Measurements of double differential charged-particle production cross sections for 55,65,75 MeV neutrons

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Abstract: We have performed the measurements of double differential charged-particle production cross section ((n,xz)DDXs) of iron and nickel for 55, 65, 75 MeV neutrons using the ^{7}Li(p,n) quasi-monoenergetic source of TIARA[1]. The experimental data were compared with the LA-150 data library, which agreed generally with the present data.

KERMA[2] coefficients(of Fe) were deduced from the experimental data and compared with the integral measurement and calculations by the LA-150 data library.

1 Introduction

Neutron-induced reactions play an important role in the particle transport, radiation effects in accelerator-based systems for transmutation, medicine and material research. Especially, charged-particle production reactions, (n,xz), are important to estimate neutron KERMA required for the evaluation of the radiation effects and the nuclear heating. For Fe and Ni, KERMA measured by integral measurements are generally lower than that derived from microscopic cross sections [1, 2]. To trace these problems , energy and angular distribution data are indispensable. However, experimental data are very scarce.

We are conducting experiments to obtain (n,xz)data, at a ^{7}Li(p,n) monoenergetic neutron source of TIARA [3, 4]. We reported the double differential proton and deuteron production cross sections data of aluminum and carbon for 75,65 MeV neutrons, at five angles by using SSD-NaI(Tl) telescopes, and compared the data with theoretical calculation codes [4]. Then, to expand the energy range and particle species, a wide range spectrometer was developed by Nauchi et al. [5].

In the present paper, we report double differential charged-particle production cross sections data of Fe and Ni taken by using the developed spectrometer and KERMA coefficient(of Fe) deduced from the present data.

2 Experiments

The experiments were carried out at the ^{7}Li(p,n) neutron source of TIARA, JAERI. The incident neutrons energies were 55, 65, 75 MeV. Figure 1 shows neutron source spec-

[1]Takasaki Ion Accelerator for Radiation Application
[2]Kinetic Energy Released in MAtter

