MEASUREMENT OF NEUTRONS PRODUCED BY 135 MEV/NUCLEON NITROGEN IONS IN AN IRON BEAM-STOPPER WITH ACTIVATION DETECTORS

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Abstract

Approximate energy- and angular- distributions of neutrons produced in an iron beam-stopper by collision of a 135 MeV/nucleon ^{14}N beam were obtained using activation detectors. As a consequence, neutron spectra used as a source term in the shielding calculations for the RIKEN Ring Cyclotron Facility were examined.

Introduction

We have only a few data of energy - and angular- distributions of neutrons produced by interactions of heavy ions of several handreds of million electron volts per nucleon with beam-stopping materials, which are needed for the shielding calculations for the RIKEN Ring Cyclotron Facility. Among authors of this report, Shikata, Nakanishi, Kosako, and Fujita used the hypothetical neutron spectra as those produced in an iron beam-stopper by collision of a 135 MeV/nucleon ^{12}C in their shielding calculation. This hypothetical distributions were obtained from the calculated spectra by Fernandez[1] for a 100 MeV/nucleon ^{12}C incident on an iron target. By the way, Fernandez obtained the spectra from those calculated by Gabriel[2] based on the intranuclear-cascade-evaporation interpretation of nuclear reactions for a 100 MeV/nucleon ^{12}C incident on ^{12}C. Neutron spectra used in the shielding calculations were approximately obtained by expanding the energy of spectral distribution calculated by Fernandez to the amount from 0 to 35 MeV so as to be proportional to its energy, because the highest energy of ^{12}C accelerated by the RIKEN Ring Cyclotron is 135 MeV/nucleon. It is important, therefore, to examine this distribution of source neutrons in order to look over the shielding and to cope,for instance, with a intensification of ion beams.

We look for neutron distributions for a 135 MeV/nucoeon ^{14}N incident on an iron beam-stopper by foil activation. Under the assumption of similar distributions for neutrons produced by two kinds of reactions-a 135 MeV/nucleon ^{12}C on Fe and a 135 MeV/nucleon ^{14}N on Fe, we examined the source neutrons used in the shielding calculations.

Hereafter, the neutron distributions calculated by Fernandez for a ^{12}C incident on Fe, those used in the shielding calculation for the RIKEN Ring Cyclotron, and those obtained from this experiment for a 135 MeV/nucleon ^{14}N on Fe, will be abbreviated as FC-SPECTRA, SC-SPECTRA, and N-SPECTRA, respectively.

Experimental

Activation detectors have been frequently used for the spectral measurement of neutrons for protons below about 50 MeV in energy incident on target materials. This methode is desirable, because it dose not occupy a wide space and does not disturb the neutron field. Though, because of insufficient activation cross section data in the high energy region, we can not expect accurate measurement, we tried to measure an approximate N-SPECTRA extrapolating moreover the cross section curves given by McLane et al.[3], those used by Broom et al.[4] and by Shin et al.[5]. In Fig.1 the cross section curves are given. Details of the activation detectors are given in Table 1. Experimental arrangement is shown in Fig.2. Plan of an iron beam-stopper is 12x12 mm and diameter of a beam spot is 2 mm.

Activation rates A_i is given by Eq.(1)

$$Ai=A(Tir).R^2/Nn.Ni\ [1-\exp(-\lambda_i.Tc)]^{-1}=\Sigma_j\,\sigma_i(Ej)\Phi(Ej) \quad (1)$$

