (this is where the thicknesses of the cells gradually increases or decreases within a layer rather than remaining identical). Each of the 3 layers may be altered independently. The gridding is based upon the formula:

$$w_i = \left(\frac{r_f^i - 1}{r_f^n - 1}\right) \times S$$

$$\Delta_i = w_i - w_{i-1}$$

$$\Delta_1 = w_1$$

where w_i represents the co-ordinate relative to zero of the ith cell boundary, Δ_i is the width of the ith cell, n is the number of cells in the layer, i varies from 1 to n and S is the thickness of the layer (i. e. RINI, DRGLAS or DRPLAS). The factor in brackets varies between 0 and 1 depending on i and the difference in cell thickness from one cell to the next is controlled by r_f (i. e. RF1, RF2 or RF3).

If r_f is almost but not quite equal to 1.0 (e. g. 0.99999) then the gridding will be linear as in the old versions of MEDUSA.

If r_f=1.0 the denominator is zero so the code resets any input from 1.0 to 0.99999. This is also the default so to obtain a linear mesh either r_f=1.0 or r_f=0.99999 can be used.

It is only possible to fix any three of the four quantities r_f, n, S and Δ_1 (or any Δ_i). Suppose, for example, we require a layer containing 10 cells to have its first cell 10 times larger than its 10th cell. Using the formula

$$r_f = \left(\frac{\Delta_n}{\Delta_1}\right)^{\frac{1}{n-1}}$$

we find $r_f = 0.7743$. Given r_f and n the thickness of the layer may be specified. If we to specify the thickness of the beginning and end cell we lose control over the total thickness of the layer. To calculate the total thickness of the layer (i. e. one of RINI, DRGLAS and DRPLAS) use

$$S = \left(\frac{r_f^n - 1}{r_f - 1}\right) \times w_1$$

If, for example, we set $\Delta_1 = 10\mu$m and $\Delta_{10} = 1\mu$m then the total thickness of the layer MUST be 40.87μm. Alternatively if we set $S = 100\mu$m (with $n = 20$ and $r_f = 0.8361$) then $w_1 = 24.47\mu$m and $w_{10} = 2.447\mu$m.

It is not possible to control the number of cells, the ratio, the total thickness and the individual thicknesses simultaneously.

This facility is very useful for a number of things. It can be used to ensure that the zoning is at its finest at the edge of a target where most detail is needed, without having to set up a large number of different layers. It can be used to interface between layers of differing cell width. This helps avoid jumps in the mass between consecutive cells that may cause problems.

B Reading in data for graphics

This appendix lists the Fortran commands used to read data into the graphics programs. All three routines start by reading in six lines of 80 character long header information. This contains most of the variables most commonly changed by the user. In this way, a user can look at a graph and know exactly what the parameters were that resulted in the data plotted.

B.1 FLIPPER

```
      PROGRAM FLIPPER

      DOUBLE PRECISION  VALS(8, 100, 100), TIME(100)

      CHARACTER  CHAR1*80,CHAR2*80,CHAR3*80,CHAR4*80,CHAR5*80,CHAR6*80

      READ(NINPUT,1030)CHAR1,CHAR2,CHAR3,CHAR4,CHAR5,CHAR6
      READ(NINPUT,1000)NMESH0
      I = 0
1     CONTINUE
      I = I + 1
      READ (NINPUT,1010,END=2) TIME(I)
      IF(I.GE.2.AND.TIME(I).EQ.TIME(I-1))THEN
        GOTO 2
      ENDIF
      DO 10 J = 1, NMESH0
        READ (NINPUT,1040 ) (VALS(K, J, I), K = 1, 8)
10    CONTINUE
      READ(NINPUT,1050)VALS(1,NMESH0+1,I),VALS(2,NMESH0+1,I)
      GOTO 1
2     CONTINUE
      NSTEP = I - 1

1000  FORMAT(I5)
1010  FORMAT(1P,1E11.4)
1030  FORMAT(A80)
1040  FORMAT(1P,3E11.4,2E10.3,3E9.2)
1050  FORMAT(1P,2E11.4)
```

