Excitation functions for the production of radio-isotopes ^{62}Cu and ^{63}Ni from ^{63}Cu

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Introduction

Neutron activation data for common elements present in accelerator and reactor facilities are important to estimate the radioactivity induced due to accelerator and reactor operation. Under proper operating conditions radioactivity is induced in the accelerator components by neutrons and not by the primary projectile. Quantitative knowledge of these induced activities is important for planning of neutron and photon shielding, hands on maintenance, decommissioning procedure and for personnel safety [1]. Cu, Fe, Al, Ta etc. are elements abundantly found in accelerator components and are thus important targets for production of induced activity.

In the present work we have calculated the excitations functions of ^{63}Cu (n, 2n) ^{62}Cu and ^{63}Cu (n, p) ^{63}Ni reactions for 1-20 MeV energy using statistical and pre-equilibrium nuclear reaction model codes. The comparison of the computed excitation functions and the reported measured data [2] have been shown in the figs.

Model codes calculations
ALICE-91

ALICE-91 code [3] calculates pre-equilibrium (PEQ) cross-sections using geometry dependent hybrid model [3,4] and evaporation through Weisskopf–Ewing formalism. The geometry dependent hybrid model is the modified version to include the effect of diffuse nuclear surface. In the present work we have used optical model inverse cross-section and Fermi gas level density options in ALICE. Excitation functions of residual nuclides upto a maximum of 11 mass number wide and 9 atomic number deep starting from

the initial target+projectile composite nucleus have been estimated.

EMPIRE-2.19

The EMPIRE-2.19 code [5], accounts for the major nuclear reaction mechanisms, including direct, pre-equilibrium (PEQ) and compound nuclear reactions. The secondary compound nuclei (CN) are formed due to subsequent particle emission. The transmission coefficients are estimated from the optical model subroutine SCAT2. Binding energies are determined using masses recommended by Audi *et al.* [6], whenever available, otherwise theoretical predictions of Moller and Nix [7] are used. The code uses several PEQ models like multistep direct (MSD), multistep compound (MSC) and Hybrid Monte-Carlo Simulation (HMS) approach to the emission of nucleons and the statistical Hauser–Feshbach theory to describe the compound nuclear emissions along with different level density options.

We have used the following input options of the code:
(a) EMPIRE MSD+MSC LD0: MSD+MSC reactions with EMPIRE specific level densities (LD0).
(b) EMPIRE HMS LD0: HMS Monte Carlo with EMPIRE specific level densities
(c) EMPIRE MSD+MSC LD1: MSD+MSC reactions with Fermi gas level density (LD1)
(d) EMPIRE HMS LD1: HMS Monte Carlo with Fermi gas level density

TALYS-1.2

In TALYS-1.2 [8] code direct reactions are calculated using any one of spherical optical model, DWBA, rotational or vibrational coupled channel analysis and giant resonances. Two component exciton model estimates the PEQ particle emission and the angular distribution of

these PEQ particles is determined using Kalbach systematics. Compound nuclear emission is calculated in the framework of Hauser-Feshbach formalism in competition to fission.

Results and Discussion

The excitations functions for the production of radio-isotopes ^{62}Cu and ^{63}Ni by (n, 2n) and (n, p) reactions on ^{63}Cu for 1-20 MeV energy have been calculated using three different nuclear model codes i.e, ALICE-91, EMPIRE-2.19 and TALYS-1.2. The calculated excitation functions along with the comparison with experimental data are shown in figs. 1 & 2. From the fig. 1 we see that measured excitation function of ^{62}Cu is well reproduced by the EMPIRE calculations with HMS PEQ emission and Fermi gas level density. ALICE largely overpredicts the data, the discrepancy being more at lower energies, while TALYS reproduces the measured values upto 14 MeV. From fig. 2 we see that measured formation cross section of ^{63}Ni via ^{63}Cu (n, p) reaction is reproduced by TALYS calculations upto ~ 13 MeV. ALICE calculations could not reproduce the data; the peak is shifted towards the higher energy end. EMPIRE calculations also under predict the data grossly above 3 MeV.

Conclusion

From the study it is observed that TALYS fairly reproduce the excitation functions of (n, 2n) and (n, p) reactions on ^{63}Cu in the energy range 1-20 MeV. The discrepancy of ALICE and EMPIRE calculations should be investigated. The main purpose of such comparison is to test the reliability of nuclear reaction models and obtaining reference cross section data for quantitative estimation of production of both useful and undesirable isotopes. The calculation based on standard nuclear reaction models using well defined and eastablished parameters will help in assessing the relative accuracy of the reported measurements and checking of validity of various parameters of the nuclear model codes.
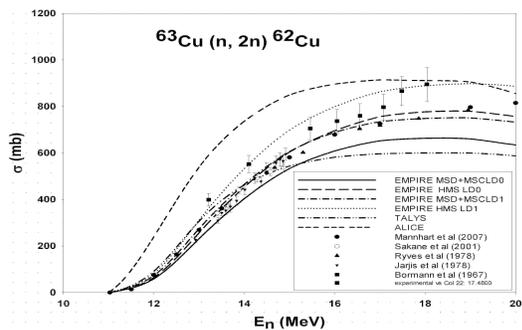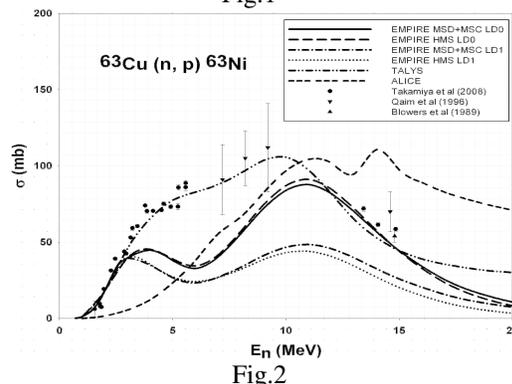
Fig.1

Fig.2

References

[1] H Hayashi, H Sakane, M Shibata, K Kawade, Y Kasugai, Y Ikeda and T Iida *Annals of Nuclear Energy* **38** 637 (2011).

[2] http://www.nndc.bnl.gov/exfor/exfor00.htm Experimental Nuclear Reaction Data (EXFOR / CSISRS) Database version of Oct. 11, 2010 latest Sept. 05, 2011.

[3] M Blann *Recent Progress and Current Status of Preequilibrium Reaction Theories and Computer Code ALICE* UCRL-JC10905 Z (LLNL, California, USA) (1991).

[4] M Blann *Code ALICE/85/300*, LLNL Report NO. UCID-20169 (1985).

[5] M Herman EMPIRE nuclear reaction model code (2.19 Lodi), IAEA, Vienna, Austria, 22 March, 2005).

[6] G Audi and A H Wapstra *Nucl Phys*. **A595** 409 (1995).

[7] P Moller and J R Nix *At. Data Nucl. Data Tables* **26** 165 (1981).

[8] A J Koning, S Hilaire and M C Duijvestjjn TALYS: Comprehensive nuclear reaction modeling, Proc. Int. Conf. on Nuclear Data for Sci. and Tech.—ND2004 AIP vol. 769 (eds) R C Haight, M B Chadwick, T Kawano and P Talou, Sept. 26 – Oct. 1, 2004 (Santa Fe, USA), p 1154–1159 (2005).