Measurement of Neutron Yield Produced by 135 MeV/nucleon H_2 and ^2D Beams Incident on a Thick Iron Target with the Activation Method

N.Nakanishi, S.Nakajima, S.Fujita, H.Matsumoto,K.Tanaka
The Institute of Physical and Chemical Research(RIKEN)
Wako-shi, Saitama 351- 01, Japan
and
T.Takagi
Fukuda Engineering Research
Hakodate-shi, Hokkaidoh 041, Japan

Abstract

The neutron production by 135 MeV/nucleon H_2 and ^2D beams incident on a thick iron target was measured with the activation method. Seven metals of C, Al, Fe, Co, Ni, In and Au were used as the detectors. Cross sections of neutron - induced reactions employed are assumed to be constant in the neutron energy region of more than several tens MeV for lack of data. The preliminary neutron yield are presented.

I. INTRODUCTION

It is indispensable to have accurate data for neutron production reactions in designing shields of accelerator, reactor, medical facilities and so on. Accumuration of those data , however, is extremely poor for intermediate energy accelerators. Actually, we were forced to take a convenient way in shielding calculation for the RIKEN Ring Cyclotron Facility.[1] A series of measurements of neutron yields has been planed for reactions of various incident particles on a thick target of iron with activation detectors.[2] Here, neutron spectra produced by 135 MeV/nucleon He_2 and ^2D incident on an iron target are given. Extensive analysis and experiments are in progress.

II. EXPERIMENTAL

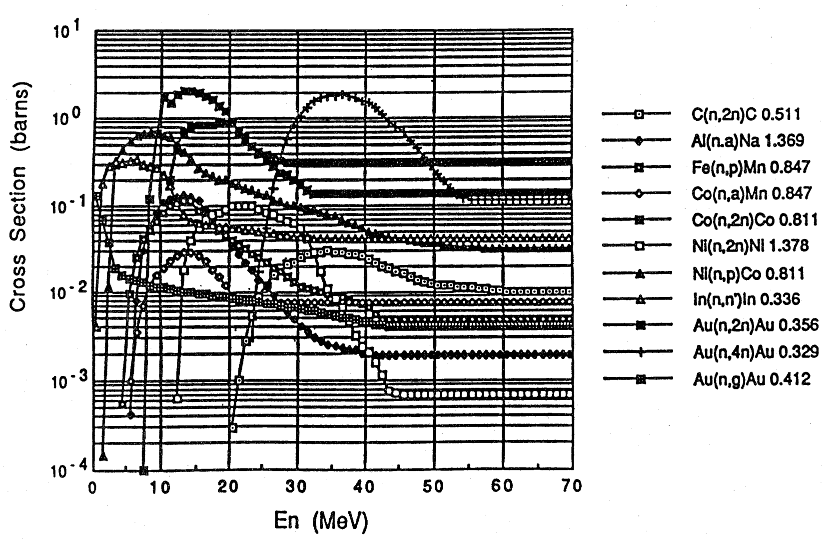

Fig.1 Cross section curves of employed reactions

The activation method has been used widely for the spectral measurement of neutrons produced by nuclear reactions. In many cases, however, the energies of incident particles were not so high, that is, less than 70 MeV, and proton beams only were used. A series of the experiments has made extension of kinds and energies of the incident particles. Having distinctive feartures, this method has two defects; (1) data of either activation cross sections or neutron fluxs are necessary because experiments give product of the two only, (2) some ambiguity in dicision of one of them exists in unfolding process. We employ cross section data cited from Refs. 3～5. The used cross section curves are shown in Fig. 1. In the energy region of more than 70 MeV these cross sections are extrapolated to be constant.

Activation rates A_i [$cm^2 \cdot sr^{-1} \cdot particle^{-1}$] is given by

$$A_i = \sum_j \sigma_i(E_j)\cdot\Phi(E_j)$$

$$= \frac{r^2\cdot\lambda_i\cdot C_i\cdot \exp(-\lambda_i\cdot t_w)^{-1}\cdot\{1-\exp(-\lambda_i\cdot t_c)\}^{-1}}{\varepsilon_i\cdot\eta_i\cdot N_0\cdot P_0\cdot\{1-\exp(-\lambda_i\cdot t_0)\}}$$

where

σ_i = cross section of the ith isotope;

E_j = jth energy segment;

$\Phi(E_j)$ = number of emitted neutrons per sr per incident particle;

r = distance between the detector and the target Fe;

λ_i = decay constant of the ith isotope;

C_i = peak count rate;

ε_i = counting efficiency of the γ ray;

η_i = branching ratio of the γ ray;

N_0 = number of nuclei in the detector;

P_0 = number of the incident particles per sec.;

t_w = waiting time;

t_c = counting time;

t_0 = irradiation time.