CHAR1 etc. contain the header information. NMESH0 is the number of cells in the simulation (determined by MESH and NP3 in the MED101 input data file). The data is read into arrays VALS and TIME. TIME stores the values of the time at the data dump (in seconds). VALS(K,J,I) is subscripted by 3 variables. K denotes the physical quantity; 1=cell edge co-ordinates(cm), 2=hydrodynamic velocities(cm/s), 3=centre-of-cell co-ordinate(cm), 4=density(g/cc), 5=Pressure(MB), 6=T_i(eV), 7=T_e(eV), 8=Average ionisation. J denotes the cell which has this value (ranging from 1 to NMESH0). I is the number of the time frame with value TIME(I). The IF Block is to stop FLIPPER reading in the last two time frames if the last three frames output by MED101 are identical.

B.2 XRLFLIP

```
      PROGRAM XRLFLIP

      DOUBLE PRECISION RADIUS(20,100)
      DOUBLE PRECISION GAIN(20,100),EGAIN(20,20)
      DOUBLE PRECISION TIME(100) ,TA(2)

      CHARACTER CHAR1*80,CHAR2*80,CHAR3*80,CHAR4*80,CHAR5*80,CHAR6*80

      READ(11,1504)CHAR1,CHAR2,CHAR3,CHAR4,CHAR5,CHAR6
      READ(11,1500)NCELL,NGAIN
      DO 10 I=1,100
        READ(11,1501,END=40)TA(1),TA(2)
C       IT=??
        TIME(I)=TA(IT)
          DO 20 J=1,NCELL
            READ(11,1502)RADIUS(I,J),GAIN(I,J)
20        CONTINUE
          DO 30 K=1,NGAIN
            READ(11,1501)EGAIN(I,K)
30       CONTINUE
10     CONTINUE
40     NTIME=I-1

1500   FORMAT(2I3)
1501   FORMAT(2E15.5)
1502   FORMAT(2E15.5)
1504   FORMAT(A80)
```

CHAR1 etc. contain the header information. NCELL is the number of cells in the simulation (determined by MESH and NP3 in the MED101 input data file). NGAIN is the number of gain lines considered (typically 3 i. e. α, β and γ). In XRLFLIP the data is placed in arrays RADIUS(I,J) and GAIN(I,J). The I coordinate is the time frame index while the J represents the cell number index. The 'experimental gain' (i. e. space-integrated gain) EGAIN(I,J) has up to NGAIN values per time frame where I is the time frame index and J is the gain line index. Two times are read in, TA(1) and TA(2). TA(1) is the absolute time (i. e. zero is at the beginning of the simulation), TA(2) refers to the time relative to the peak of the laser pulse. One of these values is read into the array TIME according to the value of IT. The user can either set the value of IT in the code or have it read in. Then gain and radius (centre-of-cell) are read in for 1 to NCELL cells. Then the effective gain (EGAIN)at that time for the chosen number of gain lines is read in. The whole process is repeated for the next time frame until the end of the data file is reached.

B.3 IONFLIP

```
      PROGRAM IONFLIP

      DOUBLE PRECISION TIME(100)
      DOUBLE PRECISION TRTOP(100)
      DOUBLE PRECISION RADIUS(20,100),DNH(20,100,11)
      CHARACTER*80 LINE1,LINE2,LINE3,LINE4,LINE5,LINE6

      READ(12,1505)LINE1,LINE2,LINE3,LINE4,LINE5,LINE6
      READ(12,1500)NCELL,ILOSTA,IHISTA
      NUMION=IHISTA-ILOSTA+1

      DO 10 I=1,20
        READ(12,1501,END=40)TIME(I),TRTOP(I)
        TIME(I)=TIME(I)*1.0E9
        TRTOP(I)=TRTOP(I)*1.0E9
        DO 20 J=1,NCELL
          READ(12,1501,END=40)RADIUS(I,J),(DNH(I,J,K),K=1,NUMION)
20      CONTINUE
10    CONTINUE
40    NTIME=I-1
1500  FORMAT(3I2)
1501  FORMAT(1E15.5)
1505  FORMAT(A80)
```

