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Neutron emission in fission

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Abstract

A model based on energy conservation with a detailed simulation of the cascade neutron emission process from exited fragments was applied for prompt neutron emission calculations. The results for the prompt neutron multiplicity, $\nu(A)$, the neutron energy, $\varepsilon(A)$, as a function of fission fragment mass A and total kinetic energy (TKE), ν(TKE) are compared with available experimental data for the spontaneous fission of ^{252}Cf, ^{244,248}Cm and thermal neutron induced fission of ^{235}U. Several problems connected with the distribution of the available energy between exited fragments and the mechanisms of neutron emission in fission are discussed. The high TKE range > 190 MeV is assumed as a possible region for scission neutron emission. In the framework of this assumption, an excellent agreement between experimental and calculated data for the TKE range from 150 MeV to 205 MeV (containing $\sim 98\%$ of all fission events) within 1–2% was found for all spontaneously fissioning isotopes mentioned above. An additional unfolding between the calculated results and the rather poor experimental energy resolution improved the agreement also in case of ^{235}U(n$_{\rm th}$, f). However, one may conclude that in spite of the good agreement between the results of three experimental investigations for ^{235}U(n$_{\rm th}$, f), they maybe all have similar systematic uncertainties which result in a common observation, namely a very low neutron multiplicity and a positive slope of $d\nu/dE$ in the low TKE range (< 150 MeV).

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1. Introduction

The theoretical and experimental investigation of the prompt fission neutron emission is important for the understanding of the fission process. Knowledge of the properties of fission neutrons, their multiplicities and energy distributions, could give answers to related questions on the mechanism of neutron emission and fission itself, how the energy is distributed between the complimentary fragments and what is the time scale of the fission process.

The energy conservation law is a very attractive and powerful tool to perform calculations of the fission neutron properties. It is difficult to say who applied this approach for the first time for neutron multiplicity calculations. In any case from 1950 onwards [1] this approach is applied in every theoretical model using different levels of details.

Indeed, if the masses and charges of the separated fragments are known one may calculate the energy release and the neutron binding energy for all neutrons in the cascade with a rather high accuracy. In the next step this result is convoluted with the proper fission fragment yield versus total kinetic energy (TKE), mass and charge to find average values. Of course, several assumptions have to be made: neutrons are emitted after fission fragment formation because otherwise the excitation cannot be fixed; one should have an idea about the energy share between the fragments; neutrons will be emitted as soon as the excitation energy is higher than the neutron binding energy. These ideas were all incorporated in the model described in Ref. [2].

In Ref. [2] the neutron multiplicity, $\nu(A)$ and the neutron energy, $\varepsilon(A)$ both as a function of mass were calculated for ^{233,235}U(n$_{\text{th}}$, f) and ^{252}Cf(sf) in the framework of a model developed along the lines mentioned above. The main conclusions were: the average values were described successfully within the experimental uncertainties; the traditional assumption of the excitation energy share between fragments on the basis of a thermo-dynamical equilibrium does not work; in a certain mass range the experimentally determined low neutron multiplicity and high neutron energy cannot be described simultaneously.

According to simple statistical equations a direct relation between low multiplicity and low average neutron energy of the emitted neutrons should exist. However, the opposite was found namely low multiplicity and high average neutron energy for some masses in several theoretical models [3–5].

Being in reasonable agreement with Ref. [2] in the description of $\nu(A)$, $\varepsilon(A)$, in Ref. [5] a systematic deviation between experimental and theoretical dependencies in ν(TKE) was observed. A tremendous difference was found for the ^{235}U(n$_{\text{th}}$, f) reaction. At TKE $\sim$ 130 MeV the difference between the theoretical calculation and the experimental data reaches about 5 neutrons which correspond to a difference in excitation energy of about 40 MeV. Even more, at TKE $<$ 150 MeV, $\mathrm{d}\nu/\mathrm{d}E$ changes sign, and becomes positive, which contradicts energy partition between fission fragment kinetic energy and excitation. This would mean one should assume an additional energy reserve.

All this stimulated the present paper. In addition new experimental data for several spontaneously fissioning isotopes became available [6]. In Section 2 we will describe the model applied for neutron multiplicity calculations. In the following chapters the theoretical and experimental results for ^{252}Cf(sf), ^{244,248}Cm(sf) and ^{235}U(n$_{\text{th}}$, f) are compared and discussed. A conclusion and outlook completes the paper.