Table 1 Characteristics of actvation detectors

Dector	Reaction	Isotopic abundance (%)	Half life	Decay const λ (sec^{-1})	γ-ray energy (MeV)	Branching ratio
C	$^{12}C(n,2n)^{11}C$	98.89	20.38m	5.669×10^{-4}	0.511	1.9952
Al	$^{27}Al(n,\alpha)^{24}Na$	100.0	15.02h	1.282×10^{-5}	1.369	1.0000
Fe	$^{56}Fe(n,p)^{56}Mn$	91.68	2.579h	7.467×10^{-5}	0.847	0.9887
Co	$^{59}Co(n,\alpha)^{56}Mn$	100.0	2.518h	7.467×10^{-5}	0.847	0.9887
Co	$^{59}Co(n,2n)^{58}Co$	100.0	70.79d	1.133×10^{-7}	0.811	0.9944
Ni	$^{58}Ni(n,2n)^{57}Ni$	68.27	35.94h	5.357×10^{-6}	1.378	0.7768
Ni	$^{58}Ni(n,p)^{58}Co$	68.27	70.79d	1.133×10^{-7}	0.811	0.9944
In	$^{115}In(n,n')^{115m}In$	95.67	4.486h	4.292×10^{-5}	0.336	0.4670
Au	$^{197}Au(n,2n)^{196}Au$	100.0	6.183d	1.298×10^{-6}	0.356	0.8770
Au	$^{197}Au(n,4n)^{194}Au$	100.0	3.955h	4.868×10^{-6}	0.329	0.6130
Au	$^{197}Au(n,\gamma)^{198}Au$	100.0	2.696d	2.976×10^{-6}	0.412	0.9550

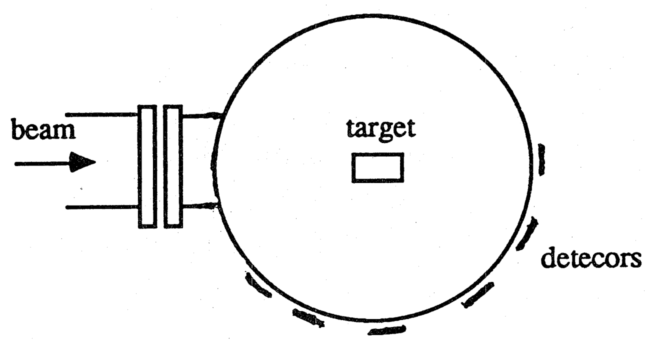

Fig. 2 experimental arrangement

Details of the activation detectors are given in Table 1. An irradiation chamber is shown schematically in Fig.2.

Unfolded spectra were obtainedby using a small code based on the same algorism as SAND-II.

III RESULTS and DISCUSSIONS

Figure 3 shows angular dependence of activities of each detector by proton and deuteron beams incident on a thick iron target, respectively. Some rough features which will be seen from the figure are as follows: (1) Neutron yields are more in the case of deuteron than proton incidences. (2)

