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RUNAWAY ELECTRONS IN THE TRIAM-1 TOKAMAK

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Pulse height analysis of soft X-rays is carried out in the TRIAM-1 tokamak. The electron temperatures determined from the soft X-ray spectrum agree well with those from Thomson scattering. It is observed that low-energy runaway (slideawav) electrons appear in the high-current-density discharges.

Keywords: Runaway electrons, TRIAM-1 tokamak, Pulse height analysis, Soft X-ray, Slideaway electrons

1. Introduction

Two main plasma regimes were identified in Alcator, depending on the value of the streaming parameter, $\xi \equiv \langle u_{//}/v_{\mathrm{the}} \rangle$, where $u_{//}$ and v_{the} are the electron drift and thermal velocities, respectively[1)~9)] For high ξ ($\gtrsim 0.4$ in H_2) (in the slideaway regime) two-component electron distribution functions were obtained, rf emission at frequencies greater than and equal to the ion plasma frequency, and strong ion heating up to temperatures of 1 keV occur. For low values of ξ (generally obtained by pulsed gas injection) (in the Coulomb régime), the distribution function is Maxwellian; nearly classical resistivity and rates of bremsstrahlung emission were observed. The energy confinement time τ_E was found to increase roughly in proportion to the density. In the extremes of the two regimes $T_i \simeq T_e$.

In this report slideaway electrons are studied, using a soft X-ray measurement system[10)] which employs a liquid-nitrogen-cooled Si(Li)

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diode[11].

2. Pulse height analysis system

The schematic diagram of the system[12] is shown in Fig. 1(a). The system is equipped with four interchangeable apertures to assure a dynamic range in $\Delta S \Delta \Omega$ of about 1.6×10^4, where ΔS is the plasma area, and $\Delta \Omega$ is the solid angle. Four interchangeable filters made of beryllium (0, 15, 30 and 45 μm in thickness) are used to change the photon counting rate and to cut off low-energy photons. The system is placed at the port located at 90° from the molybdenum limiter. The block diagram of the electronic and data processing system is shown in Fig. 1(b).

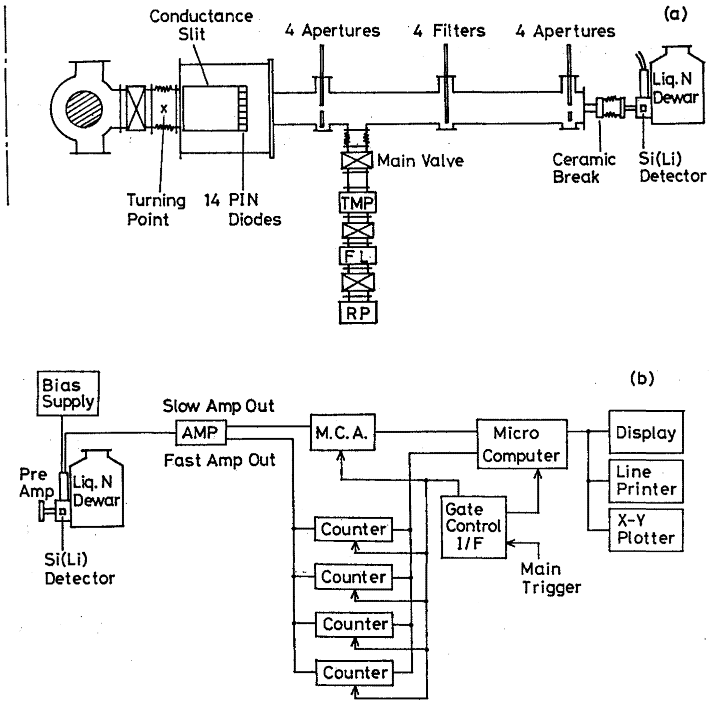


Fig. 1. (a) Schematic diagram of the pulse height analysis system.
(b) Block diagram of the electronic and data processing system.

