# Measurement of Neutron Capture Cross Section of $^{174}$Hf in The Energy Range from 162 to 1200 keV

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**【abstract】** *The cross sections for the $^{174}$Hf( n,γ)$^{175}$Hf reaction were measured relatively to the $^{197}$Au(n,γ)$^{198}$Au reaction for neutron energies from162 to 1200 keV, using the activation technique with high resolution HPGE gamma ray spectroscopy. Some experimental data were given for the first time..*

## Introduction

Natural Hf consists of six isotopes, i.e. $^{174}$Hf( 0.16% ), $^{176}$Hf( 5.26% ), $^{177}$Hf (18.60% ), $^{178}$Hf ( 27.28% ), $^{179}$Hf ( 13.62% ), and $^{180}$Hf ( 35.08% ). Before our work, there were no measurements on the cross sections for the $^{174}$Hf(n,γ), $^{175}$Hf reaction. In this work we measured the cross sections in the energy range from 162 to 1200 keV by the activation method.

## 1 Measurement

The samples are naturally metallic hafnium disks of 20 mm in diameter and 1.1mm in thickness. The gold disks of 20 mm in diameter and 0.1mm in thickness were used as the neutron fluence monitors. Each sample was sandwiched between two gold disks. The sample groups were wrapped in cadmium foils of 0.5 mm in thickness.

The irradiations were performed at 0 degree with respect to the incident proton beam. The neutrons of 164 keV were produced by the $^{7}$Li(p,n) $^{7}$Be reaction, and 469 to 1200 keV by the T(p,n)$^{3}$He reaction. The distance between the samples and the target was 10~15 mm. The proton beam currents were generally 8 to 12μA and the duration of irradiation was about 50 to 80 hours for each energy. The neutron fluence was monitored with a long counter at 0 degree at a distance of 1.8 m from the neutron source. In order to record the neutron fluence as a function of time during the irradiation, the integral count rate of the long counter per 5 minutes was recorded continuously by microcomputer multiscaler and stored in magnetic disk for correcting nonuniform irradiation history.

The activities of the samples and the gold disks were mersured with a calibreted high resolution HPGe detector. Because the activities of the samples were rather weak, they were placed on the surface of the detector for measurement. In order to obtain enough statistics for gamma ray counting, the time of activity measurement was about 45~50 hours for each sample. The relevant decay data of $^{175}$Hf and $^{198}$Au are listed in Table 1.

**Table 1 Decay data of products**

| product nucleus | $T_{1/2}$ | $E_γ$ / keV | $I_γ$ / % |
|---|---|---|---|
| $^{175}$Hf | 70 d | 343.4 | 84 |
| $^{198}$Au | 2.6935 d | 411.8 | 95.5 |

## 2 Results

The cross sections for the $^{174}$Hf(n,γ) $^{175}$Hf reaction obtained with the standard cross section of $^{197}$Au(n,γ)$^{198}$Au reaction taken from ENDF/ B-6 are listed in Table 2 .

**Table 2 Measured cross sections**

| $E_n$ / keV | σ / mb |
|---|---|
| 162±21 | 459±28 |
| 469±83 | 294±18 |
| 683±110 | 231±16 |
| 789±112 | 226±16 |
| 997±102 | 217±15 |
| 1200±102 | 209±15 |

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.