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46 mass chain yields and 2 cumulative yields from Br-83 to Tb-161 are obtained for fission of U-238 induced by 8.3 MeV neutrons. 41 of them are determined absolutely. Fission product activities are measured by Ge(Li) γ-ray spectrometry of irradiated U-238 disks and by chemical separation of the fission product elements followed by β or γ counting. The U-238 targets are attached to double-fission chamber containing two thin, standardized deposits of U-238 to monitor the fission rate absolutely. Ag-113 is measured for the first time. Mass distribution curve is given. The present yields are compared with the literature values.

Key words: Fission of U-238, Absolute fission yields, Ge(Li) gamma spectrum method, Radiochemistry method.

1. INTRODUCTION

The work presented here was done in 1984 and published in Chinese Journal of Nuclear Physics, Vol.7, 97(1985), in Chinese. Now we translate it into English to make it readable to foreign collegues of English background.

In present work the product yield of U-238 fission induced by 8.3 MeV neutron was measured by means of Ge(Li) gamma-ray spectrometry and the chemical separation of the fission product elements followed by β or γ counting (RC). 8.3 MeV neutron was produced by D(d,n)^{3}He reaction. The yields of the products in the two wings and in the valley of mass distribution were determined mainly by means of RC, whereas the yields of products short-lived and products inaccessible to RC were measured by Ge(Li). The yield data of 46 mass chains and the cumulative yields of two products were obtained, among which, 33 mass yields and 1 cumulative yield were absolutely measured by Ge(Li) γ, 25 mass yields and 1 cumulative yield were from RC. Among the yield data obtained by RC, 10 of them were relatively determined and the others absolutely. The measured product nuclides range from Br-83 to Tb-161.

2. EXPERIMENTAL

A. Radiation of the targets

The samples used in the irradiation were ϕ16mm disks of

natural uranium metal with weight of 0.6--1.5 g for Ge(Li)γ, and 0.6--3 g for RC. The uranium disks were sealed in pure Al foil of 0.2 mm thickness. The sample, which was sandwiched with two standardized thin samples when irradiating to monitor the fission rate absolutely, was mounted in a double fission chamber. The standardized thin samples were made of the same natural uranium as the thick samples. The double fission chamber was covered with Cd of 1 mm thickness in order to shield from the thermal neutron from the environment. The samples were irradiated at the distance of 6 cm from the neutron source in the direction of zero degree.

The experiment was carried out at Cyclotron in CIAE. The deuterium gas chamber, which was used to produce neutron by the bombardment of deuteron beam, was of the size ϕ22X30 mm and made of stainless steel. In order to reduce the background neutron, the bottom of the chamber was covered with Pt foil of 0.2 mm thickness, and the cylindrical wall with Ta foil of 0.2 mm thickness. The entrance window of the chamber was made of Mo with thickness of 15 μm. The purified deuterium gas of 0.4 MPa pressure was filled in the chamber. The neutron spectrum was measured with TOF technique in order to estimate the fission events induced by the background neutron of energy between 2--6 MeV from D(d,np)D reaction channel and from scattering. The neutron energy is 8.27 +0.17/-0.36 MeV, and the energy divergency was caused mainly by the thickness of the deuterium gas and the wide coverage of targets to the neutron source. The neutron fluency on the targets was $2X10^7$ $n/cm^2 sec$. The ratio of background fission events to 8.3 MeV neutron fission events was estimated to be 0.035.

B. Determination of fission products

(1) Gamma spectrometry. After the irradiation, the gamma spectra of the samples were collected directly by Ge(Li) gamma spectrometer. The spectrometer system consists in the 130 cubic centimeter coaxial Ge(Li) detector and the SCORPIO-3000 MCA-Computer system(Canberra),which can analyse spectra data on-line or off-line. The system has good resolution(FWHM) of 1.85 keV for 1332.5 keV gamma ray. The auto pile-up correction was performed by the living time corrector/pile-up rejector. The samples were 2 cm from the detector with the geometry fixed. The detecting efficiecy of the system was absolutely calibrated with the following gamma sources: Am-241, Nd-147, Ce-144, Ce-141, Mo-99, Ag-111, Na-22, Cs-137, Zr-95, Sc-46, Co-60, and Ta-182. The absolute activity of Am-241 source was determined by means of the small geometry method, whereas the others were determined by means of the 4 pie beta-gamma coincidence. The functional relation of the efficiency to the gamma energy was fitted with the logarithmic polynomial. The standard uncertainty of the efficiency including the fitting deviation was assigned to be 4.2% for gamma rays with energy less than 264.6 keV and 2.4% for the gamma rays of greater energy. The details of the efficiency calibration have been described elsewhere[5]. The samples were irradiated for the period of 30 min--2 hrs for the determination of the short-lived products and 5--25 hrs for the determination of the longer-lived products. The gamma spectra were collected successively over the period of 2--4 times of the half-lives of the products involved or longer. The collection time for each spectrum was 15 min for

short-lived product nuclides and 1--2 hrs for longer-lived products.

