EPJ Web of Conferences **239**, 03019 (2020) https://doi.org/10.1051/epjconf/202023903019
ND2019

Employing TALYS to deduce angular momentum rootmean-square values, J_{rms}, in fission fragments

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Abstract. Fission fragments exhibit large angular momenta J, which constitutes a challenge for fission models to fully explain. Systematic measurements of isomeric yield ratios (IYR) are needed for basic nuclear reaction physics and nuclear applications, especially as a function of mass number and excitation energy. One goal is to improve the current understanding of the angular momentum generation and sharing in the fission process. To do so, one needs to improve the modeling of nuclear de-excitation.
In this work, we have used the TALYS nuclear-reaction code to relax excited fission fragments and to extract root-mean-square (rms) values of initial spin distributions, after comparison with experimentally determined IYRs. The method was assessed by a comparative study on ^{252}Cf(sf) and ^{235}U(n_{th},f). The results show a consistent performance of TALYS, both in comparison to reported literature values and to other fission codes. A few discrepant Jrms values were also found. The discrepant literature values could need a second consideration as they could possibly be caused by outdated models. Our TALYS method will be refined to better comply with contemporary sophisticated models and to reexamine older deduced values in literature.

1 Introduction

The generation of angular momentum (J) is an open question in contemporary fission modeling, which upon further exploration may improve our understanding of nuclear fission [1]. Isomeric yield ratio (IYR) studies are an important tool for investigating how the angular momentum is generated and shared at scission[2]. Novel techniques enable precise measurements of IYRs and allows systematic mapping of J as a function of compound mass, A, and excitation energy E_{exc}[2, 3].

In this work we present a method to calculate average quantities of angular momenta, by utilizing the TALYS reaction code and comparing to measured IYR values[2, 4, 5]. Literature IYR data, on ^{252}Cf(sf) and ^{235}U(n_{th},f), were used to estimate the Fission Fragment (FF) spin[6] and verified to a fair amount of reported literature spin values and the GEF code[7].

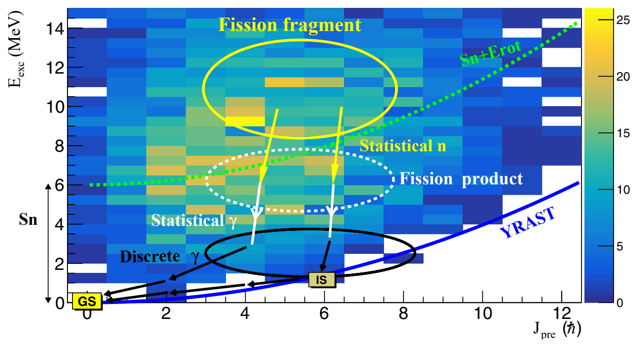

Figure 1. Simplified depiction of the de-excitation of fission fragments leading to populating the ground state (GS) or the meta-stable isomer (IS).

2 Methodology

Nuclear de-excitation is governed by the available excitation energy and spin, and involves both prompt fission neutron evaporation and γ-ray emission (see Figure 1). The evaporation model implemented in TALYS. It takes into account the competition between neutron and -γ ray emissions. At lower excitation energies, γ-rays are emitted from discrete states typically with high multipolarity. The RIPL-3 data-base is used for discrete levels at lower energies. For a given fission product (Z,A) the de-excitation of the primary fragments, (Z,A+1) and (Z,A+2), are calculated, assuming a Gaussian excitation energy distribution. The average excitation energy was derived based on the total excitation energy obtained from the GEF code[7]. It was estimated using the average excitation energy of the corresponding mass chain, $\bar{E}$(A), and the spread is obtained from the average excitation-energy spread of the respective fission reaction. The angular momentum distribution of the fragments is assumed to follow the functional dependency of the level density [8, 9]:

$$P(J) \propto (2J + 1)\exp\left(-\frac{(J + 0.5)^2}{2b^2}\right)$$

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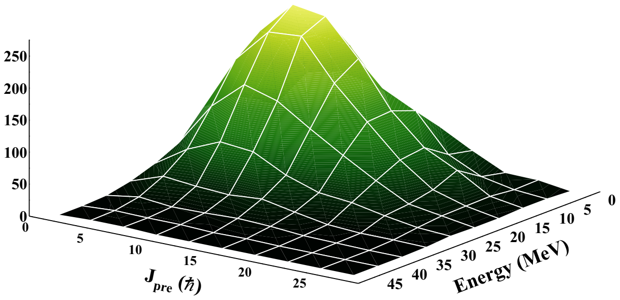

Figure 2. The population of spin versus excitation energy which was provided to TALYS,shown here for the case of ^{138}Cs at $B = \sqrt{2b^2}$=12$\hbar$

where the spin-cut off parameter, b, can be used to estimate the root-mean-square of the angular momentum, $J_{rms} \approx \sqrt{2b^2}$[6].

