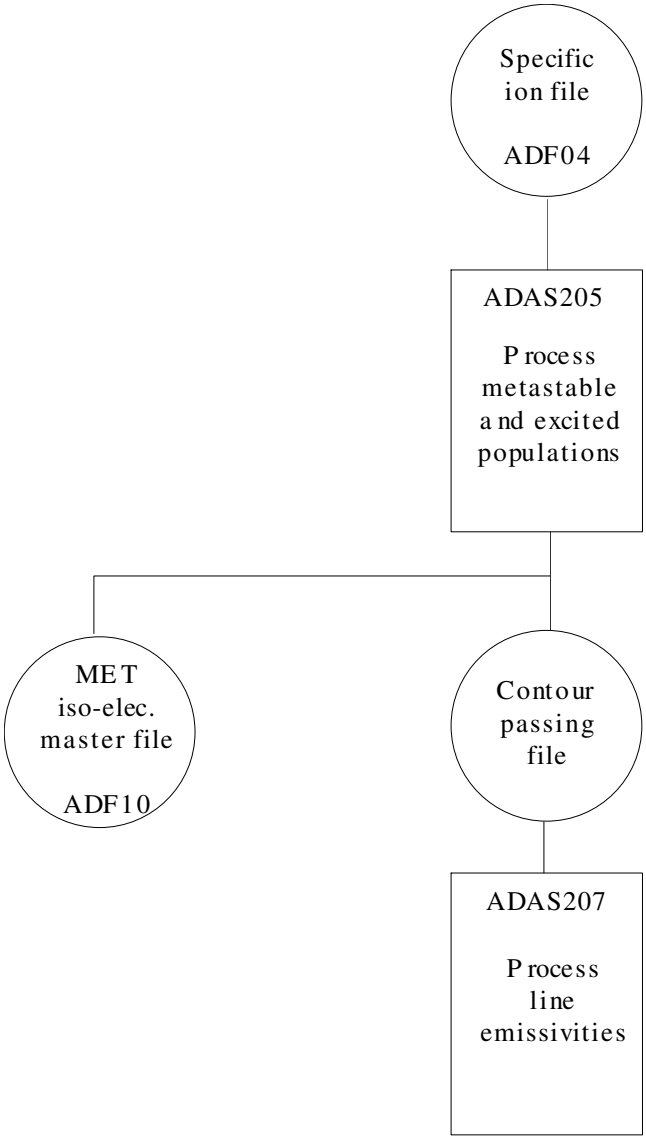
Atomic Data and Analysis Structure

Populations and line ratio studies

Two programs from ADAS2 series are presented in this section. They are designed to allow detailed study of theoretical emissivities of spectrum lines from a selected ion in a thermal plasma. The two programs are linked. The starting point is a collection of 'complete' reaction data for an identified group of levels of an individual ion, called a *specific ion file* (type ADF04). Such a dataset can include state selective recombination, charge exchange recombination, electron impact ionisation and ion impact excitation coefficient data, but the primary content is electron impact excitation data. The electron impact excitation data in such files are individually prepared for the highest precision but can also be produced semi-automatically by direct calculation or, for members of prepared isoelectronic sequences, by another ADAS2 series program. The excited level populations are calculated at an array of temperatures and densities in the quasi-equilibrium approximation with respect to identified metastables of the ion. The basic program for this is ADAS205 and it produces plots and tables of populations and prepares two output files. The first of these is a file of metastable fractions (MET) which is not of special interest at this stage. Secondly it produces a temporary 'passing' file of the complete population set for use by the program ADAS207. ADAS207 is a program which supports diagnostic line studies by plotting line emissivities and emissivity ratios as functions of temperature, density or as contours in the temperature/density plane. It is particularly useful for evaluating line ratios as potential density or temperature indicators. The organisation, data sets and linkages between the programs are shown in figure 2.0.

It should be mentioned that ADAS2 series has a second stream of advanced population modelling concerned with the prediction of effective recombination and ionisation coefficients in finite density thermal plasma. Details are given in the main ADAS User Manual. The final stage of this second stream is production of the most refined *photon emissivity* (PEC), and *generalised collisional-radiative* (GCR) data by the program ADAS208. This is an advanced version of ADAS205. A description of the use of ADAS208 is given in the last section of the present manual.

Figure 2.0


Specific ion file
ADF04
ADAS205
Process metastable and excited populations
MET iso-elec. master file
ADF10
Contour passing file
ADAS207
Process line emissivities

ADAS205: Specific z excitation - process metastable and excited state populations

The program calculates excited state and metastable state populations of a selected ion in a plasma of specified temperatures and densities by drawing on fundamental energy level and rate coefficient data from a specific ion file of type ADF04.

Background theory:

Consider ions X^{+z} of the element X. The adjacent ionisation stages are X^{+z+1} and X^{+z-1}. Let the levels of the ion X^{+z} be separated into the *metastable levels* X_ρ^{+z}, indexed by Greek indices, and *excited levels* X_i^{+z}, indexed by Roman indices. The collective name metastable states as used here includes the ground state. The driving mechanisms considered for populating the excited levels X_i^{+z} are excitation from the metastable levels X_ρ^{+z} and recombination from the ground level of the adjacent ion X_1^{+z+1}. The dominant population densities of the ions in the plasma are those of the levels X_ρ^{+z} and X_1^{+z+1}, denoted by N_ρ and N_1^+ respectively. They, or at least their ratios are assumed known from a dynamical ionisation balance. The other dominant population densities in the plasma are the electron density N_e, the proton density N_p and the neutral hydrogen density N_H. The excited populations, denoted by N_i, are assumed to be in a *quasistatic equilibrium* with respect to the dominant populations. The program evaluates the dependence of the excited populations on the dominant populations with this assumption.

Let *M* denote the number of metastable levels and *O* denote the number of excited levels, hereafter called *ordinary* levels. The statistical balance equations take the form

$$\sum_{j=1}^{O} C_{ij} N_j = -\sum_{\sigma=1}^{M} C_{i\sigma} N_\sigma + N_e N_1^+ r_i + N_e N_H q_i^{(CX)} \quad i = 1,2,.. \qquad 2.5.1$$

where the dominant populations (excluding the electron density) have been taken to the right hand side. The C_{ij} and $C_{i\sigma}$ are elements of the collisional-radiative matrix, r_i is the free electron recombination coefficient directly to the level *i* and $q_i^{(CX)}$ is the charge exchange recombination coefficient from neutral hydrogen to the level *i*. The element C_{ij} of the collisional-radiative matrix is composed as

$$C_{ij} = -A_{j\to i} - N_e q_{j\to i}^{(e)} - N_p q_{j\to i}^{(p)} \qquad i \neq j \qquad 2.5.2$$

where $A_{j\to i}$, $q_{j\to i}^{(e)}$ and $q_{j\to i}^{(p)}$ are the rate coefficients for spontaneous transition, electron induced collisional transition and proton induced collisional transition respectively.

$$C_{ii} = \sum_{j<i} A_{i\to j} + N_e \sum_{j\neq i} q_{i\to j}^{(e)} + N_p \sum_{j\neq i} q_{i\to j}^{(p)} + N_e q_i^{(I)} \qquad 2.5.3$$

is the total loss rate from level *i*, with $q_i^{(I)}$ the electron impact ionisation rate coefficient.

The solution for the ordinary populations is

$$\begin{aligned} N_j &= -\sum_{i=1}^{O} C_{ji}^{-1} \sum_{\sigma=1}^{M} C_{i\sigma} N_\sigma + \sum_{i=1}^{O} C_{ji}^{-1} r_i N_e N_1^+ \\ &\quad + \sum_{i=1}^{O} C_{ji}^{-1} q_i^{(CX)} N_H N_1^+ \qquad 2.5.4 \\ &\equiv \sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} N_e N_\sigma + F_j^{(rec)} N_e N_1^+ + F_j^{(CX)} N_H N_1^+ \end{aligned}$$

where the $F_{j\sigma}^{(exc)}$, $F_j^{(rec)}$ and $F_j^{(CX)}$ are the effective contributions to the excited populations from excitation from the metastables, from free electron capture and from charge exchange recombination from neutral hydrogen respectively. All these coefficients depend on density as well as temperature. The actual population density of an ordinary level may be obtained from them when the dominant population densities are known.

The full statistical equilibrium of all the level populations of the ion X^{+z}, that is of metastables as well as ordinary levels relative to metastables, may also be obtained from the equations

$$\sum_{\sigma=1}^{M} C_{\rho\sigma} N_\sigma = -\sum_{j=1}^{O} C_{\rho j} N_j + N_e N_1^+ r_\rho + N_e N_H q_\rho^{(CX)} \qquad 2.5.5$$

Substitution of the quasi-equilibrium solution for the ordinary levels, eqn. 3.5.4, gives

$$\begin{aligned}\sum_{\sigma=1}^{M} (C_{\rho\sigma} - \sum_{j=1}^{O} C_{\rho j} \sum_{i=1}^{O} C_{ji}^{-1} C_{i\sigma}) N_\sigma &= N_e N_1^+ (r_\rho + \sum_{j=1}^{O} C_{\rho j} \sum_{i=1}^{O} C_{ji}^{-1} r_i) \\ &+ N_H N_1^+ (q_\rho^{(CX)} + \sum_{j=1}^{O} C_{\rho j} \sum_{i=1}^{O} C_{ji}^{-1} q_i^{(CX)})\end{aligned} \qquad 2.5.6$$

Solution of these equations gives an expression for the metastable populations N_σ of the form

$$N_\sigma \equiv F_\sigma^{(exc)} N_1 + F_\sigma^{(rec)} N_e N_1^+ + F_\sigma^{(CX)} N_H N_1^+ \qquad 2.5.7$$

The effective contributions to the metastable population densities (excluding the ground level) are expressed relative to the ground population density. Note also that a full equilibrium with respect to the adjacent X^{+z+1} ion population density is not established. The ratio N_1 / N_1^+ may be specified arbitrarily in establishing actual population densities. The metastable to ground fractions in equilibrium if only excitation is included are the $F_\sigma^{(exc)}$. Substitution of eqn. 3.5.7 in eqn. 3.5.4 gives the full statistical equilibrium population densities for the ordinary levels in terms of the ground population density and adjacent ion population density.

$$\begin{aligned}N_j = &\sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} F_\sigma^{(exc)} N_e N_1 + (F_j^{(rec)} + \sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} F_\sigma^{(rec)}) N_e N_1^+ \\ &+ (F_j^{(CX)} + \sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} F_\sigma^{(CX)}) N_H N_1^+\end{aligned} \qquad 2.5.8$$

With densities N_e, N_p and the ratios N_H / N_e and N_1 / N_1^+ specified, the full equilibrium population densites relative to the ground level population density may be computed.