The self-absorption of gamma rays in the uranium disks must be taken into account. We measuered the transmittance T of gamma rays through the disks as a function of E using a series of standard gamma sources[6]. The self-absorption correction factor S was thus given by the relation S=(1-T)/(-lnT). The cascade coincidence losses and the effect of incomplete pile-up auto-rejection were corrected as we did in our previous work[5]. The correction has also been made for the effect of the background neutron on the yield data of the products in the valley and in the two wings of the mass distribution.

(2) RC Method The irradiated uranium metal disk and the sealing Al foil was dissolved in 6--10 N HCl which contains the carriers of the product nuclides to be determined. When the reaction relaxed then add a certain amount of concentrated HNO_3. Heat the solution to gentle boiling for 0.5 hr in order for the isotopes to exchange completely, then dilute it with 0.2 N HNO_3. Ag is separated as AgCl precipitate. Then evaporate the solution to 9--10 N HCl medium, divide it by the anion-exchange column into seven parts: Re-Sr-Ba, Cd, Zr, U, Te-Mo, Sn, Sb. The Re-Sr-Ba part will be separated into $Re(OH)_3$ and Sr-Ba using NH_4OH in a bottle unsealed first time. For the determination of Pd and Ru, the Uranium disk was dissolved first without the carriers, then the carriers of interest were added into the solution for the isotope to exchange.

The details of the purification procedure have been described in the reference[7] for the following elements: Ru, Mo, Zr, Sr, Ba, Cd, Re, Sb, Pd, Ag, I, etc. The element Sn was purified in the procedure as follows: prepare Sn into 30ml 6N H_2SO_4 medium after the group separation; add 10ml 2M KI to medium; extracte Sn with 20 ml benzene; wash the organic phase with 4N H_2SO_4-1M KI once; extracte Sn three times with one third of 30 ml 2N HCl each time; repeate the extraction once; back-extracte; neutralize the back-extracted solution with 12 N NaOH as the medium of pH>9; precipitate Sn with Mo Fe reagent; burn the sediment into SnO_2; finally prepare the source to be measured from SnO_2. For the purification of Br, such was the procedure: oxidize Br- into Br_2 with $KMnO_4$; extracte Br with CCl_4; back-extracte with $NaHSO_3$ after reduction; repeate the extraction and the back-extraction five times; make the source from the AgBr sediment.

The activities of the product nuclides were determined by FH-1914 low background beta spectrometer with background level of 2--3 cpm, or by FH--1906 low background gamma sintillation spectrometer. Their counting efficiencies were calibrated with the standard sources which are the same as the product nuclides if possible, in order to eliminate the error resulting from the uncertainty of the spectroscopy data. If the standard sources corresponding to the nuclides to be measured were unavailable,the functional relation of the efficiency to radiation energy and the thickness of source was used to give the efficiency desired. The spectrum data were collected successively for 2--4 half-lives normally.

3. Determination of Fission Product Yield

Consider a fission product chain: A $\rightarrow$ B $\rightarrow$ C. Given the half-lives of all the mother nuclides of A's are much shorter than the half-live of nuclide A and the irradiation period, and given nuclide C is stable enough, then A's cumulative yield Y_A is

$$Y_A = AR_B / I_\gamma \varepsilon_\gamma \left[\frac{\lambda_B}{\lambda_A(\lambda_B - \lambda_A)} K_A M_A + \left(\frac{Y_B}{\lambda_B Y_A} - \frac{\lambda_A}{\lambda_B(\lambda_B - \lambda_A)} \right) K_B M_B \right] \quad (1)$$

here

$$K_A = exp(-\lambda_A t_1)\left[1 - exp(-\lambda_A \Delta t)\right]$$

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

$$M_A = \sum_{i=1}^{N} N_{Fi}\, exp(-\lambda_A \Delta\tau_i)\left[1 - exp(-\lambda_A \Delta T_i)\right]$$