LINE1 etc. contain the header information. NCELL is the number of cells in the simulation (determined by MESH and NP3 in the MED101 input data file). ILOSTA and IHISTA are defined in section 4. Two times are read in, TIME which is the time relative to the start of the simulation and TRTOP which is the time relative to the peak of the laser pulse. The data is read into two arrays, RADIUS(I,J) and DNH(I,J,K) where index I is the number of the time frame, index J is the number of the cell (values in RADIUS are centre-of-cell) and index K is the relative ionisation stage. Note: the index K may be, for example, 1 but this does not mean that it refers to hydrogen-like ionisation data. To know what ion stage this number refers to it must be offset, using, *ionisation stage*=ILOSTA+K-1. Thus, if ILOSTA = 3, then K = 1 corresponds to lithium-like ionisation data.

C Introduction to CMS

This appendix briefly describes CMS, the operating system used on the Rutherford Appleton Laboratory IBM 3090 mainframe computer. The IBM 3090 is a powerful machine which can either be used as a front end to the Atlas Centre Cray X-MP or as a supercomputer in its own right.

You should be sent a much larger guide when you receive your user ID and password. The IBM also has an extensive on-line HELP facility (see section C.3). However there should be enough information here to obtain useful output from MED101.

C.1 Accessing the IBM

The IBM can be accessed either in full-screen mode or line-mode. Full-screen mode is considerably superior and this guide is primarily intended for full-screen users although many of the commands will also work on line-mode terminals. However XEDIT, FILELIST and RDRLIST are very different on line-mode terminals.

The IBM can be accessed either through terminals which are directly linked by co-axial cables, or via the PAD. From the PAD type one of the following

```
CALL UK.AC.RL.IBP
CALL RL.IBP
```

The VM370 logo will appear on the screen (it should appear on co-ax connected terminals when they are switched on) with the prompt

```
LOG
```

in the lower left corner. Enter your user ID, and then your password when prompted. If for some reason the VM370 logo disappears and

```
CP READ
```

appears in the lower right of the screen type

```
LOG userid
```

and you will be prompted for your password.

To access the IBM in line-mode (either because your terminal does not support full-screen mode, or if you want to use GKSMVIEW on Tektronix 4010 terminals) type

```
CALL UK.AC.RL.IB
CALL RL.IB
```

You are then asked to enter a default page-size — 22 is recommended. Then follow the commands to enter your username and password. You will not see the VM370 prompt.

C.2 The PROFILE EXEC file

When you have logged on a few lines of information will be displayed and then you must hit the <ENTER> key to proceed. This will run your PROFILE EXEC file (which is similar to a LOGIN.COM file on a VAX). Your PROFILE EXEC file tailors your virtual machine (i. e. how the IBM appears to you) and can be altered to automatically link you to various libraries, define various PF keys (Programmable Function keys – most terminals have 24 of these), etc.

If you intend to do a lot of work with MED101 you are advised to include the following lines in your profile exec

```
'GLOBAL TXTLIB NAGLIB NAGGKS GKS74 VSF2FORT CMSLIB RHELIB'
'GLOBAL LOADLIB VSF2LOAD'
'SP PRT XER4050B FORM LP60D COPY 1'
```

They should be placed after the line

```
'EXEC STANPROF'
```

which should already be there.
Lines 1 and 2 link you to the libraries which allow you to compile and run programmes, including NAG GKS graphics.
Line 3 — see the Printing section below for explanation.