Source data :

The program operates on collections of fundamental rate coefficient data called specific ion files. The allowed content, organisation and formatting of these files is specified in ADAS data format ADF04 (appendix C). The scope of operation of ADAS205 is determined by the content of the specific ion file processed. The miminum content is the ion identification, ion, effective ion and nuclear charges, ionisation potential, an indexed energy level and level assignment list, a set of temperatures and a set of level to level spontaneous transition probabilities and electron impact Maxwell averaged rate parameters at the specified temperatures. Data for upper to lower level only is required. Electron impact rate coefficients for both excitation and dexcitation are evaluated by interpolation at user selected values from the tabulated rate parameters in the specific ion file. Transition rate data is not required for all possible upper/lower level pairs, but the code checks that there are no 'untied' levels, that is without populating or depopulating processes. Strict energy ordering is not required in the specific ion file, the code reorders as necessary. Proton induced rates, free electron recombination rates and charge exchange recombination rates may only be activated

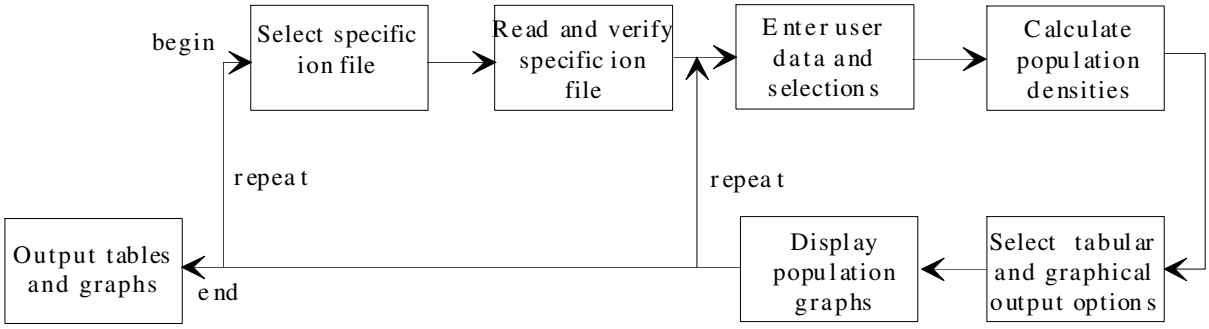
in the code if such data are present in the specific ion file. Transition data of these types are identified by a single letter code in the transition data line in the specific ion file. The code sorts the transition lines in the specific ion file into the allowed categories. Specific ion files can include additional data for the more complex excited state population calculations of code ADAS208. Such additional data, if present, are ignored by ADAS205. Centrally supported, specific ion data collections are archived in partitioned data sets. The status of these is described in the appendices.

Note that ADAS205 can only make use of free electron recombination data from the ground level of the adjacent stage. Data from metastable levels of both higher and lower adjacent stages can be present in specific ion files but the code ADAS208 must be used to access them. ADAS205 allows inclusion of a simple ionisation rate (ECIP approximation) from excited levels, however a self consistent three-body recombination coefficient in detailed balance is not calculated or included. Nor is there any correction for higher excited levels not explicitly included in the specific ion file. These more complete aspects are handled by the advanced excited population code ADAS208. Extra information, which must be present in specific ion files ADF04 to allow these extensions are ignored by ADAS205.

Program steps:

These are summarised in fig. 2.5.

Figure 2.5



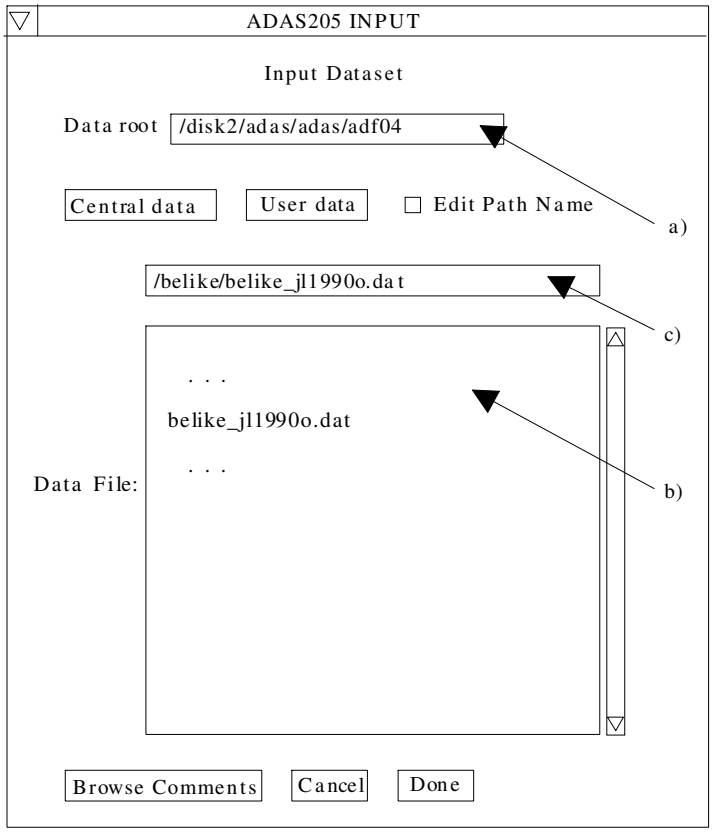
Interactive parameter comments:

The **file selection window** has the appearance shown below

1. Data root a) shows the full pathway to the appropriate data subdirectories. Click the *Central Data* button to insert the default central ADAS pathway to the correct data type. The appropriate ADAS data format for input to this program is ADF04 ('specific ion files'). Click the *User Data* button to insert the pathway to your own data. Note that your data must be held in a similar file structure to central ADAS, but with your identifier replacing the first *adas,* to use this facility.
2. The Data root can be edited directly. Click the *Edit Path Name* button first to permit editing.
3. Available sub-directories are shown in the large file display window b). Scroll bars appear if the number of entries exceed the file display window size.
4. Click on a name to select it. The selected name appears in the smaller selection window c) above the file display window. Then its sub-directories in turn are displayed in the file display window. Ultimately the individual datafiles are presented for selection. Datafiles all have the termination *.dat*.
5. Once a data file is selected, the set of buttons at the bottom of the main window become active.

6. Clicking on the *Browse Comments* button displays any information stored with the selected datafile. It is important to use this facility to find out what is broadly available in the dataset. The possibility of browsing the comments appears in the subsequent main window also.

7. Clicking the *Done* button moves you forward to the next window. Clicking the *Cancel* button takes you back to the previous window



The **processing options window** has the appearance shown below

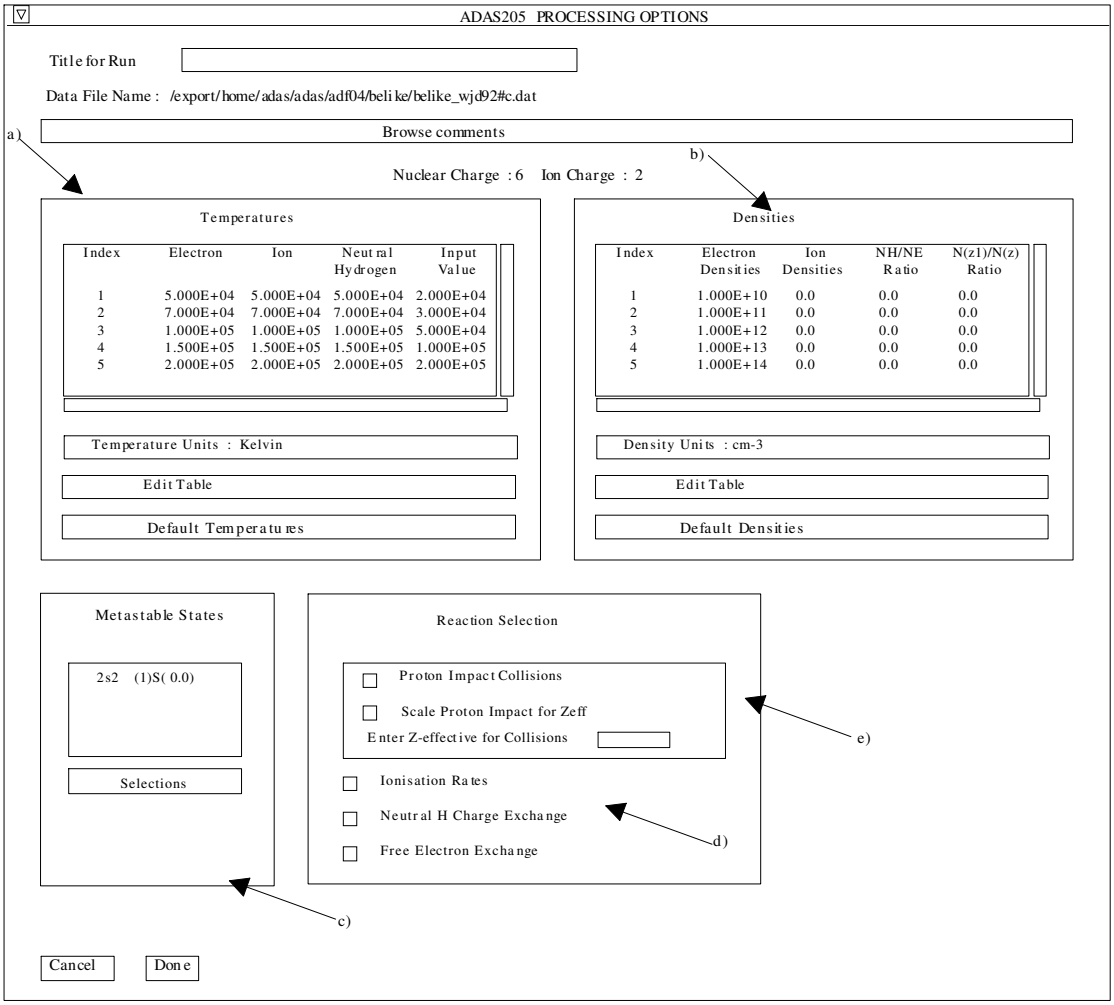
1. There are three 'pop-up' windows for setting temperatures, densities and for designating metastable levels. For the temperature window a), click on the *Edit Table* button to open up the table editor. The editing operations are as described in the introductory chapter. Note that there is a set of input electron temperatures from the selected file. These indicate the safe range of temperatures if extrapolation is to be avoided. Note that altering units (which must be done with the table edit window activated) converts the input values and interprets the output values in the selected units. It **does not convert** output values already typed in. *Default Temperatures* are inserted in the selected units on clicking the appropriate button. Note that the ion and neutral hydrogen temperatures are **only used if** such collisional data is present in the input ADF04 file.

