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Nuclear energy release from fragmentation

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Abstract

It is well known that binary fission occurs with positive energy gain. In this article we examine the energetics of splitting uranium and thorium isotopes into various numbers of fragments (from two to eight) with nearly equal size. We find that the energy released by splitting ^{230,232}Th and ^{235,238}U into three equal size fragments is largest. The statistical multifragmentation model (SMM) is applied to calculate the probability of different breakup channels for excited nuclei. By weighing the probability distributions of fragment multiplicity at different excitation energies, we find the peaks of energy release for ^{230,232}Th and ^{235,238}U are around 0.7–0.75 MeV/u at excitation energy between 1.2 and 2 MeV/u in the primary breakup process. Taking into account the secondary de-excitation processes of primary fragments with the GEMINI code, these energy peaks fall to about 0.45 MeV/u.

Keywords: Nuclear energy; Nuclear fragmentation; Statistical multifragmentation model

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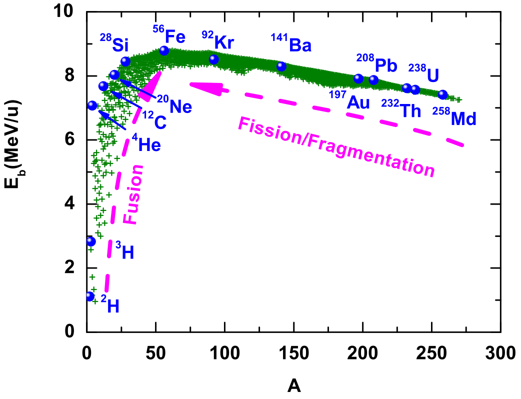

Fig. 1. (Color online.) Experimental specific binding energy as a function of mass number A for 2438 nuclei from the mass table AME2012 [1].

1. Introduction

Nuclear energy is one of the most efficient sources of energy based on the Einstein's mass–energy equivalence formula ($\Delta E = \Delta mc^2$). It originates in the strong force holding the protons and neutrons together. The specific binding energy (binding energy per nucleon) of an individual nucleus reflects the interactions of the nucleons inside the nucleus, especially the short-range nuclear force and the long-range Coulomb force. Fig. 1 shows the experimental specific binding energy for 2438 nuclei from the mass table AME2012 published in Ref. [1]. The nuclei with mass number around 56 have the largest specific binding energy, and in particular ^{56}Fe is the most stable nucleus with a specific binding energy of 8.79 MeV/u. In general, for nuclei with mass number less than 56, the short-range and attractive nuclear force has not reached saturation. Except for very light nuclei, increasing mass number corresponds to increasing the average number of nucleons around one particular nucleon, and therefore with increasing specific binding energy. However, the long-range and repulsive Coulomb force, which is proportional to Z^2 where Z is the atomic number, becomes more important for heavier nuclei. For nuclei with mass number greater than 56, the specific binding energy decreases gradually with increasing mass number. When nucleons rearrange themselves to form more stable nuclei, nuclear energy is released equal to the difference in binding energy of the initial and final nucleus. Therefore, nuclear energy can be released by the radioactive decay of unstable nuclei [2,3], fusion of light nuclei [4–9] and fission or fragmentation of heavy nuclei [10–14].

Fission technology has been widely used to generate power by neutron-induced chain reactions. This fission process occurs when a heavy nucleus such as ^{235}U or ^{239}Pu absorbs a thermal neutron and the resulting compound nucleus is excited beyond its fission barrier. Most fission modes induced by thermal neutron are binary in which one daughter nucleus has a mass of about 90 to 100 u, leaving the remaining nucleus with 130 to 140 u. In a typical fission process, such as the reaction of $\mathrm{n} + {}^{235}\mathrm{U} \rightarrow {}^{141}\mathrm{Ba} + {}^{92}\mathrm{Kr} + 3\mathrm{n}$, the total energy released is about 0.85 MeV/u, which includes the energy released in the fission process (0.70 MeV/u) and decay process of unstable daughter nuclei (0.15 MeV/u). Since the mass numbers of ^{141}Ba and ^{92}Kr are much larger than that of ^{56}Fe, the energy released in this fission process is incomplete. In 1939, Bohr and Wheeler pointed out that the energy released in ternary fission events with nearly equal fragment size is slightly greater than in binary fission. However Tsien found that the relative probability