Production of Kr-85m through proton induced fission of U-238

T. Najumunnisa[1,2,*] M.M. Musthafa[2], K.K. Rajesh[2], A. Shanbhag[3], and S. Ghugre[4]
[1] *AKNM Government Polytechnic College, Tirurangadi, Malappuram, 676317, Kerala, India*
[2] *Department of Physics, University of Calicut, Thenhippalam, Malappuram, 673635, Kerala, India.*
[3] *Health Physics Division, BARC, Trombay, Mumbai, 400085, Maharashtra, India. and*
[4] *Consortium for Scientific Research, UGC-DAE, Bidhannagar Kolkata, 700098, West Bengal, India.*

Introduction

Precise and accurate cross section data are essential for developing nuclear reaction models and improving nuclear data libraries. The requirements of nuclear data have much importance in design, operation, safety performance predictions of nuclear reactors and transmutation of nuclear waste. In Generation IV reactors, Accelerator Driven Subcritical Systems (ADS) and fast neutron reactors, a significant amount of secondary proton spectrum is formed as a result of neutron interactions with various materials within the system such as fuel, fragments, the structural components, etc., [1–3]. These protons will induce further fission and result in the production of more fission fragments. This work focuses on the production of one of such fission fragments, Kr-85m. This gaseous radionuclide will affect the safety and integrity of reactor structure. Kr-85m can be used as a burnup indicator in Pebble Bed Reactor (PBR). PBR is a high temperature gas-cooled reactor which uses graphite as a moderator and helium as a coolant.[4]. In PBR, the burnup measurement is performed by online without shutting down the reactor. Online burnup measurement is conducted by detecting passive signals such as neutrons and gamma rays from the fuel and then correlate it with the burnup.

*Electronic address: tnajumunnisa@gmail.com

Experimental Analysis

The experiment has been carried out at Tata Institute of Fundamental Research (TIFR), Mumbai, India using pelletron LINAC facility. Stacked foil activation technique has been employed. Natural Uranium samples of thickness 8.6 mg/cm^2 were prepared by the rolling method in the size of 1cm x 1cm. A stack of four Uranium samples with energy degraders were irradiated using a proton beam with 22 MeV energy and an average current of 23 nA for 88 minutes. The energy degradation was calculated using the simulation code SRIM [5]. Mean incident energies on each uranium samples were 21.44 MeV, 17.24 MeV, 12.12 MeV and 7.86 MeV respectively. The beam current was monitored continuously by current integrator connected to the Faraday cup kept behind the target stack. The activity induced in these samples were followed using 100cc HPGe detector with a low background setup, coupled to the PC based multichannel analyzer.

After priliminary cooling for 3 hours, the irradiated samples were taken one by one for counting. Thus obtained spectrum shows the peaks corresponding to the characteristic gamma rays of Kr-85m viz. 151.195 keV (75.2 %), 304.87 keV (14.0%). From the observed intensities of characteristic gamma rays, the cross-sections for the formation of Kr-85m was

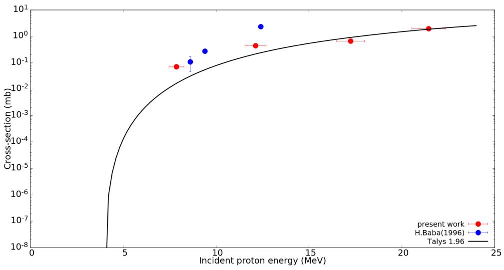

FIG. 1: Excitation function for the formation of Kr-85m

calculated using eqn. (1).

$$\sigma = \frac{A\lambda exp(\lambda t_2)}{\phi.N_o\left[1 - exp(-\lambda t_1)\right]\left[1 - exp(-\lambda t_3)\right]G\varepsilon.\theta.k} \quad (1)$$

Where A represents the total number of activities counted under the corresponding gamma peak, λ is the decay constant of the particular residual nucleus, ϕ is the incident proton flux, N_0 is the number of the target nuclear isotope per unit area of the irradiated sample, G_ε is the geometry dependent efficiency of the detector for the given gamma ray energy, θ is branching ratio of the particular gamma ray, k is the self-absorption correction factor for the gamma ray in the sample and t_1 , t_2 , t_3 are respectively the irradiation time, the cooling time and the counting time of the sample.

Theoretical analysis

The theoretical analysis has been done using nuclear reaction code TALYS 1.96.[6]. Hauser-Feshbach model is used for compound nuclear model calculations in which Moldauer model is applied for width fluctuation correction. Standard JLM imaginary potential is used for optical model potential. Preequilibrium calculations is done using Exciton model. GEF model is used for fission yield calculation and rotating liquid drop model for fission barrier calculations. Constant temperature model and Fermi gas model is used for level density calculations.

The excitation function for the formation of Kr-85m is plotted in the Fig.1. along with TALYS calculation. EXFOR data reported by H. Baba et al[7] is also plotted. Only this set of data is available in the EXFOR data library.

Conclusion

Fission fragment yield of Kr-85m is experimentally measured for proton energies 7.86 MeV- 21.44 MeV. Significant yields of Kr-85m has been observed and hence it can be used as a burnup indicator in PBR. The experimentally obtained yields are compared with literature data along with theoretical calculation using TALYS 1.96.

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