Fast Neutron Fission of 236Pu Nucleus

Cristiana Oprea 1,2[[1]](#footnote-1) and Alexandru Ioan Oprea3

1National College “Emanoil Gojdu” Oradea, Bihor county, Romania

2University of Bucharest, Faculty of Physics, Bucharest – Magurele, Romania

3Technical College “Alexandru Roman”, Alesd, Bihor county, Romania

**Abstract.** Fission variables like cross-sections, fragment mass and charge distributions, neutron spectra, isotope production of interest for many applications in fast neutron-induced fission of 236Pu nucleus were investigated. Theoretical results were compared with existing poor experimental data from literature, evidencing the necessity of new fast neutron induced fission measurements.

1. Introduction

Plutonium isotopes with atomic mass from 228 up to 247 are produced in nuclear reactors mainly by fission process followed by decay [1,2]. Among the Plutonium isotopes, produced in nuclear reactors, 236Pu nucleus is a trace element of interest for studies of the environmental impact of fuel cycles [3]. Development of new type of fast neutron research reactors based on 237Np fuel, implies the analysis of the influence of different fission products such as 236Pu [4]. In the present work, fission variables obtained in 236Pu(n,f) fast neutron induced fission process were evaluated and compared with experimental data. Previously, the authors had investigated neutron and gamma induced fission, an example being the fast neutrons induced fission of 237Np necessary for new research nuclear reactor [5].

2 Codes and elements of theory

Fission variables in 236Pu(n,f) process with fast neutrons were evaluated using Talys code and author’s programs. Talys is a free soft working under Linux where are implemented all nuclear reaction mechanisms together with a large nuclear data base containing energy levels, spin, parities, parameters of states densities, of Wood-Saxon potential and of other parameters [6]. Fission cross sections were described by compound nucleus mechanisms and Hauser-Feshbach approach [6,7]. Cross-section and angular distribution formulas contain transmission coefficients for incident and emergent channels. In the fission case, transmission coefficients were calculated using Hill-Wheeler expression [6,8]. Yields and cross sections of mass and charge distributions of fission fragments or for a given emergent nucleus with specific mass and protons were evaluated considering neutron evaporation by applying Random Neck Rupture Model [6,9].

3 Results and discussions

Results of fission cross section of 236Pu(n,f) with fast neutrons up to 15 MeV are shown in Fig. 1.



**Fig. 1.** Cross sections. a) Talys evaluation. Processes: 1-(n,2nf); 2-(n,f); 3-(n,n’f); 4-Total (sum of 1+2+3) b) Comparison with experimental data. 1-(n,f); 2-Experimental results; 3-Total (from a) )

Calculations are shown in Fig. 1a and comparison with experimental results in Fig. 1b. The code approach gives the possibility to evaluate the production of fissionable nuclei and their contribution to total fission cross section. In Fig. 1a are represented only the main contribution of fissionable nuclei produced by (n,2nf), (n,f) and (n,n’f). Experimental data [10,11] are in good agreement with theoretical evaluations. Differences exist near 3-5 keV were Talys calculations considers only averaged influence of resonances.



**Fig. 2.** Fragment mass distributions. a) Yields b) Cross sections. Black square -1 MeV. Line – 15 MeV

Mass and charge distributions of fission fragments were evaluated also up to 15 MeV. Theoretical results of mass distribution after neutron emission, for 1 and 15 MeV incident energy, respectively, are given in Fig. 2 (yields and cross section). It is easy to observe that with the increasing of the incident energy the distributions become less asymmetric. The authors had not found experimental data for mass distributions.

In fission process a large number of new isotopes are obtained. Cross sections and yields for many produced isotopes were calculated and not shown in this report. In Fig. 3.a, b are represented production cross section of 135Xe (important for nuclear technology) and yields of produced 99Mo, of interest for medicine. In the case of 135Xe precision of calculation is default but for 99Mo Talys precision is fixed to 10-10. It is easy to observe that after neutron emission (Post), yields and cross sections are larger than before neutron emission (Pre) by fission fragments. In Talys it is possible to evaluate the populations for different excited nuclear states necessary for the calculation of isomer states.

The results from Fig. 1, 2, 3 were obtained using a two-humped fission barrier. First barrier has the height of 4.35 MeV, width of 0.8 MeV with axial symmetry. The second barrier has a 5.5 MeV height, 0.8 MeV width and a left-right asymmetry type of axiality. In the neutron channel, real part of central Wood Saxon potential is 47 MeV and 0.09 MeV its imaginary part. Other parameters were also extracted but are not mentioned in the present work.



**Fig. 3.** Isotope production. a) Cross section of 135Xe. b) Yields of 99Mo. Neutron emission Circles: Empty –Pre; Black - Post



**Fig. 4.** Neutron emission. a) Average Prompt Neutron Multiplicity (APNM). b) Prompt Neutron Multiplicity Distribution (PNMD). Squares: Empty En = 1 MeV; Full En = 15 MeV

Neutron emission results is represented in Fig. 4 and theoretical data were evaluated with Talys. Average prompt neutron multiplicity (APNM) as function of fission fragment mass can be found in Fig. 4a and prompt neutron multiplicity distribution (PNMD) in Fig. 4b. Usually fission variables from Fig. 4 are smoothly increasing with energy. For 1 MeV neutron energy around A = 180 APNM is higher than in the case of 15 MeV neutron energy (Fig. 4a). In Fig. 4b, around 8 neutron value, PNMD has a high value. If we consider that calculations are correct than, the mentioned before results can be explained by the nuclear structure of fission fragments.

