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Prediction of prompt neutron spectra of the photon induced reactions on ^{238}U and ^{232}Th targets at incident energies from 4 to 22 MeV

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Abstract. The processing of experimental data for the photon induced reactions on ^{238}U and ^{232}Th investigated by quasi-monochromatic γ-ray beams (produced in Laser Compton scattering at the NewSUBARU facility) needs the prediction of prompt neutron spectra. They are obtained using reliable models and systematics, i.e. the most employed and well validated approach of the most probable fragmentation with input parameters provided by a recent systematic and fission chance probabilities based on nuclear reaction calculations performed with the EMPIRE code.

1 Introduction

The recent experimental investigations of photon-induced reactions on ^{238}U and ^{232}Th performed at the NewSUBARU laser Compton-scattering γ-ray source have brought the need for reliable predictions of photo-fission prompt neutron spectra. The measurements made use of a high-and-flat neutron efficiency detection system originally designed for such reactions with typical evaporation neutron emission spectra up to 5 MeV. Dedicated predictions of prompt neutron spectra of photon-induced fission reactions will enable the neutron detection efficiency characterization for realistic fission spectra extending well above the (γ,xn) photo-neutron energy range.

Unfortunately such prompt neutron spectra (PNS) cannot be calculated in the frame of refined prompt emission models (e.g. FIFRELIN, CGMF, PbP, DSE, HF^{3}D etc.) because any information concerning the fission fragment distributions Y(A,TKE) (necessary as input in these models) is missing in the case of photo-fission of actinides. Experimental data of prompt emission for ^{238}U(γ,f) and ^{232}Th(γ,f) are missing, too. So that the validation of model results (by their comparison with experimental data) is impossible.

Consequently the only way remains the PNS prediction for the γ + ^{238}U and γ + ^{232}Th reactions by using a most probable fragmentation approach with input parameters provided by recent systematics. At higher incident photon energies, where multiple fission chances are involved, the fission chance probabilities (necessary in the prompt emission calculations mentioned above), which are expressed as fission cross-section ratios, are based on the results of nuclear reaction codes (such as EMPIRE, TALYS, GNASH).

2 Calculation of prompt neutron spectra and input parameters

The total PNS in the photon induced fission of ^{238}U and ^{232}Th is calculated as a sum of total spectra of prompt neutrons emitted by the fission fragments $N_{FF}(E)$ and of pre-fission neutrons $N_{prefiss}(E)$ (i.e. neutrons emitted by each compound nucleus prior to fission, in the case of multiple fission chances) [1]:

$$N_{FF}(E) = \sum_{i=1}^{n} PF_i <\nu_i> N_i(E) \Big/ <\nu>_{tot} \quad (1)$$

$$N_{prefiss}(E) = \sum_{i=2}^{n} PF_i \sum_{j=1}^{i-1} \varphi_{ev\,j}(E) \Big/ <\nu>_{tot} \quad (2)$$

in which the index i denotes the fission chance. $N_i(E)$ is the prompt fission neutron spectrum (PFNS) corresponding to each fissioning compound nucleus, $\varphi_{ev\,i}(E)$ is the evaporation spectrum of each pre-fission neutron. The total average prompt neutron multiplicity $<\nu>_{tot}$ is the sum of total multiplicities of prompt neutrons emitted by fission fragments $<\nu>_{FF}$ and of pre-fission neutrons $<\nu>_{prefiss}$ [1]:

$$<\nu>_{FF} = \sum_{i=1}^{n} PF_i <\nu_i> \Big/ \sum_{i=1}^{n} PF_i \quad (3)$$

$$<\nu>_{prefiss} = \sum_{i=1}^{n} (i-1) PF_i \Big/ \sum_{i=1}^{n} PF_i \quad (4)$$

PF_i entering Eqs.(1-4) are the fission chance probabilities taken as fission cross-section ratios:

$$PF_i = RF_i = \sigma_{\gamma,inf} / \sigma_{\gamma,F} \quad (5)$$

in which $\sigma_{\gamma,F}$ is the total fission cross-section (as a sum of fission chance cross-sections).