$$M_B = \sum_{i=1}^{N} N_{Fi}\, exp(-\lambda_B \Delta\tau_i)\left[1 - exp(-\lambda_B \Delta T_i)\right]$$

where Y_B is the independent yield of product B; AR_B is the peak area of the considered gamma branch from B decay; λ_A , λ_B is the decay constant of A and B respectively; I_γ is the gamma branch ratio of B decay; ε_γ is the detecting efficiency; N_{Fi} is the mean fission rate in irradiation time interval ΔT_i ; ΔT_i is the ith time interval of irradiation; $\Delta\tau_i$ is the time span from the end of ith interval to the end of the irradiation; t_1 is the cooling time, that is, the time from the end of irradiation to the beginning of gamma spectrum collecting; Δt is the collecting time, that is, the time from the beginning to the end of the spectrum collecting.

The relative determination of product yield was carried out by using the formula

$$Y_i = Y_0 \, (N_i / N_0) \quad (2)$$

here Y_0 and Y_i is the cumulative yield of the reference product nuclide and the product nuclide to be measured respectively; N_0 and N_i is the number of atoms of the reference nuclide and the nuclide to be determined respectively. Ba-140 was used as the reference product nuclide in this work.

The Y_B / Y_A and the contribution of the nuclide C to the chain yield was calculated with the empirical formula given by Nethaway[8]. The correction made for the contribution of B and C to chain yield is 8% in the case of I-134, and it is less than 2% for other product chains.

4. RESULTS AND DISCUSSION

The nuclear spectroscopy data chosen for our previous work[5] were still used here without updating. The data not shown in

the previous work were listed in Table 1.

In order to eliminate the statistical fluctuation and the accidental error, the data was collected as much as possible. By gamma spectrometry, 13 irradiated samples were measured and 217 spectra collected. The average of measurements weighted by the peak area gave the yields of 33 product mass chains from Kr-85m to Pm-151 and the cumulative yield of Sb-130. All of the yield data from gamma spectrometry were obtained absolutely. By RC method, 32 samples were measured, and 25 mass chain yields and the cumulative yield of Sn-125 were determined, among which Br-83, Br-84, Ru-103, Ru-106, Pd-109, Pd-112, Cd-115g, Cd-115m, Sb-127, I-131, and Tb-161 were obtained relatively, and the others absolutely. The final results of the fission product yield determination are presented in Table 2,and compared with other measurements reported. The results are also depicted graphically as the mass distribution curve in Fig.1. In table 2, γS designated gamma spectrometry and RC the radiochemical separation. The yield of the mass chain 115 was given by the sum of the cumulative yields of Cd-115g and Cd-115m. The yields of mass chain 113 and 121 were determined by multiplying the cumulative yields of Ag-113g and Sn-121g with their corresponding (g+m)/g value, which is 1.35 ± 0.14 and 1.16 ± 0.11 respectively[3].

The experimental uncertainties were analysed. for gamma spectrometry method, the uncertainty of yield data mainly came from the following source items: the absolute determination of the fission rate; the absolute efficiency calibration of the Ge(Li) spectrometer; the statistical fluctuation of the gamma peak area; the spectrum analysis by computer code, specially when analysing the spectrum segment of overlapping peaks; the correction for the cascade gamma coincidence losses; the correction for the pile-up losses; the correction for the self-absorption of gamma in the samples. The source items of uncertainty are listed in Table 3. The deviations of the yields are given by the root of square sum of the items mentioned above. The uncertainties of the spectroscopy data are not included in the deviations of yields.

For RC method, the uncertainty of yield mainly came from the following source items: the absolute determination of the fission rate; the statistical error of the radioactivity determination of the product nuclide; the calibration of the instrument efficiency; the uncertainty of the reference yield in the relative determination. The items are listed in Table 4. The uncertainties of the yields are given by the root of square sum of the items. The errors of the half-lives of product nuclides are not included. The data of the half-lives and the gamma branch ratios were chosen as described elsewhere[7].