Detector	Dimension (mm)	Reaction	Isotopic abundance(%)	Half life	γ-ray energy (MeV)	Branching ratio(%)	Cross section ref.
C	20Φ x 5	$^{12}C(n,2n)^{11}C$	98.89	20.38m	0.511	200	ref.4
Al	15x15x2	$^{27}Al(n,\alpha)^{24}Na$	100	15.02h	1.369	100	ref.4
Fe	15x15x1.5	$^{56}Fe(n,p)^{56}Mn$	91.8	2.57856h	0.847	98.874	ref.3
Ni	15x15x0.7	$^{58}Ni(n,2n)^{57}Ni$	68.3	36h	1.378	77.68	ref.4
	15x15x0.7	$^{58}Ni(n,p)^{58}Co$	68.3	70.787d	0.811	0.9944	ref.4
Co	15x15x1	$^{59}Co(n,\alpha)^{56}Mn$	100	2.587h	0.847	98.87	ref.5
	15x15x1	$^{59}Co(n,2n)^{58}Co$	100	70.8d	0.811	99.44	ref.5
Ag	15x15x0.6	$^{107}Ag(n,2n)^{106m}Ag$	51.35	8.5d	0.7173	31	ref.5
In	15x15x0.4	$^{115}In(n,n')^{115m}In$	95.7	4.486h	0.336	50	ref.4
Au	15x15x0.2	$^{197}Au(n,2n)^{196}Au$	100	6.183d	0.356	92.5	ref.4
	15x15x0.2	$^{197}Au(n,4n)^{194}Au$	100	39.55h	0.3285	61.6	ref.4

Table 1 Details of activation detectors

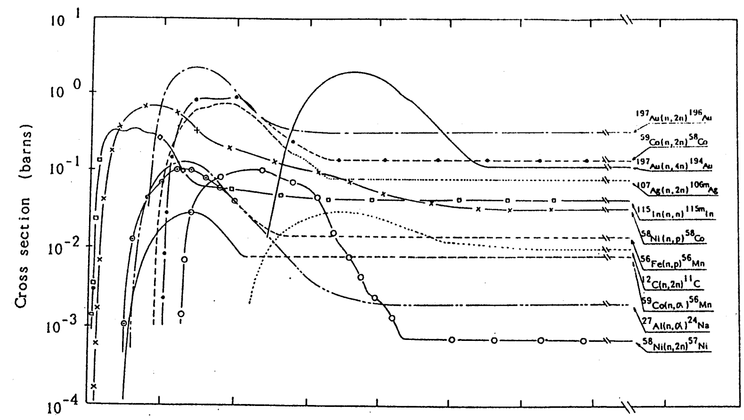

Fig. 1 Response functions

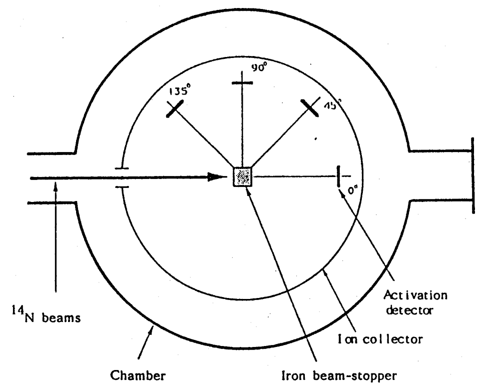

Fig.2 Experimental arrangement

where

$$A(Tir)=(Cp^{i}\cdot \lambda_{i} / \eta_{i}\, \epsilon p^{i}) \;.\; [\exp(-\lambda_{i}.Tw)]^{-1}\cdot [1-\exp(-\lambda_{i}.Tc)]^{-1}$$

Cp^i=peak count rate

λ_i=decay constant of the i th isotope

η_i=number of the photons per decay

ϵp^i=peak efficiency of Ge detector

Tir=irradiation time

Tw=waiting time

Tc=counting time

Ni=number of nuclei in the foil

Nn=total number of nitrogen ions

R=distance between the foil and the beam stopper

Φ_j=number of neutrons emitted per steradian per ion per energy bin.

σ_i=cross section of the i-th isotope

We are able to obtain neutron spectra by changing Φ in Eq.(1) so as to fit the calculated activation rates to measured ones, however, they can't be determined uniquely if the number of energy' bins is larger than that of activation reactions. Therefore, we tried to search Φ using FC-SPECTRA as the first guess.