Ni(E) entering Eq.(1) is calculated in the frame of the most probable fragmentation approach either in its

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classical form with a global treatment of sequential emission (known as the Los Alamos (LA) model [2]) or in its new version with inclusion of sequential emission, described in Ref.[3]. The input parameters are the same for both versions (with and without sequential emission). They are the average total kinetic energy <TKE> and the average nuclear temperature of initial fragments $<T_i>$ corresponding to the light and heavy fragment groups [2, 3]. $<Ti>_{L,H}$ enter the maximum temperature of the residual temperature distribution P(T) taken with a triangular form with a sharp cut-off [2 - 4]). The values of the input parameters <TKE> and $<Ti>_{L,H}$ which are used in the present calculations are provided by a new systematic reported in Ref.[5] as follows.

The average total excitation energy <TXE> of fully accelerated fission fragments corresponding to each fissioning compound nucleus is obtained either as:

$$< TXE > = < Q > (XF) + E^{*} - < TKE >_{Viola} \qquad (6)$$

or

$$< TXE > = < Q - TKE > (XF) + E^{*} \qquad (7)$$

where E* is the excitation energy of the fissioning nucleus. In Eq.(6) the Q-value systematic as a function of the fissility parameter (XF) reported Ref.[5] (given in the upper part of **Fig.1**) and a systematic of <TKE> (usually that of Viola [6]) are used. In Eq.(7) the systematic of the Q-value minus TKE <Q-TKE> as a function of XF from Ref.[5] (plotted in the lower part of Fig.1) is employed.

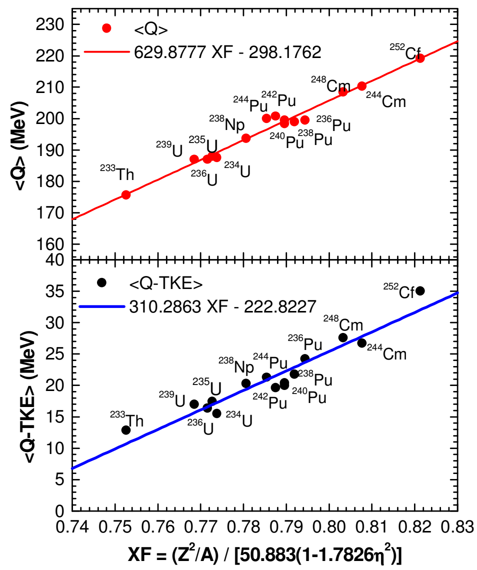

Fig.1:Systematics from Ref. [5] of <Q>(XF) (upper part) and <Q-TKE>(XF) (lower part).

Once <TXE> is calculated, the average excitation energies of fully accelerated fragments $<E^*>_{L,H}$ (corresponding to each fissioning nucleus) are obtained from the systematic of the ratios $<E^*>_{L,H}$/<TXE> as a function of XF reported in Ref.[5], too.

Using these average excitation energies of fully accelerated fragments the average temperatures of initial light and heavy fragments $<T_i>_{L,H}$ are obtained from the systematic of Ref.[5] given in **Fig.2**.

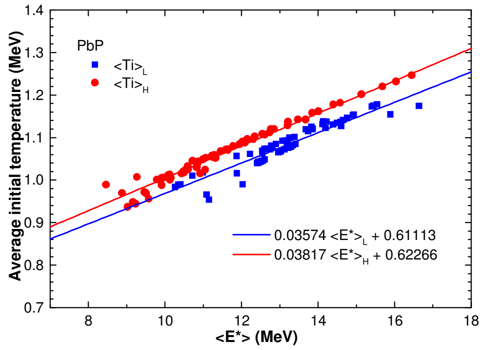

Fig.2: Systematic of the average temperatures of initial fragments [5]

3 Preliminary predicted results

Examples of predicted PNS at incident photon energies where only one fission chance is involved are given in **Fig.3** for ^{238}U(γ,f) and **Fig.4** for ^{232}Th(γ,f). These PNS results are plotted in the usual representation as ratios to a Maxwellian spectrum with the T_M parameter value indicated in the legend of the axis.

