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** See Appendix 1*

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Abstract. - The atomic data for fusion needs are described principally from the point of view of diagnostic spectroscopy. Tables are presented of areas of interest and associated atomic data usage. These and the discussion summarise the experience and practice at the JET Joint Undertaking.

1. Introduction

It requires some justification to write this article in the light of the very many discussions (for example in the meeting series organised by the International Atomic Energy Authority), the extensive compilations by data centres (such as in Belfast, Oakridge and Nagoya) and generally, the very large effort worldwide on atomic studies under the banner atomic data for fusion. Nevertheless, it is the case that discussion of needs has often been anticipatory, that is generated by studies for future machines and theoretical, in the sense that the usage is in a grossed up form as an 'atomic data package' in large scale plasma simulations. There is of course a more immediate and practical side, which is experimental diagnostic studies, especially spectroscopically based, of actual working fusion machines and their atomic data requirements. The article is concerned primarily with the latter case. Inevitably it must therefore be more specific and is subjectively written from the perspective and experience of the JET tokamak. Atomic data for diagnostics is not only more specialised but it must usually be more accurate. This is because, in reverse, the well diagnosed fusion experiment is itself a valid source for measurement of atomic coefficients and can provide a critical reply to providers of atomic data. In this sense, the large scale plasma simulations are not a good avenue to a dialogue on atomic processes. On the other hand, it is not the purpose of this article to view the fusion plasma as merely a spectroscopic source for fundamental atomic studies. We are concerned with a diagnostic return on important but elusive parameters of a fusion plasma to which spectroscopy and atomic physics can contribute.

2. Table organisation

Atomic data for JET, both current and anticipated, are summarised in tables 1 to 3 which are for ion-atom collisions, electron-ion collisions and transition probabilities respectively. Auger rates are included in the last class. Within each table a hierarchy of areas of interest are given - primary, secondary and tertiary - leading to the specific studies made at JET or planned for it. For each study, the required atomic data are identified in a final column. In the first table, the primary area is based upon the nature of the participating atoms. Tables 2 and 3 have primary areas corresponding to important plasma zones. In the descriptive text, references will be made to the tables in the form (*a.b.c.d*) according to the hierarchical organisation, and the discussion is ordered broadly according to primary area. A number of works are cited in the tables. These expand on the particular study and application.

3. Ion-atom collision data

3.1. NEUTRAL BEAMS. - There is no doubt that the most striking advances at JET in diagnostic spectroscopy have been through the 'active' technique of observations of beam penetrated plasma. In JET, the beams are composed of neutral deuterium (neutral helium was used for the first time in Oct. 1990) and are in fact the heating beams. There is no separate diagnostic beam at the present on JET. Charge transfer from the deuterium in the beam to deuterons and fully ionised impurity species in the plasma is the primary process. Consequential spectrum line emission from the recombined hydrogen-like impurity ions in the plasma is observed in visible wavelengths at various points along the beam line. The most suitable lines for observation are $\Delta n = 1,2$ principal quantum shell transitions from upper shells with $n \sim 2z_0^{3/4}$. The dominant charge transfer cross-section from deuterium in its ground state, D(1s), is into level $n_c \sim z_0^{3/4}$ so the JET observations are from high subdominant levels. The most relevant species are He, Be, C and O (intrinsic impurities in JET) together with B, N and Ne (as possible added impurities). The beam lines at JET operate at 40keV/amu and 70keV/amu primary energy at the present time and are contaminated by smaller fractions (15% by power) at 1/2 and 1/3 of the primary energy. Diagnostic deductions are impurity ion temperatures from the spectral line widths, plasma rotation (toroidal or poloidal) from line centre displacement and impurity densities from the line intensities. Deduction of densities requires knowledge of the attenuation of the beam to the observed volume. The attenuation and therefore beam power deposition profile is of course an important parameter for plasma performance. Total charge transfer and ionisation cross-sections are required for D(1s) with all the above impurity species and deuterons *(1.1.1.1)*. The precision must be quite high, < 10% error, due to exponential amplification of the error in calculated attenuated D(1s) densities. The relevant energy range stems from the need to cope with fractional energy components and averages over the thermal distribution of plasma ions, which can be very high in recent experiments (T_i < 30keV). For ion temperature and rotation deduction, charge exchange lines are used and the shape of the effective emission coefficient with energy is important at high thermal plasma ion temperature due to the relative collision speed variation. Line displacements close to true rotation shifts may arise simply because of this *(1.1.2.1)*. The fundamental data is the charge exchange cross-sections into high subdominant n-levels, which must be known absolutely for impurity density deduction *(1.1.2.2)*. Since collisional and field mixing of the l-substates is not necessarily complete, nl-resolved data is required. The greatest uncertainties are in cross-sections at energies < 40keV/amu for high subdominant levels and l distributions. Cascade also matters and so projected behaviour of cross-sections to very high n is required. An important point is that the beam induced charge exchange lines are generally superimposed on plasma edge emitted features *(1.1.2.4)* which must be subtracted.