Results

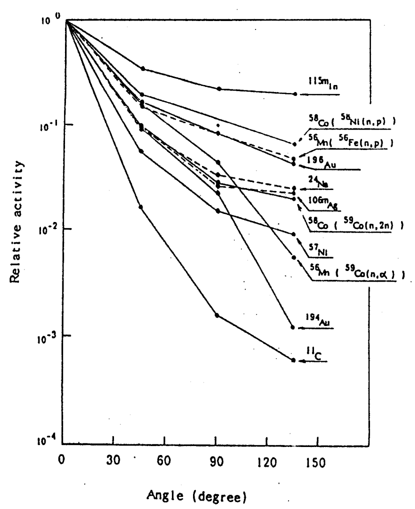

Fig.3 Angular dependense of activities

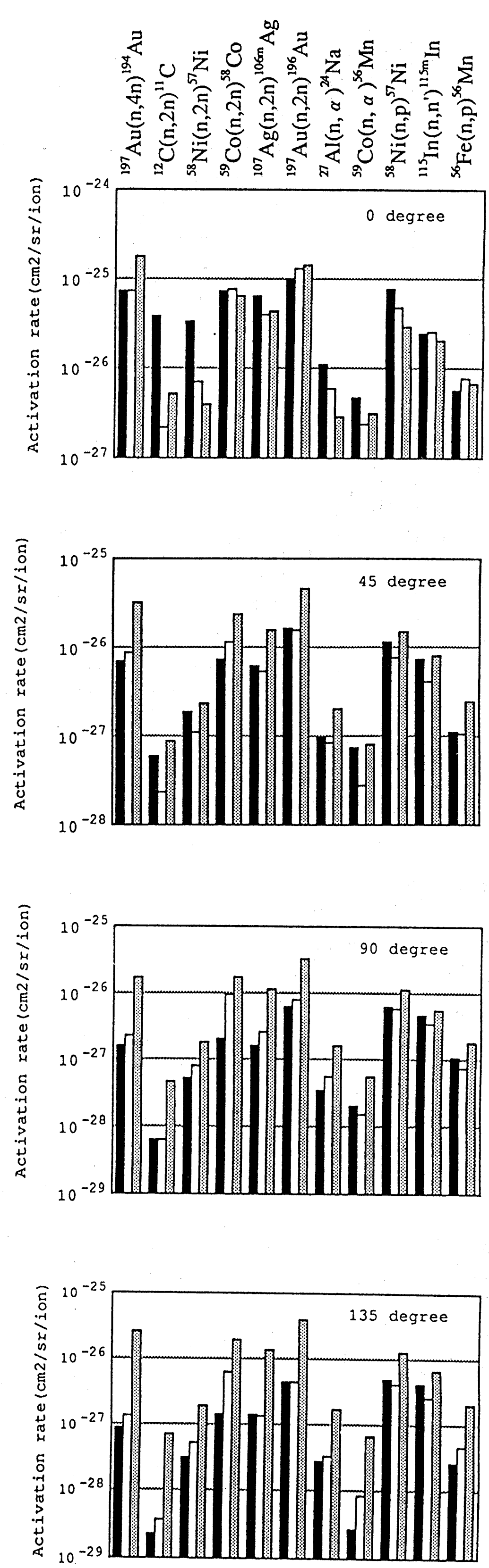

Fig. 4 Activation rate

■ Measured

□ Calculated with N-SPECTRA

▨ Calculated with SC-SPECTRA

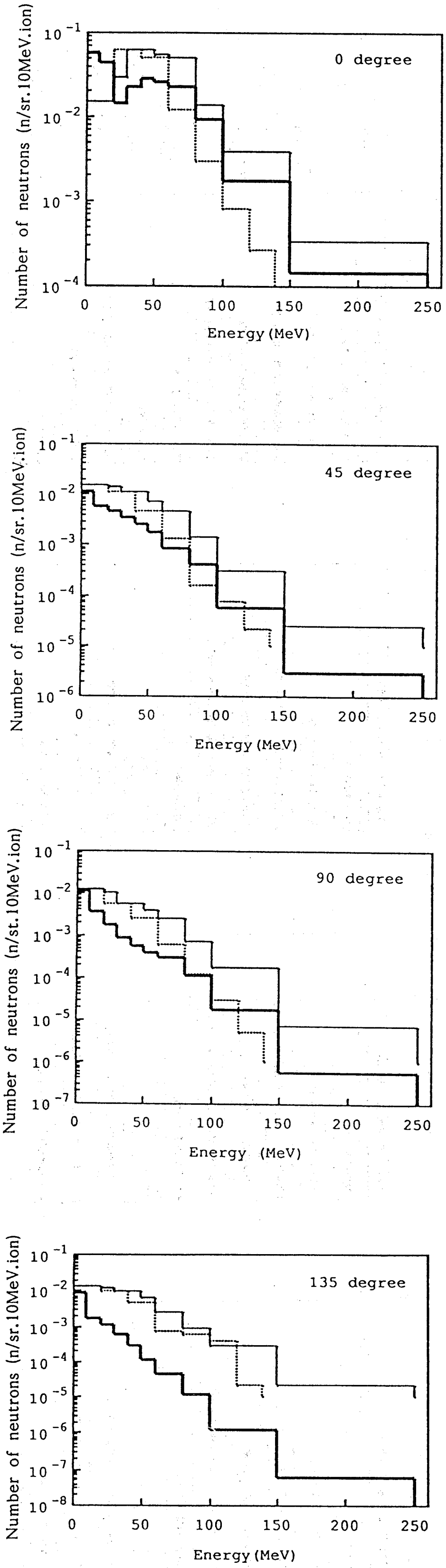

Fig.5 Energy spectra

SC-SPECTRA
N-SPECTRA
FC-SPECTRA

Angular dependence of measured activation rates are shown in Fig.3. As will be mentioned later, protons are ejected from the beam-stopper and will affect the peak count Cp^i for activation reactions other than In(n,n'), Fe(n,p) and Ni(n,p) reactions. This effect may be significant in forward directions, however, it may become negligibly small as the ejection angle increases. Remarkable features can be seen in Fig.3, namely, activities of ^{11}C and ^{194}Au decrease abruptly with increasing angle and there is a difference of about two order in the number of neutrons with energy above 20 MeV between 0 - and 135 -directions, even if we subtructing the effects of protons. However, as the data for detectors having low threshold energy show, low energy neutrons do not have remarkable forward directivity.

