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I.H. Coffey, K.D. Lawson, K.M. Aggarwal, F.P. Keenan, T. O'Neill,
V. Srigengan, and JET EFDA Contributors

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I.H. Coffey[1,2], K.D. Lawson[2], K.M. Aggarwal[1], F.P. Keenan[1], T. O'Neill[1],
V. Srigengan[1], and JET EFDA Contributors*

[1] *Department of Pure and Applied Physics, Queen's University Belfast, BT7 1NN, UK,*
[2] *EURATOM/UKAEA Fusion Association, Culham Science Centre, Abingdon,OX14 3DB, UK*
**See Annex of J. Pamela et al., "Overview of Recent JET Results and Future Perspectives",*
Fusion Energy 2000 (Proc. 18th Int. Conf. Sorrento, 2000), IAEA, Vienna (2001).

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INTRODUCTION

In a burning plasma, it is essential to be able to diagnose the alpha particles produced by the DT reactions. A novel technique is being investigated, which involves the use of XUV spectral line intensity ratios to measure the product ‘alpha particle density × collisional excitation rate’ ($c_\alpha n_e q_\alpha$, where c_α is the alpha particle concentration). In practice, several ratios from different elements and ionisation stages would be used to give information about both the alpha particle density and its energy distribution function.

The n = 2 shell of, for example, the F-like ionisation stage has 3 energy levels (fig.1), heavy particle excitation being important between the two levels, 1 and 2, of the ground configuration. Line intensity ratios between an allowed transition and the forbidden transition within the ground configuration, $I_{31}/I^{21} = n_3A_{31}/n_2A_{21}$, where A is the transition probability and n the level population, can be sensitive to heavy particles.

The steady state rate equations for levels 2 and 3 are:

$$\frac{dn_2}{dt} = 0 = n_1 n_e q_{e12} - n_2 n_e q_{e21} - n_2 n_e q_{e23} + n_3 n_e q_{e32} + n_3 A_{23} - n_2 A_{21}$$
$$+ n_1 c_d n_e q_{D12} - n_2 c_d n_e q_{D21} + n_1 c_\alpha n_e q_{\alpha 12} - n_2 c_\alpha n_e q_{\alpha 21}$$

$$\frac{dn_3}{dt} = 0 = n_1 n_e q_{e13} - n_3 n_e q_{e31} + n_2 n_e q_{e23} + n_3 n_e q_{e32} + n_3 A_{31} - n_3 A_{32}$$

n_3/n_2 can be determined experimentally leading to $c_\alpha n_e q_{\alpha 12}$

The sensitivity of the line ratio to alpha particles depends on the electron and heavy particle rates and experiments have been performed to test these rates for F-like Kr, Zr and Mo.

1. ATOMIC DATA AND MODELLING OF THE SPECTRAL LINE INTENSITY RATIOS

New R-matrix calculations of Aggarwal and Keenan [1] are used for the electron collisional excitation rates for Mo, which can be used together with earlier calculations for Ni, Fe, etc. to interpolate rates for Kr and Zr. Heavy particle collisional excitation rates are available for a number of elements in the F-like isoelectronic sequence from Foster *et al.* [2]. The alpha particle collisional excitation rates of Ni, Kr, Mo and Ag ions are shown in figure 2.

These data have been used to model spectral line intensity ratios for a number of scenarios. Both the heavy particle and the new electron collisional excitation rates need to be confirmed experimentally. Figure 3 shows the KrXXVIII I_{31}/I_{21} line ratio for a range of conditions appropriate to ICRH plasmas designed to test the electron rates. Fast rather than thermal particles contribute more to the Kr heavy particle rates and therefore are most suited to checking the heavy particle data. Figure 4 shows the change in the line intensity ratio due to fast D. The change in the ratio is less sensitive to T_e and plasma composition than the ratio itself and the dependence on n_e becomes negligible. Figures 5 and 6, respectively, show the change in the Kr and Mo line intensity ratios as a result of DT alpha particles for a range of T_e and plasma composition. The dependence on both parameters decreases with increasing Z.