2. The densities table is handled in like manner. Note that in this case there are no input density values. Thus unit changing only affects the interpretation of the output values created by the user. The N_H/N_e and $N(z_1)/N(z)$ **are only used if** neutral hydrogen charge exchange data and free electron recombination data are present in input ADF04 file. These ratio vectors are specified at each electron density so the ratio vectors and electron density vector are of the same length. That is a model is specified. By contrast the output electron temperatures are independent so that final calculated populations are obtained at points of a two-dimensional electron temperature/electron density grid.

3. The Metastable State *Selections* button c) pops up a window indexing all the energy levels. Activate the buttons opposite levels which you wish treated as metastables. See the main ADAS USER Manual for a detailed explanation of the handling of metastables in the collisional-radiative picture.

4. Various processes, supplementary to the primary electron excitation collisions and bound-bound radiative transitions, are activated as desired by clicking on the appropriate buttons d). Note again these only have an effect if such data is present in the ADF04 file except for *Ionisation rates*. This activates ionisation out of excited states and is obtained by an internal calculation of these rates in the ECIP approximation. **Warning**-ionisation should **not** be switched on if you have included autoionising levels in your ADF04 dataset but have omitted the details of alternative thresholds etc present in advanced ADF04 files.

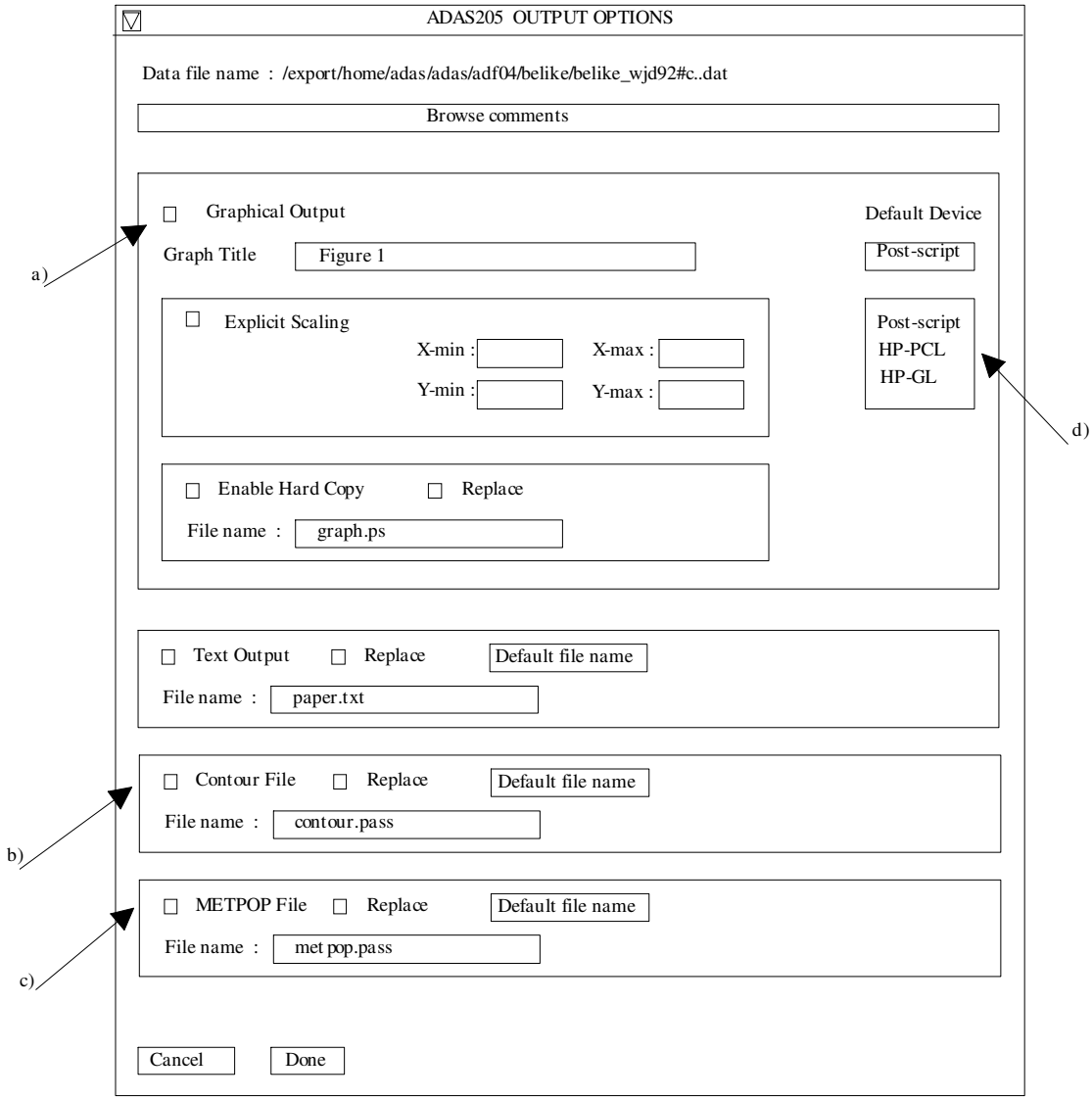
5. Proton collisions may be present in the ADF04 file. If so, these rate coefficients may be scaled to represent a mixture of other charged projectiles with a mean Z-effective e).



The **output options window** has the appearance shown below

1. As in the previous window, the full pathway to the file being analysed is shown for information. Also the *Browse comments* button is available.

2. Graphical display is activated by the *Graphical Output* button a). This will cause a graph to be displayed following completion of this window. When graphical display is active, an arbitrary title may be entered which appears on the top line of the displayed graph. By default, graph scaling is adjusted to match the required outputs. Press the *Explicit Scaling* button b) to allow explicit minima and maxima for the graph axes to be inserted. Activating this button makes the minimum and maximum boxes editable.



3. Hard copy is activated by the *Enable Hard Copy* button c). The File name box then becomes editable. If the output graphic file already exits and the *Replace* button has not been activated, a 'pop-up' window issues a warning.

4. A choice of output graph plotting devices is given in the Device list window d). Clicking on the required device selects it. It appears in the selection window above the Device list window.

5. The *Text Output* button activates writing to a text output file. The file name may be entered in the editable File name box when *Text Output* is on. The default file name 'paper.txt' may be set by pressing the button *Default file name*. A 'pop-up' window issues a warning if the file already exists and the *Replace* button has not been activated.

6. The *Contour File* button b) should be activated to write the passing file for use by the diagnostic line ratio program ADAS207. There is no arrangement for permanent storage of such files which reside only in a user's file space and are generally prepared for temporary immediate use. Usually in ADAS we store such temporary 'passed files' in a *pass* sub-library. You should create this at the first level within the adas database as

   /...../<uid>/adas/pass

   By default ADAS205 sends the contour file to

   /...../<uid>/adas/pass/contour.pass

7. The *METPOP File* button b) should be activated to write a passing file of metastable population fractions. It is of data format ADF11 and can be used in

ionisation/recombination applications of ADAS4 series programs. It goes by default into

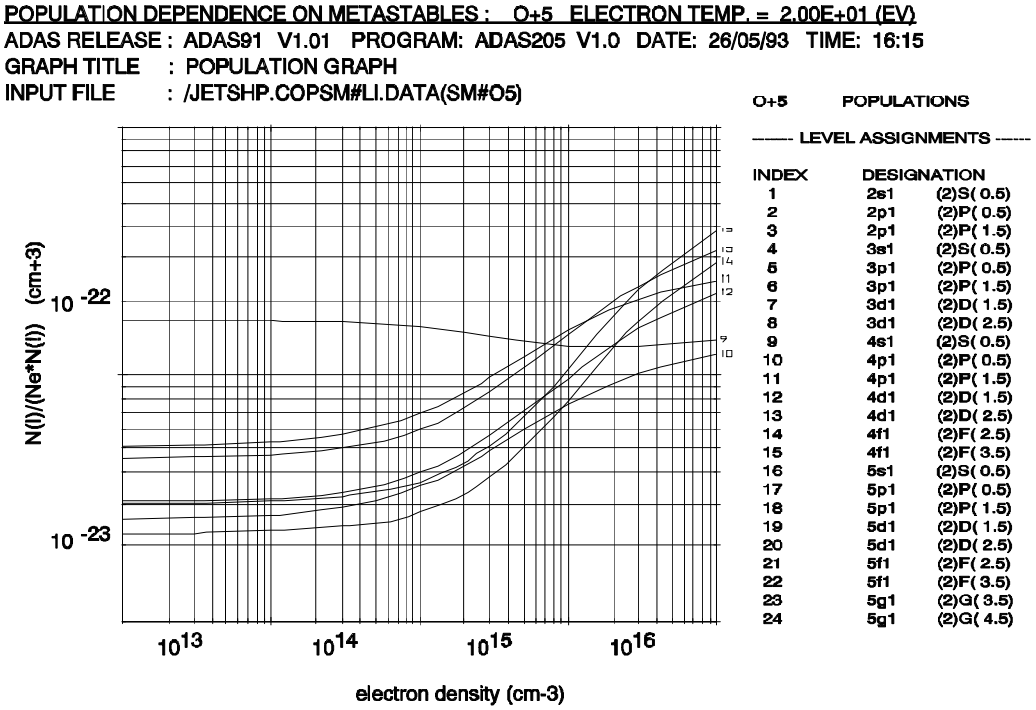
/...../<uid>/adas/pass/metpop.pass

8. The graph is displayed in a following **Graphical Output** when the *Done* button is pressed.
9. The graph has at its foot a *Done* button, and possibly *Next* and *Previous* buttons if there is a sequence of graphs to be displayed. A *Print* button is also present if the *Enable Hard Copy* button on the previous window was activated.
10. Press the *Next* button to show the next graph in a sequence and the *Previous* button to show the previous graph.
11. Press the *Print* button to make a hard copy of the currently displayed picture.
12. Pressing the *Done* button restores the previous Output Options window.

