Medical radioisotopes production research program at the Cyclotron Institute, Texas A&M University

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Introduction

One of the important applications of cyclotrons is the production of radioisotopes for use in biomedical procedures such as diagnostic imaging and/or therapeutic treatments. An advantage of using the accelerators for medical radioisotope production is the potential of high specific activities. Since the targets and the products are different chemical elements it is possible to find suitable chemical or physical means for separation [1].

Experimental work and setup

At the Cyclotron Institute, Texas A&M University a research program for the study of medical radioisotope production has been started in 2009. Beams of protons and alpha particles extracted from the K500 superconducting cyclotron have been used for the irradiation of metallic targets. The activation

FIG. 1. Experimental setup.

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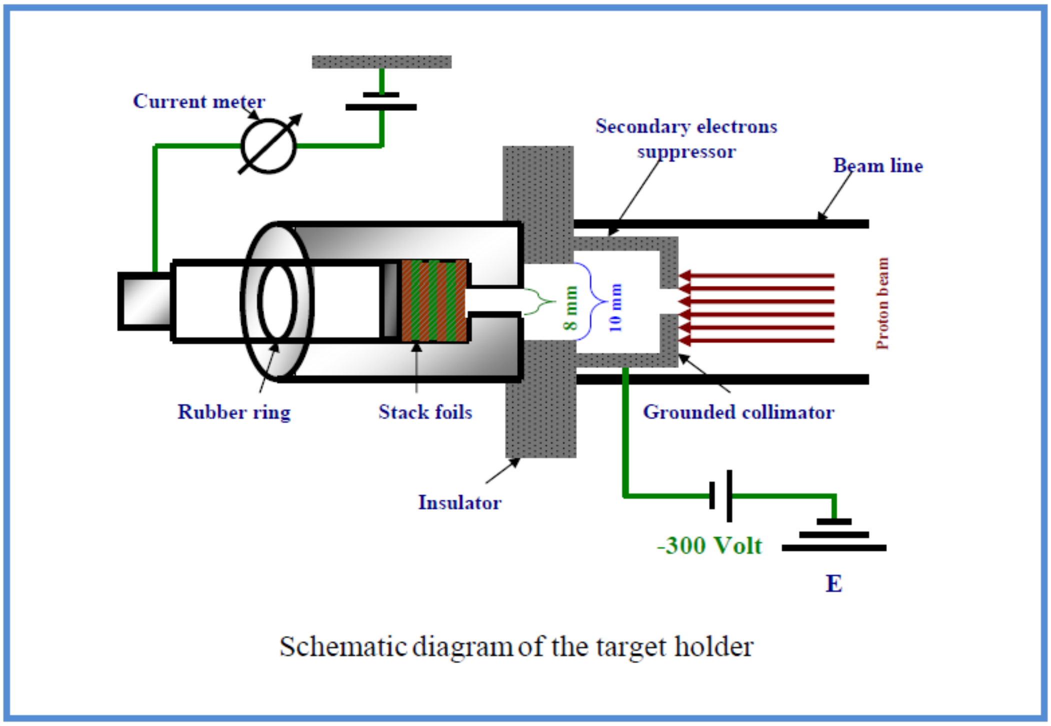
technique has been used for cross-section measurements of the nuclear reactions: ^{nat}Mo(p,x)^{95}Nb, ^{96}Tc ,^{99}Mo, ^{99m}Tc, ^{nat}Ag(p,x)^{111}In, and ^{nat}V(α,x)^{51,52}Mn which lead to the production of some important medical radioisotopes for diagnostic studies via emission tomography, viz. single photon emission computed tomography (SPECT) and positron emission tomography (PET). Two experiments were carried out to study the alpha emitter radioisotope ^{211}At for therapeutic use (in collaboration with the Nuclear Engineering Department). Table I lists the experiments that we have done to study the production of medical radioisotopes used for imaging, diagnostic as well as therapeutic proposes along with the importance of the studied radioisotope. The irradiations were made using a reaction chamber, which was adapted for the activation purpose (Fig. 1**)**.

TABLE I. The studied nuclear reactions leading to the production of medical radioisotopes that can be used for diagnostic or therapeutic purposes for tumors and some other diseases.

Experiment No.	Projectile	Beam condition	Target	Aim of the work	Medical application
Exp. 1	**Protons**	**@40MeV/u – 40 nA**	**^{nat}Mo**	**A study of the yield and the excitation functions for the longer lived medical radioisotopes and the attendant impurities for the production of the 99Mo.**	**^{96}Tc which is used for animal studies with Tc-99m.**
Exp. 2	**Alpha particles**	**@25MeV/u – 100 nA**	**^{nat}Ag**	**A detailed study of the yield and the excitation functions for the production of ^{111}In along with the attendant impurities.**	**^{111}In-Detection of heart transplant rejection, imaging of abdominal infections, antibody labeling, white blood cell imaging, cellular dosimetery, imaging tumors.**
Exp. 3	**Protons**	**@40MeV/u – 50 nA**	**^{nat}Mo**	**A study for the production of the important diagnostic medical radioisotope ^{99}Tc (relatively short lived) and ^{99}Mo (the generator system) along with some attendant impurities.**	**^{99}Mo is the parent for ^{99m}Tc generator used for brain, liver, lungs, bones, thyroid, kidney, antibodies, red blood cells and heart imaging.**
Exp. 4+5	**Alpha particles**	**@25MeV/u – 150 nA**	**^{209}Bi**	**Study the production of the therapeutically medical radioisotope ^{211}At.**	**^{211}At is used for monoclonal antibody attachment used for cancer treatment (RIT), used with ^{18}F for in vivo studies.**
Exp. 6	**Alpha particles**	**@25MeV/u – 50 nA**	**^{nat}V**	**A detailed study of the production of the important diagnostic medical radioisotopes ^{51}Mn and ^{52}Mn along with some attendant impurities to identify the optimum condition for the production.**	**^{51}Mn is used in myocardial localizing agent. ^{52}Mn is used PET scanning.**