If for some reason you find yourself at the CP level after you log on (CP READ will appear in the lower right of the screen — this sometimes happens if you are unexpectedly logged out) type

```
I CMS
```

to return to CMS. The prompt in CMS is

```
Ready;
```

C.3 HELP and FIND

There is an extensive on-line help facility on the IBM which can be accessed through the HELP or FIND commands. For example

```
HELP BATCH
FIND XEDIT
GIME USDOC 193
```

The last command links you to a disk containing a large number of listing files with information on most features of the IBM. These files can either be looked at on your screen or printed (they will have a filemode other than A — see C.9).

C.4 Filenaming convention

Files in CMS have a FILENAME, FILETYPE and FILEMODE. For example the file

```
MED101 FORTRAN A1
```

has

```
filename    MED101
filetype    FORTRAN
filemode    A1
```

Your main filespace is filemode A and is known as your A-disk or 191 disk. Filemode A0 is private and filemode A3 is temporary and should not be used. If you create extra disks, or link to other users space (see Minidisks below) they will have filemodes other than A.

C.5 XEDIT

Full details of XEDIT can be found in the files XEDINTRO LISTING, XEDTUTOR LISTING and XEDTUT LISTING on USDOC 193 and we only give some basic details here. To edit the file INPUT DATA A1 type

```
XEDIT INPUT DATA
```

XEDIT assumes a filemode of A unless told otherwise. Similarly the default filetype is FORTRAN. Therefore to edit MED101 FORTRAN simply type

```
XEDIT MED101
```

The name of the file being edited will appear at the top left of the screen and

```
====>_  (cursor)
                                                    X E D I T   1 File
```

will appear at the bottom. This is the Command Line. There will also be a guide across the centre of the screen

```
===== * * * Top of File * * *
      |...+....1....+....2....+....3....+....4....+....5....+....6...
```

and the file (if it exists already) will be listed below the guide. On full-screen terminals there will now be a grid of ===== to the left of every line of program. To insert lines type

```
I
```

on the command line and hit <ENTER>. The bottom of the screen will now read

```
====> * * * Input Zone * * *
                                                    Input-mode 1 File
```

The grid of ===== will disappear and the cursor will move to halfway up the screen on the left. Just type the line and hit <ENTER> at the end. You can type as many lines as you wish this way. When you have finished hit <ENTER> twice and you will leave Input-mode and the cursor will return to the command line. For example the beginning of a MED101 input data file might look like.

```
===== * * * Top of File * * *
      |...+....1....+....2....+....3....+....4....+....5....+....6...
===== Single-layer Target (write-up #3)
===== Carbon sphere 100mu radius
===== 7.075E9 W/m*m     0.53micron Ideal gas
===== ********************************************
=====  $NEWRUN
=====  XAMDA1=0.53E-6, GAUSS=1.0,    ANPULS=1.0,  TOFF=1.0E-1,
=====  PLENTH=4.2E-11, PMAX=7.075E9, PMULT=2.381,
=====  NGEOM=2,        PIQ(55)=0.0,  TEINI=1.0E4, TIINI=1.0E4,
=====  MESH=50,   RINI=100.0E-6,  RHOGAS=2635.0, RF1=1.0,
=====  XZ=6.0,    XMASS=12.0,     FNE=1.0,
=====  ZGLAS=0.0, DRGLAS=0.0,     ROGLAS=0.00,   RF2=0.0,
=====  XZ2=0.0,   XMASS2=0.00,    FNE2=0.0,
=====  ZPLAS=0.0, DRPLAS=0.0,     ROPLAS=0.00,   RF3=0.0,
=====  XZ1=0.0,   XMASS1=0.00,    HYDROG=0.0,
```

To change any character just move the cursor to the appropriate place in the program and type over. There is an Ins(ert) (or $\hat{a}$) key on most terminals. However to insert (as opposed to write over) more than one character it is necessary to have issued

```
SET NULLS ON
```

followed by <ENTER> from the command line. The SET NULLS ON command can sometimes lead to unexpected and irritating events when editing and can be turned off with the command

```
SET NULLS OFF
```