Spectral emission from deuterium (in practice Dα and Dβ) in the beams can be observed. It is distinctive in that it is displaced from the stationary line position by Doppler effect in inclined viewing directions and split into separate Stark multiplets in the very large $\mathbf{v}\times\mathbf{B}$ electric fields (~ 100kV/cm) in the tokamak. These reveal information on internal magnetic fields. The excitation of the beam atoms is by deuteron and impurity ion collisions and to a lesser extent by electron collisions. Consequently Dα Stark emission in conjunction with deuterium charge exchange emission reflects composite impurity density in the plasma. The excitation cross-sections by ions with nuclear charge $z_0 > 1$ are uncertain in the energy range < 50keV/amu, but are essential for the diagnostic application. The ability to deduce ground state deuterium density in the beams from the Dα emission is most important since it allows the beam attenuation to be tracked experimentally *(1.1.1.2)*. Also knowledge of the excited state content of deuterium in the beams allows corrections to charge exchange based impurity density measurements by enabling inclusion of transfer from excited states *(1.1.2.3)*. Some futher exploitation of neutral deuterium beams are given in table 1.

Neutral helium beams of similar energies can also be used. In JET, some heating beams have been converted to operate with ^{3}He and ^{4}He with energies ~50keV/amu and ~30keV/amu respectively. Very similar atomic data to that for deuterium beams are needed but with He(1s^2 ^{1}S) as the donor species in the reaction *(1.3.1)*. Helium beams may have some advantages, namely greater penetration, only a single energy component in the beam and simpler Stark features. There is a complication, namely the metastable He(1s2s ^{3}S) content of the beam. This must be minimised for power beams by He^+/He neutraliser design *(1.3.3)*. The primary neutraliser cross-sections and subsequent He/He atom-atom cross-sections are not apparently well known. Visible spectroscopic observations of the neutraliser volume are available. Helium beams are of additional interest for measuring α particles by double charge transfer and then neutral particle detection *(1.3.2.1)*.

3.2. THERMAL DEUTERIUM. - Excluding the deuterium constituting the neutral beams, neutral deuterium may be present in the plasma as; a 'halo' associated with the beam and arising from charge transfer from beam atoms to deuterons in the plasma and then their dispersion; as evaporating pellets of solid deuterium fired into the plasma core; at the periphery of the plasma associated with gas sources and absorbing surfaces which act as a recycling reservoir. Although all these are termed thermal deuterium, evidently a number of distinct 'temperature' populations are involved as revealed even by a simple line of sight observation in Dα through the plasma in the absence of beams or pellets. We are concerned with the details of diffusion of neutral deuterium into the plasma and its influence on general diagnostic spectroscopic observations of impurities. The unexpectedly high diffusion of low energy deuterium released into the plasma is due to charge transfer to more energetic deuterons *(1.2.1)*.

Thermal deuterium as an an electron donor to impurity ions is much different from neutral beam deuterium. The low collision speed causes the charge transfer to be strongly state selective. Such charge transfer appears to be involved in two sets of spectral observations of hydrogen-like impurity emission. The high $\Delta n = 1,2$ emission excited by charge transfer from beam deuterium is also present as a weaker less broad feature in the absence of beams or along viewing lines not intersecting beams. If charge transfer from thermal deuterium is involved in the formation of this feature, it must be from excited states of the deuterium. Also the feature may well have contributions from electron impact excitation and from wavelength coincident emission from lithium-like ions of the same charge state, and indeed the feature often appears to be a superposition of more than one Gaussian. A proper understanding of the feature is necessary. The charge exchange data required is unfortunately not confidently known *(1.2.1.1)*. A second observation is of the high members of the Lyman series of the impurities. The series decrements become markedly modified in circumstances when the thermal neutral deuterium presence might be expected to be high (plasma in contact with the walls). The primary mechanism is again probably charge transfer. A consistent model for such observations should also include the thermal Dα emission itself.