2. EXPERIMENTS

The first analysis is of measurements to test the electron rates in ICRH plasmas, in which Kr was gas-puffed. Figure 7 shows the main discharge parameters for a typical pulse, Pulse No: 56908, including the time histories of the allowed and forbidden lines and figure 8 and 9 show examples of the spectra obtained for this discharge. These were recorded simultaneously with the two detectors of a Schwob-Fraenkel spectrometer, each of which can be moved around the Rowland circle observing a limited wavelength range at a high spectral resolution. In order to measure the allowed / forbidden line intensity ratio, the sensitivity of each detector at different positions on the Rowland circle must be known. Unexpectedly, the sensitivity was also found to vary significantly across the individual detectors and an extensive programme was undertaken to determine this variation, which was found to be different for the two detectors as well as being a function of the central wavelength of the detector. The measured value of the ratio is 1.25 ± 0.30, the largest uncertainty being due to the sensitivity calibration at shorter wavelengths.This measurement is consistent with theory (fig.3), suggesting high values of T_e and D concentration. The contribution of the thermal D to the excitation of transition $1 \rightarrow 2$ is necessary to give this agreement

A more severe test of the heavy particle atomic data can be made using fast particles injected by neutral beams. However full power NBI was unavailable during these experiments, the maximum power being ~8MW of 80keV D beams into a plasma in which Kr was gas-puffed. In figure 4, 8MW of D beams corresponds to a 'density × rate' product of $\times 10^{-11}$ cm^3 s^{-1}. An increase in the ratio was observed, but this was in part due to neutron noise affecting particularly the weaker forbidden line. The consequent uncertainty in the measurement does not allow confirmation of the heavy particle data at these beam powers

For the case of alpha particles produced by DT reactions, illustrated in figures 5 and 6, the 'density × rate' product is estimated to be between 0.4 and 1×10^{-11} cm^3 s^{-1}. In Mo this would result in up to ~ 40% change in the ratio.

Further measurements are required to confirm the heavy particle data and calculations for higher Z elements, such as Ag, Sn and Sb, together with those for the B-like isoelectronic sequence will allow the sensitivity of the technique to DT alpha particles in ITER-like plasmas to be fully assessed.

ACKNOWLEDGEMENT

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[2]. Foster, V.J., Keenan, F.P. and Reid, R.H.G., Atomic and Nuclear Data Tables, **58**, 227-244 (1994)