The ===== can be used to COPY, MOVE and DELETE single lines or blocks of program. For example

```
===== Single-layer Target (write-up #3)
===== Carbon sphere 100mu radius
===== 7.075E9 W/m*m     0.53micron Ideal gas
===== ********************************************
=====  $NEWRUN
=====  XAMDA1=0.53E-6, GAUSS=1.0,    ANPULS=1.0,  TOFF=1.0E-1,
=====  PLENTH=4.2E-11, PMAX=7.075E9, PMULT=2.381,
=====  NGEOM=2,        PIQ(55)=0.0,  TEINI=1.0E4, TIINI=1.0E4,
=====  MESH=50,   RINI=100.0E-6,  RHOGAS=2635.0, RF1=1.0,
=====  XZ=6.0,    XMASS=12.0,     FNE=1.0,
dd===  ZGLAS=0.0, DRGLAS=0.0,     ROGLAS=0.00,   RF2=0.0,
=====  XZ2=0.0,   XMASS2=0.00,    FNE2=0.0,
=====  ZPLAS=0.0, DRPLAS=0.0,     ROPLAS=0.00,   RF3=0.0,
==dd=  XZ1=0.0,   XMASS1=0.00,    HYDROG=0.0,
```

will DELETE the four lines between the dd's (inclusive) when you hit <ENTER>. Blocks of lines can be moved as follows

```
===== Single-layer Target (write-up #3)
===== Carbon sphere 100mu radius
===== 7.075E9 W/m*m     0.53micron Ideal gas
===== ********************************************
=====  $NEWRUN
=====  XAMDA1=0.53E-6, GAUSS=1.0,    ANPULS=1.0,  TOFF=1.0E-1,
====p  PLENTH=4.2E-11, PMAX=7.075E9, PMULT=2.381,
=====  NGEOM=2,        PIQ(55)=0.0,  TEINI=1.0E4, TIINI=1.0E4,
mm===  MESH=50,   RINI=100.0E-6,  RHOGAS=2635.0, RF1=1.0,
==mm=  XZ=6.0,    XMASS=12.0,     FNE=1.0,
```

When you hit <ENTER> the lines between the mm's (inclusive) will be moved to above the line starting PLENTH (P means previous — F meaning following can also be used). To copy lines from one part of the program to another replace the mm with cc. To DELETE, MOVE or COPY single lines just use D, M or C as before. D, M, C, P and F can be used in upper or lower case.

To move to a specific line N in the program type

```
:N
```

followed by <ENTER>. To move forward, say, six lines from the current line type

```
6
```

followed by <ENTER>, and to move, say, twelve lines back from the current line type

```
-12
```

followed by <ENTER>. The PF7 and PF8 keys can be used to move up and down the program 19 lines at a time.
To locate a specific string, say ALPHA1, type

```
/ALPHA1
```

followed by <ENTER>. Be careful however as XEDIT is case-dependent. Normally all letters will be converted into UPPER CASE unless you type

```
SET CASE MIXED
```

To change one string with another on the current line type

```
C/OLD/NEW
```

```
C/OLD/NEW/100 *
```

will replace OLD by NEW everywhere it occurs for 100 lines from the current line.
If you require code from another program just issue

```
GET fn ft fm
```

from the command line.
To leave XEDIT type

```
FILE
```

Note however that this will write over the original file that you edited. If you don't want to do this type

```
SAVE NEW FILE A
```

and your file will be saved under as NEW FILE A. If you want to leave XEDIT with any changes being made type

```
QQUIT
```

C.6 Printing Files

Line 3 of section C.2 defines your PRINT command. This particular line sends output to the Xerox laser printer in R1. The output looks like table 1 in this document. If LP60D is replaced with XA4CD this output will look like table 2. You are also advised to set a distribution code with the command

```
DIRM DIST dist-code
```

You need only do this once, unless you decide to change your dist-code. The various options for dist-code can be found by typing

```
FIND DISTCODE
```

and your dist-code can be checked by typing

```
USERINFO
```

A dist-code of RL1-Z1 should have all your output placed in the Z1 pigeon-hole in R1. However you will need to check that no-one else is using the same pigeon-hole. Currently graphics files can only be printed in the Atlas Centre and if your output has a non-Rutherford dist-code it will be posted to you. Therefore you might consider switching between two dist-codes, a Rutherford dist-code for when you're working at RAL and another for your home site.

