Fission product yield distribution in ^{35}Cl+^{165}Ho reaction

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Introduction

There has been a renewed interest in the role of different neutron proton configurations in governing the contribution from asymmetric fission [1-3]. Recent studies show that the shell effects persist up to several tens of MeV of excitation energy in the actinide and pre-actinide region [2-4]. After the observation of asymmetric fission in the sub-lead mass region, efforts are being made to get a comprehensive understanding of role of single particle effects in the fission process. Recently, in the lighter mass region, proton number of light mass fragments (Z_L~34-36) and neutron number of the heavy mass fragment (N_H~52-56) have been predicted to be responsible for the asymmetric fission contribution [5]. On the other hand, proton number around Z_H~54-56 and neutron number N_H~82, 88 have been proposed to be mainly responsible for asymmetric fission in the actinide region. Thus, a better understating of the role of different neutron and proton configurations requires the measurement of the yields of mass and charge identified fission fragments / products. Recently, there have been on-line measurements of mass and charge identified fission products using inverse kinematics [3]. Yields of mass and charge identified even-even fragments have also been measured using on-line γ-γ coincidence measurement of yrast γ rays near ground state [6]. In an alternative approach, yield of mass and charge identified products can be measured using radiochemical technique involving recoil catcher technique followed by off-line γ-ray spectrometry. With the availability of fission model having the capability to predict the pre- and post- neutron evaporation fission product yield distribution [7,8], a direct comparison of theoretical and experimental yields would be more informative than comparing the final mass distribution. Further, estimation of the contribution from symmetric and asymmetric component may be more reliable when guided by theoretical calculations. Radiochemical measurements can also help in understanding the angular momentum fractionation at scission through isomer ratios which would be related to the fragment shape and thus provides information about the role of single particle effects in the fission process. Further, the neutron evaporation from fragments giving fission products is strongly correlated to single particle effects. Though, fragment yields at scission are modified subsequently due to neutron evaporation, a detailed comparison with the theoretically predicted fission product yields can be more informative due to the strong correlation of neutron evaporation with single particle effects.

In the present study, yields of fission products have been measured in the reaction ^{35}Cl+^{165}Ho$\rightarrow$^{200}Po. This system lies in between the highly neutron deficient sub-lead region and comparatively neutron rich actinides. The experimentally measured yields of the fission products have been compared with those calculated using the GEF code [7,8].

Experimental details

Experiments were carried out using 165.7 MeV ^{35}Cl beam from BARC-TIFR Pelletron-LINAC facility. In order to avoid the reaction products due to the catcher foil, ^{165}Ho target foil having thickness (25 μm) sufficient to completely stop the fission products recoiling in the forward direction was used in the reaction. The average beam energy weighed by the fusion cross section was 161.7 MeV corresponding to E_{cm}/V_c value of 1.03 and compound nucleus excitation energy of 56.4 MeV. The fusion cross section was calculated using the code CCFUS [9]. Irradiation was carried out for about ~30 hrs. After irradiation target was subjected to high resolution γ-ray spectrometry to measure the γ-ray activity of the fission products. The decay of the fission products was followed for more than a month to get multiple yield data over a period of time for most of the fission products.

Results and Discussion

The γ-ray spectra of fission products were fitted using the software PHAST [10] to determine the peak areas corresponding to the characteristic γ-lines of the fission products, which were used to determine their ‘end of irradiation’ activities, used further to determine their relative yields. The first part of the analysis was focused on those fission products whose yields were independent and therefore, did not have any contribution from the precursor. A plot of independent yields as a function of proton number and neutron numbers of the fission products is shown in the upper panel of Fig 1. The experimental yields were normalized with respect to the GEF yields using an overall normalization factor between the GEF calculations and the experimental data. It can be seen from the figure that the distribution peaks in the central region, indicating symmetric fission to be the dominant contribution. This is expected as excitation energy of the compound nucleus is 56.4 MeV. A significant scatter in the experimental data represents the fact that these yields have not been corrected for the charge distribution. It can be seen from the figure that the GEF calculations reasonably follow the experimental data. In order to make a more detailed comparison with GEF calculations, the ratio of experimental and GEF yields is plotted in the lower panel as a function of proton and neutron numbers in the lower panels of Fig. 1. It is interesting to note that the experimental data shows a systematic deviation with respect to the GEF calculations near certain proton and neutron numbers indicating the stronger single particle effects compared to those in GEF calculations. The single particle effects would become more and more pronounced with higher chance fission. According to the GEF calculations, the contribution from 1st, 2nd, 3rd, 4th and 5th chance fission were 25.1, 16.3, 21.9, 21.25 and 12.9% respectively. It should be mentioned here that even with weaker single particle effects, GEF calculated mass distribution showed clear deviation from a single Gaussian. A clear deviation in the ratio plot as shown in lower panels of Fig. 1 can be seen near Z_H ~50 which also reflects in the corresponding neutron number N_H ~67. This observation clearly shows the role of shell closure around Z_H~50 in the pre-actinide region in governing the fission product yields. It should be mentioned here that this observation does not suggest the absence of the role of other shell closures, rather it suggests stronger role of Z_H~50 compared to the theoretical prediction. Another strong enhancement compared to the GEF calculations can be seen at Z_L~30. This may possibly be due to the single particle effect in the complimentary product with Z_H~54. It should be mentioned here, that the observed deviations from the GEF calculation can be due to the calculated neutron multiplicity giving the final fission products from the actual neutron multiplicity values. Though, it is difficult to resolve the two effects, the observed deviations at specific nucleon numbers indicate their strong role in governing the yields of fission products. A comparison on the overall mass distribution with GEF calculations can shed further light on this aspect, which is in progress. Measurement of fragment mass gated neutron multiplicity can help in resolving the above mentioned effects.

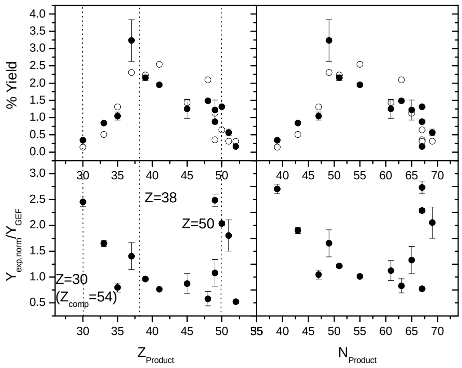

Fig. 1 *Comparison of experimental and calculated fission product yields (top panels) and their ratio (lower panel)*

Conclusions

Fission product yields have been measured in ^{35}Cl+^{165}Ho reaction at beam energy of 161.7 MeV. Here, the results of the analysis of independent fission yields, having no precursor contribution, are presented. The overall distribution shows symmetric fission to be the dominant contribution. The calculated yields using the code GEF reasonably follow the experimental trend. However, a more detailed comparison with the GEF calculations shows stronger role of specific nucleon numbers in governing the fission product yields compared to theoretical predictions. This may possibly arise from a combined effect of the deviation of the calculations at pre-neutron evaporation stage as well as deviation in neutron evaporation giving final fission products. Further studies would be required to delineate the two effects, however, deviation of theoretical calculations at specific nucleon numbers clearly establishes their role in governing the mass distribution in fission.

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