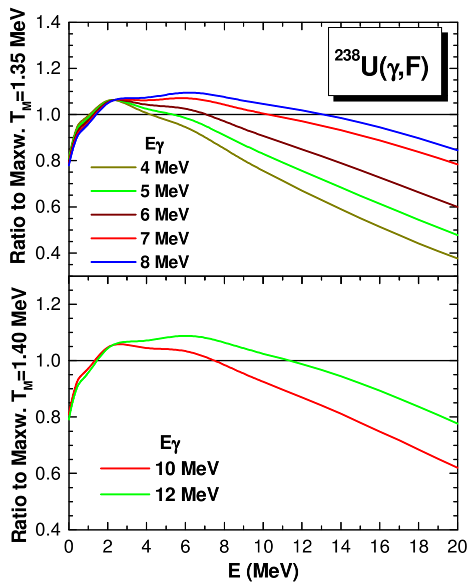

Fig.3: PFNS results for ^{238}U(γ,f) at the incident energies specified in the figure legend.

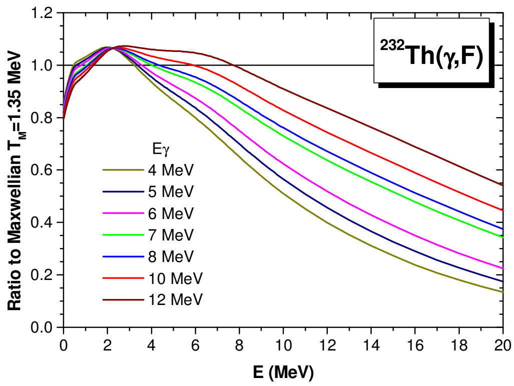

Fig.4 : PFNS results for ^{232}Th(γ,f) at the incident energies specified in the figure legend.

Another example is that of the predicted total prompt neutron multiplicity $<\nu>_{tot}$ which is illustrated in **Fig.5** together with its components $<\nu>_{FF}$ and $<\nu>_{prefiss}$ for the γ + ^{238}U reaction at incident photon energies from 4 to 22 MeV.

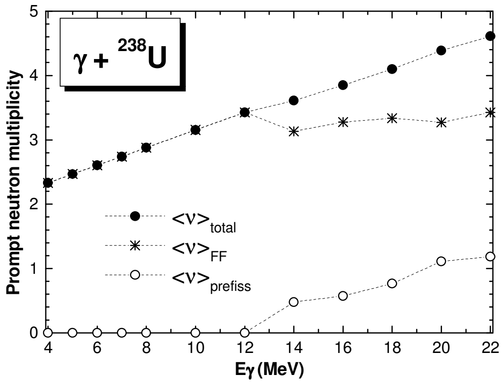

Fig.5: Predicted average total prompt neutron multiplicity $<\nu>_{tot}$ (together with its components $<\nu>_{FF}$ and $<\nu>_{prefiss}$) for γ+^{238}U at incident energies from 4 to 22 MeV.

The fission chance probabilities (taken as fission cross-section ratios according to Eq.(5)) which are used in the present calculations (at incident photon energies where multiple fission chances are involved) are obtained from the fission cross-sections provided by the nuclear reaction code EMPIRE with the input parameters of Ref.[7]. These fission cross sections are illustrated in **Fig.6** for the case of γ+^{238}U.

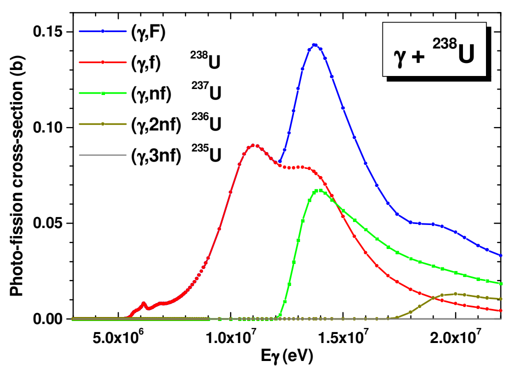

Fig.6 : EMPIRE results of photo-fission cross sections of ^{238}U using the parameters of Sin et al.

4 Conclusions

The present prediction is based on reliable models and systematics, i.e.

i) the most employed and well validated approach of the most probable fragmentation (i.e. the Los Alamos model without or with sequential emission [2, 3]) using

ii) input parameters provided by the recent systematic of Ref.[5] and

iii) fission chance probabilities based on nuclear reaction calculations performed with the EMPIRE code [7].

Consequently the predicted PNS are expected to be successfully used in the processing of experimental data obtained from the photon induced reactions on ^{238}U and ^{232}Th performed at the NewSUBARU facility (by using quasi-monochromatic γ-ray beams produced in Laser Compton scattering).

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