Illustration:

The output from the program is shown for the lithium-like ion O^{+5}. The specific ion file is assembled from the data of Sampson and co-workers.

Figure 2.5a



The tabular output is shown in table 2.5.

Table 2.5

```
ADAS RELEASE: ADAS91 V1.01  PROGRAM: ADAS205 V1.0   DATE: 26/05/93  TIME: 16:14
************************** TABULAR OUTPUT FROM METASTABLE POPULATION  PROGRAM: ADAS205 - DATE: 26/05/93 **************************

INPUT COPASE FILE NAME: /JETSHP.COPSM#LI.DATA(SM#O5)
INPUT PROTON FILE NAME: NOT YET REQUIRED

 ION      NUCLEAR        RECOMBINING      ------- IONIZATION POTENTIAL -------
        CHARGE (Z0)    ION CHARGE (Z1)    (wave number <cm-1>)     (rydbergs)
-------------------------------------------------------------------------------
O + 5         8                6                1114000.          10.151537
```

---------- ENERGY LEVELS ----------

INDEX	CONFIGURATION	(2S+1)L(J)	----- ENERGY RELATIVE TO LEVEL 1 ------ (wave number <cm-1>)	(rydbergs)	ENERGY RELATIVE TO IONISATION POTENTIAL (wave number <cm-1>)	(rydbergs)
1	1	(2)0(0.5)	0.	0.0000000	1114000.	10.1515370
2	1	(2)1(0.5)	96377.	0.8782492	1017623.	9.2732678
3	1	(2)1(1.5)	96909.	0.8831017	1017091.	9.2684199
4	1	(2)0(0.5)	640009.	5.8322054	473991.	4.3193260
5	1	(2)1(0.5)	666185.	6.0707356	447815.	4.0807926
6	1	(2)1(1.5)	666365.	6.0723758	447635.	4.0791523
7	1	(2)2(1.5)	674995.	6.1510156	439005.	4.0005099
8	1	(2)2(2.5)	675042.	6.1514457	438958.	4.0000816
9	1	(2)0(0.5)	852529.	7.7688343	261471.	2.3827003
10	1	(2)1(0.5)	863191.	7.8659938	250809.	2.2855409
11	1	(2)1(1.5)	863267.	7.8666846	250733.	2.2848484
12	1	(2)2(1.5)	867030.	7.9009738	246970.	2.2505574
13	1	(2)2(2.5)	867050.	7.9011542	246950.	2.2503751
14	1	(2)3(2.5)	868022.	7.9100145	245978.	2.2415176
15	1	(2)3(3.5)	868032.	7.9101038	245968.	2.2414265
16	1	(2)0(0.5)	948412.	8.6425836	165588.	1.5089496
17	1	(2)1(0.5)	953761.	8.6913238	160239.	1.4602060
18	1	(2)1(1.5)	953798.	8.6916637	160202.	1.4598688
19	1	(2)2(1.5)	955738.	8.7093432	158262.	1.4421902
20	1	(2)2(2.5)	955748.	8.7094334	158252.	1.4420991
21	1	(2)3(2.5)	956201.	8.7135633	157799.	1.4379710
22	1	(2)3(3.5)	956205.	8.7136034	157795.	1.4379346
23	1	(2)4(3.5)	956672.	8.7178535	157328.	1.4336790
24	1	(2)4(4.5)	956674.	8.7178736	157326.	1.4336607

-- INPUT COPASE FILE TEMPERATURES: (TE=TP=TH) --

INDEX	(kelvin)	(eV)	(reduced)
1	1.80D+04	1.55D+00	5.00D+02
2	3.60D+04	3.10D+00	1.00D+03
3	7.20D+04	6.20D+00	2.00D+03
4	1.80D+05	1.55D+01	5.00D+03
5	3.60D+05	3.10D+01	1.00D+04
6	7.20D+05	6.20D+01	2.00D+04
7	1.80D+06	1.55D+02	5.00D+04
8	3.60D+06	3.10D+02	1.00D+05

INPUT COPASE FILE INFORMATION:

NUMBER OF ELECTRON IMPACT TRANSITIONS = 132
NUMBER OF PROTON IMPACT TRANSITIONS = 0
NUMBER OF CHARGE EXCHANGE RECOMBINATIONS = 0
NUMBER OF FREE ELECTRON RECOMBINATIONS = 0

METASTABLE INFORMATION:

NUMBER OF ORDINARY LEVELS = 23
NUMBER OF METASTABLES = 1

---------- METASTABLE DETAILS ----------

METASTABLE INDEX	ENERGY LEVEL INDEX	---- DESIGNATION -----	
1	1	1	(2)S(0.5)

OUTPUT PLASMA PARAMETERS:

NUMBER OF TEMPERATURES = 12
NUMBER OF DENSITIES/RATIOS = 9

INDEX	TEMPERATURES (UNITS: eV)			INDEX	DENSITIES (UNITS: cm-3)		RATIOS	
	ELECTRON <TE>	PROTON <TP>	NEUTRAL HYDROGEN <TH>		ELECTRON <NE>	PROTON <NP>	NH/NE	N(Z+1)/N(Z)
1	1.550D+00 *	1.000D+00 #	5.000D+01 #	1	1.000D+13	0.000D+00 #	0.000D+00 #	0.000D+00 #
2	2.000D+00	1.500D+00 #	5.000D+01 #	2	3.000D+13	0.000D+00 #	0.000D+00 #	0.000D+00 #
3	3.000D+00	2.000D+00 #	5.000D+01 #	3	1.000D+14	0.000D+00 #	0.000D+00 #	0.000D+00 #
4	5.000D+00	5.000D+00 #	5.000D+01 #	4	3.000D+14	0.000D+00 #	0.000D+00 #	0.000D+00 #
5	7.000D+00	7.000D+00 #	5.000D+01 #	5	1.000D+15	0.000D+00 #	0.000D+00 #	0.000D+00 #
6	1.000D+01	1.000D+01 #	5.000D+01 #	6	3.000D+15	0.000D+00 #	0.000D+00 #	0.000D+00 #
7	1.500D+01	1.500D+01 #	5.000D+01 #	7	1.000D+16	0.000D+00 #	0.000D+00 #	0.000D+00 #
8	2.000D+01	2.000D+01 #	5.000D+01 #	8	3.000D+16	0.000D+00 #	0.000D+00 #	0.000D+00 #
9	3.000D+01	3.000D+01 #	5.000D+01 #	9	1.000D+17	0.000D+00 #	0.000D+00 #	0.000D+00 #
10	5.000D+01	5.000D+01 #	5.000D+01 #					
11	7.000D+01	7.000D+01 #	5.000D+01 #					
12	1.000D+02	1.000D+02 #	5.000D+01 #					

KEY: * = WARNING - TEMPERATURE OUT OF RANGE
- EXTRAPOLATION REQUIRED
= PARAMETER NOT USED IN CALCULATIONS

NOTE: NH/NE = NEUTRAL HYDROGEN DENSITY / ELECTRON DENSITY
N(Z+1)/N(Z) = STAGE ABUNDANCIES

PROTON IMPACT COLLISIONS - NOT INCLUDED
IONIZATION RATES - NOT INCLUDED
NEUTRAL HYDROGEN CHARGE EXCHANGE - NOT INCLUDED
FREE ELECTRON RECOMBINATION - NOT INCLUDED

TABLE KEY:

NE = ELECTRON DENSITY
TE = ELECTRON TEMPERATURE
I = ENERGY LEVEL INDEX
IMET = METASTABLE INDEX
IORD = ORDINARY LEVEL INDEX

NUMBER OF PROTON IMPACT COLLISIONS INCLUDED = 0
NUMBER OF FREE ELECTRON RECOMBINATIONS INCLUDED = 0
NUMBER OF CHARGE EXCHANGE RECOMBINATIONS INCLUDED = 0

NE(CM-3)= 1.0000E+13 3.0000E+13 1.0000E+14 3.0000E+14 1.0000E+15 3.0000E+15 1.0000E+16 3.0000E+16 1.0000E+17

EQUILIBRIUM METASTABLE POPULATION DEPENDENCE ON DENSITY AT TE = 1.55E+00 EV = 1.80E+04 KELVIN

IMET	I								
1	1	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00	1.0000E+00