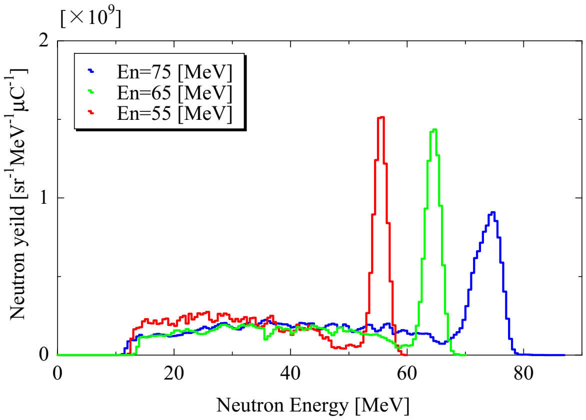

Figure 1: Neutoron source spectra

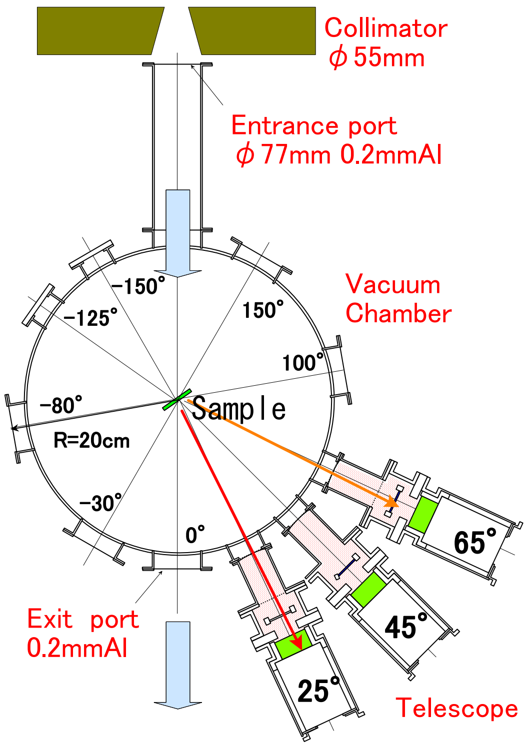

Figure 2: Experimental setup

tra, which consist of a peak part and a continuum one by break up reactions. Samples were metallic foil of elemental Fe(0.62mm×ϕ50) and Ni(0.57mm×ϕ50). The experimental setup is shown Fig.2. A spectrometer consists of three counter telescopes mounted on a vacuum chamber to reduce energy loss of secondary particles and charged particles from the air. The measurement was made mainly with a combination of a SSD(as ΔE counter) with a BaF_2 scintillator(as E counter), but α particles of a few MeV which stop in the SSD were measured by combination of a low-pressure proportional-counter(GPC, as ΔE counter) and a SSD(as E counter). The measurement angles were 25°-75° with 10° step for 75 MeV neutrons, 25°-65° with 25° step for 55 MeV neutrons, and 25°,65°,125° for 65 MeV neutrons.

We used a CAMAC system for data acquisition. Data were accumulated for 6 parameters : the pulse height(PH) of GPC, high and low gain PH of SSD, PH of BaF_2, and TOF signals of SSD and BaF_2. Valid events are chosen by either GPC-SSD coincidence or BaF_2-SSD coincidence. The signals from telescopes were amplified and converted into digital signal by voltage-type ADC. More details are described in ref. [5].

3 Data reduction

First, particle identification was made using ΔE-E spectra, then, the ^{7}Li(p,n)peak events were selected by using TOF information and pulse height of BaF_2 scintillator because the source spectra include a continuum low energy neutrons(see Fig.1). The energy scales of the spectra were determined by peak of the α particles from ^{241}Am and protons from the H(n,p) reaction using polyethylene. Then DDX $\frac{d^2\sigma}{dEd\Omega}$ [mbMeV^{-1}sr^{-1}] was determined using

$$\frac{d^2\sigma}{dEd\Omega} = \frac{1}{\Omega N\phi}\frac{dY}{dE} \qquad (1)$$

where N[#] is a number of atoms in the sample, Ω [sr] is a solid angle, ϕ [cm^{-2}] is the neutron flux obtained with a proton recoil telescope and $\frac{dY}{dE}$ [MeV^{-1}] is a measured spectrum.

We had to use thick samples to obtain acceptable counts because of limited neutron flux. Therefore, it was necessary to do energy loss correction. The correction was done using "average method" for protons, deuterons and tritons. This method was based on the relation between primary particle energy and average energy of detected particles obtained from response function by calculation. For α particles and low energy protons with large energy loss, this method was not appropriate. We applied to unfolding method based on Bayesian theorem by S.Iwasaki [6](Bayesian method).

4 Results and discussion

DDXs were obtained for proton, deuteron, triton, and α particle production for three incident energies. No experimental data of Fe and Ni are available for ten's MeV neutrons, the results are compared with the LA-150 data library [7]. Figures 3, 4 and 5 show DDXs data of Fe and Ni for 75 MeV neutrons, 65 MeV neutrons, and for 55 MeV neutrons, respectively. The solid line shows the LA-150 data library, and the present data of Ni is multiplied by 100.

The spectra have no distinct structures and are continuous. The LA-150 data agree generally with the present data, but it overestimates the high energy parts at forward angle, and this trend is enhanced especially the for deuterons, similarly in the case of the Al(n,xd)reaction [4]. In addition, it underestimates the low energy parts for deuterons at low incident neutron energy(55 MeV). Angular distributions of the LA-150 are based on the Kalbach-systematics. This angular distribution follow the present data generally.

Figure 6 shows DDXs data for α particle production of Ni and Fe. There is a same tendency that the library overestimates the high energy parts.