An aluminum target holder was designed to hold the targets and to act as Faraday cup to measure the beam intensity. We irradiated a stack of several groups of targets along with some monitor foils, which also served as beam degraders (Fig. 2**)**.



Schematic diagram of the target holder

FIG. 2. Schematic diagram of the target holder setup and the faraday cup.

The monitor foils were inserted into each stack simultaneously with the main targets and were analyzed with the same gamma ray spectrometer in a comparable geometry as the targets to confirm the beam intensity and energy. Table II shows the different monitor reactions such as: ^{27}Al(p,x)^{22,24}Na, ^{nat}Cu(p,x)^{62,63,65}Zn, ^{nat}Ti(p,x)^{48}V, ^{nat}Ni(p,x)57Ni, ^{nat}Ti(α,x)^{51}Cr, ^{27}Al(α,x)^{22,24}Na, and ^{nat}Cu(α,x)^{66,67}Ga, ^{65}Zn that were studied to measure the excitation functions [2].

The chosen irradiation geometry allows the beam to pass through every foil. The secondary effect of the background neutrons on each target was checked by foils placed in the stack far beyond the range of the fully stopped proton beam [3].

The radioactivity of the residual nuclei in the activated foils was measured using one HPGe γ-ray detector (70% relative efficiency). Each foil was recounted after different cooling times to avoid disturbance by overlapping γ-lines from undesired sources and in order to accurately evaluate cross-sections for cumulative formation of the corresponding longer-lived daughter radionuclide. The detector-source distance was kept large enough to keep the dead time below 5% and to assure the same geometry.

From the decay rates of the radioactive products and the measured beam current, the cross sections for the nuclear reactions were determined.

TABLE II. The used monitor reactions.

	Projectile	**Targets**	**Main studied reactions**	**Energy range (MeV)**
Monitor reaction	**Protons**	**^{nat}Ti**	**$^{nat}Ti(p,x)^{48}V$**	**40-5**
	Protons	**^{nat}Cu**	**$^{nat}Cu(p,x)^{62}Zn$**	**40-12**
			$^{nat}Cu(p,x)^{63}Zn$	**40-4**
			$^{nat}Cu(p,x)^{65}Zn$	**40-2**
	Protons	**^{nat}Al**	**$^{27}Al(p,x)^{22}Na$**	**40-25**
			$^{27}Al(p,x)^{24}Na$	**40-25**
	Protons	**^{nat}Ni**	**$^{nat}Ni(p,x)^{57}Ni$**	**40-12**
	Alpha particles	**^{nat}Ti**	**$^{nat}Ti(\alpha,x)^{51}Cr$**	**100-5**
	Alpha particles	**^{nat}Al**	**$^{27}Al(\alpha,x)^{22}Na$**	**100-30**
			$^{27}Al(\alpha,x)^{24}Na$	**100-30**
	Alpha particles	**^{nat}Cu**	**$^{nat}Cu(\alpha,x)^{66}Ga$**	**100-8**
			$^{nat}Cu(\alpha,x)^{67}Ga$	**100-11**
			$^{nat}Cu(\alpha,x)^{65}Zn$	**100-11**

The excitation functions of the studied reactions were constructed using the well known staked foil technique [4]. Then the determined excitation functions will be compared with the simulated calculations using TALYS and ALICE-IPPE codes and with the available previous published research [5]. The thick target yields for the production of the required isotopes as well as their impurities will be estimated from the cross section data.

The data analyses for the studied reactions are progressing. We will continue the program with further irradiations for different targets using 32 MeV/u ^{3}He particles.

[1] S. M. Qaim, *Use of cyclotron in medicine*, Rad. Phys. and Chem. **71**, 917 (2004).
[2] F. Tarkany *et al.*, *Beam Monitor Reactions*, IAEA-TECDOC-1211, (IAEA, Vienna, 2001) p. 49.
[3] J.F. Ziegler *et al.*, SRIM 2003 code, the stopping and Range of Ions in Solids (Pergamon, New York, 2003).
[4] F. Helus, Lelio G. Colombetti, *Radionuclides Production*, CRC Press Inc., (Boca Raton, Florida, 1980)
[5] K. Gul *et al.*, IAEA-TECDOC-1211, IAEA, Vienna, Austria (2001).