Observations of partially ionised impurity emission near the plasma edge is of great diagnostic importance for fusion plasmas and will be discussed in detail in the next section. However charge transfer from thermal neutral deuterium can again be involved in populating quite specific states. On the one hand this can perturb electron impact based interpretations but on the other hand can give direct information on the balance between charge transfer and electron processes for such ions. Accurate state selective charge transfer cross-sections at thermal energies are essential but again appear to be a disputed area *(1.2.3.1)*.

4. Electron-ion collision data

4.1. EDGE PLASMA. - In this area, the plasma is interacting strongly with the solid surfaces which bound it. In the 'scrape-off-layer', the magnetic field structures are open and there are strong flows of particles to the limiting surfaces. From these surfaces, impurities are released back into the plasma. Temperature and density gradients are large. It is the most dynamic and complex region of the plasma from an atomic physics point of view and is strongly influential on the central 'bulk' plasma. It is also the most difficult to diagnose. The atomic processes in the edge plasma are essentially electron collision dominated apart from the neutral deuterium influences described in the last section.

Deduction of influxes of intrinsic light impurities (Be, C, O) is from visible spectral observations along many lines of sight directed at particular surfaces of the singly and doubly ionised ions. They are ionised quite locally to the surface which is their source. Visible transitions occur between higher principal quantum shells of these ions and this determines the excitation data required *(2.1.1.1)*, that is n=2-2, 2-3 and 3-3. The non-dipole cross-sections must be included to give favourable branching for visible lines and the 3-3 cross-sections are required because of collisional-radiative mixing processes at typical edge densities. Because of the highly dynamic state, each metastable of an inflowing ion must be viewed as having an independent population to be characterised by a spectrum line observation. C^{+2} therefore requires a singlet and triplet line observation to deduce its flux. Unfortunately, detailed cross-section calculations involving excited n-shells for low ionisation stages seem to have been left behind in the advance to ever higher charge states and heavier elements. The derived quantity which reduces the observed emission to a particle flux is called a 'photon efficiency'. It is a calculated ratio of photon emissivity to ionisation rate, done separately for each metastable. So ionisation rates for each metastable are needed at the same time as the excitation rates. The same influx studies can be performed on the neutral species but there are some extra possibilities. Provided cross-section data at least up to the n=4 shell are available, visible spectrum line ratios of neutrals can yield electron density. This is because the collision limit at JET edge densities is around n=4 *(2.1.1.2.)*. Such a result is valuable since independent measurement of density is difficult. These inflowing ions are in a highly ionising plasma condition and in the evolution from one stage to another, metastable state population ratios differ from equilibrium values. In practice, this means that appropriate spectrum line ratios can characterise temperature and penetration distance into the plasma. Transient ionisation models needed for the interpretation require metastable state selective ionisation coefficients and metastable cross-coupling coefficients in the generalised collisional-radiative sense *(2.1.1.1)*.

Influx of metals such as Ni and Cr in JET can also be characterised by visible spectral measurements on the neutral and singly ionised species. There are generally many metastable states for such ions in the $3d^n$, $3d^{n-1}4s$ and $3d^{n-2}4s^2$ configurations. Resonance transitions are suitable for observation but association of a line with excitation from a particular metastable is confused by configuration interaction, parentage breakdown etc. The availability of accurate excitation and ionisation cross-sections in this case is very low indeed *(2.1.1.4)*. These are important aspects to improve. Although metal influxes are of less importance at the present time in JET due to the beryllium gettering campaigns, this area will return into main analysis as divertor studies progress. In all these influx studies, usually the emitting ion is at an abnormally high temperature for its ionisation stage, so near threshold resonance regions of cross-sections are less important than in astrophysics.

4.2. DIVERTOR PLASMA. - This section is forward looking to the next step in the JET program for 1991-1994, when it is intended to construct a pumped divertor. Such an arrangement is designed to cause a flow in the peripheral plasma along open field lines to target plates in a divertor chamber. There the very large power flux can be radiated away efficiently, sputtering of target plates minimised and impurities controlled. The divertor chamber plasma will be dense ($N_e < 8x10^{14}$ cm^{-3}) and of low temperature ($T_e \sim$ 5-100eV). Dynamic ionisation and flows will be characteristic of the plasma. The target material in JET will be beryllium, so beryllium and carbon will be the dominant impurity species. Future machines will however clearly have to consider more suitable engineering materials such as molybdenum or tungsten. Studies with a range of species will be possible in JET , introduced by laser ablation in the divertor. Titanium and molybdenum are suitable to focus on with $3p^n$ and $4p^n4d^m$ ions prominent respectively. Ionisation and recombination coefficients are required as source terms for impurity ion transport models *(2.2.1.2)*. For elements such as titanium or lighter, these are metastable resolved effective coefficients at finite density for the divertor conditions. Existing calculations for these more complex ions are probably of only modest reliability. Since the range of diagnostics in the divertor will be limited, it will be desirable to maximise the return from spectroscopy. This means that electron - ion collision data for density dependent line ratios and temperature indicators are required. The quiet sun experience should be exploited here *(2.2.1.1)*. For heavy species such as molybdenum, bundling of ionisation stages into shell groups, identification of overlapped transition arrays from similar ions and spectral interval integrated observations of the pseudo - band spectra may be a fruitful approach *(2.2.2.2)*.