POPULATION DEPENDENCE ON DENSITY AND METASTABLE 1

IORD	I								
1	2	6.1997E-07	1.8547E-06	6.1218E-06	1.7868E-05	5.4423E-05	1.3120E-04	2.5978E-04	3.6117E-04	4.1840E-04
2	3	1.1657E-06	3.4877E-06	1.1518E-05	3.3663E-05	1.0290E-04	2.4931E-04	4.9604E-04	6.9123E-04	8.0155E-04
3	4	2.2181E-28	6.6581E-28	2.2239E-27	6.7092E-27	2.2751E-26	7.0657E-26	2.4776E-25	7.5647E-25	2.3692E-24
4	5	2.1908E-30	6.8041E-30	2.5350E-29	9.8078E-29	5.5478E-28	3.0842E-27	1.7868E-26	6.8822E-26	2.4090E-25
5	6	4.2994E-30	1.3351E-29	4.9718E-29	1.9224E-28	1.0877E-27	6.0591E-27	3.5185E-26	1.3561E-25	4.7464E-25
6	7	1.6881E-30	5.1688E-30	1.8436E-29	6.5287E-29	3.2171E-28	1.6305E-27	9.3265E-27	3.8762E-26	1.6074E-25
7	8	2.5154E-30	7.7019E-30	2.7468E-29	9.7270E-29	4.7969E-28	2.4368E-27	1.3977E-26	5.8153E-26	2.4101E-25
8	9	2.7627E-36	8.2794E-36	2.7502E-35	8.1788E-35	2.6721E-34	7.9080E-34	2.6952E-33	8.2808E-33	3.0378E-32
9	10	1.5903E-37	4.9230E-37	1.8146E-36	6.8416E-36	3.6245E-35	1.7969E-34	8.8209E-34	3.1187E-33	1.2338E-32
10	11	3.1532E-37	9.7597E-37	3.5959E-36	1.3548E-35	7.1760E-35	3.5619E-34	1.7516E-33	6.1987E-33	2.4532E-32
11	12	1.7194E-37	5.2623E-37	1.8741E-36	6.6164E-36	3.2437E-35	1.6319E-34	9.1844E-34	3.8170E-33	1.7101E-32
12	13	2.5724E-37	7.8726E-37	2.8034E-36	9.8955E-36	4.8525E-35	2.4438E-34	1.3768E-33	5.7230E-33	2.5633E-32
13	14	1.2857E-37	3.9022E-37	1.3539E-36	4.5260E-36	2.0755E-35	1.1212E-34	8.3624E-34	4.4475E-33	2.2831E-32
14	15	1.7161E-37	5.2083E-37	1.8066E-36	6.0366E-36	2.7663E-35	1.4949E-34	1.1163E-33	5.9366E-33	3.0453E-32
15	16	7.9296E-40	2.3506E-39	7.5400E-39	2.0748E-38	5.9193E-38	1.6488E-37	6.2496E-37	2.2715E-36	9.8429E-36
16	17	8.5843E-41	2.6928E-40	1.0219E-39	3.8941E-39	1.8593E-38	7.8693E-38	3.7376E-37	1.4441E-36	6.3723E-36
17	18	1.7041E-40	5.3463E-40	2.0293E-39	7.7355E-39	3.6941E-38	1.5645E-37	7.4414E-37	2.8780E-36	1.2705E-35
18	19	1.0840E-40	3.3198E-40	1.1859E-39	4.2275E-39	2.0986E-38	1.0439E-37	5.7800E-37	2.3842E-36	1.0795E-35
19	20	1.6302E-40	4.9906E-40	1.7809E-39	6.3346E-39	3.1362E-38	1.5594E-37	8.6473E-37	3.5711E-36	1.6178E-35
20	21	1.3049E-40	3.9656E-40	1.3835E-39	4.7302E-39	2.3316E-38	1.2735E-37	7.8213E-37	3.3757E-36	1.5560E-35
21	22	1.7397E-40	5.2867E-40	1.8443E-39	6.3043E-39	3.1053E-38	1.6951E-37	1.0415E-36	4.4978E-36	2.0739E-35
22	23	1.9958E-41	6.0692E-41	2.1192E-40	7.2008E-40	3.4743E-39	2.2297E-38	2.7823E-37	2.5909E-36	1.9725E-35
23	24	2.4928E-41	7.5798E-41	2.6458E-40	8.9831E-40	4.3284E-39	2.7789E-38	3.4783E-37	3.2427E-36	2.4679E-35

********** EQUILIBRIUM POPULATIONS **********

LEVEL = 1 - EQUILIBRIUM POPULATION

```
-----------------------------------
NE (CM-3)      1.00D+13  3.00D+13  1.00D+14  3.00D+14  1.00D+15  3.00D+15  1.00D+16  3.00D+16  1.00D+17
TE (EV)    ------------------------------------------------------------------------------------------------
  1.55D+00 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  2.00D+00 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  3.00D+00 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  5.00D+00 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  7.00D+00 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  1.00D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  1.50D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  2.00D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  3.00D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  5.00D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  7.00D+01 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00
  1.00D+02 ³   1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00  1.00D+00

LEVEL =  2 - EQUILIBRIUM POPULATION
-----------------------------------
NE (CM-3)      1.00D+13  3.00D+13  1.00D+14  3.00D+14  1.00D+15  3.00D+15  1.00D+16  3.00D+16  1.00D+17
TE (EV)    ------------------------------------------------------------------------------------------------
  1.55D+00 ³   6.20D-07  1.85D-06  6.12D-06  1.79D-05  5.44D-05  1.31D-04  2.60D-04  3.61D-04  4.18D-04
  2.00D+00 ³   3.10D-06  9.26D-06  3.06D-05  8.96D-05  2.76D-04  6.79D-04  1.39D-03  1.99D-03  2.35D-03
  3.00D+00 ³   1.86D-05  5.57D-05  1.84D-04  5.42D-04  1.69D-03  4.29D-03  9.29D-03  1.40D-02  1.69D-02
  5.00D+00 ³   7.19D-05  2.15D-04  7.14D-04  2.11D-03  6.66D-03  1.74D-02  4.02D-02  6.42D-02  8.12D-02
  7.00D+00 ³   1.22D-04  3.65D-04  1.21D-03  3.59D-03  1.14D-02  3.04D-02  7.28D-02  1.21D-01  1.58D-01
  1.00D+01 ³   1.73D-04  5.18D-04  1.72D-03  5.10D-03  1.64D-02  4.43D-02  1.10D-01  1.91D-01  2.57D-01
  1.50D+01 ³   2.16D-04  6.46D-04  2.15D-03  6.38D-03  2.06D-02  5.65D-02  1.46D-01  2.65D-01  3.73D-01
  2.00D+01 ³   2.33D-04  6.99D-04  2.32D-03  6.91D-03  2.24D-02  6.20D-02  1.63D-01  3.07D-01  4.44D-01
  3.00D+01 ³   2.43D-04  7.27D-04  2.42D-03  7.20D-03  2.34D-02  6.56D-02  1.78D-01  3.48D-01  5.24D-01
  5.00D+01 ³   2.38D-04  7.15D-04  2.38D-03  7.09D-03  2.31D-02  6.55D-02  1.82D-01  3.72D-01  5.87D-01
  7.00D+01 ³   2.29D-04  6.87D-04  2.29D-03  6.82D-03  2.23D-02  6.35D-02  1.79D-01  3.75D-01  6.10D-01
  1.00D+02 ³   2.16D-04  6.48D-04  2.16D-03  6.44D-03  2.11D-02  6.03D-02  1.73D-01  3.70D-01  6.21D-01
```

Notes:

ADAS207: Metastable and excited population - process line emissivities

The program evaluates and displays line emissivities and their ratios for an ion. It uses a passing file of excited population data from the code ADAS205.

Background theory:

Consider emissivities of spectrum lines arising from a single ionisation stage. Ratios of such lines are frequently used as temperature, density or transient state diagnostics in plasmas. The primary advantage of seeking such ratios of lines from a single ionisation stage is that they are independent of the stage to stage ionisation balance (often uncertain). In general it is matter of some investigation to identify the most diagnostically useful ratios. The present program is designed to aid such investigation.

A necessary preliminary to evaluating line emissivities is a calculation of populations of excited states of the ion as a function of plasma parameters. This is provided by ADAS205 which must be executed before ADAS207. In practice, problems of line blending and the spectral resolution of spectrometers mean that it is useful to work with line groups rather than just individual lines. A line group is a set of lines conveniently or necessarily measured together. ADAS207 deals with two line groups which are built up by the user in the data entry section of the code.

From equation 2.5.4, the solution for the ordinary populations is

$$N_j = \sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} N_e N_\sigma + F_j^{(rec)} N_e N_1^+ + F_j^{(CX)} N_H N_1^+ \qquad 2.7.1$$

where the $F_{j\sigma}^{(exc)}$, $F_j^{(rec)}$ and $F_j^{(CX)}$ are the effective contributions to the excited populations from excitation from the metastables, from free electron capture and from charge exchange recombination from neutral hydrogen respectively. All these coefficients depend on density as well as temperature. The actual population density of an ordinary level may be obtained from them when the dominant population densities are known.

Consider a set of individual lines, or line group, G with upper levels I_G and lower levels J_G. Let $A_{i\to j}$ be the spontaneous emission coefficient for the line $i \to j$. Then the composite emissivity for the line group is

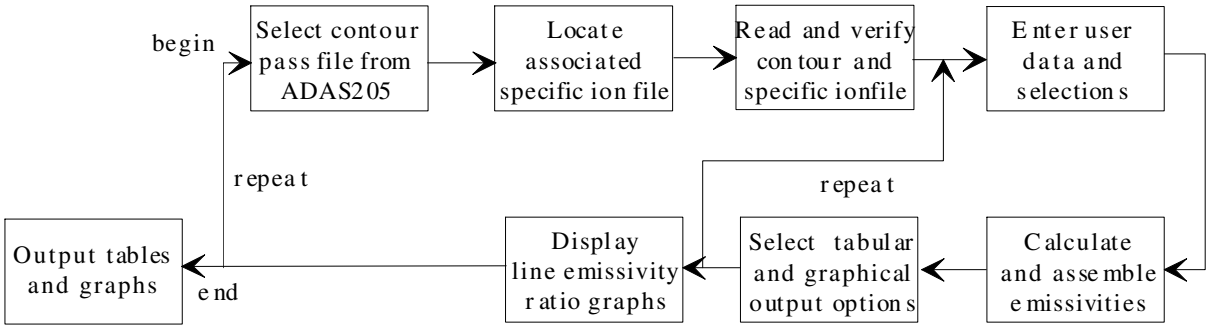
$$\begin{aligned}
\varepsilon_G &= \sum_{j\in J_G, i\in I_G} \varepsilon_{j\to i} = \sum_{j\in J_G, i\in I_G} A_{j\to i} N_j \\
&= \sum_{j\in J_G, i\in I_G} A_{j\to i} \left(\sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} N_e N_\sigma + F_j^{(rec)} N_e N_1^+ + F_j^{(CX)} N_H N_1^+\right) \\
&= N_e N_1 \sum_{j\in J_G, i\in I_G} A_{j\to i} \left(\sum_{\sigma=1}^{M} F_{j\sigma}^{(exc)} \frac{N_\sigma}{N_1} + F_j^{(rec)} \frac{N_1^+}{N_1} + F_j^{(CX)} \frac{N_H}{N_e}\frac{N_1^+}{N_1}\right)
\end{aligned} \qquad 2.7.2$$

expressed in terms of the ratios N_σ / N_1, N_1^+ / N_1 and N_H / N_1. The photon emissivity coefficient for the line group is $\varepsilon_G / N_e N_1$. The coefficient depends on electron density and temperature in general. Ratios of line group emissivities cancel the leading $N_e N_1$ dependence. The code prepares and operates primarily with a ratio $\varepsilon_{G_1} / \varepsilon_{G_2}$.

Program steps:

These are summarised in the figure 2.7.

