ION ENERGY SPECTRUM JUST AFTER THE APPLICATION OF CURRENT PULSE FOR TURBULENT HEATING IN THE TRIAM-1 TOKAMAK

Nakamura, Kazuo
Research Institute for Applied Mechanics, Kyushu University : Research Associate

Nakamura, Yukio
Research Institute for Applied Mechanics, Kyushu University : Research Associate

Hiraki, Naoji
Research Institute for Applied Mechanics, Kyushu University : Research Associate

Itoh, Satoshi
Research Institute for Applied Mechanics, Kyushu University : Professor

https://doi.org/10.5109/6777123

出版情報：Reports of Research Institute for Applied Mechanics. 29 (91), pp.49-59, 1981-07. 九州大学応用力学研究所
バージョン：
権利関係：

Reports of Research Institute for Applied Mechanics
Vol. XXIX, No. 91, 1981

ION ENERGY SPECTRUM JUST AFTER THE APPLICATION OF CURRENT PULSE FOR TURBULENT HEATING IN THE TRIAM-1 TOKAMAK

By Kazuo NAKAMURA*, Yukio NAKAMURA*,
Naoji HIRAKI* and Satoshi ITOH**

Temporal evolution and spatial profile of ion energy spectrum just after the application of current pulse for turbulent heating are investigated experimentally in TRIAM-1 and numerically with a Fokker-Planck equation. Two-component ion energy spectrum formed by turbulent heating relaxes to single one within τ_i (ion collision time).

1. Introduction

In the TRIAM-1 tokamak turbulent heating is studied experimentally as a further heating method[1]. The heating of ions is observed by neutral energy analyzer(NEA)[2]. The temporal resolution of NEA is limited by that of multi-channel scalor (MCS), $\Delta t = 100\ \mu$sec. The experimental results of turbulent heating are as follows concerning radial profile and temporal evolution of ion temperature.

1) Ion temperature is a monotonic decreasing function of minor radius before the application of current pulse ($t < 0\ \mu$s) and after that ($t > 100\ \mu$s). The measured central ion temperature is lower than the actual one due to the effect of impermeability of neutrals in plasma, and the measured peripheral ion temperature is higher than the actual one due to the effect of reflection of neutrals on vacuum chamber wall[3].

2) After the application of current pulse ($t > 100\ \mu$s) ion temperature returns to the initial temperature with time constant which is equal to the ion energy confinement time determined by neoclassical theory[4].

In this report we describe temporal evolution and spatial profile of ion energy spectrum just after the application of current pulse ($10\ \mu\text{s} < t < 100\ \mu\text{s}$).

2. Experimental equipment

The TRIAM-1 tokamak is a high-field tokamak; the toroidal field B_T

* Research Associate, Research Institute for Applied Mechanics, Kyushu University.
** Professor, Research Institute for Applied Mechanics, Kyushu University.

Table I. The discharge condition in this experiment

Toroidal field	B_T=29 kG
Plasma current	I_P=23 kA
Electron density	$\bar{n}_e$=2×10^{13} cm^{-3}
Filling pressure	P_f=12.4×10^{-4} Torr (H_2)

