# Study of increasing spin and deformation of Pu, Cm and Cf nuclei by simulation using MCNPX code

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## Abstract

In this work, the effects of spin increasing and core quadrupole shape changes for different nuclei using the results of Monte Carlo N-Particle eXtended (MCNPX) code simulations were studied. By calculating the amount of F7 in the simulations, the released energy due to fission in the target cell was measured by increasing the energy of the neutrons. Then, using Cranked Nilson-Strutinsky (CNS) calculation code, the changes in the height of the fission barrier by the increasing spin of $^{242}$Cm were studied and confirmed the simulation results by MCNPX code. Then, the effect of nuclear quadrupole shape changes on these results and its opposition with increasing spin was investigated and it was found that their results are well consistent with the results of the simulations.

**Keywords: Spin increase, MCNPX code, Neutron energy, Deformation**

## *Introduction*

By using MCNPX and CNS simulation codes, various applied studies have been done on nuclei [1-3], such as neutron production, nuclear deformation, and scattering of thermal neutrons. In this work, we simulated the increase in the spin of nuclei with MCNPX code and calculated parameters such as the deformation and fission barrier of some nuclei [4-6], the amount of energy accumulation due to fission, and the amount of neutron production due to it. The fission barrier is the maximum energy along the fission path or minimum energy required to deform the nucleus to the point where the fission process becomes irreversible [2,7]. Then we compared our results with CNS code. The results were in very good agreement. Also, the practical, industrial, and scientific effects of increasing spin of nuclei were investigated in this work.

## *Theoretical method*

The relation between the energies of nuclear structure is as follow [8]:

$$E_{tot} = E_{DL} + E_{Rot} + E_{sh} \qquad (1)$$

Where $E_{DL}$ is the energy of the liquid droplets and $E_{sh}$ is the shell energy. The second term which refers to rotational energy, after considering the appropriate corrections, can be written as:

$$E_{Rot} = \frac{I(I+1)\hbar^2}{2g} \qquad (2)$$

Drop-liquid energy, shell effects, and quadrupole shape changes of nuclei have been studied in various papers [9,10]. In the above relation, I refers to the nucleus spin that is investigated in this work, and g is directly related to the shape changes under study.

## *Results and discussion*

In this research, using the MCNPX simulating code, we have placed the neutron source in such a way that it has isotropic and homogeneous radiation on a sphere with a thickness of 1 cm and selected some nuclei according to Table 1 as suitable materials. Then the value of F7 was calculated and based on the given data in Table 1, by increasing the energy of the neutrons descending on the studied nuclei, the spin of those nuclei increases as a result of left energy in the desired cell. In Figure (1), the height changes of the Cm isotopes fission barrier are calculated by the CNS code, which confirms the results for the F7 sequence in the MCNPX code[2]. By increasing the spin according to Table 1, the number of neutrons that are produced in addition to the neutrons produced by the source was also measured with the code MCNPX. According to Figure 2 and Table 1, with the increase of nuclei spin, their neutron production also increases, which has many important applications in industry and so on. The *g*-parameter in Eqn. 2 is directly related to the amount of nucleus deformation. This equation states that as the spin increases (the energy of the landing neutrons increases), the changes in the shape of the nucleus are often incremental (as shown in Figure 2), which increases the *g*-parameter and decreases the $E_{Rot}$ and $E_{Tot}$ energies. Thus, increasing the quadrupole shape of the nuclei as a result of the collision of high-energy neutrons and increasing the spin of the nuclei, by decreasing the nucleus energy, leads the nuclei towards greater stability and no fission. However, since the effect of the spin is higher than the expected value, eventually, the increase of spin overcomes the increase of nuclei deformation and this issue causes fission occurs.

## *Tables*

**Table 1.** Comparison of F7 Tally for different isotopes of three nuclei Pu, Cm and Cf with increasing spin. ERG is the energy of neutron source.