In Fig.4 activation rates calculated both with SC-SPECTRA and N-SPECTRA, and measured ones are shown. In Fig.5 FC-SPECTRA, SC-SPECTRA and N-SPECTRA are shown. In Fig.4, measured activation rates for $^{12}C(n,2n)$ and $^{58}Ni(n,2n)$ reactions seem to be extremely high. The effect of protons on these activities may amount to about three times[6] and to the same order [7] of those by neutrons, respectively. Therefore, measured activation rates must approach to the calculated ones. However, agreement in both activation rates is insufficient yet. Moreover, since some of the activation cross sections are considered to decrease as the energy increases, high energy portion of the obtained N-SPECTRA may be of underestimation. Though considering this circumstance, the N-SPECTRA shows a remarkable forward directivity.

Conclusion

Energy- and angular- distributions of neutrons produced in an iron beam-stopper by collision of a 135 MeV/nucleon ^{14}N were searched with activation detectors using the neutron spectra for a 100 MeV/nucleon ^{12}C incident on ^{56}Fe, calculated by Fernandez, as a first guess.

Under the assumption that energy spectra for a 135 MeV/nucleon ^{14}N on Fe and for a 135 MeV/nucleon ^{12}C on Fe have similar shape, it become evident that the energy spectra used for shielding calculation were over-estimated as the emission angle increase, namely, the neutron distributions have more intense forward directivity.

References

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