C.7 FILELIST

On full-screen terminals this command will list all the files on your A-disk in a XEDIT type environment, the most recently created being at the top. The PF4 will reorder them alphabetically by filetype and the PF6 key will reorder them with the largest at the top. The PF5 key will return the original order. It is possible to XEDIT, BROWSE ,PRINT, compile etc. files in the FILELIST environment either from the command line or by typing the command opposite the appropriate file (PF10 for browse, PF11 for XEDIT). To leave FILELIST press PF3. If you just want your FORTRAN files in the FILELIST type

```
FILELIST * FORTRAN
```

etc. where * means ALL. FILELIST can be abbreviated to FILEL.

C.8 The READER

Any files sent to you by other users, other machines e. g. the Cray, or processes e. g. SLAC-Batch are stored in your READER. To list your READER files type

```
RDRLIST
```

This will lead to a FILELIST type environment. You can now use PF9 to RECEIVE these files onto your A-disk or PF10 or PF11 to look at them in your READER. DISCARD will erase the file from your READER.

C.9 Minidisks

Minidisks are probably the most confusing aspect of CMS but it is possible to progress without knowing too much about them if you use the EXEC and JOB files in chapter 2.

```
FIND MDISK
```

will give you full details about minidisks. If you have enough space you can divide it between different minidisks with the

```
MDISK CREATE
```

command. A panel will appear for you to place details of the new minidisk in. This way it is possible to create a primitive directory structure on the IBM.

If you want to link to another minidisk, say, the A-disk of user EBC type

```
 GIME EBC
```

The IBM will reply

```
 EBC191  ( 1C2 Z ) RR
```

This means you have read only access and these files have a filemode Z. You can look at them in FILELIST by typing

```
FILELIST * * Z
```

You can end the link by typing

```
 DROP Z
```

A useful feature on the IBM is the TEMPORARY disk. By typing

```
GIME 10 C
```

you will be given 10 cylinders of temporary space with filemode C (1 cylinder equals 150 blocks). All files on this cylinder will be deleted when you LOG off. Temporary files are useful for editing large files, or receiving large files from the READER to PRINT or process with graphics packages. To receive a file to a disk other than the A-disk type

```
Q RDR
```

This will list all the READER files and an associated number under the column FILE, for example

```
 ORIGINID FILE CLASS RECORDS  CPY HOLD FORM     DEST     KEEP MSG
 EBC      0228 A PUN 00000781 001 NONE STANDARD OFF      OFF  OFF
```

Then type

```
RECEIVE number filename filetype C
```

C.10 Compiling and running programs

To compile the program CROSS FORTRAN type

```
FORTVS2 CROSS
```

This will create two files: CROSS LISTING (this is useful for locating any errors which might occur when you run the program) and the executable file CROSS TEXT. To run the program type

```
RUN CROSS
```

or

```
LOAD CROSS(START
```

C.11 File handling

To COPY a file fn1 ft1 fm1 simply type

```
COPY fn1 ft1 fm1 fn2 ft2 fm2
```

The new file will be called fn2 ft2 fm2. If you only want to copy part of a file type

```
COPY fn1 ft1 fm1 fn2 ft2 fm2(FROM lineno FOR lines
```

If a file already exists under the new name and you want to write over it type

```
COPY fn1 ft1 fm1 fn2 ft2 fm2 (REP
```

To RENAME a file simply type

```
RENAME fn1 ft1 fm1 fn2 ft2 fm2
```

The RENAME command will only work if the new and old files have the same filemode. The (REP option can not be used.