In Fig.1, the solid line is the mass distribution curve depicted through the experimental points. The sum of the yields directly measured is 70.45% for the light mass group, and 74.133% for the heavy mass group. Including the mass yields not measured but obtained by interpolating or extrapolating, the sum is 101.52% for the light mass group and 100.28% for the heavy mass group, both of which are agreement with 100% excellently. This implies that we monitored the fission rate to an very good accuracy. The mean mass numbers are 97.3u and 138.3u for the light and heavy mass group respectively, which gives the mean fission

neutrons $\bar{\nu}$ =3.4 ±0.2. The number agrees well with the evaluated experimental data of the mean fission neutrons of U-238 3.606± 0.008[11]. The ratio of peak-to-valley is 30, which agrees well with the result reported by S. Nagy et al.[3]. The good results were obtained in the fission product yield determination by combining the gamma spectrometry and the RC. For the U-238 fission induced by 8.3 MeV neutron, this work gave mass yield data more than other reported works, and the yield of product Ag-113 was obtained for the first time.

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REFERENCES

[1] Bunney, L. R. et al.,Proceedings of the International Conference on the peaceful Uses of Atomic Energy, Geneva, United Nations, P/643,Vol.15,1958, P.449.
[2] Flynn, K. F. et al., Trans. Am. Nucl. Soc.,22,667(1975).
[3] Nagy S. et al, Phys. Rev.,C17,163(1978).
[4] Champman T.C. et al., Phys. Rev.,C17,1089(1978).
[5] Li Ze et al, Chinese J. of Nucl. Phys.,7,97(1985).
[6] Liu, C. et al., Chinese J. of Nucl. Phys.,7,235(1985).
[7] Zhang, C. et al, J. of Nuclear and Radiochemistry,7,1(1985)
[8] Nethaway, D. R., UCRL-51640, (1974).
[9] Liu, Y. Z. et al., Decay Schemes of Isotopes, Atomic Energy Press, Beijing, (1982).
[10] Lederer, C. M. et al.,Table of Isotopes,Wiley-Interscience, Seventh Edition,(1978).
[11] Manero, F. et al., At. Energ. Rev., 10, 637(1972).

表1 裂变产物核谱学数据

a) 核素	b) 能量, keV	c) 绝对强度, %	d) 半衰期, min	e) 先驱核素	f) 半衰期, min	g) 参考文献
^{87}Kr	402.578	49.2	76.3	^{87}Br	0.927	[9][10]
^{89}Rb	1031.9	58.5	15.60	^{89}Kr	3.18	[10]
^{91}Sr	1024.3	33	570	^{91}Rb	0.970	[9][10]
^{91}Y	266.9	6.82	615.0	^{91}Sr	8.221	[10]
^{97}Nb	657.92	98.2	72	^{97}Zr	1014	[9]
^{127}Sb	473.0	25.31	5830.4	^{127}Sn	126.0	[10]
^{136}Sn	482.3	58.2	59.35	^{136}In	0.02	[10]
^{136}Sb	330.9	78	40.95	^{136}Sn	1.71	[10]
^{141}Ba	190.22	46.3	18.277	^{141}Ce	0.415	[10]
^{146}Pr	453.8	48.3	24.01	^{146}Ce	13.96	[10]

Table 1 Spectroscopy Data of Product Nuclides

a) Product Nuclide B b) Gamma Energy
c) Absolute Intensity of Gamma
d) Half-life of Nuclide B e) Mother Nuclide A
f) Half-life of Nuclide A g) Reference