4.3. BULK PLASMA. - Central temperatures in JET are such that nickel, the main metallic impurity, is fully ionised. Spectral observations of resonance line emission in the X-ray, XUV and VUV of hydrogen-like to beryllium-like stages and then sodium-like and magnesium-like stages are the normal pattern. Standard analysis seeks impurity concentrations and to this end, most simply, line intensities are merged empirically with bolometric and pulse height analysis measurements of total radiation. A fuller analysis computes the radial emission shells with an impurity diffusive transport model. This is a somewhat disappointing area from an atomic physics point of view. Over the years, broad and heavy requirements for atomic data have come from it - ionisation rates, dielectronic rates etc. for all ionisation stages of many species. Yet, apart from a few exceptions *(2.3.4.1)*, higher quality atomic data is not well exploited in this work, uncertainties in transport parameter variation and plasma symmetry confusing detailed comparisons.
Helium-like lines and associated three electron satellite lines are modelled in detail. The approach parallels that used in solar flares, namely matching of synthetic spectra. In JET, the width of the resonance line of NiXXVII is used for ion temperature, but the fixed X-ray line of sight coupled with differential rotation of the plasma and the annular shell of the emission makes significant corrections necessary. Charge exchange spectroscopic data is used to help in this. The cross-section data is largely worked out *(2.3.3.1)*. Line ratio studies involving forbidden lines in the boron-like and fluorine-like systems are relevant in fusion plasmas. Here it is the ion impact collisional transitions amongst fine structure levels which are the key, the object being deduction of ion temperature or deuterium dilution. In practice, the set of electron collision rates for the ion are also required. Choice of suitable species depends on the electron temperature. It is necessary in JET to work with quite heavy species to probe the core plasma, such as krypton *(2.3.2.1)*. They are introduced by laser ablation or gas puffing, but restriction on allowable amounts to prevent disruptions inhibits spectroscopic measurements. Use of line ratios for electron density and temperature in the solar corona manner suffers from uncertain localisation and is in competition with laser scattering, interferometry, electron cyclotron emission and reflectometry.
In this rather negative view of the use made of good atomic rate data for the bulk plasma, it should be noted that absolutely calibrated measurements of radial emission shells would markedly alter the situation. There are some prospects of this in both the XUV and VUV at JET.

5. Energy level and transition probability data

In this section it is only necessary to draw brief attention to one or two points. The availability of energy level and transition probability data far exceeds that of collision data, where the real bottlenecks to diagnostic progess lie.

5.1. EDGE AND DIVERTOR PLASMA. - Most data required for light atom influx deductions from neutral and singly ionised ions are well known. However lifetimes of upper n = 3 levels of observed transitions can be influenced by two-electron transitions to n = 2 complexes. A-values for these have sometimes proved unreliable *(3.1.1.1)*. For metal influxes (Cr, Fe, Ni, Cu) from neutral and singly ionised ions, choice of lines for observation and calculation of branching ratios to parents rely heavily on large computer generated tabulations. Concerns about cross-sections have so far inhibited much detailed consideration of accuracy and completeness here. This situation is improving *(3.1.1.2)*. For heavy species (Mo, W), no start on spectral observations for influx has been made yet.

5.2. BULK PLASMA. - Spectral features in the VUV and XUV in metal rich plasma conditions can still remain unexplained. Further work on the detailed positions of transition arrays of heavy species is required *(3.2.4.3)*. Forbidden line transition probabilities for studies described in section 4.3 are required and of special value would be identification of visible wavelength forbidden line markers of highly ionised heavy species in the plasma *(3.2.2.2)*. Visible spectroscopic observations are convenient in fusion tokamaks. Remaining transition probability data needs, including Auger rates, relate to general ionisation and recombination of plasma impurities *(3.2.4)*.

