Ternary fission of Thorium

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Introduction

The formation of two fragments from a compound nucleus known as binary fission [1]. The decay of compound nuclei into three fragments is defined as ternary fission [2]. The third fragment formed usually an alpha particle known as light charged particle (LCP). Ternary fission has been studied in the heavy nuclei ^{252}Cf [3]. The third fragment formed perpendicular to the axis of the first two fragments is called equatorial configuration [4].

Based on level density approach [5] the possible fission fragment of ^{236}U has been identified by keeping ^{28}Si and ^{48}Ca as the third fragment. In the study of probable alpha ternary fission of ^{257}Fm [6], it was reported that alpha accompanied ternary fission of ^{257}Fm with ^{48}Ca and ^{205}Pt are most favorable fission fragments. Since, literature studies shows inadequate information on possible ternary fission fragments of heavy nuclei thorium. We have made an effort to study possible fission fragment combinations using Coulomb and proximity potential model. The branching ratio of ternary fission with respect to binary fission, an alpha decay and cluster radioactivity is also studied.

Theoretical Frame work

The amount of energy released during α-accompanied ternary fission is as follows;

$$Q = M - \sum_{i=1}^{3} m_i > 0 \tag{1}$$

Here M and mi are the mass excess of the parent and fission fragments. The total interacting potential consists of Coulomb and nuclear proximity potential and it is expressed as;

$$V = \sum_{i}^{3} \sum_{j>i}^{3} (V_{Cij} + V_{Pij}) \tag{2}$$

Where, V_{cij} and V_{pij} are the Coulomb and proximity potential functions and it is evaluated as explained in literature [6]. The universal function is given by;

$$\Phi(S_0) = \begin{cases} -3.437\exp\left(-\frac{S_0}{0.75}\right) & \text{for } S_0 > 1.2511 \\ \left(-\frac{1}{2}\right)(S_0-2.54)^2 - 0.0852(S_0-2.54)^3 & \text{for } S_0 < 1.2511 \end{cases} \tag{3}$$

The probability of penetration through the barrier is $P = [1+\exp(K)]^{-1} \cong \exp(-K)$, where K is the action integral. Hence, barrier penetrability P with the ternary fragments is expressed as;

$$P = \exp\left\{-\frac{2}{\hbar}\int_{Z_1}^{Z_2}\sqrt{2\mu(V-Q)}\,dz\right\} \tag{4}$$

The turning points are determined as explained in literature [6]. Where Q is the decay energy. The μ is the reduced mass parameter. The branching ratio of ternary fission with respect to cluster and alpha radioactivity is evaluated as follows;

$$BR = \frac{\lambda_{TF}}{\lambda_{CR/\alpha}} \tag{5}$$

Results and Discussions

The amount of energy released during alpha accompanied ternary fission is calculated using the following equation;

$$Q = \Delta M(A,Z) - \sum_{i}^{n} \Delta M(A_i, Z_i) \tag{6}$$

where $\Delta M(A,Z)$ and $\Delta M(A_i,Z_i)$ are mass excess of the parent and emitted nuclei respectively. For alpha accompanied ternary fission n varies from 1 to 3. The alpha accompanied ternary fission half-lives are evaluated as explained in the literature [7-8]. The shorter half-lives corresponding to each fission fragment combination is identified. The identified fission fragment combination for $^{208-238}Th$ are Be+Pb+He, Kr+Xe+He, Sr+Xe+He, Zr+Te+He, Mo+Sn+He and Ru+Cd+He. The variation shorter logarithmic half-lives of an alpha accompanied ternary fission of heavy element $^{208-238}Th$ with mass number of parent nuclei is shown in figure 1. Among all the $^{208-238}Th$ nuclei, the nuclei ^{227}Th is having shorter alpha accompanied ternary fission half-lives with the fission fragment combination of ^{88}Sr+^{135}Xe+^{4}He. Which are due to shell closure of fission fragment combinations.

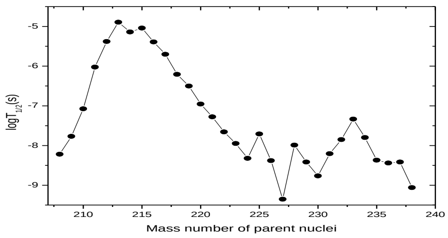

Fig 1: Variation shorter half-lives of an alpha accompanied ternary fission of heavy element $^{208\text{-}238}$Th with mass number of parent nuclei.

Similarly, an alpha decay and cluster radioactivity half-lives are evaluated as explained in literature [8].

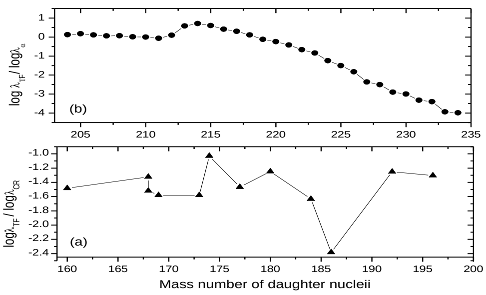

Fig 2: (a) Branching ratio of ternary fission with respect to cluster radioactivity from the parent nuclei ^{208}Th (b) and with respect to alpha decay from the parent nuclei $^{208\text{-}238}$Th.

The branching ratio of alpha accompanied ternary fission of heavy nuclei ^{208}Th with mass number of daughter nuclei during different cluster emissions (^{12}C, ^{14}N, ^{16}O, ^{22}Ne, ^{24}Mg, ^{28}Si, ^{31}P, ^{34}S, ^{35}Cl, ^{40}Ar, ^{39}K, ^{40}Ca and ^{48}Ca) is studied and it is presented in figure 2(a). From this figure it is observed that the branching ratio of ternary fission with respect to cluster emission of ^{22}Ne shows smaller value when compared to other cluster emissions studied. Furthermore, the branching ratio of $\log T_{1/2}$ of an alpha ternary fission to an alpha decay is also studied and it is shown in figure 2(b). The branching ratios gradually decreases with increase in mass number of daughter nuclei. The table-1 shows the comparison of yield produced from the present work is also compared with that of available experiments.

Table-1: Comparison of yield obtained from the present work with that of experiments.

Fission Fragment	yield(exp)[6]	Present work
$^{116}_{46}Pd+^{132}_{50}Sn$	6.00E-03	6.15E-03
$^{112}_{44}Ru+^{136}_{52}Te$	1.10E-02	6.23E-03
$^{108}_{42}Mo+^{140}_{54}Xe$	7.00E-03	7.20E-03
$^{104}_{40}Zr+^{144}_{56}Ba$	1.70E-02	5.65E-03

Conclusions:

An alpha accompanied ternary fission of heavy element $^{208\text{-}238}$Th have been studied using Coulomb and proximity potential model. The identified fission fragment combination for $^{208\text{-}238}$Th consists of fission fragment combination in which the proton number or neutron number of fission fragments are magic or near magic nuclei. Among , all the nuclei studied the ^{227}Th is having shorter alpha accompanied ternary fission half-lives for the fission fragment combination of ^{88}Sr+^{135}Xe+^{4}He . The smaller branching ratio of ternary fission with respect to cluster decay and an alpha decay shows larger possibility of ternary fission when compared to an alpha and cluster radioactivity. This study finds an important role in future experiments of an alpha ternary fission of $^{208\text{-}238}$Th.

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