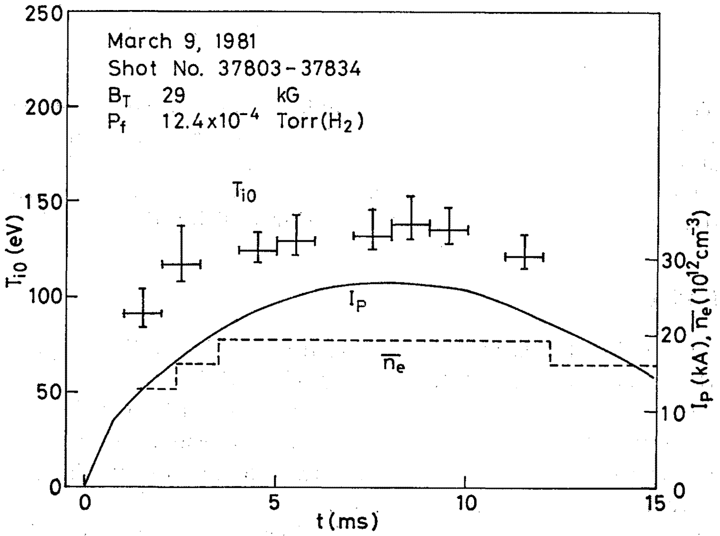


Fig. 1. The temporal evolution of plasma current, line-average electron density measured by a high-speed direct-reading type 140 GHz microwave interferometer[7] and central ion temperature without the application of current pulse for turbulent heating.

=40 kG, the major radius R=25.4 cm and the minor radius a_L=4 cm. The discharge condition in this experiment is summarized in Table I. The temporal evolution of plasma current, line-average electron density and central ion temperature is shown in Fig. 1. The energy spectrum of charge-exchanged neutrals is measured by NEA. In this experiment, however, MCS is not used because of the temporal resolution Δt=100 μs. The temporal evolution of pulse rate is measured by observing the series of pulses on the oscilloscope with temporal resolution Δt=10 μs.

3. Experimental results

Figure 2 shows the temporal evolution of neutral energy spectrum observed at the height z=−2 cm. The fitting curve (broken line) is determined assuming the spectrum is two-component Maxwellian; the low-temperature one characterizes bulk ions and the high-temperature one charactrizes high-energy tail ions. The bulk ion temperature increases gradually with time constant of about 100 μs as the temperature of high-energy tail ions decreases as shown in Fig. 3 and the number of the tail ions decrease. This implies that the energy of high-energy tail ions is transfered to bulk ions. But there is also a possibility of spatial energy flow. Figures 4 (a) and (b) show the temporal evolution of ion temperature profile. In Fig. 2 there was a possibility that the tail ions (observed at $z=0$ cm) emerged from the peripheral region. As shown in Fig. 4 (b), however, at $t=5.05-5.06$ ms there exist higher-temperature tail ions in the inner region than in the peripheral region. Accordingly the tail ions in Fig. 2 have emerged from the region near $r=2$ cm (r is minor radius of plasma).

From Figs. 4 (a) and (b) the tail ions in the peripheral region are

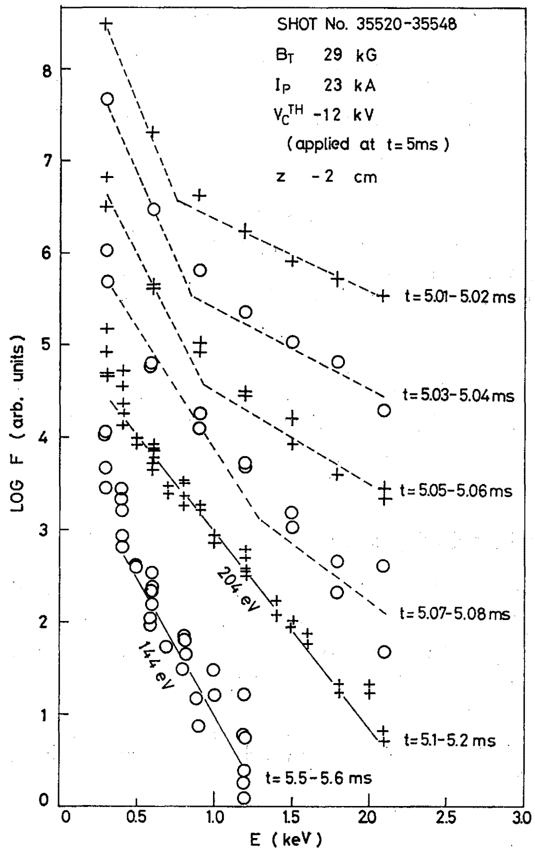


Fig. 2. The temporal evolution of ion energy spectrum observed at the height $z=-2$ cm. The minus sign of charged voltage V_C^{TH} of fast condenser bank for turbulent heating means a pulsed electric field of negative polarity.