3. Experimental results

A typical soft X-ray spectrum with correction of detecting efficiency is shown in Fig. 2. The molybdenum L-line is observed in the photon energy range from 2.2 to 2.8 keV. The electron temperature is determined from the slope of the spectrum in the energy range from 1.0 to 2.0 keV in case of the 15 μm Be filter. The comparison between the electron temperatures determined from the soft X-ray spectrum and those from Thomson scattering is shown in Fig. 3(a). The difference between them is within 15 % and the agreement is satisfactory. The typical plasma parameters described in this report are as follows: the toroidal magnetic field is 29 kG, and the plasma current, average electron density and ion temperature are shown in Fig. 3(b). The time evolutions of the enhancement factor (ζ) and Z-effective are shown in Fig.

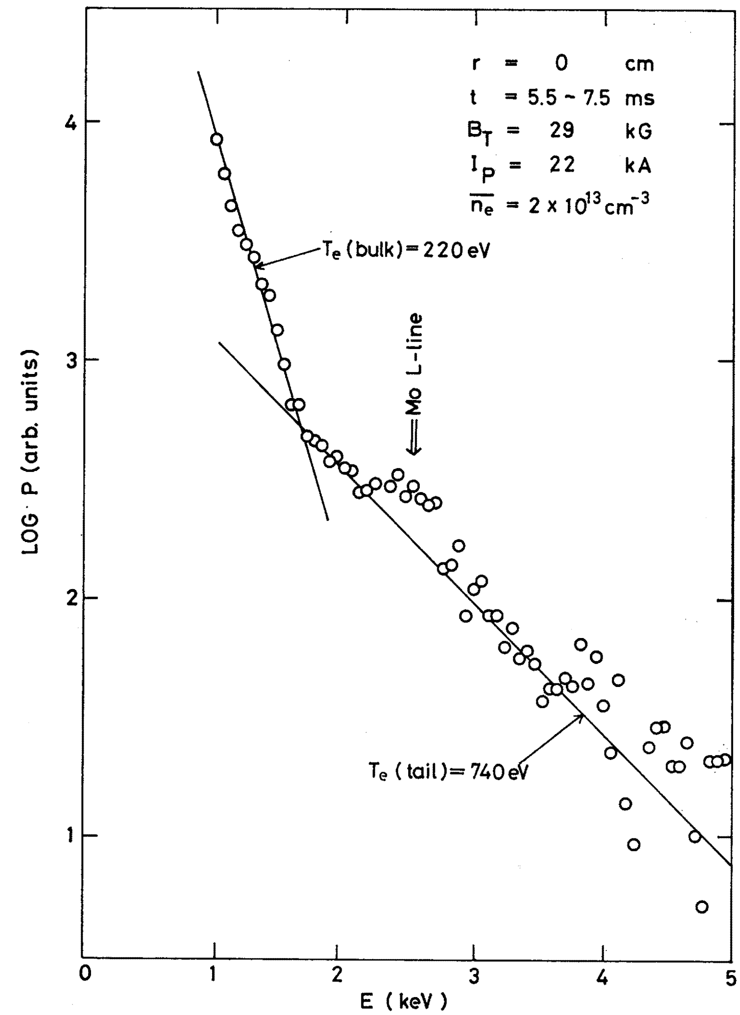
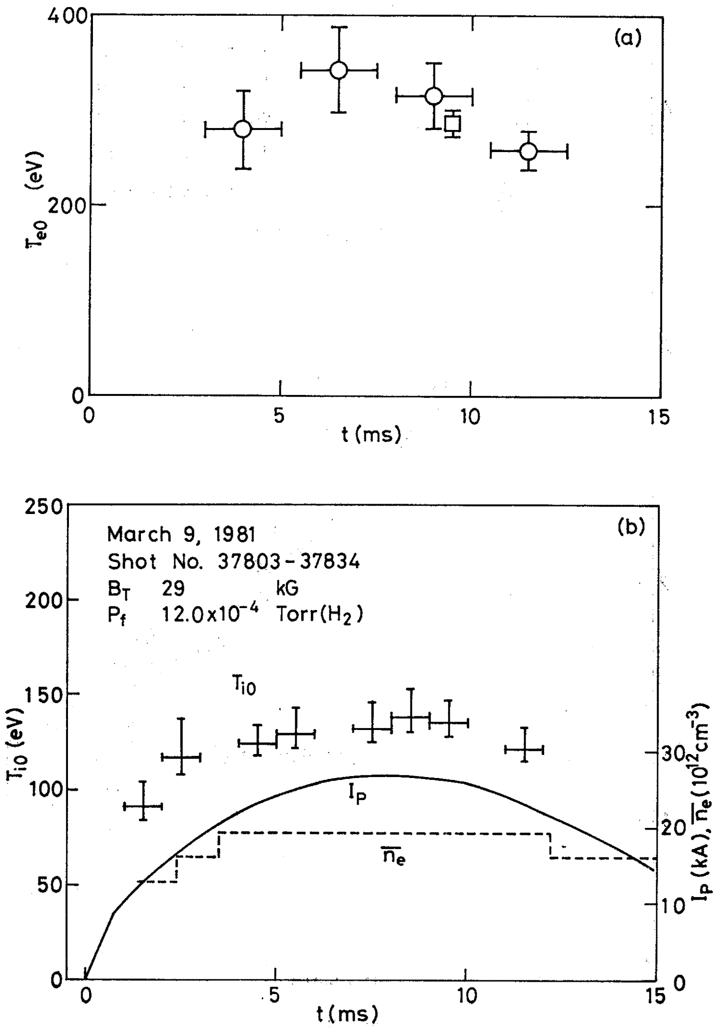