TALYS is provided with a matrix containing E_{exc} and *P(J)* as illustrated in figure 2. From each TALYS calculation, a value of IYR can be extracted and compared to experimentally determined values. By repeating the calculations for different values of the parameter $B = \sqrt{2b^2}$, the value which best reproduces the data can be determined, resulting in a unique set of parameters(A,Z,ν, E_{exc} and B) for the initial fragments.

3 Results

The study was performed on the following isotopes: ^{81}Br, ^{90}Rb, ^{128,130,132}Sb, ^{131,133}Te,^{132,134,136}I, ^{133,135}Xe, ^{138}Cs and ^{146}La[6]. Root mean square values obtained from the TALYS code generally agree rather good with GEF values and with most literature data. However, some discrepancies from earlier reported data were observed, which was extensively discussed in ref.[6]. Figure 3 demonstrates an example where all methods agree and another where TALYS and GEF disagree with the reported literature value (in Figure 4)[10, 11]. The IYR is reported as the cross section of the high spin state relative to the total cross section. In a few cases (e.g. I-136), TALYS was unable to match the measured IYR, since the population of high-spin state was not sufficiently high. To remedy this, one could alter the results by improving the information in the level structure data[4, 6].

A sensitivity analysis was performed to quantify the importance of the neutron multiplicity, number of considered levels, level density models and excitation energy, respectively. The calculations were proven to be rather robust, albeit care has to be put especially on the choice of excitation energy and the level structure.

4 Outlook

In the future, we will further improve the model by enhancing the excitation energy assumptions and by accounting for an energy-dependence in the spin cut off parameter. The calculation uncertainty quantification will be enhanced by invoking the General Least Square method.

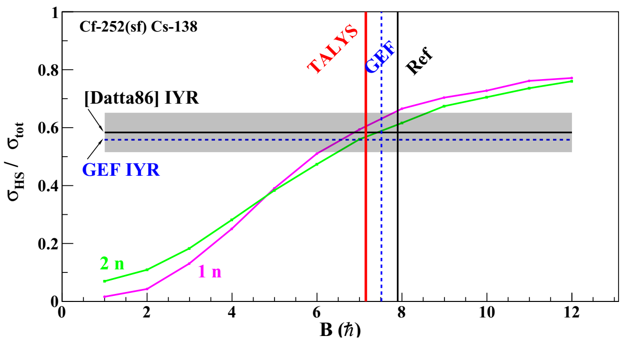

Figure 3. The calculations for Cs-138 assuming 1 or 2 emitted neutrons. The horizontal lines show the experimental IYR value [10] and the GEF calculations, respectively. The vertical lines show B as extracted from GEF (dashed blue line), TALYS (full red line) and the experiment (full black line). All three data-sets agree on a rms spin of 7 - 8$\hbar$.

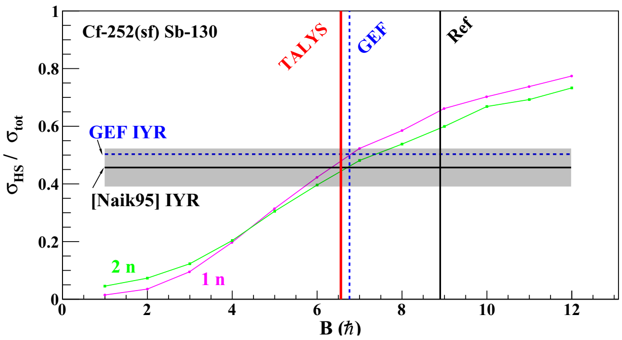

Figure 4. In this case, TALYS and GEF agrees but a large discrepancy is noticed to the literature data [11].

We would like to thank S. Goriely, J. Randrup, K.-H. Schmidt, C. Schmitt and O. Litaize for fruitful discussions. Funding for this work was received from the Swedish Radiation Safety Authority.

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