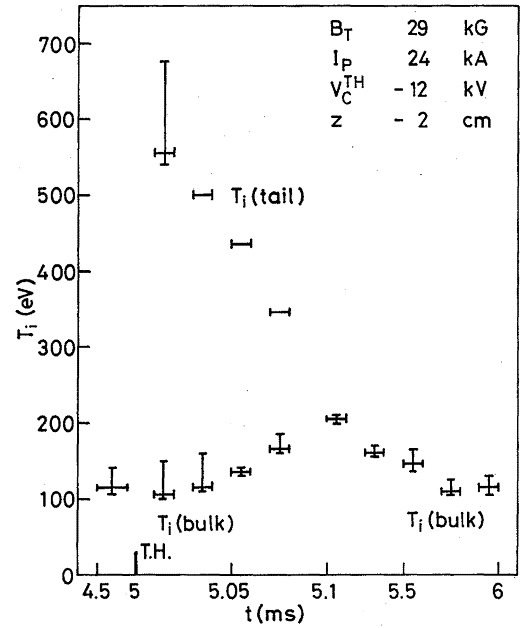


Fig. 3. The temporal evolution of tail ion temperature and bulk ion temperature observed at $z=-2$ cm. The current pulse for turbulent heating is applied at $t=5$ ms.

heated more than at the central region but the temperature decreases more rapidly. This is because high-energy ions in the peripheral region escape more easily to the wall.

4. Relaxation in velocity space

In this section we investigate the relaxation in velocity space numerically. For simplicity the followings are assumed: The ion distribution function is isotropic in velocity space and only the relaxation due to ion-ion collision is taken into account[5].

$$\frac{\partial f}{\partial \tau}=\frac{1}{3}\frac{\partial^2 f}{\partial^2 u}\left\{I_1+\frac{1}{u^3}I_4\right\}+\frac{2}{3u}\frac{\partial f}{\partial u}\left\{I_1+\frac{3}{2u}I_2-\frac{1}{2u^3}I_4\right\}+f^2, \tag{1}$$

$$u\equiv v/\left(\frac{2T_1}{M}\right)^{1/2}, \tag{2}$$

$$\tau\equiv t\times\frac{16\pi^2 Z^3 e^4 n_e}{M^2(2T_1/M)^{3/2}}\,\ell n\left(\frac{3T_1}{Z^2 e^2}L_D\right), \tag{3}$$

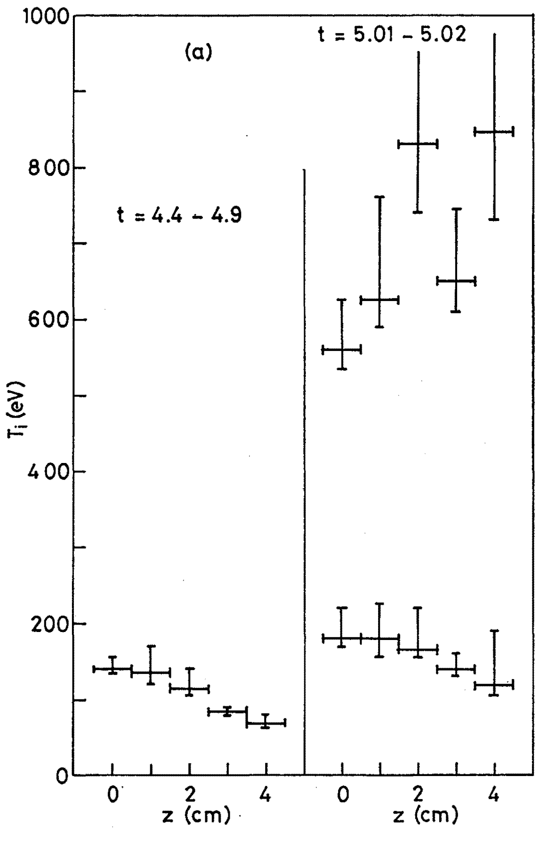
$$f \equiv f_1 \left(\frac{2T_i}{M} \right)^{3/2}, \tag{4}$$