| Nuclei | F7 Tally for ERG=0.2 MeV ≈ (I = 4) (MeV) | F7 Tally for ERG=2 MeV ≈ (I = 12) (MeV) | F7 Tally for ERG= fission barrier ≈ (I = 16-18) | F7 Tally for ERG=10 MeV ≈ (I = 26) (MeV) | Error ٪ |
|---|---|---|---|---|---|
| $^{238}_{94}Pu$ | 25.8423 | 55.4073 | 56.7305 | 81.4546 | 0.001 |
| $^{239}_{94}Pu$ | 46.1304 | 50.2682 | 49.0956 | 62.9353 | 0.001 |
| $^{240}_{94}Pu$ | 22.4630 | 30.0772 | 28.3301 | 39.5958 | 0.001 |
| $^{242}_{94}Pu$ | 0.0724 | 20.8081 | 20.5902 | 29.7157 | 0.001 |
| $^{244}_{94}Pu$ | 0.0267 | 15.9175 | 15.7452 | 22.7314 | 0.001 |
| $^{242}_{96}Cm$ | 0.1290 | 21.0408 | 31.8143 | 38.9927 | 0.003 |
| $^{244}_{96}Cm$ | 20.5932 | 40.5258 | 46.6959 | 62.2817 | 0.002 |
| $^{246}_{96}Cm$ | 0.0871 | 27.4813 | 23.8400 | 37.3714 | 0.002 |
| $^{248}_{96}Cm$ | 14.7845 | 30.9101 | 34.6745 | 52.9423 | 0.002 |
| $^{250}_{98}Cf$ | 75.1260 | 91.1733 | 92.7154 | 129.7210 | 0.002 |
| $^{252}_{98}Cf$ | 10.4843 | 128.3320 | 128.5110 | 169.9150 | 0.003 |

## *Figures*

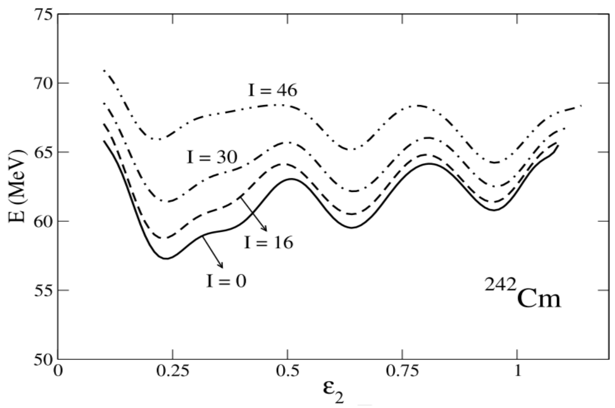


Figure 1. Decrease the height of the $^{242}$Cm fission barrier by increasing the spin calculated by the CNS code.

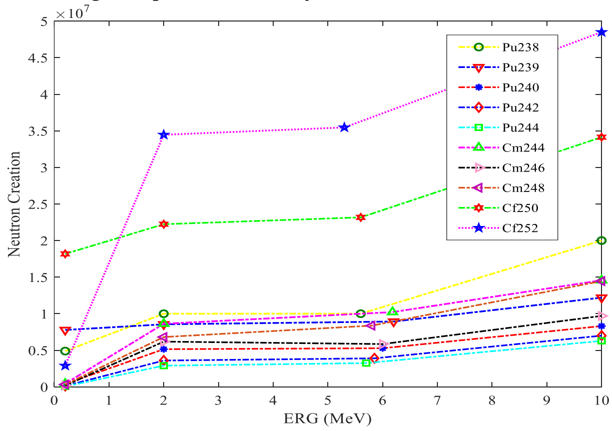


Figure 2. The calculated amount of neutrons produced after the increase of nuclei spin by MCNPX code.

## *Conclusions*

Justification of the MCNPX results by theoretical CNS code shows the accuracy of the work and its governed theory. Neutron radiation from a neutron source, according to Table 1, has different energies. In each energy, we write (approximately) the spin that is added to the target nucleus as a result of the neutron collision, to have a common parameter between the two codes used to compare their results. Increasing the spin and decreasing the height of the fission barrier in the CNS code caused the energy left by the fission to increase in the target cell, as shown in Table 1. In other words, we multiply the value of F7 by the mass of the target cell to convert its energy to MeV to create a common point between the two codes to make it easier to compare their results. For these nuclei, by increasing their spins, we were able to receive more energy from them, either in heat or otherwise, and also increase neutron production, as shown in Figure 2. Neutron production is a very important parameter in nuclear reactors, at airport gates for detection of explosive and illicit materials and other items. Theoretically, these calculation can be used for different materials to determine their neutron production for different energies. This issue helps to increase human safety and reduce the dangers that threaten us. One of the important results of this study is that if neutrons with different energies collide with the nucleus, even if no reaction occurs, there will be an increase in the spin of nuclei.

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