Nuclear transmutation of long-lived fission fragment ^{126}Sn using protons

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Introduction

Recently there has been research and technological developments made to manage high level radioactive waste produced from nuclear power station. Management of high level radioactive waste from reactors has become one of the top priority issues. The nuclear waste includes long-lived fission fragments (LLFF), minor actinides which emits radiation, which makes it a particular hazard for human health and the environment. LLFF need to be converted into either short-lived or stable ones so that it can be managed. If we want to continue producing power from nuclear reactors, the LLFF should be isolated from human environment for a very long time period. It must therefore be managed with special care, from production to final disposal. In general, radioactive waste is to be solidified into a deep geological formation several hundred meters below the ground level. On realizing the importance of long-lived nuclear waste management, many countries have developed their own programme [1,2].

Light particles or gamma rays can be used as projectile for transmutation to convert LLFFs to short-lived or stable ones. Slow as well as fast neutrons are not useful because the thermal neutron capture cross-section is very small, of the order of 0.03 b. It should be emphasized that while trying to reduce the half-life of (LLFF) by nuclear transmutation, one should make sure that the same isotope or some other isotopes having longer half-lives should not be created. In case of ^{126}Sn, the proton route through (p,n) and (p,2n) reactions for transmutation seem to be ideal. Optimization of proton-induced cross section for transmutation route for LLFF, ^{126}Sn (half-life 2.3 x 10^5 y) can be carried out by first deciding on the bombarding energy [3]. To understand the peak bombarding energy, we first perform calculation using the nuclear reaction code for stable isotopes of Sn. Using the optical model and level density parameters obtained for stable Sn isotopes, we can predict the cross section for ^{126}Sn radioactive isotope.

Nuclear reaction model

The cross section calculations for (p,n) and (p,2n) reactions on stable isotopes $^{112\text{-}124}$Sn are performed using the modular nuclear reaction computer code TALYS-1.95 [4] for the analysis and prediction of nuclear reactions. They are compared with data where available. The cross section for (p,n) and (p,2n) have been calculated as a function of proton energy from threshold to 30 MeV using two types of level densities, phenomenological back-shifted Fermi gas model (BSFM) and microscopic LD based on Skyrme force from Goriely's tables. The microscopic LDs are calculated level densities from drip line to drip line on the basis of Hartree-Fock calculations. The Koning-Delaroche optical model available in the code was used for all calculations. The details of calculations are given in Ref. [5]. The results have been compared with default TALYS-1.95 calculation, TENDL-2019 and experimental data. The calculations are then extended to obtain the cross section for unstable isotopes of interest.

Results & Discussion

The excitation function for (p,n) and (p,2n) reaction cross sections for stable isotope, ^{124}Sn is presented in Fig. 1 from threshold proton energy to 30 MeV. The same are plotted for default TALYS 1.95, TENDL 2019 and compared with corresponding cross section data [6]. The total reaction cross section (σ_R) are shown in figure and compared with data [7].

It is seen from the figure that the microscopic LD is in good agreement with that of the (p,n) cross section data. While those calculated using Talys-default parameters, BSFM, and TENDL-2019, all show a shift in the (p,n) cross section to the left when compared with corresponding data [6]. Similar behaviour is seen for (p,2n) cross section as well. However, there are no experimental values available to ascertain the (p,2n) results. The total reaction cross section calculated for microscopic LD for protons scattering off ^{124}Sn target does not show good agreement with that of data [7]. The agreement with data [7] can be improved significantly by optimizing the optical model parameters.

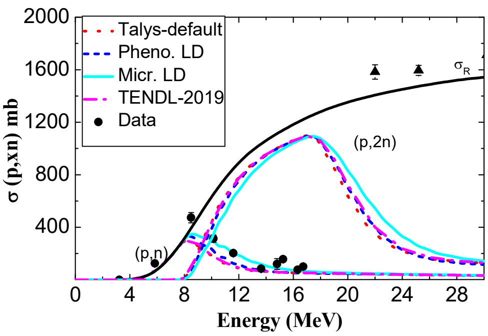

Fig. 1. The calculated excitation function for ^{124}Sn(p,n)^{124}Sb and ^{124}Sn(p,2n)^{123}Sb reactions using phenomenological and microscopic level densities (LDs) compared with corresponding data [6], Talys-default and TENDL-2019. The Koning-Delaroche optical model potential was used in the calculation. The total reaction cross section using microscopic LD calculation are also plotted and compared with data [7].

Similar results are seen for (p,n) and (p,2n) cross sections in case of other stable isotopes (^{112,114,116,117,119,120,122}Sn). Using these results, prediction of cross sections for (p,n) and (p,2n) reactions can be carried out.

In this case, the cross section is nearly 800 mb for protons below 15 MeV. Interestingly, all the residual nuclei produced in the (p, n) reactions on the Sn isotopes are short-lived with half-lives less than 3 months. Certainly, the proton-based transmutation should be explored.

Conclusion

In this work, statistical model calculations using both phenomenological and microscopic nuclear level densities TALYS-1.95 has been carried out. The excitation functions for (p,n) and (p,2n) reactions on stable ^{124}Sn isotope for incident proton energies from the threshold values to 30 MeV has been reported. Using the results of cross sections on other stable isotopes of Sn, prediction of corresponding cross section can be made for nuclear transmutation of long-lived ^{126}Sn isotope.

References

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