Figure 2.7



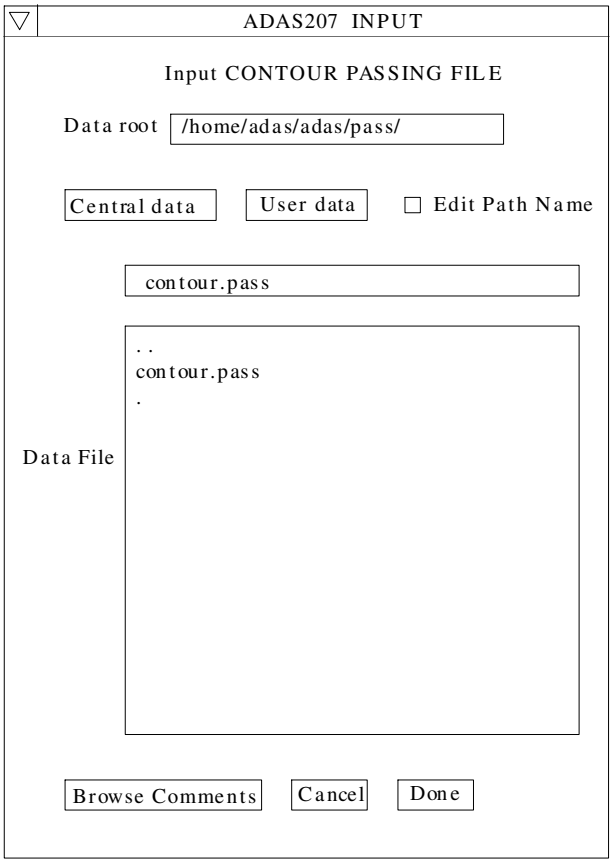
Interactive parameter comments:

The **file selection window** has the appearance shown below

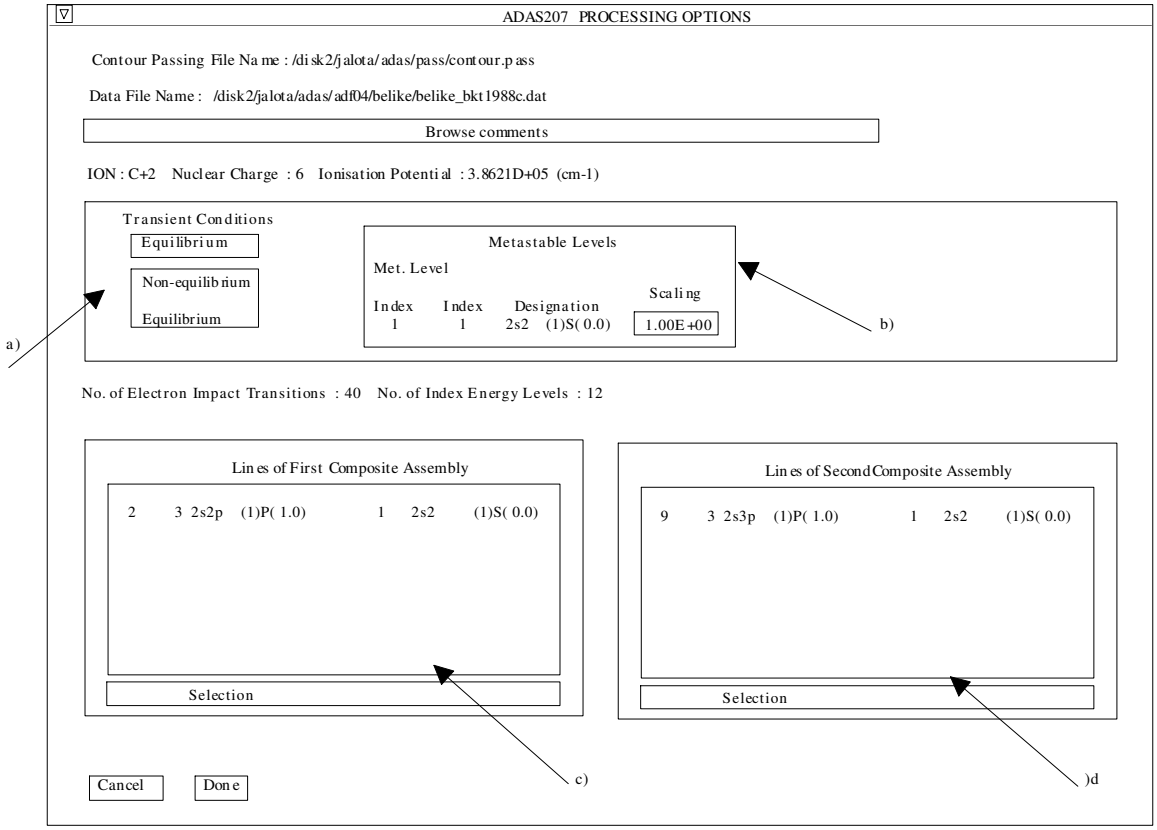
1. The program requires selection of the 'contour' data file prepared as output from ADAS205 (see description of ADAS205). There is no arrangement for central ADAS storage of such files which reside only in a user's file space and are generally prepared for immediate use. Usually in ADAS we store such temporary 'passed files' in a *pass* sub-library. You should create this at the first level within the adas database as

   /...../<uid>/adas/pass

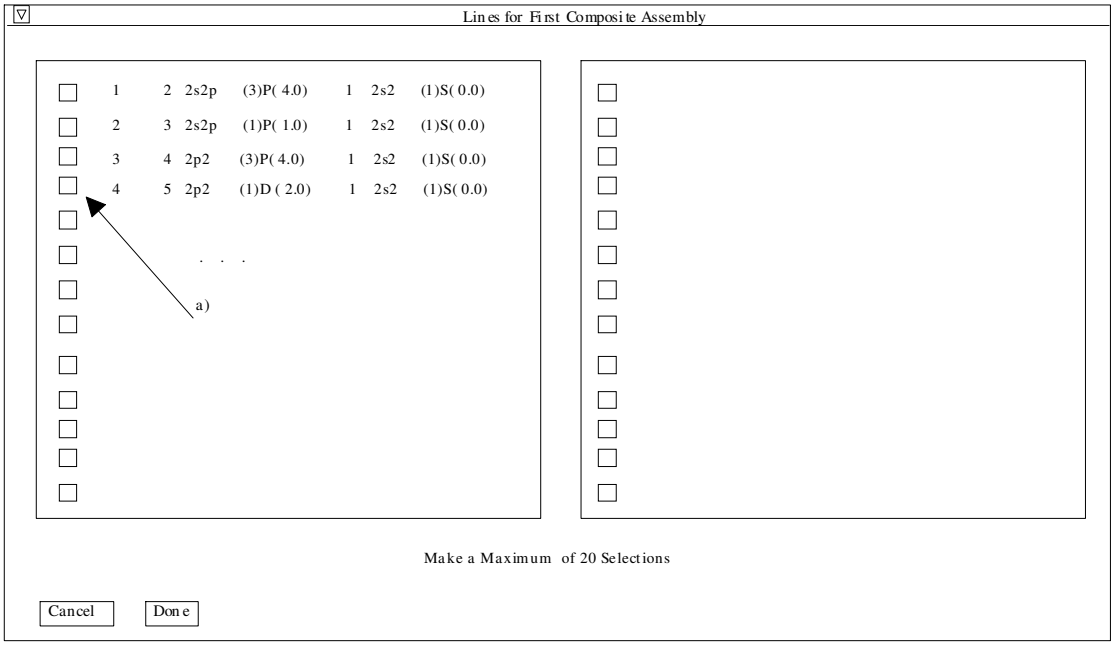
   to which the program looks by default.



The **processing options window** has the appearance shown below. It displays information from the *contour file* together with information from the ADF04 file used in the prior ADAS205 program run.



1. Select *Non-equilibrium* or *Equilibrium* conditions by clicking the appropriate case in the list a). The selection made is shown in the selection window above. Note that a non-equilibrium choice is only meaningful if there is more than one metastable. The metastables selected in the ADAS205 run are shown in the adjacent window b). This window becomes active when non-equilibrium conditions are selected. The values to be entered for each metastable is a multiplier on the equilibrium metastable population. Thus 1.00 for each metastable gives the equilibrium case.

