Neutron induced activation studies for low background experiments

S. Thakur[1],* A. Mazumdar[2,3],† V. Vatsa[2,3], M.S. Pose[4], S. Mallikarjunachary[4], S. Pal[5], V. Nanal[4], P.P. Singh[1], R.G. Pillay[1], and P.K. Raina[1]

[1]*Department of Physics, Indian Institute of Technology Ropar, Rupnagar, Punjab - 140001, INDIA*
[2]*INO, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA*
[3]*HBNI, Anushaktinagar, Mumbai - 400094, INDIA*
[4]*DNAP, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA and*
[5]*PLF, Tata Institute of Fundamental Research, Mumbai - 400005, INDIA*

Introduction

Underground locations are preferred for rare event studies like neutrinoless double beta decay (NDBD) and dark matter (DM). The ambient background at these locations can significantly affect the sensitivity of the experiment. The present work, for the first time, reports the neutron activation studies of the rock samples collected from Aut in Himachal Pradesh. Neutron induced reactions were studied with an emphasis on long-lived activities, which can be a limiting factor for low background experiments.

Experiment & Data Analysis

The neutron activation experiment was performed at the neutron irradiation setup of the Pelletron Linac Facility, Mumbai [1]. Proton beams of E_p = 12 and 22 MeV were used on ^{9}Be target to generate neutrons of broad energy range upto E_{max} = 9.9 and 19.9 MeV, respectively via the ^{9}Be(p,n)^{9}B reaction (Q = -1.85 MeV). Table I gives the details of the irradiation and samples. The energy integrated neutron flux was estimated to be $\sim 10^6$ n cm^{-2} s^{-1}, using ^{56}Fe(n,p)^{56}Mn reaction. The irradiated rock samples and iron foils were counted offline in low background counting setups at TIFR - TiLES [2] and CRADLE [3], in a close geometry and after a sufficient cooldown time t_c ($\geq$ 1-2 hr). In both the setups data was recorded using a commercial CAEN N6724 digitizer (14-bit, 100 MS/s).

TABLE I: Details of sample irradiation

Sample	Mass (g)	E_{beam} (MeV)	$T_{irradiation}$ (hr)	$< I >$ (nA)
AUT1A	10.6220	22	15.5	136
AUT4E	6.6985	12	16.0	148
BWH2A	8.2211	22	5.2	167
BWH2B	5.4729	12	16.0	148

The gamma ray spectra were analyzed using LAMPS [4]. A typical spectrum of the irradiated Aut rock sample (E=22 MeV) is shown in Fig. 1 after the t_c of 5 d, where various gamma rays of activated products ($T_{1/2} \sim$ few days) are visible.

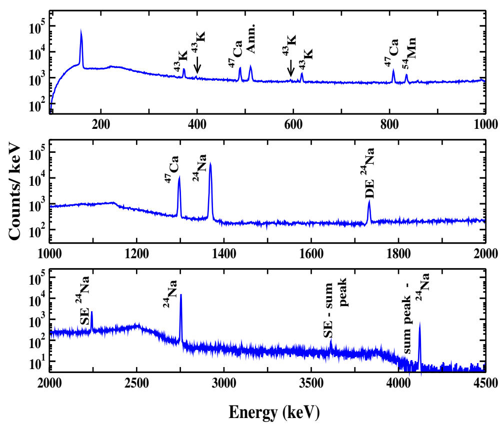

FIG. 1: Gamma ray spectrum of AUT1A, irradiated at 22 MeV, after a t_c of 5 d (t = 1 d).

Reaction products were identified by characteristic gamma rays and half-life tracking was done for the verification. Further, in the

*Electronic address: swatithakur1520@gmail.com
†Present address: TIF - AWaDH, IIT Ropar, Rupnagar, Punjab - 140001, INDIA

case of multiple gamma rays of the same nuclide, relative branching ratios were checked. Products arising from (n,p), (n,α), (n,γ) and (n,2n) reactions are visible and are listed in Table II. Irradiation at two different incident energies provides an independent check for the yield of the observed products on neutron energy.