6. Conclusions

The paper has focussed on the JET plasma and identified the detailed atomic data needs for its spectroscopic diagnostics. It should be noted however that other large scale fusion experiments tend to have very similar instrumentation and objectives. Thus although particular species invloved may differ somewhat (B rather than Be, Fe rather then Ni etc.) the diagnostic methodology given here is likely to be followed. The next generation machines are expected to emphasise even more the edge and divertor regions as the resilience of materials to very high power loads and neutron fluxes is investigated. Also neutral beams are likely to be more energetic to improve penetration at high density, a direction in which ion-atom cross-section data is less uncertain. The stressing of higher precision data of a more selective sort given here is also likely to be the case in the future. More precise power inventories are relevant to ignited or breakeven machines.

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Table 1a. - *ion-atom collision data*

Primary area	Secondary area	Tertiary area	Study	Ion-atom collision data
(1.1) Neutral hydrogen beams	*(1.1.1)* Characterising of the beam	*(1.1.1.1)* Attenuation of the beam in the plasma	Local n_D in beam allowing impurity density deduction No stepwise processes	$D+D^+$, $D+He^{+2}$, $D+Be^{+4}$, $D+C^{+6}$, $D+O^{+8}$ CX and ionis. σ_{tot}:5kev $<$ E/amu $<$ 140kev
		(1.1.1.2) Radiation by D in the beam [3]	σ & π Dα measurements to obtain internal B-field. Excited D content of beam. Deduction of Zeff.	$D_{nkm}+D^+$, $D_{nkm}+He^{+2}$, $D_{nkm}+Be^{+4}$, $D_{nkm}+C^{+6}$, $D_{nkm}+O^{+8}$: $1<n<6$ Excit., ionis and CX σ_{nkm}:5kev $<$ E/amu $<$ 140kev
		(1.1.1.3) Enhanced attenuation of the beam.	Collisional radiative calculation of beam attenuation coefficients	As *(1.1.1.2)* above
		(1.1.1.4) Formation of the beam halo and its effects	Beam / halo conversion Correction to plasma deuteron density deduction due to halo	$D+D^+ \dashrightarrow D^+ + D_{nlj}$: $0<n<6$ σ_{nl}:5kev $<$ E/amu $<$ 140kev
	(1.1.2) Illumination of plasma ions & stripped impurities	*(1.1.2.1)* D & stripped light impurity CX induced line shapes [2]	Deduction of local T_i for D, He, Be, C & O at radial pts. Deduction of local v_{rot} for plasma at radial pts.	As *(1.1.2.2)* below.
		(1.1.2.2) CX induced emissivities [1]	Deduction of local n_i for D, He, Be, C & O at radial pts.	$D_{1s}+D^+ \dashrightarrow D^+ + D_{nlj}$ $(n<6)$, $D_{1s}+He^{+2} \dashrightarrow D^+ + He^{+1}_{nlj}$$(n<9$ $D_{1s}+Be^{+4} \dashrightarrow D^+ + Be^{+3}_{nlj}$$(n<13$ $D_{1s}+C^{+6} \dashrightarrow D^+ + C^{+5}_{nlj}(n<21)$ $D_{1s}+O^{+8} \dashrightarrow D^+ + O^{+7}_{nlj}(n<21)$ σ_{nlj}:5kev $<$ E/amu $<$ 140kev
		(1.1.2.3) Excited states of D in beam	Correction to n_i from CX from excited D in the beam	As *(1.1.2.2)* from D_{nkm} $(1<n<6)$ as donor.
		(1.1.2.4) Interfering edge features [1]	Subtraction of coincid. edge features - isolate beam CX	See *(1.2.2.1)*
		(1.1.2.5) Alpha particles [2]	Deduction of α-particle D-T fusion source rate. Deduction of α-particle D-T cooling distr. function param.	$D_{1s}+He^{+2} \dashrightarrow D^+ + He^{+1}_{nlj}$ $(0<n<9)$ σ_{nlj}:5kev $<$ E/amu $<$ 300kev
	(1.1.3) Ionisation balance and transport	*(1.1.3.1)* Local balance in beam traversed region	Deduction of distrib. of ionisation stages of all impurity elements when CX from beams active	See *(1.1.3.2)* below
		(1.1.3.2) Average balance in 1-D impurity transport modelling	Deduction of distrib. of ionisation stages of all impurity elements averaged for 1-D modelling when CX from beams active	As *(1.1.1.1)* above extended to Be-like stages including Cl and Ni at present.