Table 2. Yields of U-238 + 8.3MeV neutron

Mass number	Nuclide	Yields, %							
		Present work (8.3MeV)		Nagy (7.7MeV)(6)		Flynn (8MeV)(7)		Chapman (8.1MeV)(8)	
		γS	RC	γS	RC	γS	RC	γS	γS, RC
83	^{83}Br		0.51±0.04		0.74±0.04	0.80	0.62		
84	^{84}Br		0.98±0.06					1.1102±0.44	
85	^{85m}Kr	0.79±0.05		0.74±0.04					
87	^{87}Kr	1.80±0.06		1.82±0.09		2.00		1.7395±0.32	
88	^{88}Kr	2.08±0.11		2.32±0.15		2.28			
89	^{89}Rb	2.77±0.09	3.33±0.10	2.68±0.33		2.64	2.49		2.6125±0.22
91	^{91}Sr	4.14±0.13	4.54±0.16	4.04±0.23		4.40	3.70		3.7717±0.38
92	^{92}Sr	4.20±0.13		4.23±0.27		4.83			
93	^{93}Y	5.41±0.22		5.05±0.34		5.33			
94	^{94}Y	4.29±0.15		4.51±0.38		5.01			
95	^{95}Zr	5.42±0.16	5.68±0.16	5.36±0.19		5.96	5.91		4.9810±0.40
97	^{97}Nb(Zr)	5.73±0.18	6.01±0.21	5.62±0.16		6.28			5.3968±0.54
99	^{99}Mo	6.23±0.20	6.22±0.19	5.96±0.25		6.82	7.68		6.0623±0.49
101	^{101}Tc	6.13±0.20		6.79±0.46		7.34			
103	^{103}Ru	6.01±0.18	5.19±0.34	6.22±0.27		6.45	5.12		5.2195±0.48
104	^{104}Tc	3.74±0.13		4.44±0.31				4.5611±1.25	
105	^{105}Ru	3.71±0.12		3.75±0.21		3.96			3.5643±0.39
106	^{106}Ru		2.68±0.18		3.02±0.30		3.11		
107	^{107}Rh	1.83±0.07		0.71±0.18		2.36			
109	^{109}Pd		0.523±0.028		0.32±0.03		0.32		
111	^{111}Ag		0.346±0.03		0.26±0.03		0.24		0.1945±0.017
112	^{112}Pd		0.257±0.011		0.20±0.04		0.20		0.1688±0.015
113	^{113}Ag		0.25±0.01						
115	^{115}Cd		0.227±0.009		0.191±0.032		0.16		0.1352±0.0097
121	^{121}Sb		0.263±0.025		0.175±0.024		0.16		
125	^{125}Sn		0.076±0.003		0.091±0.022		0.16		
127	^{127}Sb	0.56±0.02	0.728±0.027	0.53±0.06	0.047±0.07	0.57	0.37		0.5390±0.28

Table 2. (Continued)

Mass number	Nuclide	Yields, %							
		Present work (8.3MeV)		Nagy (7.7MeV)(6)		Flynn (8MeV)(7)		Chapman (8.1MeV)(8)	
		γS	RC	γS	RC	γS	RC	γS	γS, RC
128	^{128}Sn	0.70±0.03						0.4604±0.96	
129	^{129}Sb	1.32±0.05		1.23±0.08	1.16±0.13	1.29	0.79		
130	^{130}Sb	0.66±0.04						0.7328±0.14	
131	^{131}I	3.29±0.11	3.16±0.10	3.89±0.14		4.33	2.30		
132	^{132}Te	5.13±0.24	4.61±0.12	5.22±0.13		5.06	4.35		4.6612±0.28
133	^{133}I	7.21±0.22		7.04±0.20		7.33	8.07		6.7132±0.98
134	^{134}I	6.55±0.23		7.02±0.43					
135	^{135}Xe	6.75±0.34		6.79±0.20		6.28	7.61		
136	^{136}Cs								0.0105±0.003
137	^{137}Cs								3.8148±0.77
138	^{138}Cs	5.87±0.16		5.16±0.21		5.52			
139	^{139}Ba	4.89±0.30		4.54±0.35		4.91			
140	^{140}Ba	5.71±0.17	5.64±0.16	5.69±0.14		5.82	5.71		5.1455±0.42
141	^{141}Ba, Ce	4.68±0.24	5.49±0.16	5.51±0.33		5.92	5.39		4.6197±0.44
142	^{142}La	4.21±0.15		4.35±0.26		4.43		4.6722±1.76	
143	^{143}Ce	4.66±0.14		4.58±0.27		4.61	4.35		4.7749±0.48
144	^{144}Ce		4.06±0.12						4.3396±0.42
146	^{146}Pr	3.62±0.15		3.19±0.25		3.40			
147	^{147}Nd	2.70±0.13	2.58±0.07	2.66±0.24		2.85			2.6285±0.26
149	^{149}Pm,Nd			1.91±0.19		2.03	0.69		
151	^{151}Pm	0.70±0.024				0.70	0.54		0.8208±0.14
153	^{153}Sm		0.434±0.013				0.19		
156	^{156}Eu		0.0905±0.0066						0.0770±0.011
161	^{161}Tb		0.0040±0.0003						