Fig. 2. Typical soft X-ray spectrum. *E* is the photon energy.

3(c). The enhancement factor is the ratio of the measured continuum intensity to the calculated bremsstrahlung intensity for pure hydrogen plasma. We calculate the intensity for pure hydrogen taking account of the Gaunt factor[13),14)] and the measured electron temperature and density distributions. The Z-effective is obtained assuming that the dominant plasma impurities are oxygen and they are in ionization equilibrium[15)].

As shown in Fig. 2 the electron energy spectrum consists of two-component Maxwellian: the low-temperature component represents bulk electrons and the high-temperature one represents tail electrons. The density of each component is calculated by using that the value of each



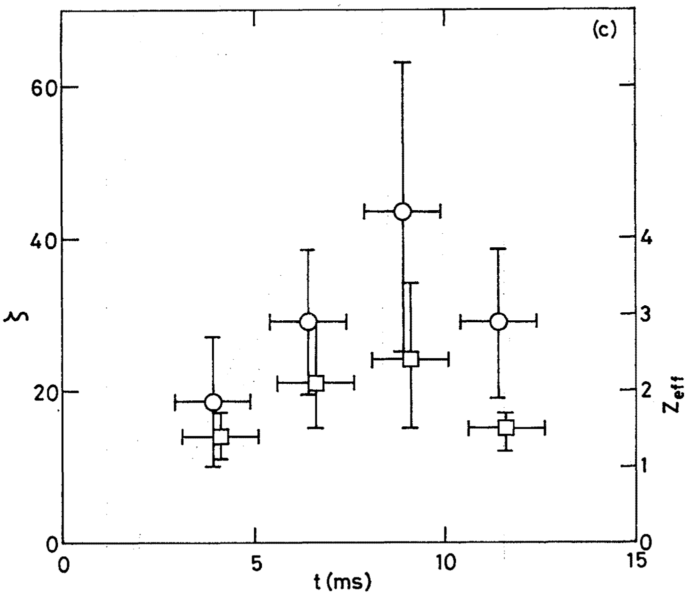


Fig. 3. (a) Comparison between electron temperatures determined from soft X-ray spectrum (○) and those from Thomson scattering (□).
(b) Time evolutions of the plasma current, average electron density and ion temperature.
(c) Time evolutions of the enhancement factor (○) and Z-effective (□). ζ and Z_{eff} are central values.

component at $E=0$ keV is proportional to $n_e/T_e^{1/2}$.