Figure 7 shows KERMA coefficients for Fe by the present data together with integral measurement and calculations by the LA-150 library. Partial KERMA coefficients for each type of secondary charged particle are derived by

$$k_\phi^i = \frac{C}{M_\mathrm{A}}\bar{\epsilon}_i\sigma_i^{prod} = \frac{C}{M_\mathrm{A}}\int\left[\int E\cdot\frac{d^2\sigma_i^{prod}}{dEd\Omega}dE\right]d\Omega \qquad (2)$$

where σ_i^{prod}[b] is the production cross section of ejectile i, $\bar{\epsilon}_i$ is the average energy of ejectile i, M_A is the target mass, and the factor C converts partial KERMA coefficients from MeV$\cdot$b unit to S.I. units of fGy$\cdot$m^2[femto(f)=10^{-15};Gray(Gy)=Jkg^{-1}]. The calculations by LA-150 include estimations of the inelastic contribution [1]. The present KERMA coefficients are sum over proton, deuteron, triton, α partial KERMA coefficients. The KERMA coefficients deduced from the present data were deduced with interpolation of log liner for angles and for events above $\sim$ 10 MeV because energy loss correction in low energy part was rather uncertain. The difference of KERMA according to the angular extrapolation scheme is smaller than 10%. The contribution to the KERMA coefficients of low energy part is 20-30%. The present results are smaller than both integral measurement and calculations by the LA-150 library. The energy correction in low energy part should be checked to trace the difference.

References

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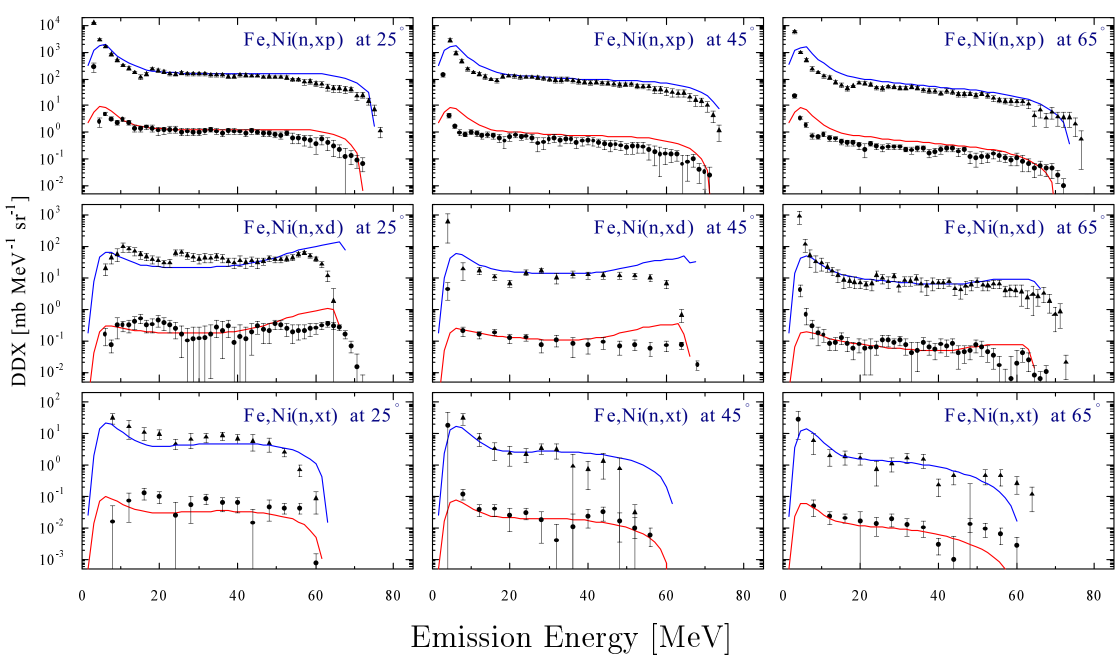

Figure 3: (n,xz)DDXs data of Ni(upper) and Fe at 25°, 45° and 65° for 75MeV neutron with LA-150 library