$$I_1 \equiv \int_u^\infty u\, f \mathrm{d}u\,, \tag{5}$$

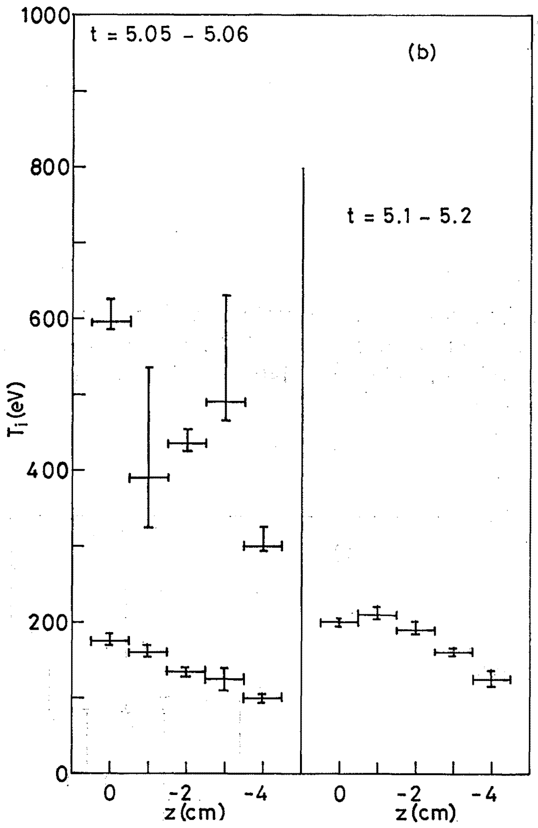
$$I_2 \equiv \int_0^u u^2\, f \mathrm{d}u\,, \tag{6}$$

$$I_4 \equiv \int_0^u u^4\, f \mathrm{d}u\,, \tag{7}$$

where v, T_i, M, t, Z, n_e and L_D are velocity, ion temperature, ion mass, time, ion charge, electron density and Debye length, respectively. The right hand side of eq. (1) consists of friction term and dispersion term. The former is



(a)



(b)

Fig. 4. The temporal evolution of radial profile of tail and bulk ion temperature. The current pulse for turbulent heating is applied at t=5 ms.

$$\left(\frac{\partial f}{\partial \tau}\right)_F = \frac{2}{u^2}\frac{\partial f}{\partial u} I_2 + 2f^2. \tag{8}$$