表3 γ 能 谱 法 误 差 来 源

a) 质量数	b) 核素	相对误差，% c) 裂变率的测量	d) γ 探测器效率刻度	e) γ 峰面积的统计误差	f) γ 堆积校正	g) γ 级联相加符合校正	h) 自吸收的校正	i) 解谱	j) 总误差
85	^{85m}Kr	1.50	4.20	0.58			1.66	3.00	5.66
87	^{87}Kr	1.58	2.40	0.86		0.12	0.66	1.00	3.23
88	^{88}Kr	1.50	4.20	0.88		0.35	1.39	1.00	4.87
89	^{89}Rb	1.82	2.40	0.38	0.7	1.40	0.64	1.00	3.62
91	^{91}Sr	1.50	2.40	0.48			0.64	1.00	3.11
92	^{92}Sr	1.50	2.40	0.61			0.64		2.97
93	^{93}Y	1.50	2.40	1.19		0.49	0.84	1.00	3.37
94	^{94}Y	1.73	2.40	0.64	0.6	0.28	0.65	1.00	3.32
95	^{95}Zr	1.50	2.40	0.66			0.65		2.98
97	^{97}Nb	1.50	2.40	0.22			0.65	1.00	3.08
99	^{99}Mo	1.50	2.40	0.32		0.75	0.65	1.00	3.18
101	^{101}Tc	1.82	2.40	0.16	0.7		0.73	1.00	3.33
103	^{103}Ru	1.50	2.40	0.39			0.65		2.93
104	^{104}Tc	1.79	2.40	0.23	0.6	0.26	0.66	1.00	3.28
105	^{105}Ru	1.50	2.40	0.88			0.66	1.00	3.20
107	^{107}Rh	1.66	2.40	1.68	0.5		0.73	1.00	3.62
127	^{127}Sb	1.50	2.40	1.76		0.79	0.66	1.00	3.63
128	^{128}Sn	1.66	2.40	1.55			0.66	1.00	3.51
129	^{129}Sb	1.50	2.40	1.62		1.14	0.65	1.00	3.65
130	^{130}Sb	1.66	2.40	1.80		2.47	0.68	1.00	4.40
131	^{131}I	1.50	2.40	1.24			0.67		3.16
132	^{132}Te	1.50	4.20	0.12			1.14		4.6
133	^{133}I	1.50	2.40	0.37		0.12	0.65		2.93
134	^{134}I	1.66	2.40	0.21		1.28	0.65		3.26
135	^{135}Xe	1.50	4.20	0.40			0.96	1.00	4.69
138	^{138}Cs	1.73	2.40	0.54			0.63		3.07
139	^{139}Ba	1.58	4.20	2.05			1.66	3.00	6.01
140	^{140}Ba	1.50	2.40	0.35			0.66	1.00	3.09
141	^{141}Ba	1.80	4.20	1.07	0.6	1.37	1.39	1.00	5.21
142	^{142}La	1.50	2.40	0.88		0.92	0.65	1.00	3.32
143	^{143}Ce	1.50	2.40	0.15			0.82		2.95
146	^{146}Pr	1.82	2.40	1.17		1.01	0.66	1.00	3.59
147	^{147}Nb	1.50	2.40	3.71			0.86		4.71
151	^{151}Pm	1.50	2.40	1.05			0.80	1.00	3.28

Table 3 Source Items of Uncertainty (Ge(Li)γ)

a) Mass Number b) Product Nuclide c) Fission Rate
d) Detecting Efficiency e) Fluctuation of Peak Area
f) Correction for Gamma Pile-up
g) Correction for Coincidence Losses
h) Correction for Self-absorption i) Spectrum Analysis
j) Inclusive Uncertainty