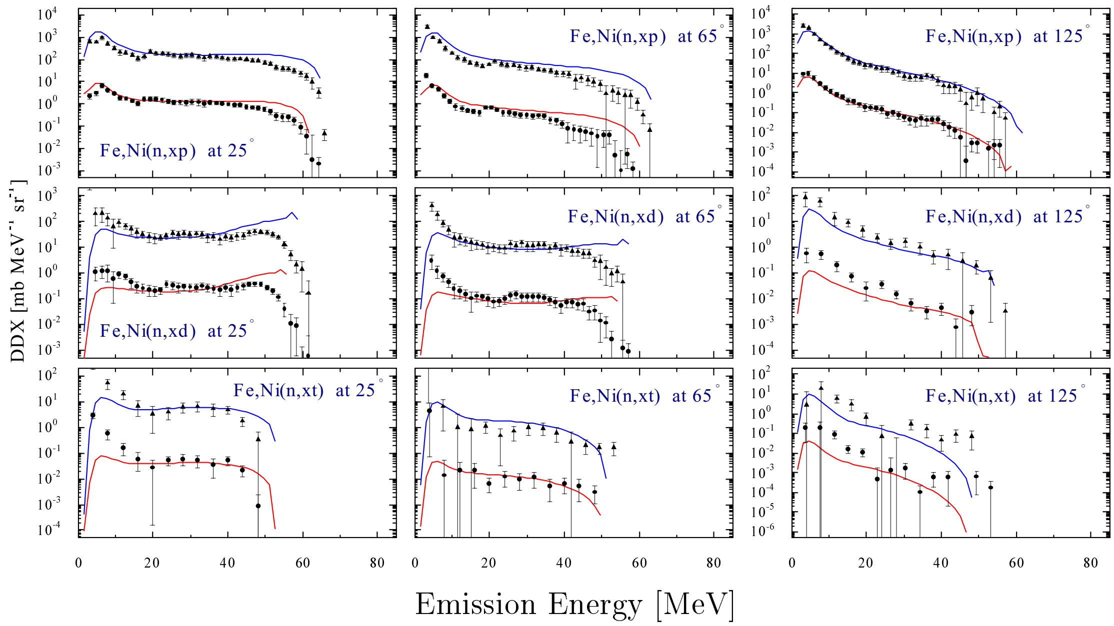

Figure 4: (n,xz)DDXs data of Ni(upper) and Fe at 25°, 65° and 125° for 65MeV neutron with LA-150 library

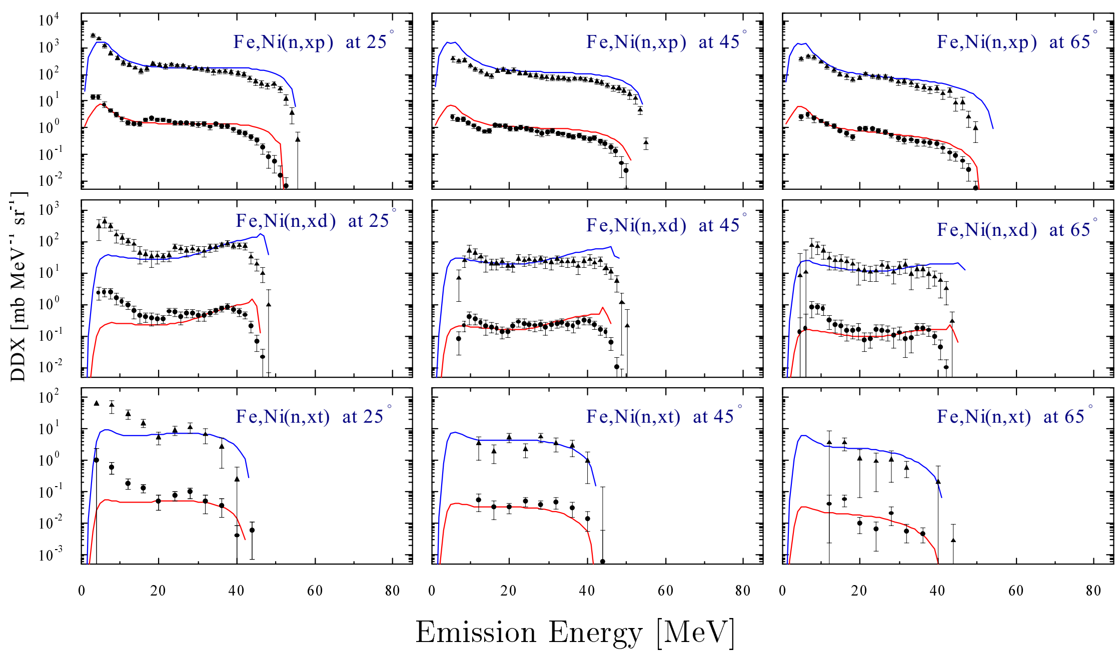

Figure 5: (n,xz)DDXs data of Ni(upper) and Fe at 25°, 45° and 65° for 55MeV neutron with LA-150 library