Table 1b. - *ion-atom collision data*

Primary area	Secondary area	Tertiary area	Study	Ion/atom collision data
(1.2) Thermal hydrogen	*(1.2.1)* Propagation of neutral D into plasma		Deduction of density and decay length of neutral hydrogen into plasma. Scrape off layer energy balance	$D_{1s}+D^{+} \rightarrow D^{+}+D_{nl}$ $(0<n<6)$ σ_{nl}: $1ev < E/amu < 10kev$
	(1.2.2) Influence on stripped light impurities	*(1.2.2.1)* CX induced emissivities	Deduction of neutral hydrogen density at plasma periphery	$D_{1s}+Be^{+4} \rightarrow D^{+}+Be^{+3}{}_{nlj}$ $(0<n<13)$ $D_{1s}+C^{+6} \rightarrow D^{+}+C^{+5}{}_{nlj}$ $(0<n<21)$ σ_{nlj}: $100ev < E/amu < 3kev$
		(1.2.2.2) Excited states of D [4]	Direct investigation of CX from excited states of D. Consistency with $D\alpha$ measurements	As *(1.2.2.1)* but from D_{nl} $(1<n<6)$
		(1.2.2.3) Ionisation balance	Study of modifications of ionisation balance at plasma periphery due to CX from thermal neutral hydrogen	$D_{1s}+C^{+6}$, $D_{1s}+C^{+5}$, $D_{1s}+C^{+4}$ Likewise for Be and O σ_{tot}: $20ev < E/amu < 3kev$
	(1.2.3) Influence on partially stripped impurities	*(1.2.3.1)* Influx deduced from visible spectroscopy	Corrections to deduced influx from CII, CIII, OII, OIII visible spectra due to state selective capture from thermal D	$D_{1s}+C^{+3}{}_{g,m} \rightarrow D^{+}+C^{+2}{}_{nl}$ ($n = 3,4$ all substates) also C^{+2}, O^{+2} and O^{+3} σ_{nl}: $20ev < E/amu < 200ev$
		(1.2.3.2) VUV spectral emission	Direct investigation of neutral hydrogen density from CII, CIII, OII, OIII VUV emission Correlation of low and high spectral series members	$D_{n'}+C^{+3}{}_{g,m} \rightarrow D^{+}+C^{+2}{}_{nl}$ $(4<n<13)$ $\sigma_{n',nl}$: $1ev < E/amu < 200ev$
	(1.2.4) Influence on nearly stripped medium Z species		Investigation of CX dimension of high series members of helium-like resonance lines of medium z elements. Study of neutral D density in deeper layers	$D_{n'}+Cl^{+16} \rightarrow D^{+}+Cl^{+15}{}_{nl}$ $(0<n'<6,\ 4<n<31)$ $\sigma_{n',nl}$: $1kev < E/amu < 10kev$
	(1.2.5) Ionisation balance		General correction of recombination rates for modelling to include CX from thermal hydrogen	As *(1.1.3.2)* extended to singly ionised species $(0<n<9)$ σ_{tot}: $20ev < E/amu < 5kev$
(1.3) Neutral helium beams	*(1.3.1)* As *(1.1)* with helium			As *(1.1.1.1)*, *(1.1.1.2)* and *(1.1.2.2)* but with He replacing D.
	(1.3.2)	*(1.3.2.1)* Detection of fusion alpha particles	Neutralisation of D-T fusion alpha particles by helium.	$He+He^{+2} \rightarrow He^{+2}+He$ σ_{tot}: $E/amu < 880kev$
	(1.3.3) Beam formation	*(1.3.3.1)* Neutraliser design	He^{+}/He neutralising and metastable He content of beam.	$He+He^{+} \rightarrow He^{+}+He^{*}$, $He+He \rightarrow He^{*}+He^{*}$, $He+He^{*} \rightarrow He+He^{+}$ (* denotes singlet and triplet states with $n<4$) σ: $25keV < E/amu < 60keV$