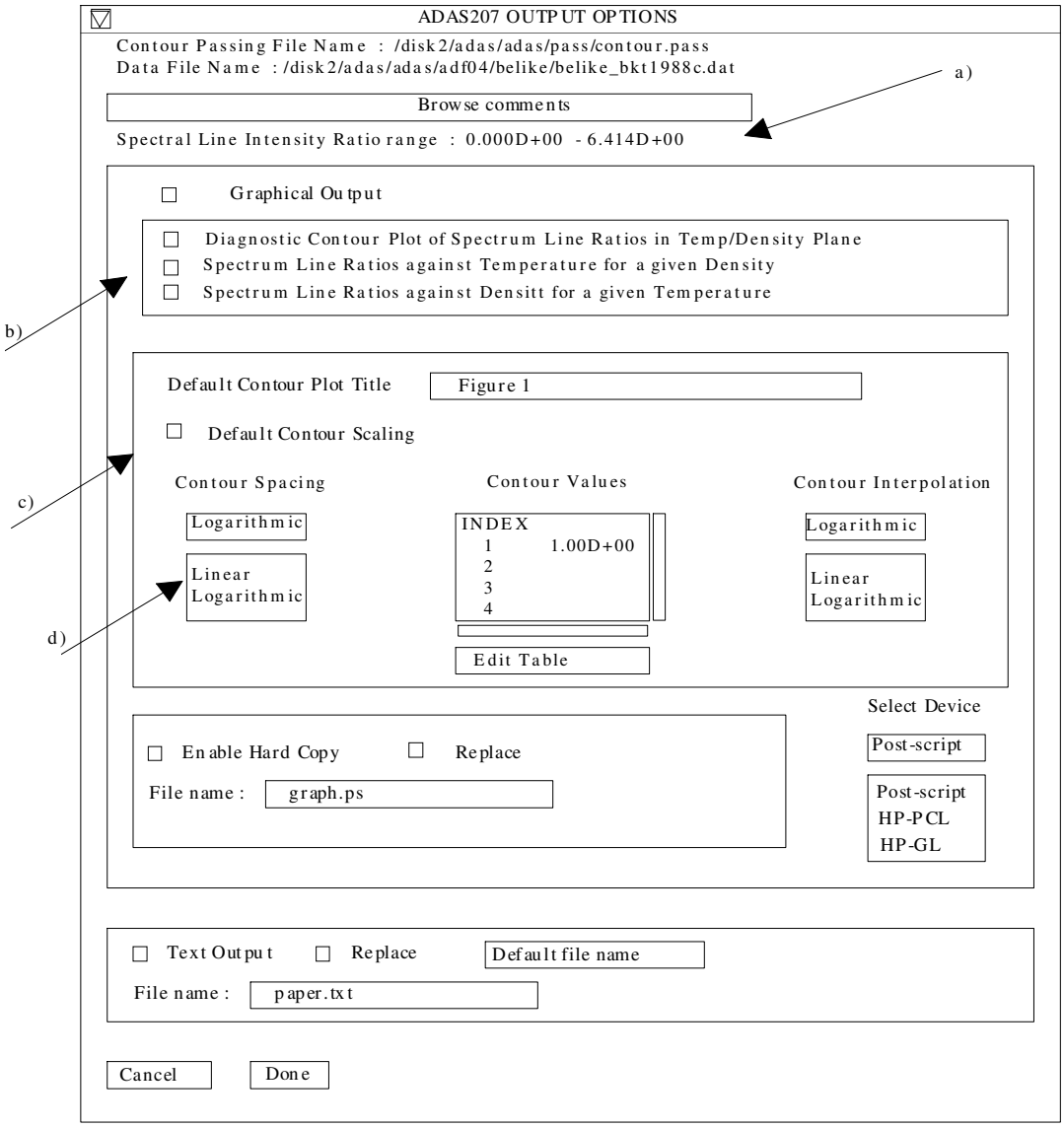


2. A ‘line ratio’ in the present context is a ratio of line groups. The current line groups are shown in the list windows. The columns of the each row show the transition index and then for the upper and lower levels of the transition, the level index, configuration designation and the outer quantum numbers. These data are taken from the associated ADF04 file.

3. Each line group is assembled by clicking on the appropriate *Selection* button c) or d). A new window is presented with all available transitions listed. This is shown above. Clicking on the button alongside a transition a) allows it to be selected or de-selected.

The **output options window** appearance is shown below.

1. The limits of the calculated line group ratio are shown on the output window a). It is important to check this range. Subsequent plots may be selected as logarithmic and it is easy to obtain vanishing line ratios by choice of abnormally low temperatures in the ADAS205 run. In these circumstances meaningless contour plots may be produced.



2. There are three distinct types of plot of the line ratio allowed b), namely contours, plots as a function of temperature and plots as a function of density. Click on the appropriate button. The further options selection window c) changes according to this choice.

3. For the contour plot case, logarithmic or linear choices of contour are permitted. Click on the required type in the lower list window d). The chosen type appears in the selection window above.

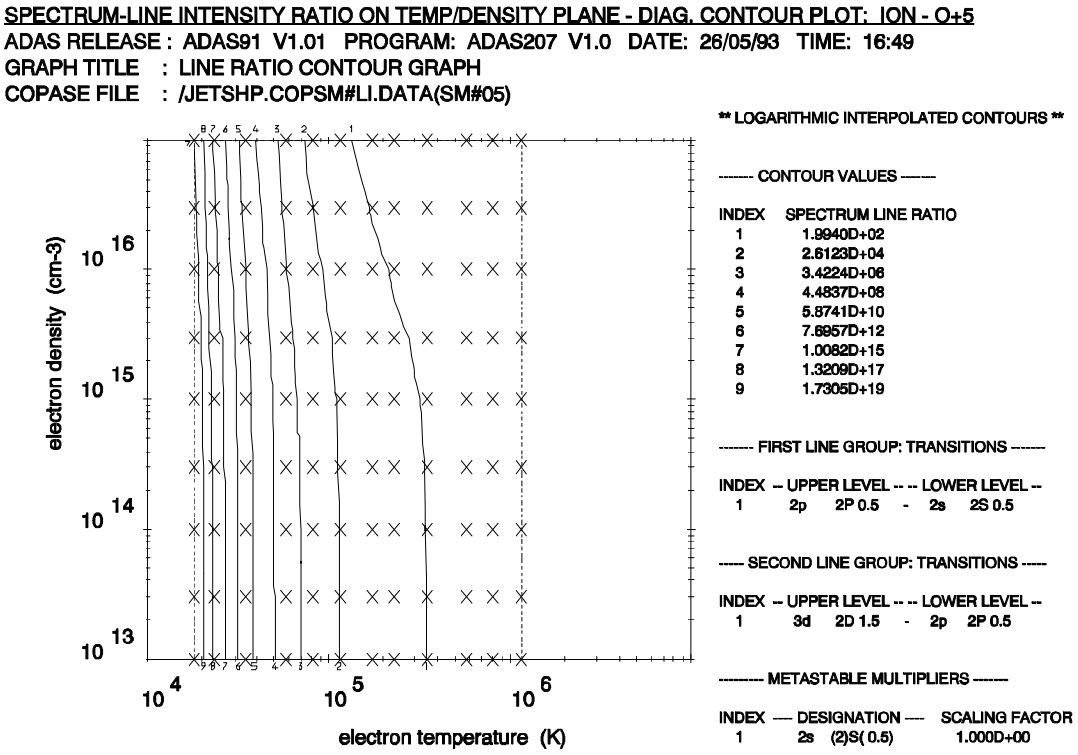
4. The displayed graph has the usual overall layout, but with supplementary information on the right side listing the line group assemblies and metastable fraction multipliers.

Illustration:

The output from the program is illustrated for the ion O^{+5}. Figure 2.7a shows a contour plot on the temperature/density plane of the emissivity ratio

$$\varepsilon_{2s_{1/2}-2p_{1/2}}(T_e, N_e) / \varepsilon_{2p_{1/2}-3d_{3/2}}(T_e, N_e).$$

Figure 2.7a



The tabular output is shown in table 2.7.

Table 2.7

ADAS RELEASE: ADAS91 V1.01 PROGRAM: ADAS207 V1.0 DATE: 26/05/93 TIME: 16:46

********** TABULAR OUTPUT FROM SPECTRUM LINE DIAGNOSTIC PROGRAM: ADAS207 - DATE: 26/05/93 **********

INPUT CONTOUR-PASSING FILE DSN: /JETSHP.CONTOR.PASS

ASSOCIATED COPASE FILE DSN: /JETSHP.COPSM#LI.DATA(SM#O5)

ION	NUCLEAR CHARGE (Z0)	RECOMBINING ION CHARGE (Z1)	IONIZATION POTENTIAL (wave number <cm-1>)	IONIZATION POTENTIAL (rydbergs)
O + 5	8	6	1114000.	10.151537