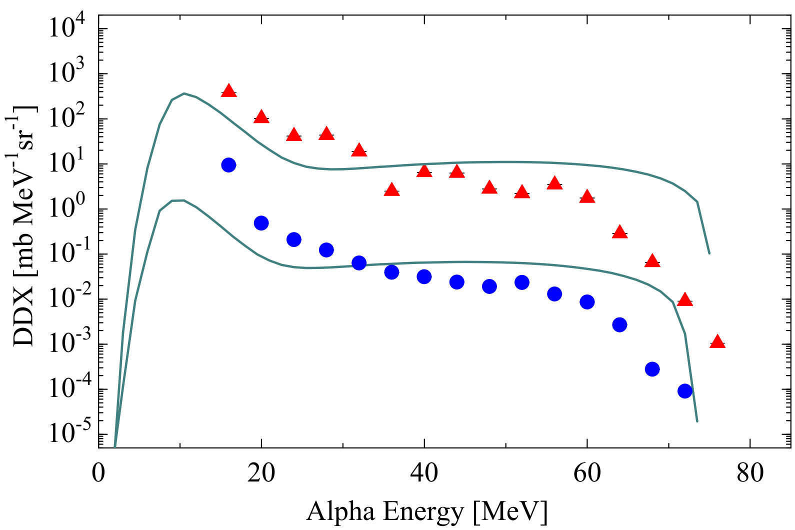

Figure 6: DDXs data for α particle production of Ni(upper) and Fe at 25° for 75MeV neutron with LA-150 library

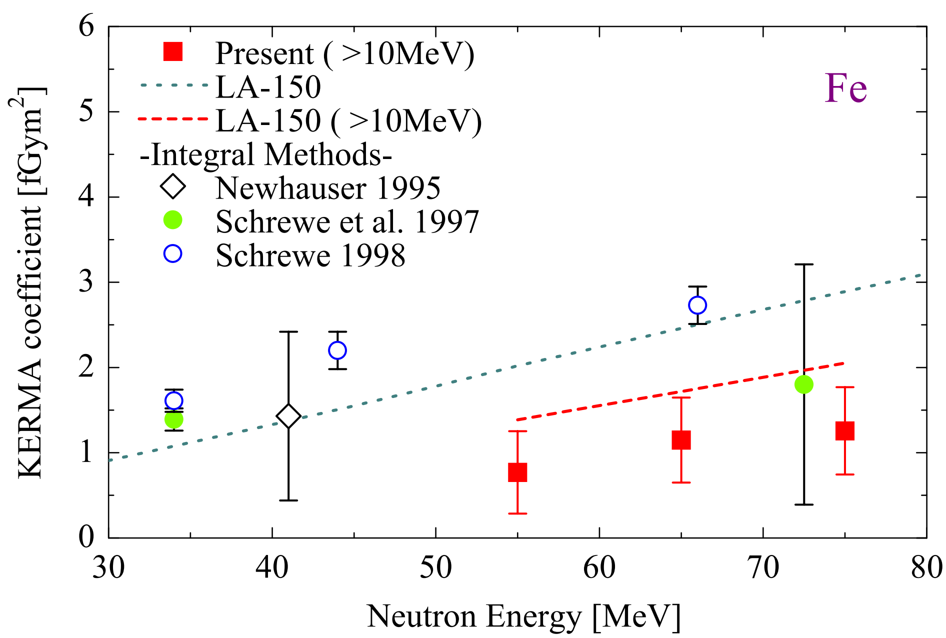

Figure 7: KERMA coefficient of Fe with integral measurement and calculations by the LA-150 data library