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Measurement of ^{93}Nb(n, $n\alpha$)^{89m}Y, ^{93}Nb(n, α)^{90m}Y and ^{93}Nb(n, $2n$) ^{92m}Nb Cross Sections for 14 MeV Neutrons

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^{93}Nb(n, $n\alpha$) ^{89m}Y, ^{93}Nb(n, α) ^{90m}Y 과 ^{93}Nb(n, $2n$) ^{92m}Nb 반응의 14 MeV 중성자 반응 단면적 측정

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Abstract

The ^{93}Nb(n, $n\alpha$)^{89m}Y, ^{93}Nb(n, α)^{90m}Y and ^{93}Nb(n, $2n$)^{92m}Nb cross sections at a neutron energy of 14.6 MeV have been measured relative to the ^{27}Al(n, p)^{27}Mg and ^{27}Al(n, α)^{24}Na cross sections. A small accelerator utilizing T(D, n)^{4}He reaction was used as a neutron source and the neutron energy spread is about 0.4MeV at the sample. All induced activities were measured with a 70cc HPGe detector in the same geometry.

요 약

^{93}Nb(n,$n\alpha$)^{89m}Y, ^{93}Nb(n, α)^{90m}Y과 ^{93}Nb(n, $2n$)^{92m}Nb의 14.6MeV 중성자 반응단면적을 ^{27}Al(n, p)^{27}Mg과 ^{27}Al(n, α)^{24}Na 반응 단면적과 비교하여 측정하였다. T(D, n)^{4}He 반응을 이용하는 소규모 가속기를 중성자 원으로 사용하였으며 시료에서의 중성자 에너지 퍼짐은 0.4MeV 정도였다. 생성된 방사능은 모두 같은 기하학적 조건에서 70cc HPGe 검출기로 측정하였다.

I. Introduction

Niobium is likely to be used in the construction of fusion reactors and since most of the neutrons in the fusion reactors have energy around 14MeV, a precise determination of it's reaction cross sections with 14 MeV neutron is required. More-over, ^{93}Nb(n, $2n$)^{92m}Nb reaction may be very useful for the intercomparison of fast neutron spectra in neutron dosimetry applications because of the comparatively large reaction cross section, long half life(10.14d) and simple decay scheme of the induced activity.[1, 2]

Generally, there are two methods in determining neutron flux during irradiation of a sample; associated particle technique and reference reaction method. The former measures the alpha particle emitted from the T(D, n)^{4}He reaction whereas the latter uses a reaction whose cross section is well known such as ^{27}Al(n, α)^{24}Na, ^{56}Fe(n, p)^{56}Mn, etc. [1-7, 9]

In the reference method, the most important point during irradiation is that the neutron flux in both the reference and the sample should be the same, hence the reference and the sample should be irradiated at the same position either by mixed together in powder or sandwitched one by one in foil form. The latter is preferred in spite of not exactly the same flux both in the reference and the sample because the former method results in mutual interference when measuring activity. [1, 5] Many of the previous experiments[1-5] were made by counting activities of the reference and the sample with different detectors or in different geometry, but this results in large error from the calibration of the detectors.

In this experiment, (n, $n\alpha$) reaction cross section was measured relative to the ^{27}Al(n, p) ^{27}Mg reaction cross section and (n, α), (n, $2n$) reaction cross sections to ^{27}Al(n, α)^{24}Na. The choice of the reference reaction was made from the point of view of minimizing error occuring from neutron flux variation and eliminating the interference of the activities from unwanted reactions. Nb and Al were sandwitched one by one in foil form and irradiated by a small neutron generator (Sealed tube type, Kaman A-711, U.S.A.). The sample and the reference were counted in the same geometry using a HPGe detector (70cc, CANBERRA, U.S.A.).

II. Experimental

1. Sample preparation and irradiation

Nb and Al foils were all 0.127mm thick and 1.27cm in diameter. Three Nb foils were sandwitched one by one between four Al foils and placed 1cm from the tritium target along the beam axis. Kaman A-711 neutron generator in KIER (Korea Institute of Energy and Resources) utilizing T(D, n)^{4}He reaction was used to irradiate the sample. In order to obtain sufficient neutron flux, 3mA deuteron beam was maintained with accelerating voltage 160KV during irradiation. Neutron flux was continuously monitored by a BF_3 counter in order to compensate the time variation of the flux level. The sandwitched Nb and Al foils were irradiated for 180 sec. for determining the (n, $n\alpha$) cross section and for 1 hour for (n, α) and (n, $2n$) cross sections.

2. Activity measurement and cross section determination

After irradiation the samples were counted using a HPGe detector attached to a 4096 channel MCA (CANBERRA S-90, U.S.A.). The counting time was selected basically based on reducing the counting error less than 1%. The activity of each sample was determined by the photopeak area[10-12] taking into account the

Table 1. Related Nuclear Data

Nuclide	Cross section(mb)	Half life	Gamma energy(keV)	Gamma intensity
^{27}Mg	75±8	9.462±0.12m	843.8	0.73±0.01
^{24}Na	114.2±1.4	15.030±0.003h	1368.5	1.0
^{89m}Y		16.06±0.04s	909.2	0.9914±0.004
^{90m}Y		3.19±0.01h	479.5	0.91±0.04
^{92m}Nb		10.14±0.03d	934.3	0.992±0.002

