Proton-induced reactions on Se isotopes

M. Hemalatha[1],* A. Saxena[2], and S. Kailas[1,2]
[1]UM-DAE Centre for Excellence in Basic Sciences, Mumbai - 400098, INDIA
[2]Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA
** email: hema@cbs.ac.in*

Introduction

Management of long-lived nuclear waste is an important aspect for any sustainable nuclear energy programme. The long-lived Pu isotopes, the minor actinides and fission products [1] which constitute nuclear waste, need to be transmuted (or incinerated) to reduce the waste burden. Amongst the long lived fission products (LLFP), the important ones are ^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{126}Sn, ^{129}I and ^{135}Cs. Several strategies are being explored for the transmutation of the LLFPs. Neutrons, protons and photons are being considered as suitable probes for this programme. While neutrons, both slow and fast, are effective in inducing these transmutation reactions, in a few cases the neutron-induced cross sections are not large. e.g the thermal neutron capture cross section for ^{126}Sn is about 0.03 b. As isotopic separation is not feasible, it is not possible to transmute only the radioisotope of interest from the isotopes of a given element produced in the nuclear fission reaction. This being the case, we have to consider about not only transmutation of the radioisotope of concern but also ensure that the other isotopes (stable and short lived) present do not lead to long lived products due to transmutation reaction. It has been seen in a few cases, that neutron-induced reactions produce residues both with reduced and enhanced half lives. In the case of Se isotopes produced as fission products, the isotopes are ^{77,78,79,80,82}Se. While neutron induced reaction on LLFP ^{79}Se will convert it to stable ^{80}Se, the stable ^{78}Se will get transformed to long lived ^{79}Se (the isotope we want to transmute) through the neutron capture reaction. As a result, neutrons are not suitable for the transmutation of Se isotopes. It turns out that proton-induced reactions in particular and low energy protons (upto around 20 MeV) are suitable [2] for converting LLFP ^{79}Se (2.95 x 10^5 y) to short-lived ^{79}Br while transmuting the other Se isotopes to either stable or short-lived Br isotopes. While (*p,n*) data exist for stable Se isotopes over a limited energy range, there are no data for the radioactive ^{79}Se. In this paper, we have carried out statistical model analyses of the (*p,n*) data available for Se isotopes so that calculations can be extended to the radioactive ^{79}Se isotope and also for other isotopes over energy range where data are not available. This information is essential in dealing with the transmutation of radioactive ^{79}Se isotope.

The (*p,n*) cross section data available are taken from the EXFOR database [3]. The statistical model code EMPIRE [4] has been employed in these calculations. The proton and neutron global optical model parameters are the ones due to Koening *et al.* [5] available as an option in the EMPIRE code. Both the discrete and continuum levels for the various nuclei have been considered. The masses are the experimental values as provided in the code.

Calculations of reaction cross sections using the EMPIRE 3.2 code were carried out taking into account pre-equilibrium exciton model processes (PCROSS = 1.5). Cross sections of the (*p,n*) reaction have been calculated from threshold energy to about 20 MeV for Se isotopes with A = 76, 77, 78, 79, 80, 82 and they are shown in Fig. 1. Experimental data, in the energy region of interest, are available for ^{76,77,80,82}Se [6] and are shown in the same figure. Predictions have been made for ^{78,79}Se. From the figure, it can be seen that the calculated cross sections for ^{76,77,82}Se agree with the data. However, in the case of ^{80}Se, calculation over-predicts the observed cross sections. The calculations show lower cross sections for ^{76,77,82}Se, while for ^{78,79,80}Se somewhat higher cross sections are seen. The excitation function is peaked around 11-13 MeV. The (*p,2n*) threshold are also marked in the figure for the various Se isotopes.

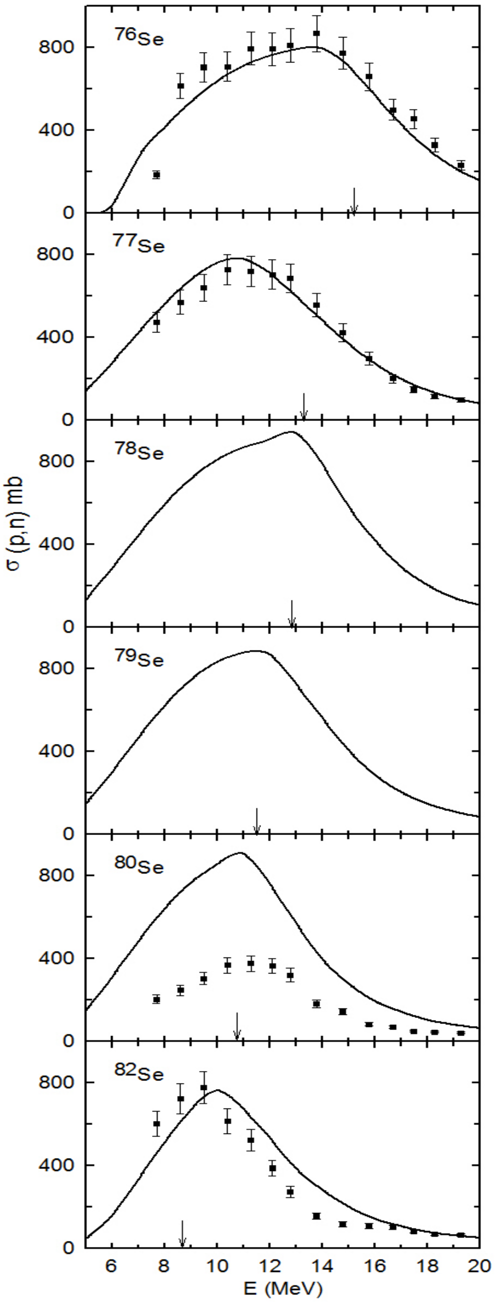

Fig. 1 Calculated (*p*,*n*) cross section for different Se isotopes. Experimental data [6] are shown by filled symbols. Arrows indicate the (*p*,*2n*) threshold for various Se isotopes.

The (*p*,*2n*) reaction on various Se isotopes leads to either stable or short-lived Br isotopes.
To make more reliable predictions, good cross section data are required and these measurements are planned with existing facilities.

References

[1] W. S. Yang *et al.*, Nucl. Sci. and Eng. **146,** 291 (2004).
[2] A. Hermanne, J. Nucl. Sci. and Tech. Supplement **2,** 1202 (2002).
[3] IAEA Nuclear data section - EXFOR data base, www-nds.iaea.org.
[4] EMPIRE code (M. Hermann (BNL) and R. Capote (IAEA).
[5] A.J. Koning, J.P. Delaroche, Nucl. Phys. A **713**, 231 (2003).
[6] V.N. Levkovskij, Book on Activation cross section by protons and alphas, Moscow (1991).