Table 2a. - *electron-ion collision data*

Primary area	Secondary area	Tertiary area	Study	Electron impact data
(2.1) Edge plasma	*(2.1.1)* Impurity influx	*(2.1.1.1)* Influx of light impurities from limiters [5]	Calculation of photon efficiencies for BeI, BeII, CI, CII, CIII, OI, OII, OIII. Finite density, restricted level model	n=2-2 and 2-3 dipole & non-dipole x-sects. from ground & metastables, LS-resolved. 3-3 dipole x-sects. for coll. redistribution. Cascade following excit. to n>3 must be estimated. 30% acc. on principal excitations. 10eV < E < 200eV.
		(2.1.1.2) Diagnostics using light neutrals. [6]	Electron density deductions from BeI, CI & OI. Generalised collisional radiative model.	As *(2.1.1.1)* but with spin change x-sects and extended to higher n, LS-resolved to n=4. Supplement with bundle-n excit. and ionis. x-sects. at high n. 5eV < E < 200eV.
		(2.1.1.3) Dynamic ionisation. [6]	Calculation of time dependent and/or spatial non-equilibrium metastable populations for species as above. Generalised collisional radiative model.	As *(2.1.1.1)* and *(2.1.1.2)* but including initial and final metastable state selective ionisation coefficients. Same species. 5eV < E < 300eV.
		(2.1.1.4) Influx of metal. impur. from limiters & antennae [5]	Calculation of photon efficiencies for CrI, CrII, FeI, FeII, NiI, NiII	n=3-4 & 4-4 dipole x-sects. Parent & metastable resolution with parent changing transitions included. Initial state metastable selective, ionisation x-sects. of same precision. 40% acc. would exceed any measurement 10eV < E < 200eV;
(2.2) Divertor plamsa	*(2.2.1)* medium weight metals	*(2.2.1.1)* Influx from divertor target plates	Photon efficiencies for TiI and TiII. Relevant species may change.	n=3-4 and 4-4 dipole, non-dipole and spin change x-sects. Parent changing x-sects. included. 40% acc. 5eV < E <200 eV;
		(2.2.1.2) Ionisation balance, radiated power	Ionisation, recombination, emissivities and diagnostic line ratios for TiV - TiXI. Generalised collisional radiative model.	n=3-3, 3-4 and 4-4 x-sects. Complete set. Zero density state selective partial dielectronic coeffts. with initial metastable distinquished. 40% acc. 5eV < E <200 eV;
	(2.2.2) Heavy elements	*(2.2.2.1)* Influx from divertor plates	As *(2.1.1.4)* for MoI, MoII.	Detailed needs undefined
		(2.2.2.2) Ionisation balance, radiated power	Shell group approach to ionisation and recombination tied to pseudo-band emission including Mo, W.	Ionis. incl. multiple autoionis., recom. and excit. x-sects for Mo & W ions to n=3 shells and n=4 shells resp. Factor 2-3 accuracy. 1eV < E < 1keV.

Table 2b. - *electron-ion collision data*

Primary area	Secondary area	Tertiary area	Study	Electron impact data
(2.3) Bulk plasma	*(2.3.1)* Light impurity densities	*(2.3.1.1)* Charge exchange [4]	Studies of Lyman series and $\Delta n = 1,2$ lines of H-like ions Contrast of electron impact and CX processes for edge features	Excit. x-sects. from $n = 1,2$ to high n, l-resolved at 20% accur. He,Be,C & O main species. $100eV < E < 5keV$
		(2.3.1.2) Radiation by D in the neutral beams [3]	σ & π D measurements to obtain internal B-field; full, 1/2 and 1/3 energy beam attenuation measure; excited D content of beam; Zeff measure	Excit. x-sects. from $n = 1$ to $n = 2,3,4$. Differential x-sects. in Stark state picture. $5eV < E < 1keV$
	(2.3.2) VUV & EUV diagnostics	*(2.3.2.1)* Ion temperature / deuterium dilution	Use of boron-like ground term fine structure mixing by ion collisions. Applies also to fluorine-like.	Excit. x-sects. within ground complex at 20% accur. Ni, Kr, Mo ions $1keV < E < 10keV$
	(2.3.3) X-ray diagnostics	*(2.3.3.1)* Ion & electron temperature, ionisation balance [7] & [8]	Ni^{+26} lines and associated satellites. Line ratio comparisons. Applies also to Cl	Consistent excit. & diel. x-sects. at 10% accur. All energies.
	(2.3.4) General plasma simulation.	*(2.3.4.1)* Dielectronic recombination [9]	Dielectronic coeffts. for generalised collisional radiative models He, Be, C, O, Fe, Ni main elements	Zero density total coeffts. Metastable parent and spin system resolved. State selective low n values. Parent changing A_r & A_a behaviour with n. 20% acc. for shell boundary ions. All temperatures
		(2.3.4.2) Ionisation	Ionisation coeffts. for generalised collisional radiative models He, Be, C, O, Fe, Ni main elements	Metastable to metastable x-sects. Direct x-sects., inner shell excit. x-sect., Auger/radiative branching, resolved initial & final states 20% acc. as above All temperatures
		(2.3.4.3) Radiated power; line emission	Radiated power coeffts.; principal monitor line theoretical emissivities He, Be, C, O, Fe, Ni main elements	Principal excit. x-sects. for coll./rad. modelling, metastable & spin system coupling x-sects. 40% acc. on each ion. stage power & 20% on principal emissivities. All temperatures
(2.4) Special studies	*(2.4.1)* X-ray diagnostics	*(2.4.1.1)* Non-thermal electron distributions & >20keV temperature studies	Kinematic relativistic corrections to x-sects.	excit. x-sects. with revised asymptotic behaviour & high energy projection; dipole & non-dipole.

