Fission Energy from Neutron-rich Uranium and Thorium Isotopes

R. N. Panda[1],* M. Bhuyan[2], and S. K. Patra[3]
[1]*Department of Physics, ITER, Siksha O Anusandhan University, Bhubaneswar-751030, India*
[2]*School of Physics, Sambalpur University, Jyotivihar, Burla-768 019, India. and*
[3]*Institute of Physics, Sachivalaya Marg, Bhubaneswar-751 005, India.*

Introduction

World-wide rapid economic growth has created an anxiety that energy scarcity will occur in the near future. In addition to this the limited amount of the bio-reservoir, such as coal and petroleum product force us to think seriously for a sustainable alternative. In this context, the nuclear or solar energy could be the possible potential substitution for the world's energy need.

Although the nuclear fusion could be a vast energy source to face any kind of energy requirement, till date it has not been possible to use for civilian purpose. The other nuclear energy source is the nuclear fission. This is used in most of the advanced countries as a viable energy supply.

There are only three known thermally fissile nuclei ^{233,235}U and ^{239}Pu. Out of these, only ^{235}U is naturally available, whereas ^{233}U and ^{239}Pu are synthesised from ^{232}Th and ^{238}U respectively. It is worthy to emphasise that recently, it has been predicted the existence of some other thermally fissile U and Th neutron-rich isotopes [1, 2]. These newly predicted thermally fissile elements are $^{244-262}$Th and $^{246-264}$U centering the neutron magic number N=164 in the superheavy region. These nuclei are capable to produce several order of magnitude more fission energy than that of ^{233,235}U or ^{239}Pu.

In this contribution our aim is to study the structural and reaction properties of these $^{244-262}$Th and $^{246-264}$U nuclei which are highly neutron-rich and thermally fissile using relativistic mean field (RMF) formalism [3, 4].

*Electronic address: rnpanda@iopb.res.in

Theoretical Framework

The use of RMF formalism for finite nuclei as well as the infinite nuclear matter are well documented and details can be found in [5]. The deformed or spherical nuclear densities obtained from the RMF model is fitted to a sum of two Gaussian functions with suitable co-efficients is expressed as

$$\rho(r) = \sum_{i=1}^{2} c_i exp[-a_i r^2]. \qquad (1)$$

The expression for total reaction cross-sections at high energies in Glauber model is [3, 4, 6]:

$$\sigma_r = 2\pi \int_0^\infty b[1 - T(b)]db\,, \qquad (2)$$

where $T(b)$ is the transparency function with impact parameter b, and details can be found in [7].

Result and Discussion

First of all we calculate the bulk properties, such as binding energy (B.E.), root mean square charge radius r_{ch}, matter radius r_m and quadrupole deformation parameter β_2 for the thermally fissile nuclei $^{244-262}$Th and $^{246-264}$U in the RMF formalism. The calculated results are compared with the finite range droplet model (FRDM) [8] in Table I.It is clear that our RMF results agree remarkably well with the FRDM values.

We have estimated σ_r at various incident energy for $^{244-260}$Th and $^{246-262}$U target with ^{16,24}O as projectiles which are plotted in Figure 1. Similar to our earlier investigation [7], σ_r increases with target mass in the isotopic chain for both Th and U isotopes. The

TABLE I: Calculated results for the binding energy(B.E), charge radius(r_c), matter radius(r_m) and deformation parameter(β_2) for various Thorium and Uranium isotopes. The values of finite range droplet model (FRDM) [8] are also given for comparison. Energy is in MeV and radius is in fm.

Nucleus	B.E.		r_{ch}	r_m	β_2	
	RMF	FRDM			RMF	FRDM
^{244}Th	1821	1824	5.921	6.082	0.269	0.225
^{246}Th	1829	1832	5.926	6.098	0.255	0.217
^{248}Th	1836	1839	5.926	6.111	0.235	0.209
^{250}Th	1844	1846	5.929	6.125	0.215	0.209
^{252}Th	1854	1854	5.938	6.156	0.199	0.219
^{254}Th	1862	1860	5.946	6.170	0.172	0.192
^{256}Th	1865	1865	5.955	6.175	0.155	0.088
^{258}Th	1876	1871	5.965	6.209	0.145	0.088
^{260}Th	1883	1877	5.973	6.228	0.131	0.098
^{262}Th	1890	1884	5.981	6.247	0.120	−0.129
^{246}U	1839	1841	5.948	6.093	0.282	0.225
^{248}U	1846	1849	5.956	6.111	0.271	0.217
^{250}U	1855	1857	5.960	6.126	0.257	0.218
^{252}U	1865	1865	5.958	6.147	0.227	0.218
^{254}U	1873	1873	5.965	6.163	0.207	0.219
^{256}U	1881	1880	5.973	6.177	0.179	0.201
^{258}U	1888	1886	5.982	6.196	0.164	0.162
^{260}U	1896	1893	5.990	6.213	0.147	0.116
^{262}U	1899	1899	5.996	6.214	0.118	0.107
^{264}U	1903	1906	5.996	6.230	0.124	−0.138

increase in reaction cross-section with mass number could be a finite possibility for power generation in near future. Right now the formation of such a neutron-rich heavy nuclei looks like hypothetical. However after the completion of Facility for Antiproton and Ion Research (FAIR) at GSI, Germany, there is every possibility for an accelerator based reactor where these thermally fissile neutron-rich Th and U nuclei could be a viable nuclear fuel for the power generation of the entire world.

Summary and Conclusion

In summary, we have studied the structural properties of the recently predicted thermally fissile neutron-rich $^{244-262}$Th and $^{246-264}$U nuclei in the frame-work of RMF model. The results are compared with the most popular FRDM calculations and found remarkably closure with its predictions. The obtained RMF

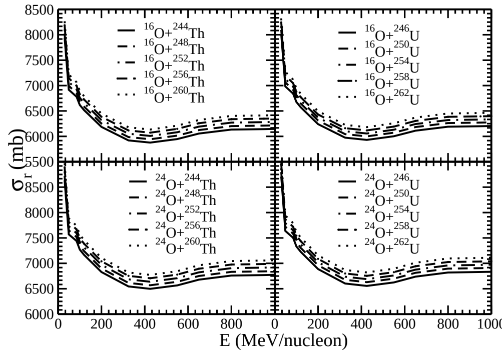

FIG. 1: The total nuclear reaction cross-section σ_r for thermally fissile $^{244-260}$Th and $^{246-262}$U target with ^{16,24}O as projectiles at different incident energies.

densities are used to estimate the reaction cross-section taking these thermally fissile isotopes as target with ^{16,24}O and as projectile. This results may be useful for experimentalists for the synthesis of neutron-rich thermally fissile Thorium and Uranium for the energy generation in future.

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