In this report the local streaming parameter ξ is defined as

$$\xi \equiv \frac{u_{//}}{v_{the}} = \frac{J_p/en_e}{(kT_e/m_e)^{1/2}}. \tag{1}$$

The current density J_p is calculated from the plasma current I_p, assuming that J_p is proportional to $T_e^{3/2}$. The electron temperature profile is shown in Fig. 4. The electron density profile was measured by Thomson scattering[16).

The ξ-dependence of the tail electrons are shown in Fig. 5. The ξ-value in the plasma center was changed from 0.1 to 0.4 by changing I_p from 10 to 30 kA. The ξ-value in case of $I_p=26$ kA was changed from 0.2 to 0.4 by changing the chord radius from 0 to 3 cm. As the ξ-value increases, T_e(tail) increases, T_e(tail)/T_e(bulk) increases, n_e(tail) decreases, and accordingly the energy density n_eT_e(tail) does not depend on the ξ-value.

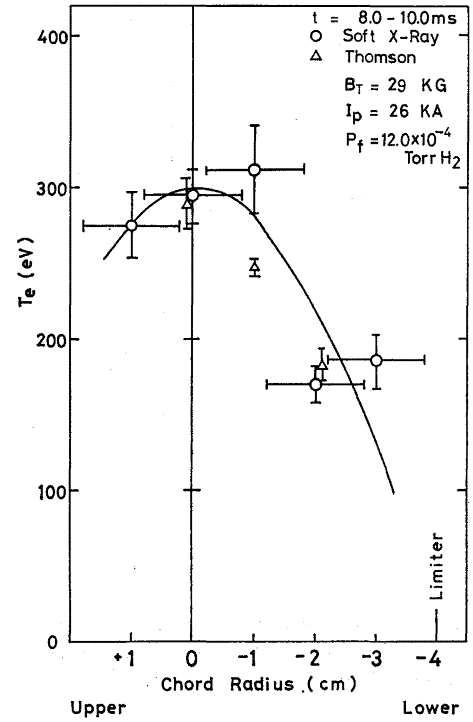


Fig. 4. Radial profile of the electron temperature.

4. Discussions and conclusions

The I_p-dependence of the electron temperature T_e and ion temperature T_i is shown in Fig. 6. The values T_e and T_i increase in proportion to the I_p-value. The average electron density n_e, however, does not depend on the I_p-value and is $2\times10^{13}\,\mathrm{cm}^{-3}$ in this experiment (the filling pressure is const.). Therefore the β-poloidal decreases in inverse proportion to the I_p-value. The ion temperature is about the half of the electron temperature, and the value is about equal to the Artsimovich's value[17]. If the above dependences, however, hold also in the higher plasma current region, the ion temperature is much higher than the Artsimovich's value, since the latter is proportional to $I_p^{1/3}$.

In this report we present the incipient experimental results concerning the slideaway electrons.

a. As the ξ-value increases, T_e(tail) increases, T_e(tail)/T_e(bulk) increases, n_e(tail) decreases, and the energy density n_eT_e(tail) does not depend on the ξ-value in the region $0.1\lesssim\xi\lesssim0.4$.