Table 3. - *energy/A-value data*

Primary area	Secondary area	Tertiary area	Study	Energy & transition probability data
(3.1) Edge and divertor plasma	*(3.1.1)* Visible spectroscopy	*(3.1.1.1)* Influx of light impurities from limiters	Deduction of suitable lines & photon efficiencies for BeI, BeII, CI, CII, CIII, OI, OII, OIII	n = 3-3 & 4-3 A-values; 2-electron transition probs. from n = 3; cascade paths from n < 7
		(3.1.1.2) Influx of metal. impur. from limiters	Deduction of suitable lines & photon efficiencies for CrI, CrII, FeI, FeII, NiI, NiII Extend to TiI & TiII.	Association of lines with metastables; A-values; branching to different metastables; parent mixing
		(3.1.1.3) Fluxes of heavy elements in divertors	As *(3.1.1.2)* above.. MoI, MoII, WI, WII	Detailed needs undefined.
		(3.1.1.4) Thermal deuterium	Evidence of CX from excited states of D to fully ionised and helium- like ions	Energies of high nl levels of lithium-like ions in terms of polarisabilities
	(3.1.2) VUV & EUV	*(3.1.2.1)* Thermal hydrogen	Evidence of CX from ground & excited states of D to partially stripped light impurities	As *(3.1.1.1)* extended to 2 < n < 6. Include Auger probabilities from excited parents.
		(3.1.2.2) Radiated power by heavy species in divertors	Stages, radiat. power, observable spectral features for 10-200 eV plasma. Shell group / pseudo - band structure approach ?	Energies & A-values for describing integral emission of pseudobands and shell-shell ionis./recom. Mo, W
	(3.1.3) Special studies	*(3.1.3.1)* ion/surface interaction	Secondary electron emission by impact of highly ionised ions on graphite & metal surfaces	Radiat./Auger probs. & cascade paths for multi - spectator & strongly correl. neutralisation for Be^{+4}, C^{+6} etc.
(3.2) Bulk plasma	*(3.2.1)* Visible spectroscopy	*(3.2.1.1)* Bremsstrahlung emission	Deduction of local Zeff	free-free Gaunt factors.
	(3.2.2) VUV & EUV diagnostics	*(3.2.2.2)* Line ratio diagnostics	Deuterium dilution from boron-like line ratios in Ni^{+23} & Kr^{+31} Also fluorine-like.	Ground term M1 fine structure transition probabilities and $2s^2 2p\ ^2P_{1/2,3/2}$- $2s\ 2p^2\ ^2D_{3/2,5/2}$ etc A-values.
	(3.2.3) XUV & X-ray diagnostics	*(3.2.3.1)* Ion temperature, plasma rotation and transport	Plasma heating, electron-ion thermalisation and dynamic ionisation state. Cl and Ni main species - especially helium-like stages. Extension to added species.	Resonance, forbidden, intercomb. & satellite line parameters
	(3.2.4) General plasma simulation.	*(3.2.4.1)* Dielectronic recombination [9]	Dielectronic coeffts. for generalised collisional radiative models He, Be, C, O, Fe, Ni main elements	Very high Rydberg state energy level separations - dipole polarisabilities with ground & metastable cores; A-values
		(3.2.4.2) Radiative recombination	Radiative recombination coeffts. for generalised collisional radiative models He, Be, C, O, Fe, Ni main elements	Zero density total coefficients. Metastable parent and spin system resolved. State selective low n values 20% accur. All temperatures
		(3.2.4.3) Radiated power by heavy species	Identification of observable features in the XUV and EUV Arbitrary species	Energies & A-values for describing transition array emission for higher charge states especially n = 3 and 4 shells.

APPENDIX 1.

THE JET TEAM

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