

## Neutron multiplicity in the proton-fission of some actinides

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### Introduction

Mean prompt fission neutron multiplicity,  $\bar{\nu}$  and mean neutron energies,  $\bar{E}_n$  of the neutron spectra are calculated for the proton-fission of 6 actinides ( $N/Z = 1.57 \pm 0.02$ ). The calculation was performed for the incident proton energy from 5 - 10 MeV.

### Calculation and Results

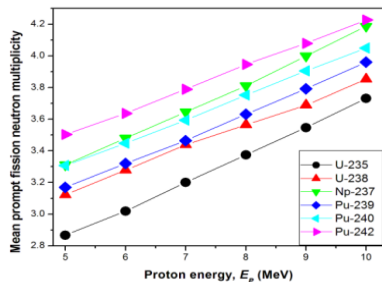
A total of  $10^5$  fission events were simulated using the GEF code, Version 2018/1.1 [1].  $\bar{\nu}$  and  $\bar{E}_n$  were calculated for U-235, U-238, Np-237, Pu-239, Pu-240 and Pu-242 for incident proton energies from threshold to 10 MeV. The threshold energy values were determined by the JENDL-4.0 Library [2] data.

All the actinides show the straight line behavior as

$$\bar{\nu}_i(E_p) = a_i + b_i E_p \quad (1)$$

$a_i$  and  $b_i$  values are given in the table for all the actinides.  $a_i$  represents value of  $\bar{\nu}$  as  $E_p \rightarrow 0$ , while as  $b_i$  represents the rate of increase of  $\bar{\nu}$  with  $E_p$ .

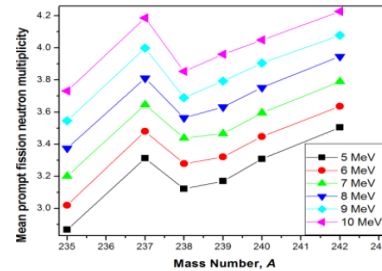
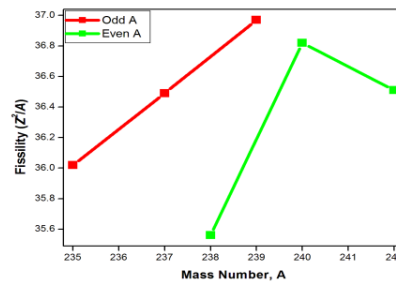
Actinide	$a_i$	$b_i$
U-235	1.98	0.17
U-238	2.42	0.14
Np-237	2.43	0.17
Pu-239	2.37	0.16
Pu-240	2.55	0.14
Pu-242	2.77	0.14



It is seen that the odd nuclei (U-235, Np-237, Pu-239) have the higher rate of increase (0.17) of neutron multiplicity with  $E_p$  than the even nuclei (U-238, Pu-240, Pu-242), which corresponds to

the ratio  $\frac{\bar{\nu}_{Odd}}{\bar{\nu}_{Even}} = 1.2$  for the same energy  $E_p$ . The

$\bar{\nu}$  values for the actinides is found to fall in the range  $3.5 \pm 0.7$ . The fissility parameter,  $f (= Z^2/A)$ , plotted shows that odd nuclei fissility values lie on a straight line with a positive slope, while as the even ones show the quadratic variation with the mass number  $A$ . Of all the actinides, U-235 has the lowest  $\bar{\nu}$  values for all the energies, while as Pu-242 acts as the hottest system.



with highest  $\bar{\nu}$  value for all the  $E_p$ . Higher neutron emission from Pu-242 may be assigned to the higher nucleon number and hence the lower binding energy.

Np-237 and Pu-242 attain almost the same value of  $\bar{\nu}$  ( $\approx 4.2$ ) at  $E_p = 10$  MeV. Np-237 has  $\bar{\nu}$  value next only to Pu-242 for all the  $E_p$  energies.  $\bar{E}_n$  versus  $E_p$  shows an oscillatory behavior for all the actinides. At 5 MeV, U-238 (least  $f$ ) has the least value of  $\bar{E}_n$  (2.08 MeV), while as Np-237 has the maximum value (2.25 MeV) at 10

MeV. For U-238, the maximum value of  $\bar{E}_n$  occurs at 6 MeV proton energy.

### Conclusion

$\bar{\nu}$  obtained fall in the range  $3.5 \pm 0.7$  for all the actinides considered and show the linear variation with the  $E_p$ . For all  $E_p$ , U-235 has the lowest value of  $\bar{\nu}$ , while as Pu-242 acts as the hottest system with the highest value of  $\bar{\nu}$ . At 10 MeV, Np-237 and Pu-242 attain almost the same value of  $\bar{\nu}$  ( $\approx 4.2$ ).

$\bar{E}_n$  versus  $E_p$  shows an oscillatory behavior for all the cases. At 5 MeV, U-238 with the least  $f$  has the least value of  $\bar{E}_n$  (2.08 MeV), while as at the same energy Pu-239 (maximum  $f$ ) has the maximum value (2.18 MeV). At 10 MeV, U-238 keeping the lowest value (2.06 MeV), Np-237 attains the highest one (2.25 MeV).

### References

- [1] <http://www.khs-erzhausen.de>, GEF Nuclear Reaction Program, Schmidt KH, Jurado B.
- [2] <https://www-nds.iaea.org>.