*All data are taken from reference (14) except cross sections efficiency of the detector and the related nuclear data in Table 1. The efficiency was obtained with a ^{152}Eu standard point source(1μCi, Amersham, U.K.) performing weighted least square fit with six calibration points(344.3keV, 773.9 keV, 964.0keV, 1112.0keV, 1408.1keV). [13]

^{93}Nb (*n*, *nα*)^{89m}Y

Al and Nb foils were measured as soon as the generator was turned off to obtain maximum activity. It took about 14-16 sec to get the foils out of irradiation position, remove Al foils from Nb foils and start counting the ^{89m}Y activity. The cooling time had to be kept as short as possible because of the short half life of ^{89m}Y. Nb foils were counted 1cm from the detector for 80 sec. 909.2 keV photopeak was used to determine the activity. After the measurement of ^{89m}Y, Al foils were measured at the same position to get the ^{27}Mg spectrum. 843.8 keV photopeak was used to determine the activity. 75$\pm$8 mb[8] was used as ^{27}Al(*n*, *p*)^{27}Mg cross section in the calculation.

^{93}Nb(*n*, *α*)^{90m}Y and ^{93}Nb(*n*, 2*n*)^{92m}Nb

^{90m}Y induced from (*n*, *α*) reaction was measured 20 minutes after the end of irradiation. As the induced activity was not so small as the above case, ^{90m}Y was counted for 1000 sec. at 6cm from the detector to minimize the summing effect. 479.5keV photopeak was used to determine the activity. 1368.5 keV photopeak activity of ^{24}Na was measured at the same position for 1000sec. after 2-6 hours cooling. 114.5$\pm$1.4mb [9] was used as ^{27}Al(*n*, *α*)^{24}Na cross section in the calculation. ^{92m}Nb activity was measured at the same position for 3000sec. after waiting the ^{90m}Y activity to decay out. This was necessary because ^{90m}Y activity can be an interference in measuring ^{92m}Nb activity. 934.3keV photopeak was used to determine the ^{92m}Nb activity.

III. Result and Discussion

The average neutron energy was calculated taking into account the geometry of the tritium target and the samples, and the accelerating voltage. The sample and the target areas are devided into 400 meshes each and each contribution of energy and flux from target mesh was numerically integrated at each sample mesh, then summed and averaged. Thus obtained average neutron energy is 14.6 MeV with the energy spread of 0.4 MeV when accelerating voltage is 160KV and beam radius, sample radius and distance from target to sample are 0.79 cm, 0.64cm and 1cm, respectively. This calculation is particularly important when target to sample distance is relatively small, because bombarding neutrons have rather a large range of energy in this case.

Small corrections were made to the final cross section values due to the absorption of gamma rays in the sample during counting which are 0.3% for (*n*, *nα*), 0.9% for (*n*, *α*) and 0.6% for (*n*, 2*n*) cross sections. Time variation of the flux level during irradiation was less than 0.2% for all cases and no correction was made.

Typical errors involved in the experimental

Table 2. Resulting Uncertainty of Cross Section

Source of error		uncertainty(%)		
		(*n*,*nα*)	(*n*, *α*)	(*n*,2*n*)
Counting	r	0.45	0.6	0.6
	s	2.7	1.0	0.6
Reference Cross section		10.7	1.0	1.0
Gamma intensity	r	1.4	—	—
	s	0.4	4.4	0.2
Half-life	r	1.5	—	—
	s	0.4	0.3	0.3
Efficiency		0.3	5.5	2.0
Total		11.3	7.2	2.4

**r* and *s* refer to the reference and the sample

Table 3. Result and Comparison

Reaction	Author	Energy(MeV)	Cross section(mb)
^{93}Nb$(n, n\alpha)^{89m}$Y	Present work	14.6	2.47±0.28
	Bramlitt et al. (1963)	14.5	2.5±1.1
^{93}Nb$(n, \alpha)^{90m}$Y	Present work	14.6	5.38±3.19
	Gaiser (1979)	14.1	5.2±0.5
	Rybes et al. (1981)	14.68	5.56±0.18
	Harper et al. (1982)	14.2	5.8±0.5
^{93}Nb$(n, 2n)^{92m}$Nb	Present work	14.6	455±11
	Nethaway (1978)	14.68	462±18
	Rybes et al. (1981)	14.68	453±11
	Harper et al. (1982)	14.2	527±47

result are given in Table 2. All uncertainties listed in Table 2 are evaluated based on 1σ confidence level and summed quadratically to give the total error. The reaction with the neu trons from the $D(D, n)^3$He reaction has been-reported negligible in most previous measureme-nts, and errors from weighing and timing are neglected.

The results obtained for ^{93}Nb$(n, n\alpha)^{89m}$Y, ^{93}Nb$(n, n\alpha)^{90m}$Y and ^{93}Nb$(n, 2n)^{92m}$Nb reaction cross sections are 2.47±0.28, 5.38±0.39 and 455±11mb, respectively, for an average neutron energy of 14.6±0.4 MeV as shown in Table 3. The errors quoted are based on 1σ confidence level. Present value of $(n, n\alpha)$ cross section is in good agreement with that of Bramlitt. The value of (n, α) cross section is somewhat smaller than that of Rybes which was measured relative to ^{56}Fe$(n, p)^{56}$Mn cross section but agrees wit-hin error limit. The values of Gaiser and Harper are also within error limit of present value. For $(n, 2n)$ cross section, present value is in good agreement with those of Rybes and Nethaway. The result should be renewed if the reference cross section value is -updated.

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