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Fission fragment angular distributions and fission cross sections have been measured for the ^{19}F + ^{181}Ta reaction over the bombarding energy range from 99.2 to 159.3 MeV. The experimental K_0^2 values are extracted from the fission fragment angular distributions. The K_0^2 values are compared with the calculated values using J_{eff} obtained from a rotating finite range model (RFRM) and a rotating liquid drop model (RLDM). The calculated K_0^2 values by RFRM agree with the data better than those calcualted by RLDM.

Keywords: Fission, ^{19}F + ^{181}Ta Reaction, High Angular Momentum, Bass Model, Liquid Drop Model, Statistical Model, Excitation Energy

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$^{19}F + ^{181}Ta$ 反応における高角運動量状態からの核分裂片の角度分布

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(1991年10月14日受理)

高角運動量状態からの核分裂片の角度分布は，複合核のサドル点における変形に関する情報をもっている。原子核の形状に関する情報で，測定データから，その情報（K_0^2 の値）を求め，それを既存の2つの理論（Rotating liquid drop model と Rotating finite range model）と比較した。その結果，Rotating finite range model による予想値とより一致をする事が分かった。又，核分裂断面積のデータを今までの報告より高励起エネルギーまでとる事ができ，Bass model による予想値と比較できた。

その結果，測定データは，高励起エネルギー領域（100 MeV 以上）で理論値より大きくなっている事がわかった。これらの結果は，高励起・高角運動量状態からの核分裂現象を理解する上で重要である。

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1. Introduction

Fission decay mode of excited compound nucleus produced in heavy ion fusion reaction has been studied experimentally and theoretically. The measurements of fission fragment angular distributions and excitation functions are important to test the validity of current theories.

The ^{19}F + ^{181}Ta fusion reaction has been studied(1,2) in a bombarding energy range from 80 to 125 MeV. In this paper we present the experimental results of excitation functions and angular distributions of fission fragments in the ^{19}F + ^{181}Ta fusion reaction in the energy range from 99.2 to 159.3 MeV. The measured results of fission excitation function are compared with the statistical model calculation using the code PACE2(3). The K_0^2 values extracted from the fission fragment angular distributions are compared with the calculated values using J_{eff} obtained from a rotating finite range model (RFRM) and a rotating liquied drop model (RLDM).

2. Experimental Procedure

The experiment was performed at the JAERI tandem accelerator. A self supporting target ^{181}Ta of thickness of 0.8 mg/cm^2 was bombarded by the ^{19}F beam of 99.2, 109.2, 114.2, 119.2, 124.2, 129.3, 135.3, 143.5, 151.3 and 159.3 MeV. Fission fragment were detected and identified using a gas ionization chamber. The gas ionization chamber consists of a single anode (ΔE) and 8 energy counters (E), which enable to measure fission fragment at 8 different laboratory angles. The gas ionization chamber was filled with 10 Torr isobutane gas. A polyester foil of thickness 65 μg/cm^2 was used as an entrance window of the ionization chamber. Fission fragment angular distributions were measured at laboratory angles between 30° and 172°. The total fission cross sections were obtained from the angular distribution data by fitting them with Legendre polynomial with even terms up to sixth degree. In the transformation from the laboratory to the centre-of-mass systems, the total kinetic energy estimated via Viola's systematics(4) was used.

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3. Results and Discussions

The meausred fission cross sections of the ^{19}F + ^{181}Ta reaction are listed in Table 1 and are plotted in Fig. 1 as a function of the bombarding energy E_{Lab}. In the figure the present data are shown by the solid circles. The present data agree with the measured values of Charity(1) and Forster(2), which are shown as open circles and triangles in Fig. 1, in the over lapping energy region. The solid line in the figure is the calculated result of the statistical model code PACE2. In this calculation the fusion cross section was estimated by the Bass model(5), which is shown by the dashed curve. The level density parameter of a = A/10, where A is the mass number, and the ratio of the level density parameter of the saddle point deformation to the ground state deformation a_f/a_n = 1 was assumed. The fission barrier height B_f was assumed to be $0.91B_{RFRM}$ according to the analysis of ref.(1), where B_{RFRM} is a value calculated by RFRM. Although the agreement between the measured fission cross section and the calculated results is good at lower bombarding energies, the theoretical prediction underestimates the fission cross section at higher bombarding energies. The calculated fission cross section increases with increasing the ratio a_f/a_n and decreasing B_f. However, the ratio a_f/a_n is limited in the range 1.00-1.04 to reproduce the pre-scission neutron data(6).

The measured fission fragment angular distributions of the ^{19}F + ^{181}Ta reaction are shown in Fig. 2. The solid curves represent the best fit to the data obtained by using the expression:

$$W(\theta) = \pi\lambda^2 \sum_{\ell=0}^{\infty}(2\ell+1)T_\ell \sum_{k=-\ell}^{\ell} 0.5(2\ell+1)|d^\ell_{0k}(\theta)|^2 \exp(-k^2/2k^2)/ \sum_{k=-\ell}^{\ell}\exp(-k^2/2k_0^2), \quad (1)$$

were T_ℓ is a transmission coefficients and K is the projection of the angular momentum on the nuclear symmetry axis. The transmission coefficients were determined to reproduce the experimental evaporation residue cross sections and fission cross sections(1). The fits to the experimental angular distributions shown in Fig. 2 were obtained by varying K_0^2, which is the only one free parameter in this expression. The obtained K_0^2 values are listed in Table 2 as a function of the compound nucleus excitation energy and are plotted in Fig. 3 as solid circles.

The parameter K_0^2 was calculated as $K_0^2 = J_{eff}T/\hbar$, where J_{eff} is the effective moment of inertia, $J_{eff} = J_{\parallel} J_{\perp} / (J_{\perp} - J_{\parallel})$, at the saddle point; $J_{\parallel}$ and $J_{\perp}$ are the moments of inertia parallel and perpendicular to the symmetric axis, respectively. The nuclear temperature T at the saddle point was estimated as $T = \sqrt{(U-B_f-E_{rot})/a}$, where U is the excitation energy of the compound nucleus and E_{rot} is the rotation energy at the saddle point. The theoretical K_0^2 values have been calculated using the J_{eff} values obtained by RFRM and RLDM. In Fig. 3 the solid line and the dashed line represent the calculated results assuming these J_{eff} estimated by RFRM and RLDM at the average angular momentum for each excitation energy, respectively. The calculated K_0^2 values by RFRM agree with the data better than those calculated by RLDM. The calculated K_0^2 values, however, deviate from the data with increasing excitation energy.

The fission fragment anisotropies W(180°)/W(90°) are shown in Fig. 4 as a function of the compound nucleus excitation energy. The data show that the fission fragment anisotropies become constant in the excitation energy range from 82.6 to 114.3 MeV. The two model calculations are also shown in the figure. The anisotropies at high excitation energies are reproduced by RFRM.

4. Summary

We have measured fission cross sections and fission fragment angular distributions over the bombarding energy range from 99.2 to 159.3 MeV. The experimental K_0^2 values are extracted from the fission fragment angular distributions. The calculated K_0^2 values by RFRM agree with the present data better than these of RLDM. However the calculation of RFRM underestimates values at high bombarding energy. The fission fragment anisotropies become constant in the excitation energies of compound nucleus range from 82.6 to 114.3 MeV. Further investigation of the fission fragment angular distribution at the high excitation energy is necessary to clarify the throretical models.

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We wish to thank the crew of the JAERI tandem accelerator for their cooperation during the experiment.

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Table 1 Fission cross sections as a function of the bombarding energy

E_{lab}(MeV)	U(MeV)	σ_{fiss}(mb)
99.2	59.9	152±23
109.2	69.0	428±43
114.2	73.5	578±58
119.2	78.0	721±72
124.2	82.6	835±84
129.3	87.2	937±94
135.3	92.6	1054±158
143.5	99.1	1262±126
151.3	107.1	1331±133
159.3	114.3	1434±143

Table 2 The experimental K_0^2 values as a function of the compound nucleus excitation energies U

E_{lab}(MeV)	U(MeV)	K_0^2(exp.)	K_0^2(RFRM)	K_0^2(RLDM)
99.2	59.9	97±10	110	94
109.2	60.0	110±10	123	107
114.2	73.5	118±10	130	113
119.2	78.0	128±10	136	118
124.2	82.6	147±12	138	123
129.3	87.2	157±12	148	128
135.3	92.6	174±15	156	135
143.5	99.1	195±15	171	144
151.3	107.1	205±15	181	152
159.3	114.3	220±15	195	158

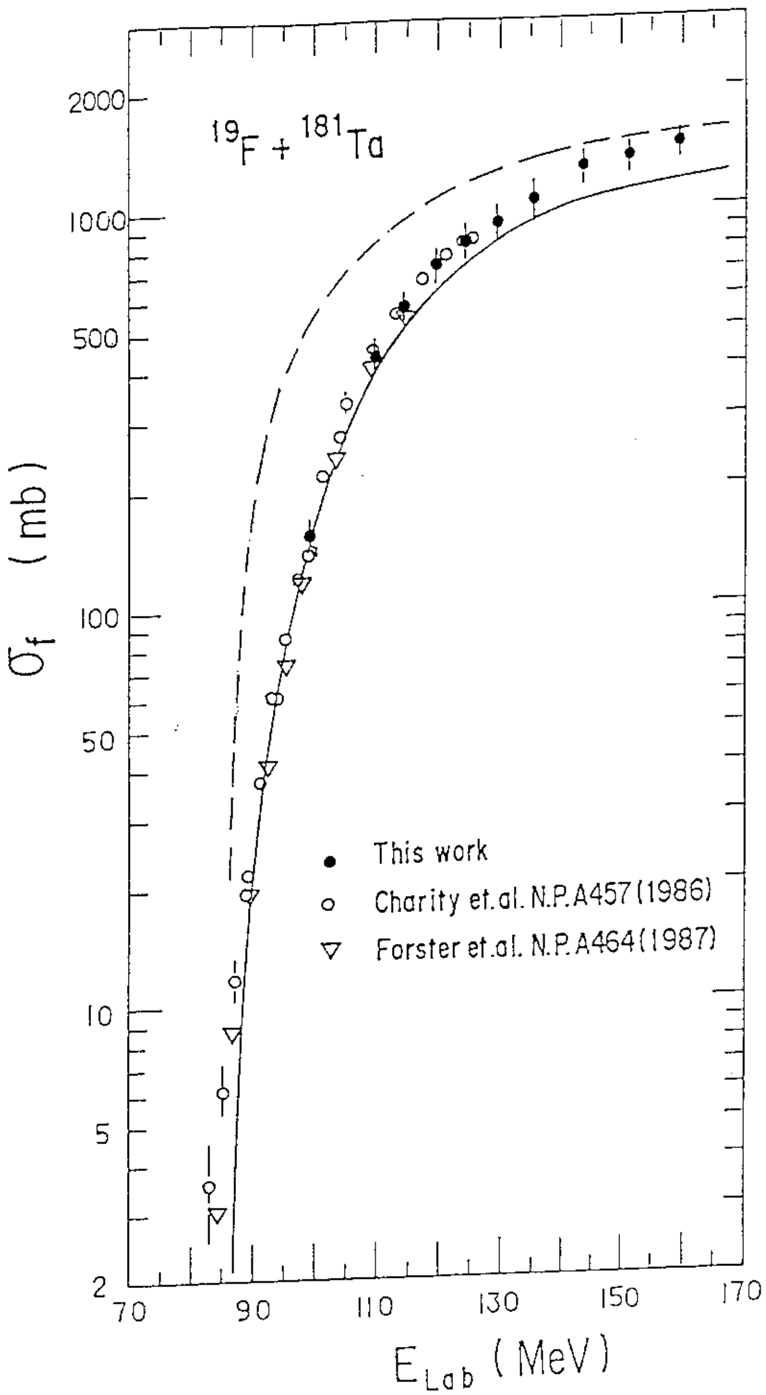

Fig. 1 Experimental fission excitation function for the $^{19}F + ^{181}Ta$ reaction together with the calculations of statistical model code PACE2. The solid line and dashed line represent the calculated fusion and fission cross sections, respectively. The fussion cross section is calculated by the Bass model. The present data are represented by the solid circles and the fission cross sections measured by Charity[1] and Forster[2] are represented by open circles and triangles, respectively.

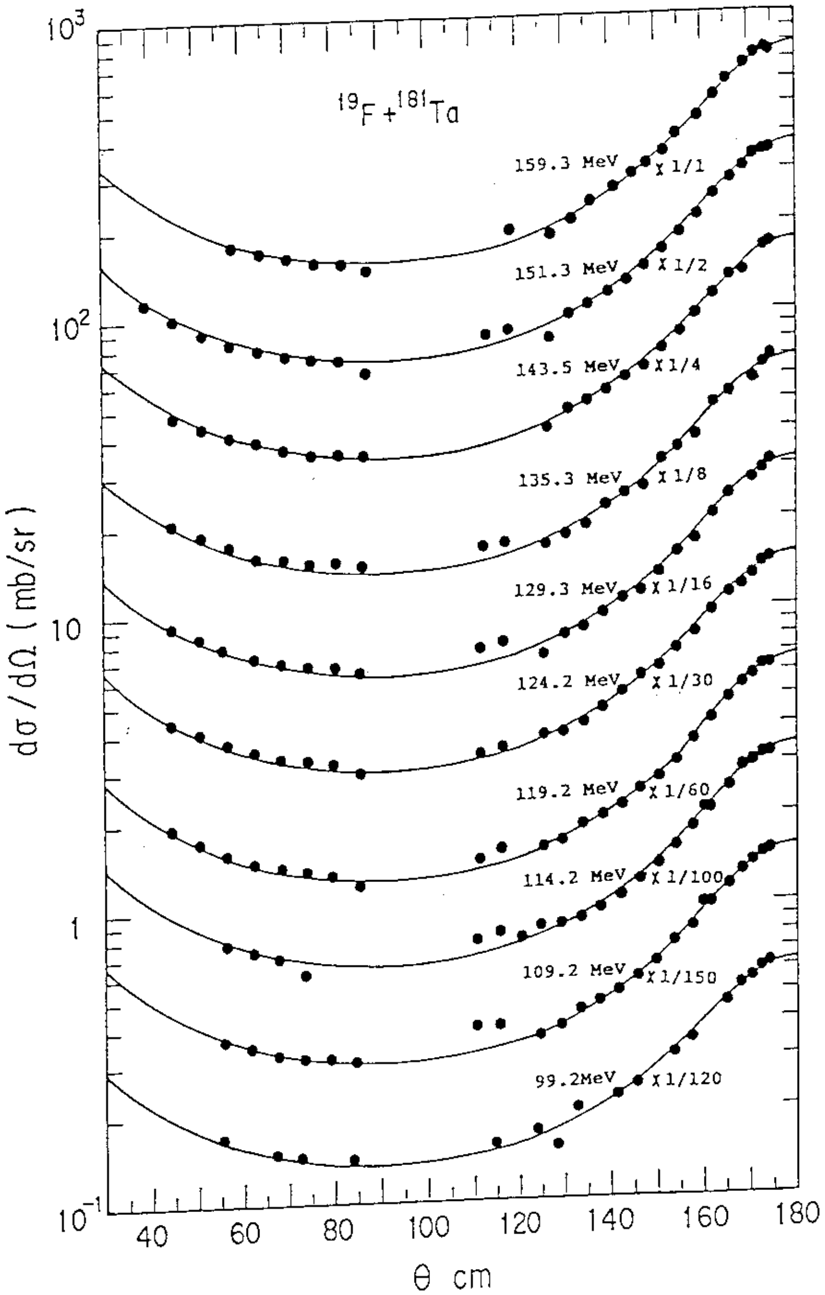

Fig. 2 Fission fragment angular distributions for the $^{19}F + ^{181}Ta$ reaction at ten bombarding energies. The solid lines are the theoretical calculations of eq.(1)(see text).

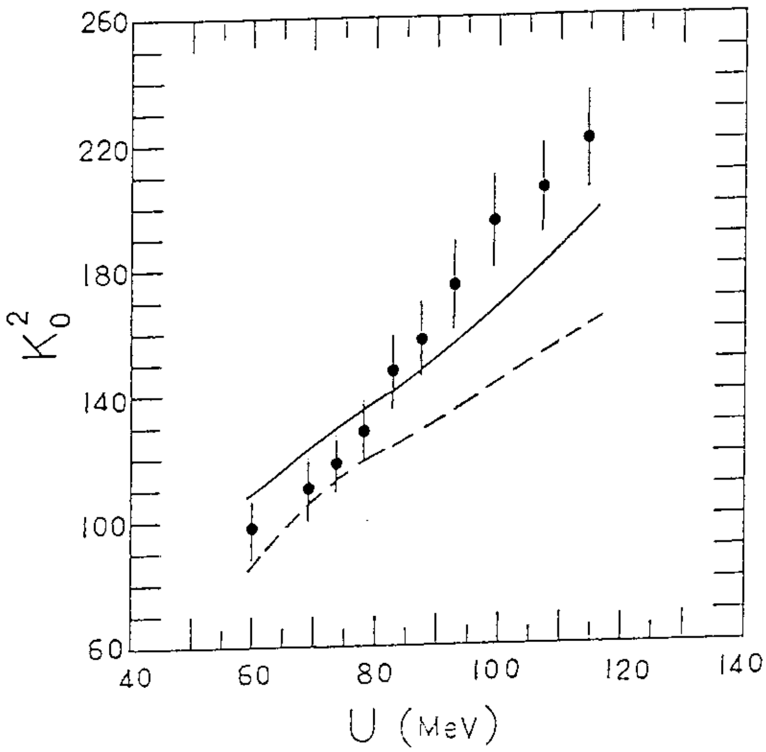

Fig. 3 K_0^2 as a function of the compound nucleus excitation energy U. The solid circles represent the K_0^2 values extracted from the experimental fission fragment angular distributions. The solid line and the dashed line represent the calculated values with J_{eff} estimated by RFRM and RLDM, respectively.

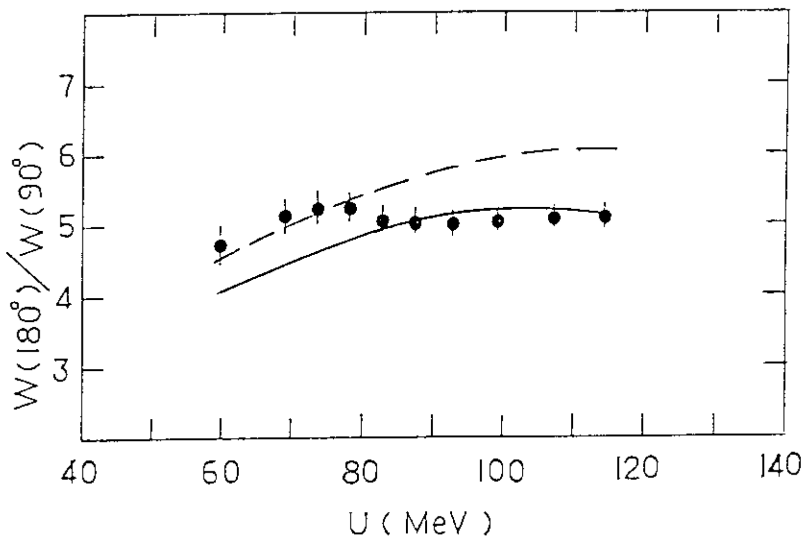

Fig. 4 Fission fragment anisostropies as a function of the compound nucleus excitation energy U. The solid line and the dashed line represent the calculated results by RFRM and RLDM, respectively.