ENERGY LEVELS

INDEX	CONFIGURATION	(2S+1)L(J)	ENERGY RELATIVE TO LEVEL 1 (wave number <cm-1>)	ENERGY RELATIVE TO LEVEL 1 (rydbergs)	ENERGY RELATIVE TO IONISATION POTENTIAL (wave number <cm-1>)	ENERGY RELATIVE TO IONISATION POTENTIAL (rydbergs)
1	1	(2)0(0.5)	0.	0.0000000	1114000.	10.1515370
2	1	(2)1(0.5)	96377.	0.8782492	1017623.	9.2732678
3	1	(2)1(1.5)	96909.	0.8831017	1017091.	9.2684199

```
   4      1              (2)0(   0.5)            640009.          5.8322054              473991.          4.3193260
   5      1              (2)1(   0.5)            666185.          6.0707356              447815.          4.0807926
   6      1              (2)1(   1.5)            666365.          6.0723758              447635.          4.0791523
   7      1              (2)2(   1.5)            674995.          6.1510156              439005.          4.0005099
   8      1              (2)2(   2.5)            675042.          6.1514457              438958.          4.0000816
   9      1              (2)0(   0.5)            852529.          7.7688343              261471.          2.3827003
  10      1              (2)1(   0.5)            863191.          7.8659938              250809.          2.2855409
  11      1              (2)1(   1.5)            863267.          7.8666846              250733.          2.2848484
  12      1              (2)2(   1.5)            867030.          7.9009738              246970.          2.2505574
  13      1              (2)2(   2.5)            867050.          7.9011542              246950.          2.2503751
  14      1              (2)3(   2.5)            868022.          7.9100145              245978.          2.2415176
  15      1              (2)3(   3.5)            868032.          7.9101038              245968.          2.2414265
  16      1              (2)0(   0.5)            948412.          8.6425836              165588.          1.5089496
  17      1              (2)1(   0.5)            953761.          8.6913238              160239.          1.4602060
  18      1              (2)1(   1.5)            953798.          8.6916637              160202.          1.4598688
  19      1              (2)2(   1.5)            955738.          8.7093432              158262.          1.4421902
  20      1              (2)2(   2.5)            955748.          8.7094334              158252.          1.4420991
  21      1              (2)3(   2.5)            956201.          8.7135633              157799.          1.4379710
  22      1              (2)3(   3.5)            956205.          8.7136034              157795.          1.4379346
  23      1              (2)4(   3.5)            956672.          8.7178535              157328.          1.4336790
  24      1              (2)4(   4.5)            956674.          8.7178736              157326.          1.4336607

METASTABLE INFORMATION:
-----------------------
NUMBER OF ORDINARY LEVELS        =  23
NUMBER OF METASTABLES            =   1
---------------- METASTABLE DETAILS -----------------
METASTABLE    ENERGY LEVEL    ---- DESIGNATION -----
  INDEX          INDEX
-------------------------------------------------------
    1              1          1           (2)S( 0.5)

***** NEUTRAL HYDROGEN CHARGE EXCHANGE  NOT INCLUDED *****
*****   FREE ELECTRON RECOMBINATION  NOT  INCLUDED   *****


INPUT PLASMA PARAMETERS:
------------------------

NUMBER OF ELECTRON TEMPERATURES = 12
NUMBER OF ELECTRON DENSITIES    =  9
INDEX   -------- TE:  ELECTRON TEMPERATURES --------          INDEX   -- NE: ELECTRON DENSITIES --
          (kelvin)         (eV)          (reduced)                        (cm-3)       (reduced)
-------------------------------------------------------          ------------------------------------
  1       1.800D+04      1.551D+00      5.000D+02              1       1.000D+13     3.572D+07
  2       2.320D+04      1.999D+00      6.444D+02              2       3.000D+13     1.072D+08
  3       3.480D+04      2.999D+00      9.667D+02              3       1.000D+14     3.572D+08
  4       5.800D+04      4.998D+00      1.611D+03              4       3.000D+14     1.072D+09
  5       8.120D+04      6.997D+00      2.256D+03              5       1.000D+15     3.572D+09
  6       1.160D+05      9.995D+00      3.222D+03              6       3.000D+15     1.072D+10
  7       1.740D+05      1.499D+01      4.833D+03              7       1.000D+16     3.572D+10
  8       2.320D+05      1.999D+01      6.444D+03              8       3.000D+16     1.072D+11
  9       3.480D+05      2.999D+01      9.667D+03              9       1.000D+17     3.572D+11
 10       5.800D+05      4.998D+01      1.611D+04
 11       8.120D+05      6.997D+01      2.256D+04
 12       1.160D+06      9.995D+01      3.222D+04
-------------------------------------------------------          ------------------------------------

TABLE KEY:
----------
NE    = ELECTRON DENSITY
TE    = ELECTRON TEMPERATURE
****************************************** SPECTRUM LINE INTENSITIES & RATIOS: CONTROL DATA ******************************************
TRANSIENT CONDITIONS: NON-EQUILIBRIUM
 ---------- METASTABLE LEVEL SCALING FACTORS ----------
 INDEX  LEVEL       DESIGNATION        SCALING FACTOR
-------------------------------------------------------
   1      1    1           (2)S( 0.5)     1.0000D+00
```

```
--------------------------------- FIRST  COMPOSITE LINE GROUP ASSEMBLY ---------------------------------
       TRANSTN   -- UPPER LEVEL -- ------------------- TRANSITION --------------------
INDEX   INDEX      INDEX    TYPE   ----- UPPER LEVEL ------   ----- LOWER LEVEL ------    A-VALUE (SEC-1)
-------------------------------------------------------------------------------------------------------
  1       1          2      ORD    <1           (2)P( 0.5)> - <1           (2)S( 0.5)>       4.21D+08

--------------------------------- SECOND COMPOSITE LINE GROUP ASSEMBLY ---------------------------------
       TRANSTN   -- UPPER LEVEL -- ------------------- TRANSITION --------------------
INDEX   INDEX      INDEX    TYPE   ----- UPPER LEVEL ------   ----- LOWER LEVEL ------    A-VALUE (SEC-1)
-------------------------------------------------------------------------------------------------------
  1      28          7      ORD    <1           (2)D( 1.5)> - <1           (2)P( 0.5)>       6.82D+10


************************************ SPECTRUM LINE INTENSITIES & RATIOS:  RESULTS ************************************

FIRST  COMPOSITE LINE GROUP ASSEMBLY - SPECTRUM LINE INTENSITIES
----------------------------------------------------------------
NE  (CM-3)     1.00D+13  3.00D+13  1.00D+14  3.00D+14  1.00D+15  3.00D+15  1.00D+16  3.00D+16  1.00D+17
TE (KELVIN)-----------------------------------------------------------------------------------------------
  1.80D+04 ³   2.61D+02  7.81D+02  2.58D+03  7.52D+03  2.29D+04  5.52D+04  1.09D+05  1.52D+05  1.76D+05
  2.32D+04 ³   1.30D+03  3.90D+03  1.29D+04  3.77D+04  1.16D+05  2.86D+05  5.87D+05  8.40D+05  9.89D+05
  3.48D+04 ³   7.83D+03  2.34D+04  7.76D+04  2.28D+05  7.12D+05  1.81D+06  3.91D+06  5.88D+06  7.13D+06
  5.80D+04 ³   3.03D+04  9.06D+04  3.00D+05  8.87D+05  2.81D+06  7.34D+06  1.69D+07  2.70D+07  3.42D+07
  8.12D+04 ³   5.13D+04  1.54D+05  5.10D+05  1.51D+06  4.81D+06  1.28D+07  3.06D+07  5.10D+07  6.64D+07
  1.16D+05 ³   7.28D+04  2.18D+05  7.25D+05  2.15D+06  6.89D+06  1.86D+07  4.63D+07  8.04D+07  1.08D+08
  1.74D+05 ³   9.08D+04  2.72D+05  9.04D+05  2.68D+06  8.66D+06  2.38D+07  6.13D+07  1.12D+08  1.57D+08
  2.32D+05 ³   9.81D+04  2.94D+05  9.77D+05  2.91D+06  9.41D+06  2.61D+07  6.88D+07  1.29D+08  1.87D+08
  3.48D+05 ³   1.02D+05  3.06D+05  1.02D+06  3.03D+06  9.86D+06  2.76D+07  7.49D+07  1.47D+08  2.21D+08
  5.80D+05 ³   1.00D+05  3.01D+05  1.00D+06  2.98D+06  9.74D+06  2.76D+07  7.67D+07  1.57D+08  2.47D+08
  8.12D+05 ³   9.65D+04  2.89D+05  9.63D+05  2.87D+06  9.39D+06  2.67D+07  7.55D+07  1.58D+08  2.57D+08
  1.16D+06 ³   9.10D+04  2.73D+05  9.08D+05  2.71D+06  8.88D+06  2.54D+07  7.27D+07  1.56D+08  2.61D+08


SECOND COMPOSITE LINE GROUP ASSEMBLY - SPECTRUM LINE INTENSITIES
----------------------------------------------------------------
NE  (CM-3)     1.00D+13  3.00D+13  1.00D+14  3.00D+14  1.00D+15  3.00D+15  1.00D+16  3.00D+16  1.00D+17
TE (KELVIN)-----------------------------------------------------------------------------------------------
  1.80D+04 ³   1.15D-19  3.53D-19  1.26D-18  4.45D-18  2.19D-17  1.11D-16  6.36D-16  2.64D-15  1.10D-14
  2.32D+04 ³   1.91D-14  5.85D-14  2.07D-13  7.22D-13  3.47D-12  1.74D-11  1.01D-10  4.28D-10  1.78D-09
  3.48D+04 ³   1.79D-08  5.45D-08  1.91D-07  6.51D-07  3.01D-06  1.48D-05  8.75D-05  3.81D-04  1.60D-03
  5.80D+04 ³   9.82D-04  2.98D-03  1.03D-02  3.44D-02  1.52D-01  7.21D-01  4.33D+00  1.96D+01  8.41D+01
  8.12D+04 ³   1.00D-01  3.03D-01  1.05D+00  3.44D+00  1.47D+01  6.83D+01  4.11D+02  1.91D+03  8.36D+03
  1.16D+05 ³   3.07D+00  9.30D+00  3.19D+01  1.04D+02  4.32D+02  1.95D+03  1.17D+04  5.57D+04  2.50D+05
  1.74D+05 ³   4.19D+01  1.27D+02  4.32D+02  1.39D+03  5.63D+03  2.46D+04  1.47D+05  7.19D+05  3.33D+06
  2.32D+05 ³   1.50D+02  4.52D+02  1.54D+03  4.90D+03  1.96D+04  8.39D+04  4.99D+05  2.48D+06  1.17D+07
  3.48D+05 ³   5.11D+02  1.54D+03  5.24D+03  1.66D+04  6.49D+04  2.71D+05  1.59D+06  8.06D+06  3.92D+07
  5.80D+05 ³   1.28D+03  3.86D+03  1.31D+04  4.11D+04  1.58D+05  6.41D+05  3.71D+06  1.92D+07  9.64D+07
  8.12D+05 ³   1.83D+03  5.50D+03  1.86D+04  5.83D+04  2.22D+05  8.89D+05  5.10D+06  2.66D+07  1.36D+08
  1.16D+06 ³   2.31D+03  6.96D+03  2.35D+04  7.35D+04  2.78D+05  1.10D+06  6.23D+06  3.28D+07  1.72D+08


SPECTRUM LINE INTENSITY RATIO
-----------------------------
NE  (CM-3)     1.00D+13  3.00D+13  1.00D+14  3.00D+14  1.00D+15  3.00D+15  1.00D+16  3.00D+16  1.00D+17
TE (KELVIN)-----------------------------------------------------------------------------------------------
  1.80D+04 ³   2.27D+21  2.22D+21  2.05D+21  1.69D+21  1.04D+21  4.97D+20  1.72D+20  5.75D+19  1.61D+19
  2.32D+04 ³   6.81D+16  6.67D+16  6.22D+16  5.23D+16  3.35D+16  1.64D+16  5.80D+15  1.96D+15  5.57D+14
  3.48D+04 ³   4.37D+11  4.30D+11  4.06D+11  3.50D+11  2.37D+11  1.22D+11  4.47D+10  1.54D+10  4.46D+09
  5.80D+04 ³   3.08D+07  3.04D+07  2.91D+07  2.58D+07  1.85D+07  1.02D+07  3.91D+06  1.38D+06  4.07D+05
  8.12D+04 ³   5.12D+05  5.07D+05  4.87D+05  4.39D+05  3.26D+05  1.87D+05  7.45D+04  2.67D+04  7.95D+03
  1.16D+05 ³   2.37D+04  2.35D+04  2.27D+04  2.07D+04  1.59D+04  9.57D+03  3.95D+03  1.44D+03  4.33D+02
  1.74D+05 ³   2.17D+03  2.15D+03  2.09D+03  1.94D+03  1.54D+03  9.67D+02  4.16D+02  1.55D+02  4.72D+01
  2.32D+05 ³   6.56D+02  6.51D+02  6.35D+02  5.93D+02  4.81D+02  3.11D+02  1.38D+02  5.22D+01  1.60D+01
  3.48D+05 ³   2.00D+02  1.99D+02  1.94D+02  1.83D+02  1.52D+02  1.02D+02  4.70D+01  1.82D+01  5.63D+00
  5.80D+05 ³   7.85D+01  7.80D+01  7.66D+01  7.27D+01  6.17D+01  4.30D+01  2.06D+01  8.17D+00  2.56D+00
  8.12D+05 ³   5.28D+01  5.26D+01  5.17D+01  4.93D+01  4.23D+01  3.00D+01  1.48D+01  5.94D+00  1.88D+00
  1.16D+06 ³   3.94D+01  3.92D+01  3.86D+01  3.69D+01  3.20D+01  2.31D+01  1.17D+01  4.76D+00  1.52D+00
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Notes: