
ADAS504: PZD - graph and fit radiated power coefficients

The program interrogates zero density radiated power coefficient (PZD) files of type ADF19. The data may be interpolated using cubic splines at selected electron temperatures. A minimax polynomial approximation is made to the interpolated data. The interpolated data are displayed and a tabulation prepared. The tabular and graphical output may be printed and includes the polynomial approximation.

Background theory:

Emitted radiation is usually categorised into line radiation, free-bound continuum radiation and free-free bremsstrahlung continuum radiation. The composition of the line radiation is complex and includes spontaneously emitted photons from collisionally excited states of ions, satellite photons merging with resonance lines arising from the dielectronic process and cascade photons emitted as electrons recombined onto highly excited states percolate towards the ground states. The proper assessment of this line radiation requires the detailed analysis of the population structure of the excited states of ions as performed in ADAS2 series codes. Simplified summary radiative power data is often useful, while for complex species the full analysis may not be feasible. It is convenient to recategorise the emitted radiation into power loss due to excitation of the leading lines, recombination cascade power loss and bremsstrahlung power loss.

The radiative power loss by an element X of total number density N^X may be written as

$$\begin{aligned}
 N_e N^X P^X &= N_e N^X \sum_{z=0}^{z_0} \frac{N^{+z}}{N^X} P^{(z)} \\
 &= N_e N^X \sum_{z=0}^{z_0} \frac{N^{+z}}{N^X} (P_L^{(z)} + P_R^{(z)} + P_B^{(z)})
 \end{aligned}
 \tag{6.4.1}$$

where N^{+z} / N^X is the fractional abundance of the ions of charge z of element X . P^X is called the 'radiative power loss function' for the element X and $P^{(z)}$ the 'radiative power loss coefficient'. Most often, radiative power loss functions are given with the fractional abundances in equilibrium ionisation balance.

Leading line power loss

For some ions of high charge, ($z > 8$), fine structure splitting of the LS terms becomes pronounced. At low electron density, the population of an ionisation stage is effectively concentrated in the lowest energy level. For $z < 8$, this corresponds to the ground LS term and for $z > 8$ to the particular ground J fine-structure level. Collisional excitation at low density takes place from the lowest level. As the density increases, redistribution of the ground population amongst the ground term fine-structure levels occurs, tending to establish a relative statistical population amongst these levels. The variation of the line power loss depending upon whether the population is concentrated in the lowest fine structure level or statistically distributed within the ground term is generally quite small. On the other hand the presence of low metastable levels, usually in the opposite spin system from the ground levels is more serious. At tokamak densities, significant collisional excitation takes place from the metastable states of light ions. The error of assuming excitation only from the ground state may be >20% in an ion such as O^{+4} .

Most leading line power estimates exclude the effect of metastables so that

$$P_L^{(z)} = \sum_j \Delta E_{ji} q_{1 \rightarrow i}^{(e)}
 \tag{6.4.2}$$

Recombination-cascade power loss

For electron densities $N_e < 10^{16} \text{ cm}^{-3}$ only radiative and dielectronic recombination are significant. The dielectronic power loss occurs as two parts, namely, the dielectronic stabilising photon emission and the cascade emission of the recombined electron. The stabilising photon contribution to the power loss coefficient is

$$\sum_j \Delta \bar{E}_{ij} \sum_{nl} \alpha_d(i, j; nl) \quad 6.4.3$$

Of the electrons which recombine via the dielectronic process onto excited levels, only a proportion $\alpha_{CD} - \alpha_{rad}^{tot}$ will cascade to the ground level. Also since these electrons arrive primarily on highly excited states, each will liberate radiant energy close to the ionisation potential χ , hence the dielectronic cascade power loss coefficient is approximately

$$\sum_j \Delta \bar{E}_{ij} \sum_{nl} \alpha_d(i, j; nl) + \chi(\alpha_{CD} - \alpha_{rad}^{tot}) \quad 6.4.4$$

Radiative recombination preferentially selects free electrons close to zero energy, also, all the radiatively recombined electrons may be assumed to cascade to the ground state. Hence the radiative recombination cascade power loss coefficient is approximately

$$\chi \alpha_{rad}^{tot} (1 + \beta) \quad 6.4.5$$

where the factor β takes account of the electron's energy prior to recombining. Thus

$$P_R^{(z)} = \sum_j \Delta \bar{E}_{ij} \sum_{nl} \alpha_d(i, j; nl) + \chi \alpha_{CD} + \chi \beta \alpha_{rad}^{tot} \quad 6.4.6$$

where z is the charge of the recombining ion. i and j denote ground and excited states of the recombining ion. The excitations $i \rightarrow j$ occur in the first stage of the dielectronic process.

Bremsstrahlung power loss

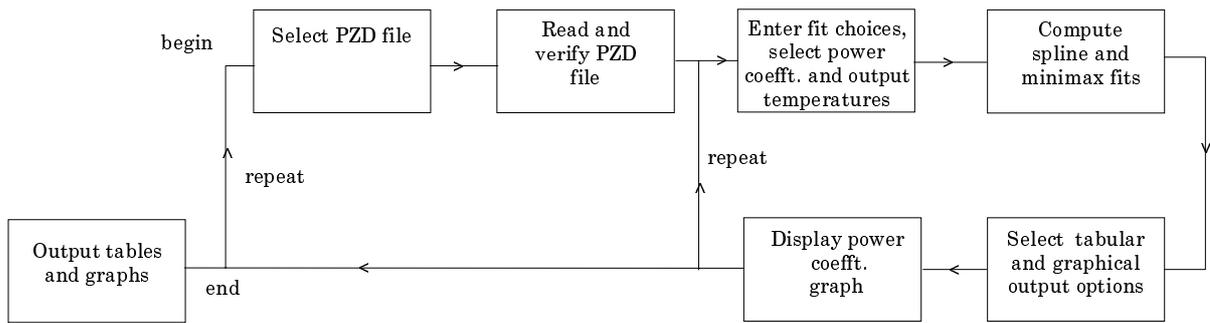
Bremsstrahlung calculations up to electron temperatures at the fusion reactor ignition point use non-relativistic theory and include only electron-ion dipole contributions with only small error. Many approximate formulae have been developed relating to a wide variety of conditions. In general, in view of the basic z^2 dependence of the bremsstrahlung emission on the effective ionic charge and the equilibrium distribution of ionisation stage abundances of elements as a function of temperature, significant bremsstrahlung emission arises from a variety of stripped and partially stripped species. For partially stripped species, distortion of the asymptotic Coulomb field of the ions by the bound electrons leads to deviation from the pure Coulomb case by only a few per cent at temperatures at which bremsstrahlung is significant. Thus most calculations evaluate pure Coulomb bremsstrahlung with further approximations in the Gaunt factors.

PZD data are extracted from archived files of type ADF19. These data are drawn from a variety of sources with varying degrees of attention to the issues above. The data can include power loss functions for elements and power loss coefficients for ions. Sub-division into leading line (ground or metastable), recombination-cascade or bremsstrahlung may be present. Letter identification codes used are specified in the ADAS data format description (ADF19) in appendix B. It is of importance to view the information section attached to each PZD data file to identify approximations and sources used. Extracted data are interpolated by cubic splines in electron temperature provide results at an arbitrary set of temperatures. The interpolated data are approximated by a minimax polynomial and a graph produced. A tabulation of the interpolated spline data and the minimax approximation is prepared.

Program steps:

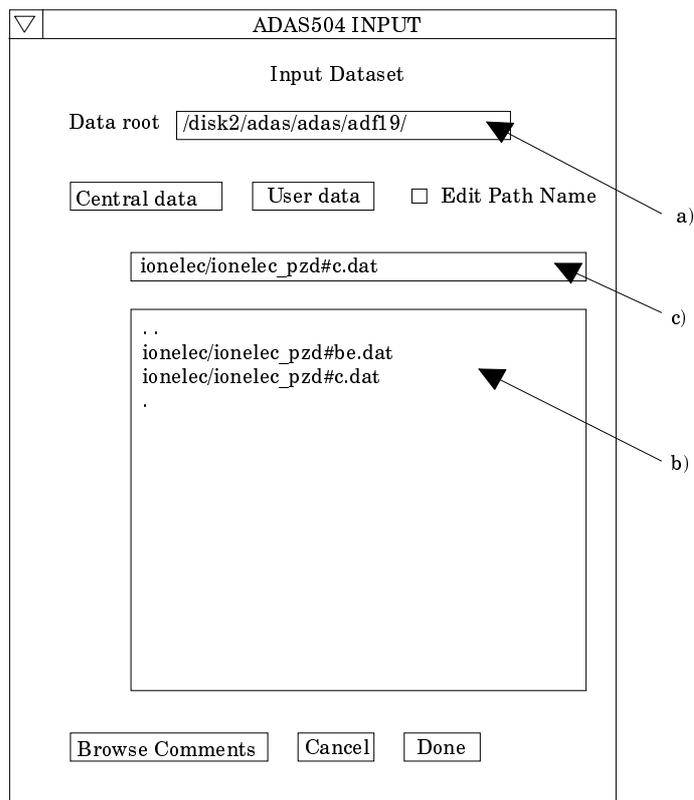
These are summarised in figure 6.4.

Figure 6.4



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. Note that each type of data is stored according to its ADAS data format (*adf* number). 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.
N. B. Under the IDL Graphical User Interface which controls the window operations, you must remember to press the *return* key on the keyboard for any change to be recorded.
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

ADAS504 PROCESSING OPTIONS

Title for run

Data file name :

Polynomial fitting

Fit Polynomial value % :

Select data block

Index	Initial Ion	Radiation Type	Additional Information
1	C	Total	Bonnin et al. (1992)
1	C	Total	Bonnin et al. (1992)
2	C + 0	Total	Bonnin et al. (1992)

Select Temperatures for output file

Output Electron Temperature

Index	Output	Input
1	1.000E+00	1.000E+00
2	2.000E+00	2.000E+00
3	5.000E+00	5.000E+00
4	1.000E+01	1.000E+01
5	2.000E+01	2.000E+01
6	5.000E+01	5.000E+01
7	1.000E+02	1.000E+02
8	2.000E+02	2.000E+02

Temperature units :

Edit the processing options data and press Done to proceed

8. An arbitrary title may be given for the case being processed a). For information the full pathway to the dataset being analysed is also shown. The button *Browse comments* again allows display of the information field section at the foot of the selected dataset, if it exists.
9. The output data extracted from the datafile, in the case of ADAS504, an 'radiated power function', may be fitted with a polynomial. This is as a function of temperature. Clicking the *Fit polynomial* button b) activates this. The accuracy of

the fitting required may be specified in the editable box. The value in the box is editable only if the *Fit Polynomial* button is active. **Remember to press the return key on the keyboard to record the value.**

10. Available radiative power functions and coefficients in the data set are displayed in the coefficient list display window. This is a scrollable window using the scroll bar to the right of the window. Click anywhere on the row for a coefficient to select it. The selected rate appears in the selection window c) just above the coefficient list display window.
11. Your settings of electron temperatures (output) are shown in the temperature display window d). The temperature values at which the ionisation rate coefficients are stored in the datafile (input) are also shown for information.
12. The program recovers the output temperatures you used when last executing the program. Pressing the *Default Temperature values* button inserts a default set of temperatures equal to the input temperatures.
13. The Temperature Values are editable. Click on the *Edit Table* button if you wish to change the values. A 'drop-down' window, the ADAS Table Editor window, appears.

The output options window appearance is shown below

ADAS504 OUTPUT OPTIONS

Data file name : /disk2/adas/adas/adf19/ionelec/ionelec_pzd#c.dat

Browse comments

Graphical Output

Graph Title : Figure 1

Explicit Scaling

X-min : X-max :

Y-min : Y-max :

Enable Hard Copy Replace

File name : graph.ps

Text Output Replace Default file name

File name : graph.ps

Cancel Done

Default Device: Post-script

Post-script HP-PCL HP-GL

14. As in the previous window, the full pathway to the file being analysed is shown for information. Also the *Browse comments* button is available.
15. 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.

16. Hard copy is activated by the *Enable Hard Copy* button c). The File name box then becomes editable. If the output graphic file already exists and the *Replace* button has not been activated, a 'pop-up' window issues a warning.
17. 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.
18. 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.
19. The graph is displayed in a following Graphical Output window.

Illustration:

Figure 6.4a shows the total zero density radiated power function for argon from the work of Summers & McWhirter. (1979). The solid line connects the spline fit points obtained in the main interpolation and the dashed curve is the minimax fit. Note that in this case, the minimax polynomial gives a poor representation. The code fails to achieve the requested minimax accuracy.

Figure 6.4a

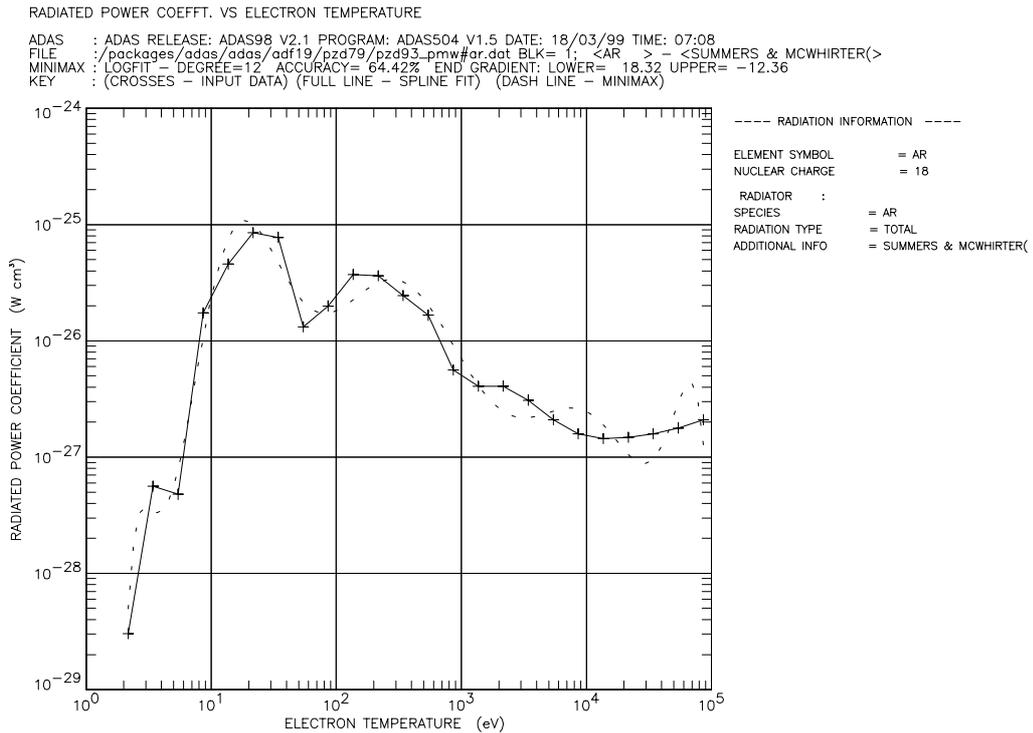


Table 6.4a

ADAS RELEASE: ADAS98 V2.1 PROGRAM: ADAS504 V1.5 DATE: 18/03/99 TIME: 07:08
 TABULAR OUTPUT FROM ZERO DENSITY RADIATED POWER COEFFT. INTERROGATION PROGRAM: ADAS504 - DATE: 18/03/99