To COMPARE two files simply type

```
COMPARE fn1 ft1 fm1 fn2 ft2 fm2
```

To ERASE a file simply type

```
ERASE fn ft fm
```

The default filemode is A.

C.12 Miscellaneous

FILEDEFs
Files can be assigned to different input and output streams as follows

```
FILEDEF 1 DISK INPUT DATA A
FILEDEF 2 DISK OUTPUT DATA A
```

etc. The default names for streams 1 and 2 are

```
FILE FT01F001 A1
FILE FT02F001 A1
```

Recording the sessions
To record your session type

```
SPOOL CONSOLE START *
```

to begin and

```
SPOOL CONSOLE STOP CLOSE
```

to end. This will cause a file containing all the commands you have issued and the computer responses to be sent to your READER.

NOTE and SENDFILE
To send another IBM user a note type

```
NOTE USERID
```

This creates an XEDIT-type environment. Follow the prompts and hit PF5 to send the note. If the user is on another machine with a JANET address RL.ABC then type

```
NOTE USERID @RL.ABC
```

Files can be sent using the SENDFILE command (abbreviated to SF)

```
SENDFILE THIS FORTRAN XYZ
```

This will send the file THIS FORTRAN A to user XYZ.

Reset and Clear
Occasionally you will make an error and you will not be able to proceed until you hit the RESET key. The location of this key can vary from terminal to terminal.

Full-screen terminals do not scroll and frequently the words

```
... MORE
```

or

```
HOLDING
```

will appear in the lower right of the screen. To proceed hit the CLEAR key. Again this will vary from terminal to terminal.

Simple EXECs
In section 2.1 we list an EXEC for running MED101 in SLAC-Batch. EXECs can also be run interactively by simply typing the name of the EXEC file. An EXEC file must begin with a comment (which may be blank) between /* and */ and the commands must appear between single quotation marks. Any command (FORTVS2, COPY, RUN etc.) can be used. They provide a convenient short-hand for commands which may be difficult to remember.

Example EXEC 1
The file SQB EXEC is listed below

```
/* SQB - Exec to check queue on R1 laser printer*/
'VMFCLEAR'
'CP QUERY FILES XER4050B'
'CP QUERY RDR XER4050B'
```

To run this EXEC simply type.

```
SQB
```

Line 1 is a comment
Line 2 clears the screen
Line 3 lists on one line the number of files waiting to be printed by the R1 laser printer (XER4050B)
Line 4 lists all the files waiting to be printed.
Obviously if XER4050B were replaced by XER4050A (say in a file SQA EXEC) the same information would be displayed about the Atlas Centre laser printer. The progress of files on the Atlas Centre Versatec (VER9242A), microfiche printer (NCR5330A) and corrosion printer (IBM4250A) can also be checked. If you don't wish to use an EXEC the CP QUERY commands can be entered directly from CMS.

Example EXEC 2

The file COST EXEC is listed below

```
/*COST - Exec to check on cpu usage*/
'VMFCLEAR'
'ACCT CMS CF'
'AUS'
'ACCT QUSAGE cmsac CMS-AU'
'ACCT QUSAGE crayac COS-AU'
```

Line 3 gives the current rate being charged for cpu time— this can vary from 1.0 during peak hours (10–12 and 2-4 weekdays) to 0.1 during slack periods (weekends etc.)
Line 4 gives the number of AUs (the unit cpu time is allocated in) used that day
Lines 5 gives the total number of CMS AUs used on account cmsac this week
Lines 6 gives the total number of COS AUs (i. e. Cray time) used on account crayac this week
To find which accounts you are authorised to use type

```
ACCT QCOMB USER userid
```

PF Keys

If you hit PF9 in CMS it should list the default values of all your PF keys. These defaults can be changed in your PROFILE EXEC with the following command

```
'CP SET PFn  IMMED new command    '
```

For example

```
'CP SET PF12 IMMED FILELIST * * Z1'
```

In this example PF12 will do a FILELIST on any minidisk you may be connected to with filemode Z.

Logging off

Simply type

```
LOG
```