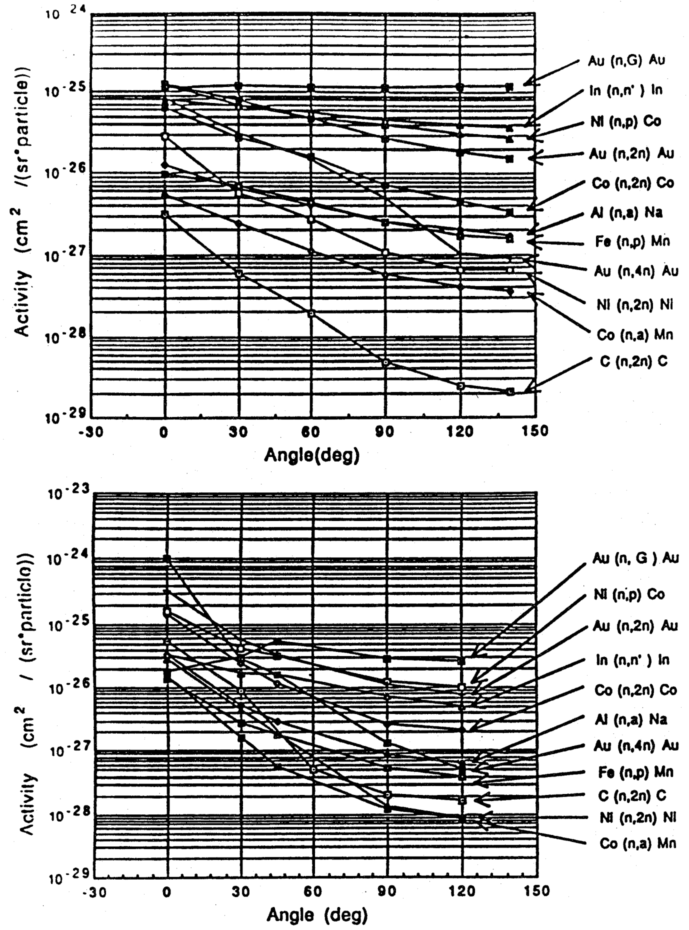

Fig.3 Angular dependennce of activities for proton(upper) and deuteron(lower) incidences

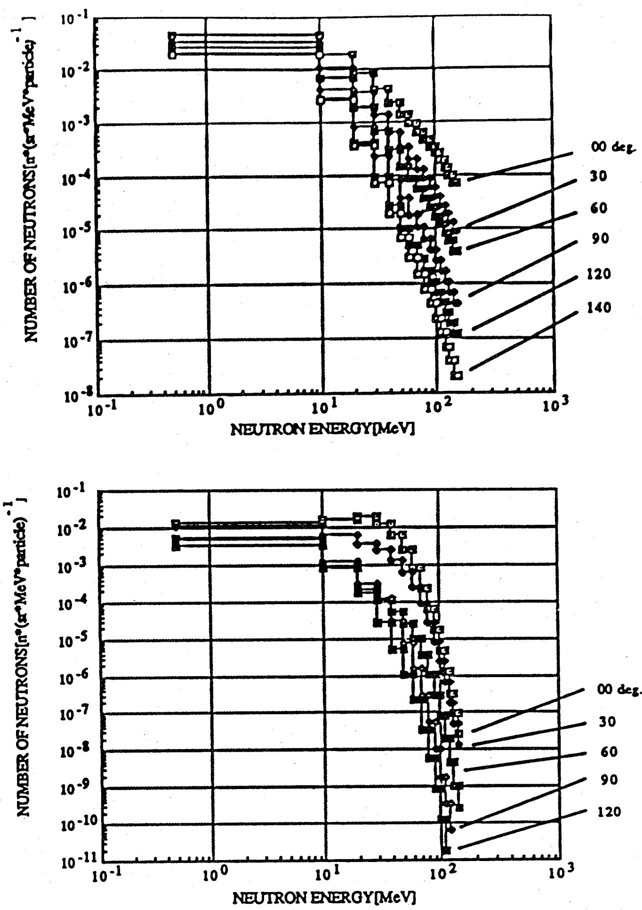

Fig.4 Preliminary neutron fluxes for proton (upper) and deuteron(lower) incidences

Angular dependence of neutron yields is larger in reactions by deuterons than protons.

Preliminary neutron fluxes are shown in Fig.4. The activation method has essentially the defect that results are influenced by the first guess in unfolding process. A fanction $\phi = \exp(-E_n/a)$ was used as first guesses,where a's are taken between 5 and 20. Values and energy dependence of neutron fluxes were affected strongly by the values. It will be seen that low energy neutrons are rather more in proton reactions. Extensive analyses are in progress.

REFERENCES

1) T.Shikata et ai. : Proc. 5th Simpo. on Accel. Sci. and Tech., Ibaragi, 391('84)

2)T.Shikata et al. : Proc. 8th Sympo. on Accel. Sci. and Tech., Saitama, 434('91)

3) L.R.Greenwood : ANL/FPP/TM-115, 1978

4) K.Shin et al : Nucl. Instr. Meth., 187,587('81)

5) T.A.Broome et al : Health Phys.44,487('83)