ZERO-DENSITY RADIATED POWER COEFFICIENT AS A FUNCTION OF ELECTRON TEMPERATURE

DATA GENERATED USING PROGRAM: ADAS504

/packages/adas/adas/adf19/pzd79/pzd93_pmw#ar.dat - DATA-BLOCK: 1

RADIATION INFORMATION:

ELEMENT NAME = ARGON
 ELEMENT SYMBOL = AR
 NUCLEAR CHARGE (Z0) = 18

RADIATING ION:

ION = AR
 ION CHARGE (Z) =

NOTES:

RADIATION TYPE = TOTAL
 SCALING CHARGE FOR TE (Z1) = 1
 ADDITIONAL INFO = SUMMERS & MCWHIRTER(

ELECTRON TEMPERATURE			RADIATED POWER COEFFT.
kelvin	eV	K/Z1**2	W cm**3
2.511D+04	* 2.164D+00	* 2.511D+04	3.020D-29
3.981D+04	3.430D+00	3.981D+04	5.625D-28
6.310D+04	5.437D+00	6.310D+04	4.786D-28
1.000D+05	8.617D+00	1.000D+05	1.738D-26
1.585D+05	1.366D+01	1.585D+05	4.570D-26
2.511D+05	2.164D+01	2.511D+05	8.509D-26
3.981D+05	3.430D+01	3.981D+05	7.760D-26
6.310D+05	5.437D+01	6.310D+05	1.318D-26
1.000D+06	8.617D+01	1.000D+06	1.995D-26
1.585D+06	1.366D+02	1.585D+06	3.715D-26
2.511D+06	2.164D+02	2.511D+06	3.631D-26
3.981D+06	3.430D+02	3.981D+06	2.455D-26
6.310D+06	5.437D+02	6.310D+06	1.660D-26
1.000D+07	8.617D+02	1.000D+07	5.623D-27
1.585D+07	1.366D+03	1.585D+07	4.074D-27
2.511D+07	2.164D+03	2.511D+07	4.074D-27
3.981D+07	3.430D+03	3.981D+07	3.090D-27
6.310D+07	5.437D+03	6.310D+07	2.089D-27
1.000D+08	8.617D+03	1.000D+08	1.585D-27
1.585D+08	1.366D+04	1.585D+08	1.445D-27
2.511D+08	2.164D+04	2.511D+08	1.479D-27
3.981D+08	3.430D+04	3.981D+08	1.585D-27
6.310D+08	5.437D+04	6.310D+08	1.778D-27
1.000D+09	8.617D+04	1.000D+09	2.089D-27

NOTE: * => RADIATED POWER COEFFTS. EXTRAPOLATED FOR ELECTRON TEMPERATURE VALUE

MINIMAX POLYNOMIAL FIT - TAYLOR COEFFICIENTS:

- LOG10(RATE-COEFFICIENT<W CM**3>) VERSUS LOG10(ELECTRON TEMPERATURE<eV>) -

A(1) =	-8.403536716D+01	A(2) =	4.786748948D+02
A(3) =	-1.675006341D+03	A(4) =	3.194538016D+03
A(5) =	-3.719689076D+03	A(6) =	2.828443321D+03
A(7) =	-1.462185412D+03	A(8) =	5.246346738D+02
A(9) =	-1.310993072D+02	A(10) =	2.245207278D+01
A(11) =	-2.519621736D+00	A(12) =	1.673012841D-01
A(13) =	-4.991634944D-03		

LOGFIT - DEGREE=12 ACCURACY= 64.42% END GRADIENT: LOWER= 18.32 UPPER= -12.36

Notes: