To our knowledge, no other experimental data have been found for the $^{174}Hf(n,\gamma)$ ^{175}Hf reaction up to now. These cross sections given by present measurements are the first experimental data. The main uncertainties came from the counting statistics in γ-activities, the standard cross section, the efficiency of γ-ray full energy peak, various corrections, ect.

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Mass Distributions of 22.0 MeV Neutron-induced Fission of ^{238}U

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【abstract】*Chain yields of 32 chains were determined for the fission of ^{238}U induced by 22.0 MeV mono-energetic neutrons for the first time. Fission product activities were measured by HPGe γ-ray spectrometry without chemical separation. Absolute fission rate was monitored with a double-fission chamber. The efficiency of the fission chamber was checked by determination of ^{198}Au activity from $^{197}Au(n,\gamma)$ ^{198}Au reaction[1].*

Introduction

The mass distributions in fission of ^{238}U has been extensively investigated, but only a few of those investigations deal with fission induced by mono-energetic neutrons. S. Nagy et al. Studied the mass distribution of ^{238}U with mono-energetic neutrons of 1.5, 2.0, 3.9, 5.5, 6.9, and 7.7 MeV [2]. Champman et al. determined the mass distribution for the fission of ^{238}U induced by neutrons with energies of 6.0, 7.1, 8.1, and 9.1 MeV[3]. Some of the determination of the fission product yields of ^{238}U induced by mono-energetic neutrons were also measured at CIAE. For instance, Li Ze et al. at 8.3 MeV neutrons [4], Zhang Chunhua et al. at 3.0 MeV neutrons[5], and Wang Xiuzhi et al. at 5.0 MeV neutrons[6]. And Su Shuxin et al. measured the mass distribution for the fission of ^{238}U with fission spectrum neutrons[7]. Several other measurements of the mass distribution are with 14MeV neutrons[8, 9]. In this work, measurements were carried out for the mass distribution of the fission of ^{238}U induced by 22.0 MeV neutrons, and 32 chain yields were obtained.

1 Experiment

The experiment was carried out at the HI-13 Tandem of CIAE. The tritium gas chamber was used to produce neutrons by the bombardment with the deuteron beam [10].

The neutron spectrum was measured with TOF technique in order to estimate the fission events by the low energy neutrons of energy between 0.8~8 MeV from D(d,np) ^{2}H and D(d,n) ^{3}He reaction, and from the scattering by environment. The ratio of low energy neutron fission events to 22.0 MeV neutron fission events was estimated. The samples used in the neutron irradiation were uranium metal disks of 1.6 cm diameter×0.05cm thickness with an average weight of about 1.5 g. The uranium disks were packaged in a pure aluminum foil of 0.2 mm thickness. The sample, which was sandwiched between standardized thin samples to monitor the fission rate absolutely, was mounted in double fission chamber. The efficiency of the fission chamber was checked by $^{197}Au(n,\gamma)$ ^{198}Au reaction with thermal neutrons. The standardized thin samples were made of the same natural uranium as the thick samples.

The double fission chamber was covered with cadmium of 1 mm thickness in order to shield it from the thermal neutrons from the environment. Four samples were irradiated for a period varying form 0.5 to 30 h at a distance of about 5 cm from the neutron source in the direction of zero degree.

After the irradiation, the samples were measured by a HPGe-92X Spectrum Master of γ-spectrometer. The resolution of the 120 cm^3 HPGe detector made by ORTEC Company, USA, was 1.85 keV (FWHM) for the 1.33 MeV γ-ray of ^{60}Co. The γ-rays spectra were collected successively over a period varying from several hours up to two months to encompass the wide range of half-life of fission products involved, and to eliminate the cross interfering of the γ-ray from product nuclides of almost the same energy that can not be resolved by the HPGe detector.

Table 1 Fission product γ decay data used in fission yield measurement [11]

Product Nuclide	Energy (keV)	Half-life (min)	γ Intensity (%)
^{84g}Br	881.2	31.8	42
^{85m}Kr	304.9	268.8	14.0
^{87}Kr	402.6	76.3	49.6
^{88}Kr	196.3	170.4	25.58
^{89}Rb	1248.1	15.15	42.57
^{91}Sr	555.6	577.8	61.5
^{92}Sr	1384.1	162.6	90
^{93}Y	266.9	610.8	7.3
^{94}Y	918.8	18.7	56
^{95}Zr	756.7	92189	54.46
^{97}Zr	742.7	1014	93.06
^{99}Mo	739.5	3956.7	12.14
^{101}Tc	306.5	14.2	88
^{103}Ru	497.1	56526	90.9
^{104}Tc	358	18.3	89
^{105}Ru	724.2	266.4	47.3
^{112}Ag	617.5	187.8	43.5
^{115}Cd	336.3	3208.3	50.1
^{127}Sb	473.2	5544	25.6
^{128}Sn	482	59.1	59
^{131}I	637	11577.6	7.17
^{132}Te	228.3	4694.4	88.2
^{133}I	529.8	1248	87
^{134}I	847.1	52.6	95.4
^{135}I	1131.5	394.2	22.74
^{138}Cs	1435.8	33.41	76.3
^{140}Ba	537.3	18354	24.39
^{141}Ba	190.3	18.27	46
^{142}La	641.3	91.1	47.4
^{143}Ce	293.3	1980	42.8
^{146}Pr	453.9	24.15	48
^{147}Nd	531	15811.2	13.1

Table 2 Chain yields of ^{238}U fission induced by 22.0 MeV neutrons

Mass Number	Yield / %	error
84	0.79	±0.108
85	1.63	±0.096
87	1.90	±0.041
88	2.67	±0.052
89	3.68	±0.107
91	3.58	±0.019
92	3.94	±0.017
93	4.21	±0.237
94	3.99	±0.058
95	5.81	±0.089
97	6.09	±0.180
99	5.99	±0.103
101	5.03	±0.083
103	4.02	±0.024
104	3.67	±0.093
105	3.32	±0.025
112	1.63	±0.016
115	1.41	±0.040
127	1.78	±0.024
128	2.06	±0.865
131	3.96	±0.073
132	4.31	±0.053
133	5.69	±0.021
134	6.04	±0.178
135	6.03	±0.232
138	4.76	±0.126
140	4.05	±0.044
141	3.81	±0.213
142	3.52	±0.070
143	3.64	±0.019
146	2.18	±0.129
147	1.75	±0.140

2 Results and Discussion

The decay data used[11] and 32 chain yields measured are given in Table 1 and Table 2 respectively. The yields were calculated from the directly collected γ-ray spectra. For chain A→B→C, if half life of nuclides before A is much shorter than A's, B can be measured by gamma spectrum method, then accumulative yield of A can be calculated from:

$$Y_A = \frac{AR_B}{I_\gamma \varepsilon_\gamma M f_s f_\Omega f_c f_n \{ \frac{\lambda_B}{\lambda_A(\lambda_B-\lambda_A)} K_A M_A + (\frac{Y_B}{\lambda_B Y_A} - \frac{\lambda_A}{\lambda_B(\lambda_B-\lambda_A)}) K_B M_B \}}$$

where $K_A = [1-\exp(-\lambda_A \Delta t)]\exp(-\lambda_A \Delta t_1)$;

$K_B = [1-\exp(-\lambda_B \Delta t)]\exp(-\lambda_B \Delta t_1)$;

$$M_{\mathrm{A}}=\sum_{i=1}^{n}N_i[1-\exp(-\lambda_{\mathrm{A}}\Delta T_i)]\exp(-\lambda_{\mathrm{A}}\Delta\tau_i);$$

$$M_{\mathrm{B}}=\sum_{i=1}^{n}N_i[1-\exp(-\lambda_{\mathrm{B}}\Delta T_i)]\exp(-\lambda_{\mathrm{B}}\Delta\tau_i);$$

AR_{B} is the peak area of gamma ray from decay of B; I_γ is the intensity; ε_γ is the detector efficiency for this γ-ray; M is mass of sample; N_i is fission rate monitored by double-fission chamber; f_s, f_Ω, f_c, and f_n are the correction factors of γ self-absorption, γ geometry, γ cascade coincidence losses and fission induced by background neutrons. After correction of independent yields on the decay chain after nuclide A, chain yields were got. Uncertainties (1σ) of the yields were obtained by consideration of all known sources of systematic and random errors such as mass determination of standard sample, detector efficiency of HPGe spectra system, statistic error of γ-ray peak area, and corrections, with the usual rules of error propagation. Uncertainties of decay data are not included. The complete mass distribution plotted in Fig.1 was derived from the chain yields. The sum of the yields directly measured was 64.15% for the light mass group, and 57.48% for the heavy mass group. To compare our data with other data published in literatures, some product yields are also shown in Fig.1. It can be seen that the fission yields increase with increasing neutron energy for the products in the valley region.

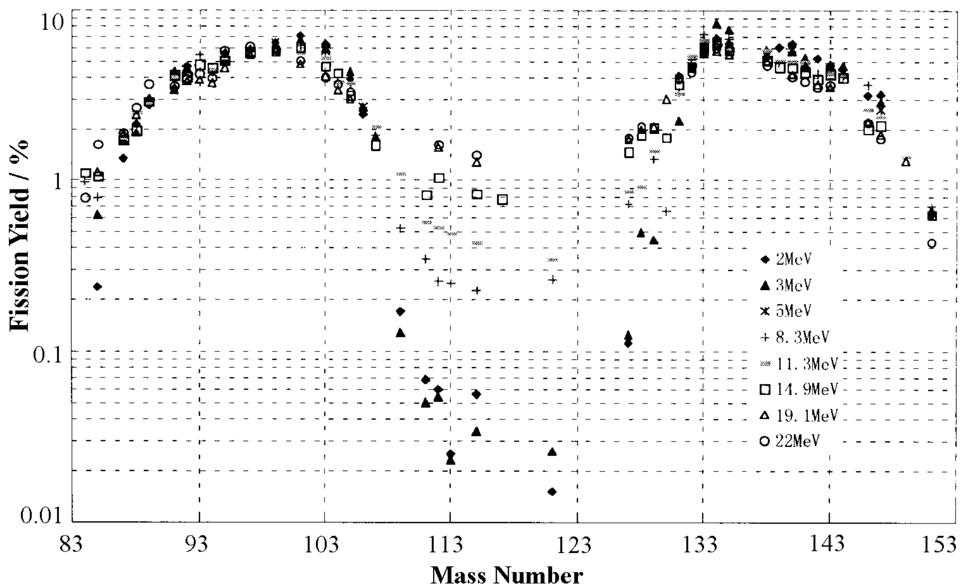

Fig. 1 Mass distribution of ^{238}U fission induced by neutrons

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