For both fission variables, APNM and PNMD, nu-bar prompt parameter is related. In Table 1 neutron energy dependence of nu-bar prompt calculated values are shown. As is expected, nu-bar prompt is increasing with neutron incident energy.

**Table 1.** Neutron energy dependence of nu-bar prompt

|  |  |
| --- | --- |
| **En [MeV]** | **nu-bar prompt** |
| 0.1 | 2.95 |
| 1 | 3.08 |
| 5 | 3.74 |
| 10 | 4.20 |
| 15 | 4.65 |

4 Conclusions

Cross sections, mass distributions, neutron spectra, and isotope productions in 236Pu(n,f) were among the fission variables that were assessed. The experimental data are very poor since the 236Pu nucleus is a trace fission product. The contribution of produced fissionable nuclei to the total fission cross section was determined as a result of the computer approach that was employed. The theory provides a good description of the experimental cross section, with the (n,f) channel providing the main contribution. Additionally, fission barrier and optical potential parameters were extracted. Future plans call for new experimental data, computer simulations, and improved theoretical predictions for the fast neutron-induced fission process of the 236Pu nucleus.

References

1. G. Audi, O. Bersillon, J. Blanchot, A. H. Wapstra, The NUBASE Evaluation of Nuclear and Decay Properties. Nucl. Phys. **A729**, 1, 3 (2003).

<http://dx.doi.org/10.1016/j.nuclphysa.2003.11.001>

1. F.G. Kondev, M. Wang, W.J. Huang, S. Naimi, G. Audi, The NUBASE2020 evaluation of nuclear physics properties. Chinese Physics C45, 3, 030001 (2021). [10.1088/1674-1137/abddae](http://doi.org/10.1088/1674-1137/abddae)
2. H. Yamana, T. Yamamoto, K. Kobayashi, T. Mitsugashira, H. Moriyama, Production of Pure Pu Tracer for the Assessment of Plutonium in the Environment.. Journal of Nuclear Science and Technology, **38**, 10, 859 (2001). [10.1080/18811248.2001.9715106](http://dx.doi.org/10.1080/18811248.2001.9715106)
3. E. P. Shabalin, V. L. Aksenov, G. G. Komyshev. A. D. Rogov, Neptunium-Based High Flus-Pulsed Research Reactors, 124, 364 (2018).

<https://doi.org/10.1007/s10512-018-0424-3>

1. C. Oprea, M. Ayaz Ahmad, A. I. Oprea, J. H. Baker, N. Amrani, Nuclear Reaction Mechanism of Neutron Induced Fission of 237Np Nucleus. European Journal of Engineering Science and Technology, **1**, 83 (2020).

<https://doi.org/10.33422/ejest.v4i4.600>

1. A.J. Koning, S. Hilaire, M.C. Duijvestijn, . TALYS-1.0., International Conference on Nuclear Data for Science and Technology, 211 (2007). [http://doi.org/10.1051/ndata:07767](http://doi.org/10.1051/ndata%3A07767)
2. W. Hauser, H. Feshbach, The Inelastic Scattering of Neutrons. Phys. Rev., **87**, 2, 366 (1952).

<https://doi.org/10.1103/PhysRev.87.366>

1. D.L. Hill, J.A. Wheeler, Nuclear Constitution and the Interpretation of Fission Phenomena. Phys. Rev, **89**, 1102 (1953).

<https://doi.org/10.1103/PhysRev.89.1102>

1. U. Brosa, S. Grossmann, Nuclear Scission. Phys. Rep. **197**, 4, 167 (1990).

[https://doi.org/10.1016/0370-1573(90)90114-H](https://doi.org/10.1016/0370-1573%2890%2990114-H)

1. E.A. Gromova, S.S. Kovalenko, Yu.A. Selitskii, A.M. Fridkin, V.B. Funshtein, V.A. Yakovlev. S.V. Antipov, P.E. Vorotnikov, B.M. Gohberg, V.V. Danichev, V.N. Dement’ev, V.S. Zenkevich, S.A. Isakov. Neutron Cross Section of 236Pu. Soviet Atomic Energy, **68**, 223 (1990). <https://doi.org/10.1007/BF02074090>
2. R. O. Hughes, C. W. Beausang, T. J. Ross, J. T. Harke, R. J. Casperson, N. Cooper, J. E. Escher, K. Gell, E. Good, P. Humby, M. McCleskey, A. Saastimoinen, T. D. Tarlow, and I. J. Thompson, 236Pu(𝑛,𝑓),237Pu(𝑛,𝑓), and 238Pu(𝑛,𝑓) cross sections deduced from (𝑝,𝑡), (𝑝,𝑑), and (𝑝,𝑝′) surrogate reactions. Phys. Rev. C90, 014304 (2014). <https://doi.org/10.1103/PhysRevC.90.014304>
1. Corresponding author: coprea2007@yahoo.co.uk [↑](#footnote-ref-1)