Measurement of residual radioactivity generated inside K500 Cyclotron at VECC

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Introduction

Cyclotrons are used in the field of nuclear physics studies as well as to produce a wide variety of radio nuclides for various applications. In K500 superconducting cyclotron at VECC different heavy ion beams can be delivered to the experimental users. During the tuning process, the energetic beam may inadvertently strike various components of the cyclotron, leading to the radio-activation of those components. This residual radioactivity accumulates within the cyclotron due to the continuous operation of the machine poses a potential radiation hazard to workers, particularly during maintenance. Detailed studies of these residual radioactive nuclides are crucial for ensuring effective radiological protection. By assessing the radiation levels produced, it becomes possible to implement measures that would minimize the radiation dose to maintenance personnel. Though the phenomena are well understood, there is scarcity of experimental information regarding the residual activities produced by heavy ions [1, 2] in such complex machines like superconducting cyclotron. In the K500 superconducting cyclotron at VECC during tuning of the N^{4+} beam, the internal beam passes through key components, including two deflectors and several magnetic channels, before being extracted from the cyclotron. One such component, the first magnetic channel (M1), which is composed of natural copper (Nat-Cu), experiences interactions that result in the production of radioactive nuclides. Studying the characteristics of the nuclides and their impacts on the corresponding radiation levels is essential for improving the safety protocols during cyclotron maintenance.

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Materials and Methods

The experimental procedure involved collecting irradiated Nat-Cu dust, which was generated during the maintenance process where the metal was filed. Since Nat-Cu consists of two stable isotopes, ^{63}Cu (69.15%) and ^{65}Cu (30.85%), the interaction of the N^{4+} beam of energy 18 MeV/u with these isotopes initiated various nuclear reactions, leading to the formation of several radioactive isotopes. To accurately identify the radionuclides, a high-resolution gamma-ray spectroscopy technique was employed. The gamma emissions from the isotopes were measured using a High Purity Germanium (HPGe) detector, coupled with a 4K multi-channel analyzer (MCA). Each radionuclide produces gamma ray of characteristic energy, which can be detected and correlated with the isotope responsible for the gamma emission. The gamma spectra obtained from the HPGe detector thus provide a fingerprint of the various isotopes formed during the interactions of the N^{4+} beam with Nat-Cu. To complement the experimental findings, the statistical model code PACE4 [3], based on nuclear reaction models, was employed to predict the residual radionuclides produced from the nuclear interactions of N^{4+} with Nat-Cu. PACE4 provides a theoretical prediction of the radionuclides that should be produced, along with their respective yields. By comparing the theoretically predicted isotopes and their expected gamma emissions with the experimentally observed gamma peaks, the validity of the experimental data was assessed.

Results:

The gamma spectrum of the irradiated Nat-Cu sample is presented in Figure 1, illustrating the various radioisotopes produced during the interaction of the N^{4+} beam with the Nat-Cu target, along with their corresponding gamma energies. A PACE4 theoretical calculation was performed using an 18 MeV/u N^{4+} beam on a Nat-Cu target to predict the potential residual nuclides formed following these nuclear interactions. In this calculation, the cross-sections associated with the formation of specific residual isotopes were also evaluated, providing insights into the likelihood of their production in the reaction. The PACE4 results indicated the formation of various residual isotopes, some of which are radioactive and decay through the emission of gamma photons, while others are either stable or possess very short half-lives. The gamma-emitting radioactive isotopes were of particular interest for identifying the residual activity. Table 1 summarizes the radionuclides that were formed and subsequently identified through the gamma spectra measurements.

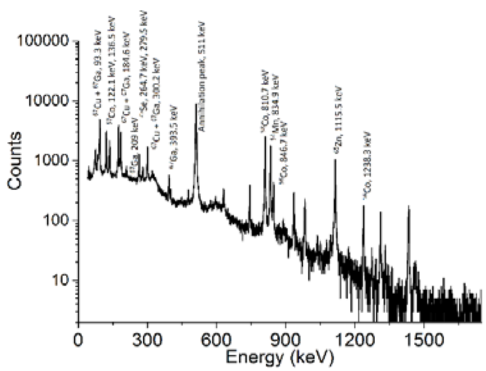

Figure 1: Gamma spectra of irradiated Nat-Cu

Table 1: Radioisotopes that has been identified in the measured spectra with their corresponding gamma energies along with cross section and yield obtained from PACE4

Product	Cross Section(mb)	Half Life	γ-energy (keV)
^{67}Cu	0.0264	61.83 h	93.3 184.6 300.2
^{67}Ga	1.73	3.3 d	93.3 184.6 300.2 209 393.5
^{57}Co	81.2	271.7 d	122.1 136.5
^{56}Co	67.6	77.2 d	846.7 1238.3
^{77}Ge	-	11.2 h	264.5
^{75}Se	-	119.8 d	264.7 136 279.5 121.1
^{58}Co	65.7	70.9 d	810.7
^{54}Mn	37.2	312.2 d	834.9
^{65}Zn	11.7	243.9 d	1115.5

Summary and Discussion

The irradiated copper target was studied to analyze the residual radioactivity produced during N^{4+} beam tuning at the K500 cyclotron, VECC, Kolkata. From the measured gamma spectra, evidence of radionuclides such as ^{67}Cu, ^{67}Ga, ^{57}Co, ^{56}Co, ^{77}Ge, ^{75}Se, ^{58}Co, ^{54}Mn, and ^{65}Zn was observed. The PACE4 calculation successfully predicted the production yields of these radionuclides, with the exception of ^{77}Ge and ^{75}Se. Three gamma energies—174 keV, 630 keV, and 744 keV—were detected in the spectra for which no associated radionuclides could be identified. This may be because of some impurities in the metal. Further comprehensive studies will be conducted to quantitatively estimate the residual activities and to identify products with shorter half-lives. This work will help refine the understanding of the radiation environment and further improve safety protocols during cyclotron maintenance.

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