表4 放 化 法 误 差 来 源

a) 质量数	b) 核 素	h) 相对误差，%				
		c) 偶然误差	d) 裂变率测定	e) 效率刻度	f) 内标核偶然误差	g) 总 误 差
83	^{83}Br	4.7	1.5	3.0	1.4	7.0
84	^{84}Br	5.0	1.5	2.0	1.4	5.8
89	^{89}Sr	1.5	1.5	2.0		2.9
91	^{91}Sr	2.5	1.5	2.1		3.6
95	^{95}Zr	1.3	1.5	2.1		2.9
97	^{97}Zr	1.1	1.5	3.0		3.5
99	^{99}Mo	1.7	1.5	2.0		3.0
103	^{103}Ru	5.5	1.5	1.4	1.4	6.5
106	^{106}Ru	5.8	1.5	3.0	1.4	6.8
109	^{109}Pd	4.3	1.5	3.0	1.4	5.5
111	^{111}Ag	7.9	1.5	3.0		8.6
112	^{112}Pd	3.2	1.5	2.0	1.4	4.3
113	^{113}Ag	5.6	1.5	3.0		6.5
115	^{115}Cd	2.8	1.5	1.5	1.4	3.9
121	^{121}Sn	3.9	1.5	5.0		9.5
125	^{125}Sn	2.8	1.5	2.0		3.8
127	^{127}Sb	2.4	1.5	2.0	1.4	3.7
131	^{131}I	1.8	1.5	1.6	1.4	3.2
132	^{132}Te	1.6	1.5	1.5		2.7
140	^{140}Ba	1.4	1.5	2.0		2.9
141	^{141}Ce	1.6	1.5	2.0		3.0
144	^{144}Ce	1.5	1.5	2.0		2.9
147	^{147}Nd	1.1	1.5	2.0		2.7
153	^{153}Sm	1.4	1.5	2.0		2.9
156	^{156}Eu	6.1	1.5	2.0	1.4	7.3
161	^{161}Tb	5.2	1.5	3.0	1.4	6.3

Table 4 Source Items of Uncertainty (RC)

a) Mass Number b) Product Nuclide c) Accidental Error
d) Fission Rate e) Efficiency Calibration
f) Uncertainty of Interior Label Nuclide g) Inclucive

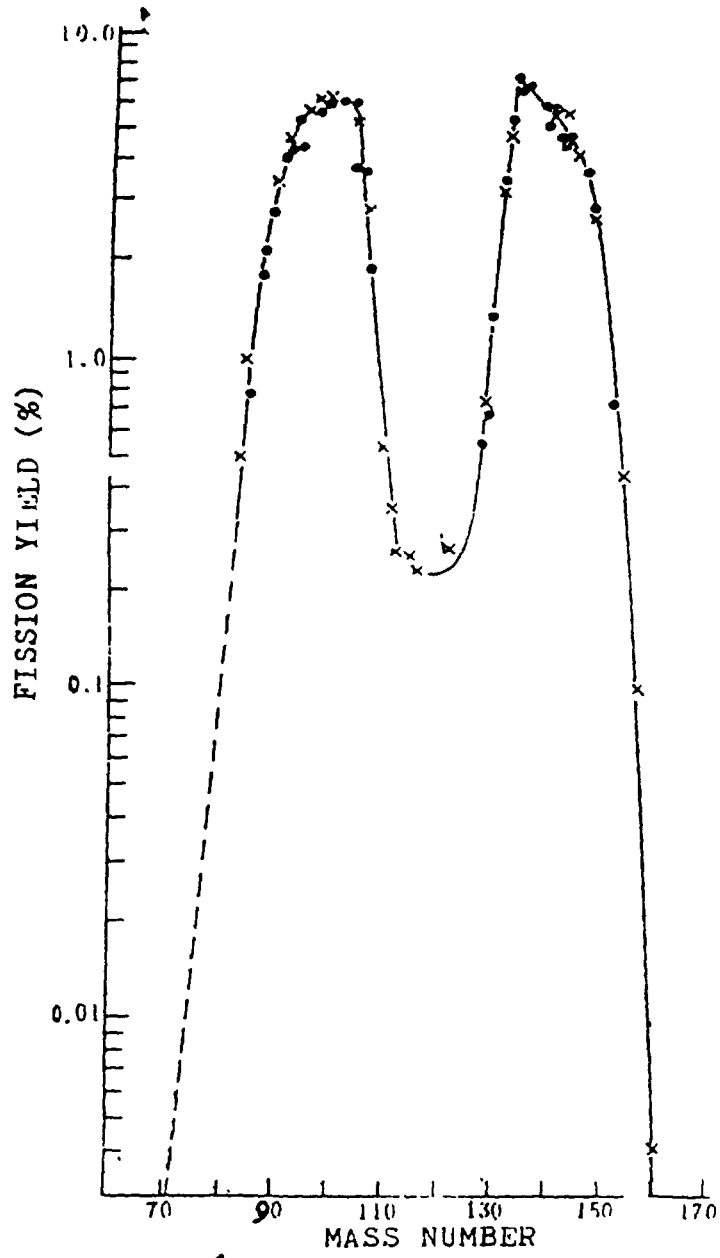

Fig. 1. Fission of U-238 induced by 8.3MeV neutron

● -- γ-ray spectrum X -- Radiochemistry