TABLE II: Observed products and gamma rays

Channel	E_γ	$T_{1/2}$
^{43}Ca(n,p)^{43}K	372.8, 617.5	22.3 h
^{54}Fe(n,p)^{54}Mn	835.0	312.2 d
^{56}Fe(n,p)^{56}Mn	846.5	2.58 h
^{41}K(n,γ)^{42}K	1524.7	12.36 h
^{48}Ca(n,2n)^{47}Ca	489.2, 807.9, 1297.1	4.54 d
^{24}Mg(n,p)^{24}Na	1368.6, 2754.0	14.96 h
^{23}Na(n,2n)^{22}Na	1274.5	2.60 y

The source of the observed peak at 159.2 keV could not be clearly identified. It can originate either from ^{117m}Sn (E_γ= 158.6 keV, $T_{1/2}$ = 13.76 d) or ^{47}Sc, which is produced via β-decay of ^{47}Ca (E_γ= 159.4 keV, $T_{1/2}$ = 3.35 d). The observed lifetime is not consistent with either.

In order to assess the impact of the long-lived neutron induced activity on the residual background, a comparison of the gamma ray spectra of the Aut rock samples before and after irradiation was carried out. Fig. 2 shows the gamma ray spectrum of the AUT1A (10.6220 g, t_c = 31 d) together with that for AUTB (27.5430 g) prior to neutron activation. It should be noted that a few gamma rays upto 1300 keV, corresponding to neutron induced reaction products, are still visible after fairly long cooldown t_c = 31 d and corresponding Compton tails lead to the enhanced low energy background. The gamma rays belonging to natural radioactive decay chains (from the rock and the ambient background) are also indicated (*) in the spectra. No significant differences are visible at E > 1500 keV, although the statistics are very poor.

A comparison of Aut rock background with that of INO laboratory site at Bodi West Hill (BWH) [5] is of interest and hence neutron activation was also carried out on the BWH samples. The BWH rock is known to have higher levels of potassium. The presence of high energy gamma ray 2167.5 keV ($t_c \sim$ 42 m) in the spectrum of the irradiated BWH rock sample, may originate from ^{39}K(n,2n)^{38}K reaction.

In summary, neutron activation studies of Aut rock have revealed mostly short-lived activity. However, long-lived products like ^{54}Mn and ^{47}Ca can result in the enhanced background at E < 1000 keV. A detailed comparison of neutron induced activity in BWH (INO) and Aut rock samples will be presented.

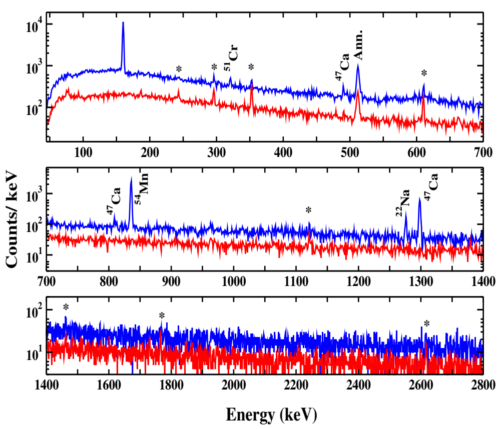

FIG. 2: Gamma ray spectra of the AUT1A (blue line, t_c = 31 d, scaled by a factor of 2.5 for better visualization) and AUTB (red line), (t = 1 d).

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References

[1] S. Paul *et. al.* Rev. Sci. Instru. **85**, 063501 (2014).
[2] N. Dokania *et. al.* NIM A **745**, 119 (2014).
[3] G. Gupta *et. al.* DAE Symp. Nucl. Phys. **63**, 1142 (2018).
[4] http://www.tifr.res.in/~pell/lamps.html
[5] N. Dokania *et. al.* JINST **10**, T12005 (2015).