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Excitation functions for (p,x) reactions of niobium in the energy range of E_p = 40–90 MeV

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ABSTRACT

A stack of thin Nb foils was irradiated with the 100 MeV proton beam at Los Alamos National Laboratory's Isotope Production Facility, to investigate the ^{93}Nb(p,4n)^{90}Mo nuclear reaction as a monitor for intermediate energy proton experiments and to benchmark state-of-the-art reaction model codes. A set of 38 measured cross sections for ^{nat}Nb(p,x) and ^{nat}Cu(p,x) reactions between 40–90 MeV, as well as 5 independent measurements of isomer branching ratios, are reported. These are useful in medical and basic science radionuclide productions at intermediate energies. The ^{nat}Cu(p,x)^{56}Co, ^{nat}Cu(p,x)^{62}Zn, and ^{nat}Cu(p,x)^{65}Zn reactions were used to determine proton fluence, and all activities were quantified using HPGe spectrometry. Variance minimization techniques were employed to reduce systematic uncertainties in proton energy and fluence, improving the reliability of these measurements. The measured cross sections are shown to be in excellent agreement with literature values, and have been measured with improved precision compared with previous measurements. This work also reports the first measurement of the ^{nat}Nb(p,x)^{82m}Rb reaction, and of the independent cross sections for ^{nat}Cu(p,x)^{52g}Mn and ^{nat}Nb(p,x)^{85g}Y in the 40–90 MeV region. The effects of ^{nat}Si(p,x)^{22,24}Na contamination, arising from silicone adhesive in the Kapton tape used to encapsulate the aluminum monitor foils, is also discussed as a cautionary note to future stacked-target cross section measurements. *A priori* predictions of the reaction modeling codes CoH, EMPIRE, and TALYS are compared with experimentally measured values and used to explore the differences between codes for the ^{nat}Nb(p,x) and ^{nat}Cu(p,x) reactions.

1. Introduction

Every year, approximately 17 million nuclear medicine procedures (both diagnostic and therapeutic) are performed in the U.S. alone [1,2]. Most of the radionuclides currently used for these procedures are produced by low- (E < 30 MeV/ A) and intermediate-energy (30 < E < 200 MeV/ A) accelerators, e.g., ^{11}C, ^{18}F, ^{68}Ga, ^{82}Rb, and ^{123}I. These accelerators also produce non-medical radionuclides with commercial value, such as ^{22}Na, ^{73}As, ^{95m}Tc, and ^{109}Cd [3,4]. Novel applications are being explored for several radionuclides whose production methodologies are not established, but their production requires accurate, high-fidelity cross section data. Candidate isotopes to meet these needs have been identified based on their chemical and radioactive decay properties [2,5,6], and a series of campaigns are underway to perform targeted, high-priority measurements of thin-target cross sections and thick-target integral yields. These studies will serve to facilitate the production of clinically relevant quantities of radioactivity.

Accurate cross section measurements using activation methods benefit from well- characterized monitor reactions. Currently there is a paucity of such data at intermediate energies, and much of what exists have high uncertainties (> 15%). Indeed, the development of new monitor reaction standards and the improved evaluation of existing standards is one of the areas of greatest cross-cutting need for nuclear data [6]. New reactions can expand the available range of options for the monitoring of charged particle beams. This work is an attempt to characterize a new monitor reaction for proton beams in excess of 40 MeV, for possible use at isotope production facilities such as the

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