Yields of n-rich nuclei in P-and γ- induced ^{238}U fission

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Introduction

World wide initiative have already been taken for producing neutron-rich radioactive ion beam by the photofission using electron beam. As an extension of the present RIB development, a facility called ANURIB will be coming up at VECC with e-LINAC as primary accelerator for photofission [1]. However, low energy proton induced fission can also produce n-rich nuclei substantially in a specific mass region. For this one can have low energy proton beam (either from cyclotron or proton LINAC) opposite to e-LINAC, so that n-rich RIBs, produced in 2nd target station be put subsequently, in the same post-accelerator module.

In the present work, we would like to perform a simultaneous analysis of the behavior of the symmetric and asymmetric modes of proton induced fission for different excitation energies of ^{238}U and make a comparison with that of photofission [2].Finally the role of proton induced fission of actinides,specially ^{238}U towards the production of n-rich nuclei in the mass range $110 < A < 125$ are explored.

Theoretical framework

The empirical formula employed in our calculation is taken from Ref. [3] as

$$\sigma_f(E_p) = P_1(1 - exp[-P_2(E_p - P_3)]) \quad (1)$$

where σ_f, is the total fission cross-section (mb); E_p is the incident proton energy (MeV). $P_i(i = 1, 2, 3)$ are the arbitrary fitting parameters with physical meaning: the saturation cross-section, the increasing rate of cross-section with energy and apparent threshold energy respectively. The P_i has been parametrized with fissility parameter Z^2/A as:

$$P_i(Z^2/A) = exp[Q_{i,1}+Q_{i,2}(Z^2/A)+Q_{i,3}(Z^2/A)^2] \quad (2)$$

where Q_is are the coefficient of power of (Z^2/A) and are also determined by fitting the experimental fission cross-section data by Fukahori [4]. With the availability of precise data of fission cross-section time to time the systematic improved quite a lot. Systematics used by Prokofiev [3] is found to be very effective in the energy range 12-63 MeV for calculation of total fission cross-section σ_f as described in Eqn.(2) by fitting experimental data [5, 6], while P_1 is as parametrized differently as:

$$P_1(Z^2/A) = R_{11}[1 - exp(-R_{13}(Z^2/A - R_{12}))] \quad (3)$$

The values of $P_2 = 0.111$ and $P_3 = 12.1$ are considered as constant value from Ref [4] as it is found to be invariant for Z^2/A in the range 35.9 to 36.1 for ^{132}Th - ^{239}Pu. The values of $R_1j(j = 1 - 3)$are fitted by least square fit and found to be $R_{11} = 3703$, $R_{12} = 34.99$ and $R_{13} = 2.07$.

Calculations and Results

The production cross sections of individual fission fragments induced by protons are obtained by multiplying fission cross section, $\sigma_f(E_p)$, as calculated by the empirical formula in Eqn. (1), by charge distribution which means: $\sigma_f(A, Z) = \sigma_f(E_p).Y(A, Z)/100$.

The total fission cross-section $\sigma_f(E_p)$ increases with increasing proton energy, but it saturates almost at 30 MeV. However, for photofission, the cross section maximizes in the GDR range for mean photon energy of 13.7 MeV. In Fig.1 $\sigma_f(E_p)$ vs proton energy has been plotted using PACE4 and TALYS along

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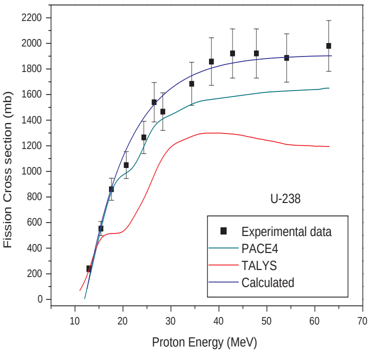

FIG. 1: Total fission cross-section (full circles) [5, 6] of ^{238}U by proton with the prediction (solid line), TALYS and PACE4

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TABLE I: The theoretical cross sections for production of nuclei with same A/Z.

Nuclei	A/Z	$\sigma_\gamma^{13.7}$ (mb)	σ_P^{35}(mb)	$\sigma_P^{35}/\sigma_\gamma^{13.7}$
^{80}Zn	2.66	2.6×10^{-3}	1.1×10^{-1}	40.00
^{96}Kr	2.66	2.1×10^{-3}	1.9×10^{-1}	91.43
^{106}Zr	2.66	3.9×10^{-3}	2.2×10^{-1}	56.15
^{133}Sn	2.66	2.2×10^{-3}	3.9×10^{-2}	17.59
^{143}Xe	2.66	6.6×10^{-3}	1.5×10^{-1}	23.18
^{154}Ce	2.66	2.2×10^{-3}	2.5×10^{-2}	11.32

with our empirical formalism to compare with experimental data [5, 6].

In Fig.2 the comparison is shown where,Z versus N are plotted for exotic nuclei produced by both the process with respective energy for max. cross-section. The results presented here are most neutron rich isobars subject to production cross-section $>$ 100fb. It can be noted that proton induced fission is little ahead towards n-drip line than the other one. Table-I contains the production cross-sections of some r-process nuclei,where it is interesting to note that ^{96}Kr can be produced two order of magnitude more by proton than γ induced fission.

Summary and Conclusion

We find that the empirical formalism nicely reproduces total fission cross-section for various actinide elements in a wide range of proton energy and in the high energy domain, it fits better than TALYS and PACE4 codes, where competition of other reaction channels are considered.

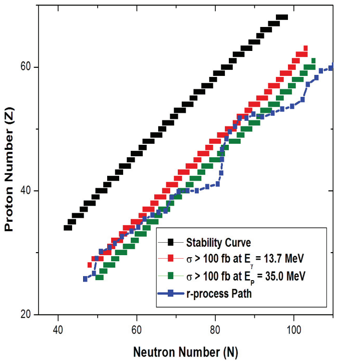

FIG. 2: Plots of atomic number Z vs neutron number N for exotic nuclei produced by photon and proton induced fission of ^{238}U

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The calculation indicates clearly that many of the r-process nuclei can be obtained in the laboratory by both proton and γ induced fission (slightly better by proton). The betterment is almost two orders of magnitude in the mass range 110-120 in the symmetric fission mode. However, people prefer to produce r-process nuclei through photon induced fission (bremsstrahlung photons from energetic electron by e-LINAC) because of better thermal management in the target design by having two targets (converter target and fission target)instead of one.

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