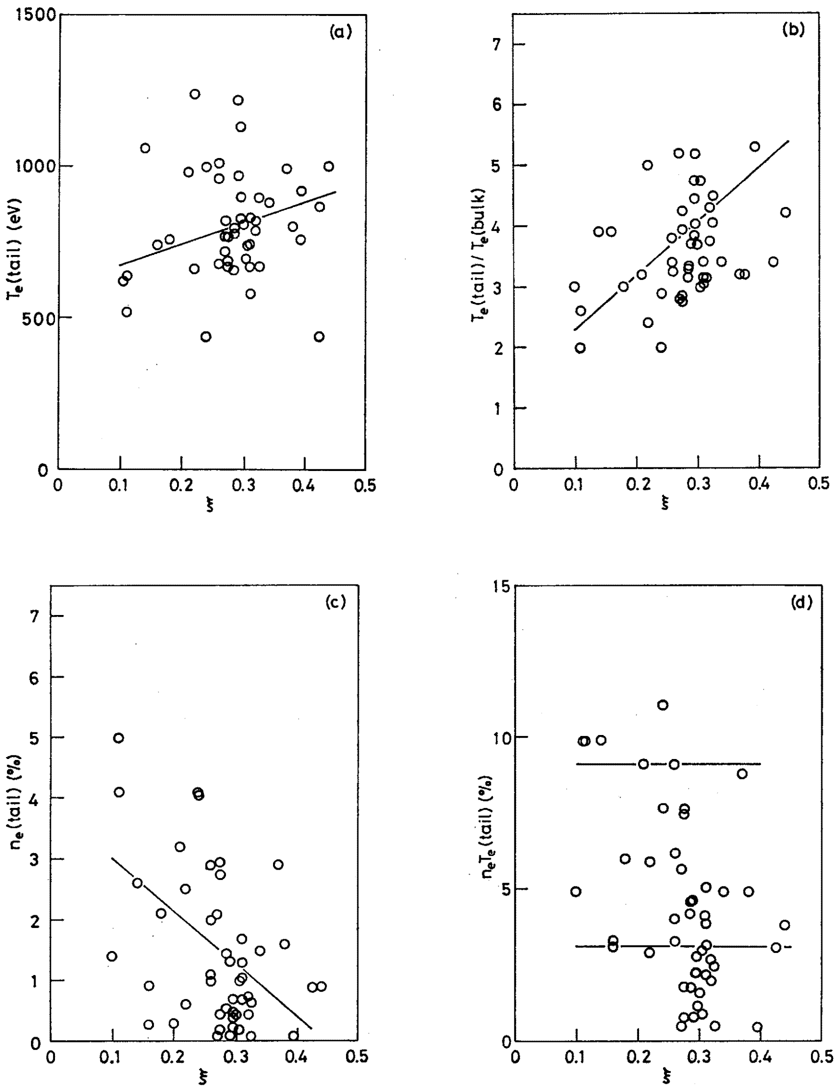


Fig. 5. ξ-dependence of the tail electron temperature (a), the ratio of the tail to the bulk electron temperature (b), the percentage of the tail electron density (c) and the percentage of the tail energy density (d).

The following experiments remain necessary:

a. the ξ-dependence of the electrical resistivity,

b. the ξ-dependence of the rf emission, and

c. the ξ-dependence in the region $\xi \lesssim 0.1$ and $\xi \gtrsim 0.4$.

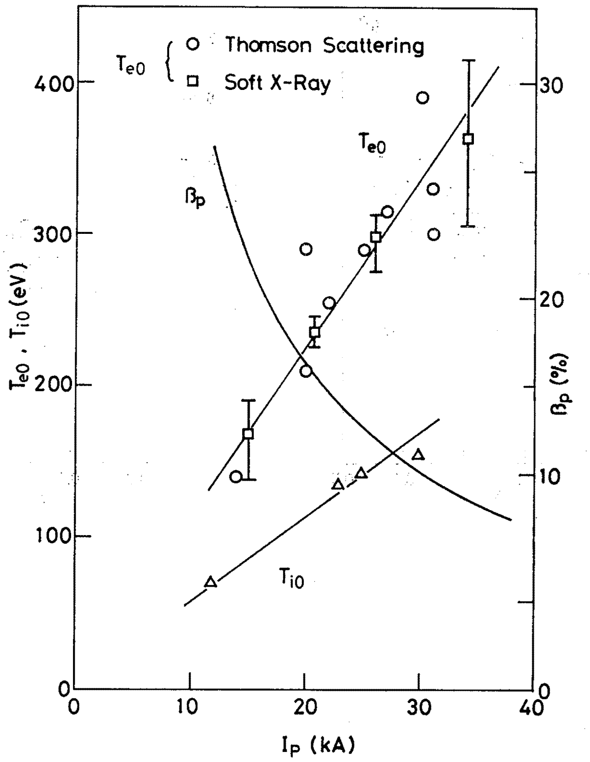


Fig. 6. I_p-dependence of the electron and ion temperatures and β-poloidal.

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