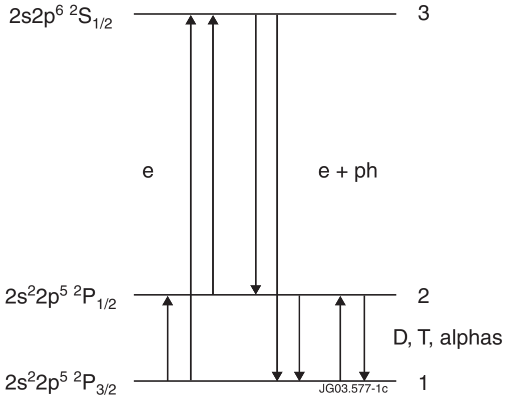

Figure 1: Term scheme of F-like n = 2 shell

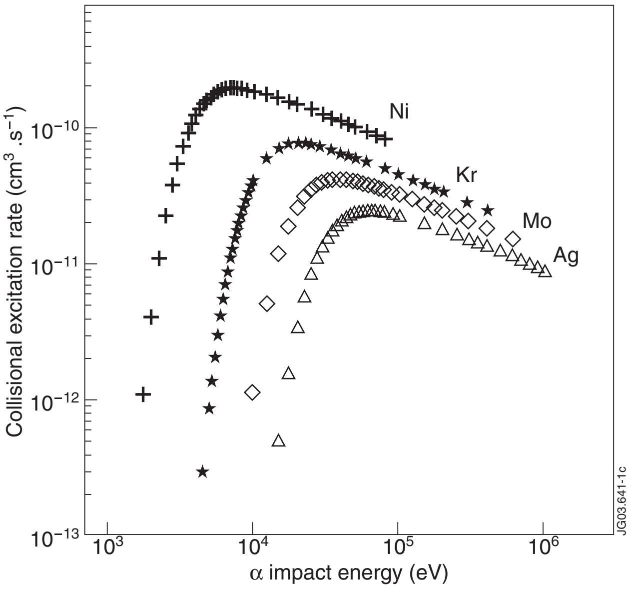

Figure 2: Alpha particle collisional excitation rates

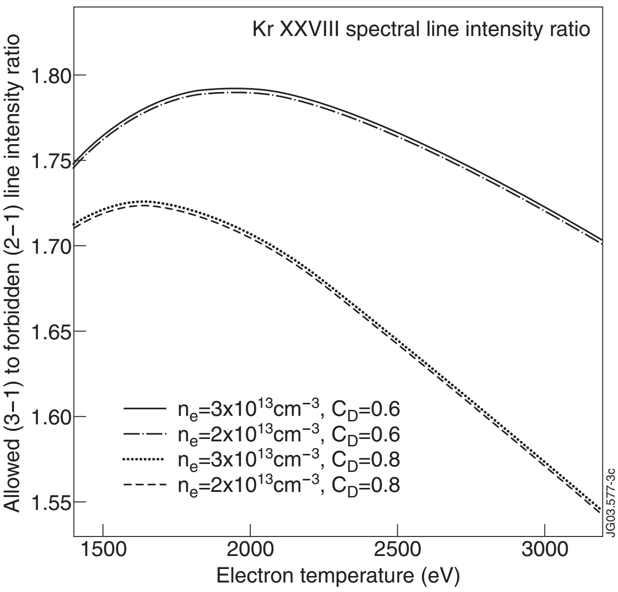

Figure 3: Kr spectral line intensity ratio (I_{31}/I_{21}) for conditions appropriate to ICRH plasmas

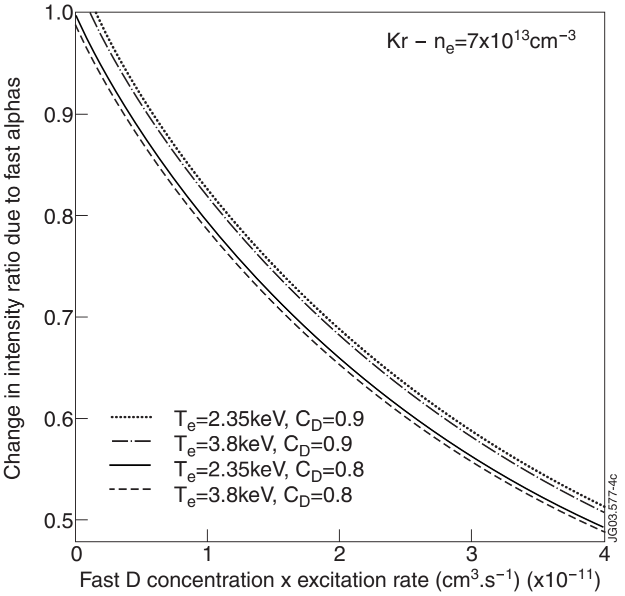

Figure 4: Change in the Kr spectral line intensity ratio due to fast D particles

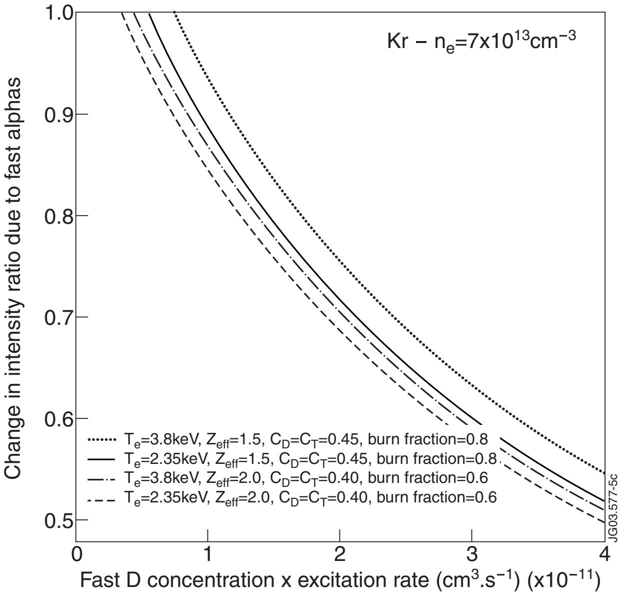

Figure 5: Change in the Kr spectral line intensity ratio due to fast alpha particles