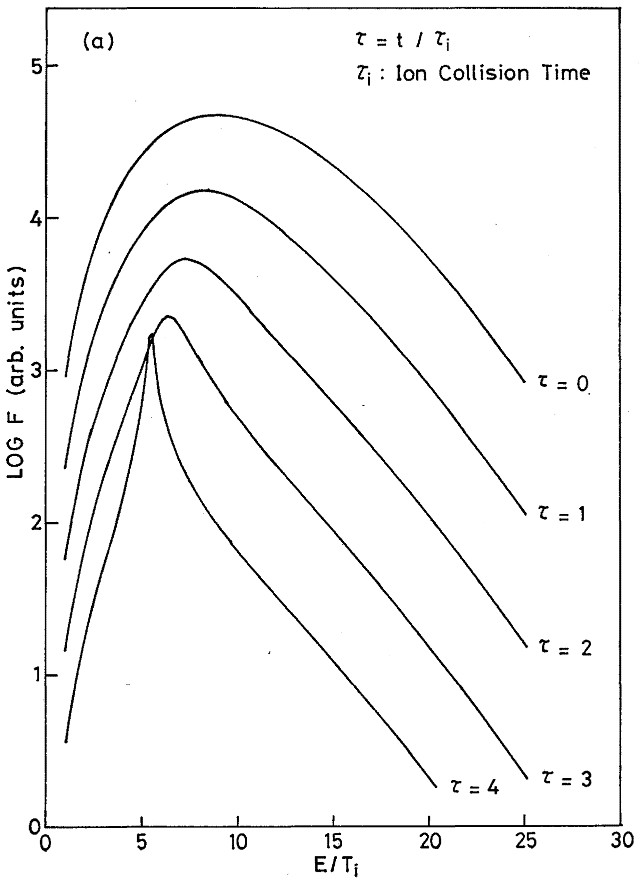
In order to know the role of each term the temporal evolution of beam whose drift veloctiy is 3 times as large as the ion thermal velocity. As shown in Figs. 5 (a) and (b) the friction term reduces the drift energy and the dispersion term reduces the peak of velocity distribution function. Figure 5 (c) shows the total temporal evolution. The τ-value in Fig. 5 is the time normalized by the ion collision time of Braginskii[6] and is different from τ defined by eq. (3).

Figure 6 shows the temporal evolution of two-component Maxwellian, whose initial distribution function simulates the energy spectrum during t=5.01-5.02 ms in Fig. 2: The number of tail ions is 10% of that of bulk ions and the temperature of tail ions is 8 times as high as that of bulk ions. The bulk ion temperature increases gradually as the number of high-energy tail ions decreases. The temperature of tail ions, however, does not decrease. The relaxation time is about 1000 μs since τ_i $=127$ μs in case of $\overline{n}_e=2\times10^{13}$ cm^{-3}, $T_i=144$ eV and $Z=1$.

5. Comparison of experimental and computational results

Comparison of Figs. 2 and 6 shows the difference in relaxation of energy spectrum and the relaxation time.

i) In Fig. 2 the bulk ion temperature increases gradually as the *temperature* of tail ions decreases and the number of tail ions decreases, while in Fig. 6 the buik ion temperature increases gradually

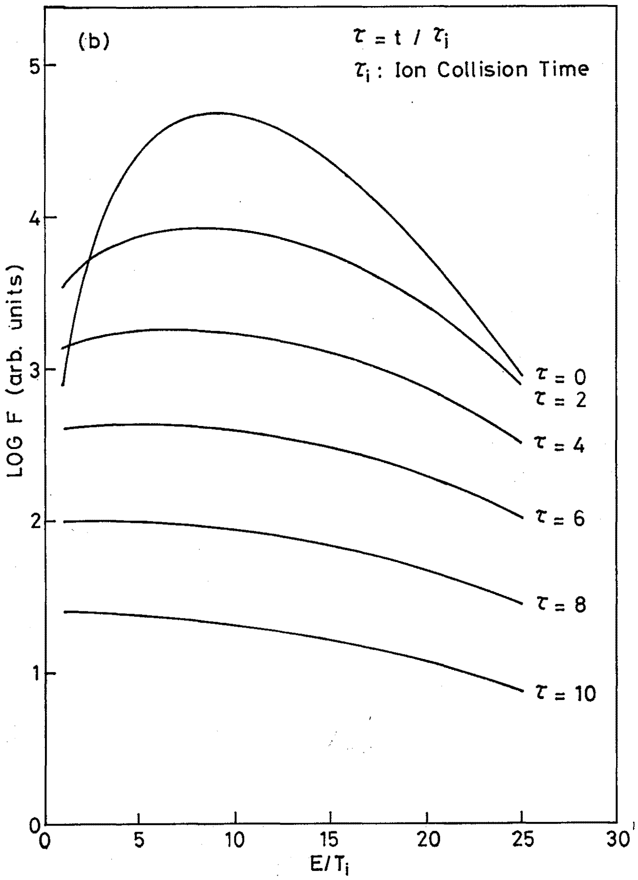


(a)

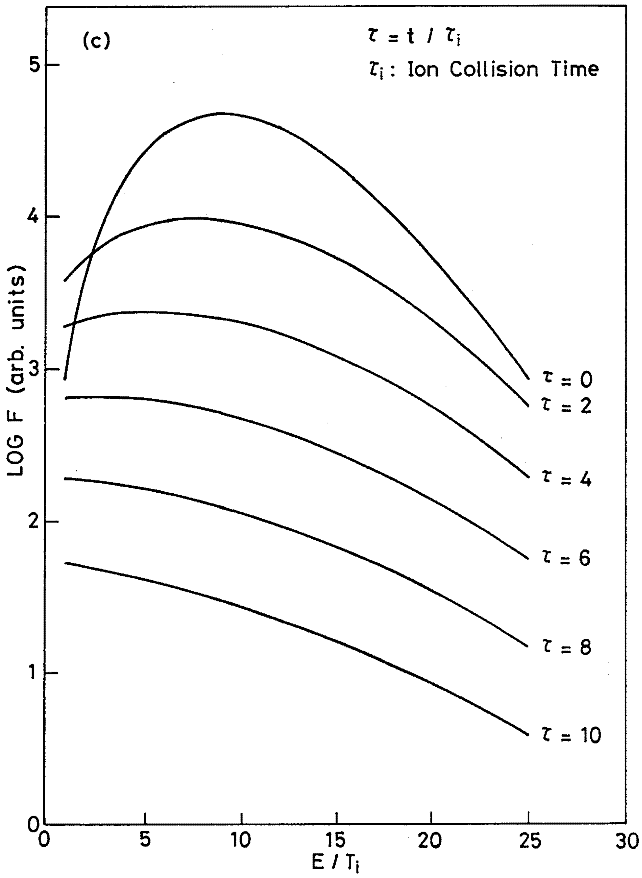
as the number of high-energy tail ions decreases but the *temperature* does not decreases.

ii) As shown in Fig. 2 the two-component Maxwellian relaxes to one-component Maxwellian with time constant of about 100 μs which is equal to τ_i, while according to the numerical simulation with time constant of about 1000 μs as shown in Fig. 6.

Concerning the former the reason why the temperature of tali ions does not decreaes in numerical simulation is as follows: The escape of the tail ions from perpendicular velocity space to parallel one and the escape of the tail ions to the wall in real space are not taken into account. concerning the latter the assumption $Z_{eff}=2$ (which results from weak turbulence caused by turbulent heating) would reduce the difference, since collision time decreases in proportion to Z_{eff} cubed.



(b)



(c)

Fig. 5. The temporal evolution of velocity distribution function of ion beam whose drift velocity is 3 times as large as the ion thermal velocity: The initial distribution is $f(u)=\{0.026/\pi^{3/2}\}\exp\{-(u-3)^2\}$, where the constant 0.026 is the normalizing constant. Only friction term is considered in (a), only dispersion term in (b) and both in (c).

6. Conclusion

Just after the application of current pulse for turbulent heating in the toroidal direction ($10\,\mu s < t < 100\,\mu s$), two-component ion energy spectrum formed by turbulent heating relating relaxes to single one within τ_i (ion collision time).

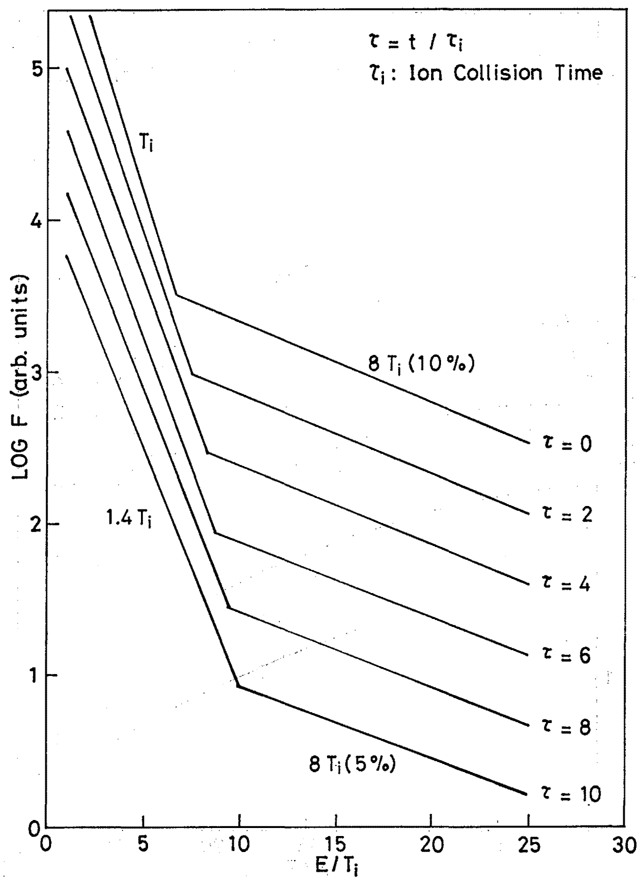


Fig. 6. The temporal evolution of two-component Maxwellian, whose initail distribution function simulate the energy spectrum during $t=5.01$–5.02 ms in Fig. 2; $f(u)=\{0.91/\pi^{3/2}\}\exp\{-u^2\}+\{0.091/(8\pi)^{3/2}\}\exp\{-u^2/8\}$. The τ-value is the time normalized by the ion collision time of Braginskii.

Acknowledgements

The authors would like to express their gratitude to Mr. S. Kawasaki and Mr. H. Nakashima for their technical assistance in the experiments.

The numerical solution of a Fokker-Planck equation was obtained on MELCOM COSMO 900 computer system at Research Institute for Applied Mechanics.

References

1) Hiraki, N., Itoh, S., Kawai, Y., Toi, K., Nakamura, K. and Mitarai, O.: *Confinement of Ohmically Heated Plasmas and Turbulent Heating in High-Magnetic-Field Tokamak TRIAM*-1, Reports of Research Institute for Applied Mechanics **27** No. 85 (1979) 85.
2) Nakamura, K., Hiraki, N., Toi, K. and Itoh, S.: *Ion Temperature Measurement by Neutral Energy Analyzer in High-Field Tokamak TRIAM*-1, Reports of Research Institute for Applied Mechanics **27** No. 86 (1980) 125.
3) Nakamura, K., Hiraki, N., Toi, K. and Itoh, S.: *Derivation of the Radial Profile of Ion Temperature from the "Measured" Energy Spectra of Charge-Exchanged Neutrals*, Reports of Research Institute for Applied Mechanics **28** No. 87 (1980) 1.
4) Toi, K., Hiraki, N., Nakamura, K., Mitarai, O., Kawai, Y. and Itoh, S.: *Observation of Bulk-Ion Heating in a Tokamak Plasma by Application of Positive and Negative Current Pulses in TRIAM*-1, Nucl. Fusion **20** No. 9 (1980) 1169.
5) Montgomery, D. C. and Tidman, D. A.: *Plasma Kinetic Theory* (McGraw-Hill, 1964) 34.
6) Braginskii, S. I.: *Transport Processes in a Plasma, Reviews of Plasma Phys.* (Consultants Bureau, New York, 1965) Vol. 1, 215.
7) Mitarai, O., Nakashima, H., Nakamura, K., Hiraki, N., Toi, K., Kawai, Y. and Itoh, S.: *Electron Density Measurements in the TRIAM*-1 *Tokamak*, Reports of Research Institute for Applied Mechanics **27** No. 86 (1980) 147.

(Received April 28, 1981)