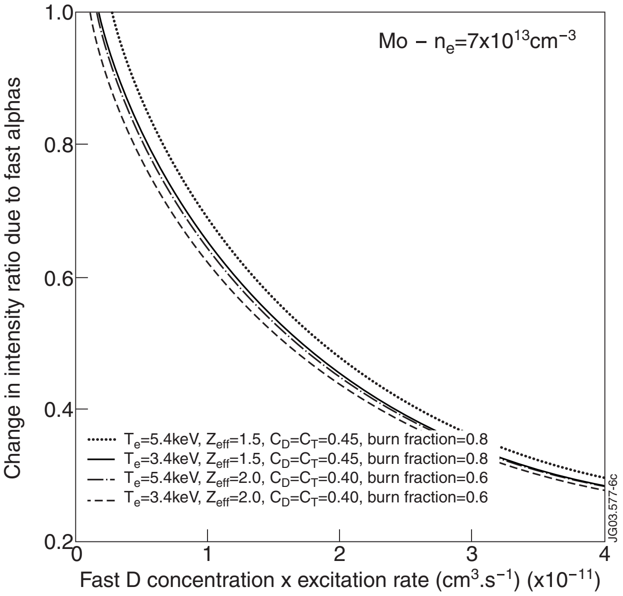

Figure 6: Change in the Mo spectral line intensity ratio due to fast alpha particles

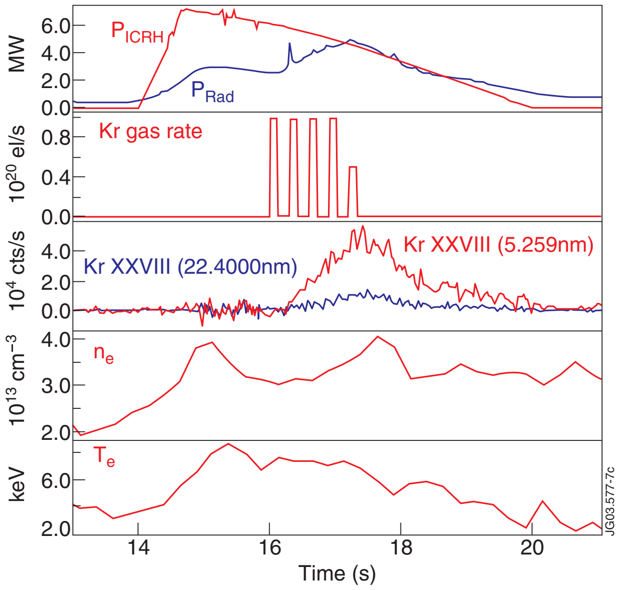

Figure 7: Discharge parameters for Pulse No: 56908

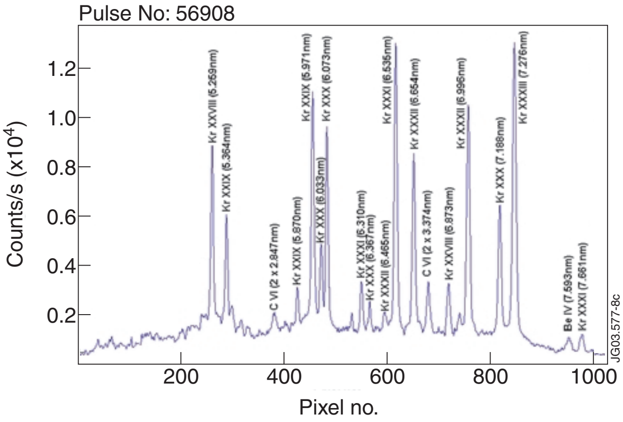

Figure 8: Kr spectrum from Pulse No: 56908 containing the allowed F-like line (5.259nm)

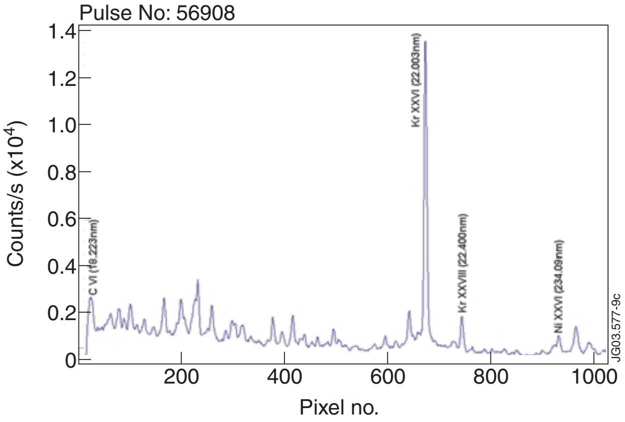

Figure 9: Kr spectrum from Pulse No: 56908 containing the forbidden F-like line (22.400nm)