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# Predicting Intensity of Neutron-Induced of Nuclear Reactions in a Cyclotron Accelerator

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**ABSTRACT:** In the Cyclotron accelerator the radioisotopes of $^{201}$Tl and $^{67}$Ga can be produced using the proton projectile on the $^{203}$Tl and $^{68}$Zn targets by the nuclear reactions of and $^{68}$Zn (p, 2n) $^{67}$Ga. More over the neutron particles also are produced during these reactions beside mentioned radioisotopes. These particles are known as undesirable particles and because of crashing with the facilities and concrete wall of shield of the solid targets by the neutron capturing reactions are activated. So calculation of the produced neutrons flux based on the energy unit is important. So first using the calculation code of SRIM-2013 the incident beam energy loss in each target layers and their copper substrate is calculated and then the cross section of the possible nuclear reactions which will lead to the neutrons production can be calculated by the calculation code of ALICE-91. Finally the total number of the produced neutrons and their energy spectrum are calculated.
**Keywords:** Cyclotron accelerator, Radioisotopes, Neutrons flux

## INTRODUCTION

In order to produce the $^{201}$T1 radiopharmaceutical in a cyclotron accelerator, the $^{203}$T1 with the thickness of almost 70 micron should be is located on the copper substrate with the thickness of some millimeters subjected to a beam of proton by the intensity of 150μA and the energy value of 28/5MeV and based on the following reactions, the $^{201}$T1 radiopharmaceutical will be produced [1].

$$^{203}_{81}\mathrm{Tl} + \mathrm{p} \rightarrow ^{201}_{82}\mathrm{Pb}^* + 3\mathrm{n} \qquad [2]$$

$$^{201}_{82}\mathrm{Pb}^* \xrightarrow{^{+}\beta,\mathrm{E.C.}} ^{201}_{81}\mathrm{Tl} \qquad [3]$$

Also in order to produce the $^{67}$Ga radiopharmaceutical, the 68Zn target which is in form of a layer with the approximate thickness of 41μmis located on the copper substrate with the approximate thickness of some millimeters subjected to a proton beam with the intensity of 150μA and energy value of 19MeV. Finally based on the following reactions the $^{67}$Ga radiopharmaceutical will be produced.

$$^{68}_{30}\mathrm{Zn} + \mathrm{p} \rightarrow ^{67}_{31}\mathrm{Ga} + 2\mathrm{n} \quad [3]$$

It is worthy to be stated that incident proton beam loses its energy in the copper substrate y the reaction of Thallium and zinc which are located under the target layers with the copper substrate as follows:

$$^{63}_{29}\mathrm{Cu} + \mathrm{p} \rightarrow ^{63}_{30}\mathrm{Zn} + \mathrm{n} \quad [4]$$

The collision between the Produced Neutrons and concrete walls of the target shield and its facilities causes the activation of these neutrons. For example the existing elements in the concrete wall like Europium, Cesium and Cobalt by neutron capturing nuclear reactions with the produced neutrons cause the increasing in the activation of concrete wall of the protective shield. So in order to predict the established activity it is required to calculate the produced neutrons' energy amount and spectrum. Thus first using the calculation code of SRIM-2013 the energy loss of incident proton beam in different thicknesses of the each target (Thallium and Zinc) layers and the copper substrate should be determined [4]. Then by calculation of the proton beam energy in each substrate and replacing this value in the ALICE-91 calculation code and also by determining the neutron production cross section, the total number of emitted neutrons and their energy spectrum can be obtained[5, 6].

## MATERIAL AND METHODS

**Calculation of energy loss of incident proton beam in the target layer:** Incident proton beam is emitted to the thallium target layer with the horizontal angle of $6^{\circ}$. So the distance travelled by the incident beam in the thallium target layer is the larger than its thickness. By considering its real thickness value of 70 μm the travelled

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distance is equal to 700μ. Also the copper substrate is designed in a way that the beam energy after passing through it will be zero.

In order to calculate the proton beam energy in each depth of the target layer, it can be divided into some layers with the little thickness values of almost 20μ. Then using the srim software the loss of incident proton beam energy can be calculated after travelling this distance. So the mean energy of poton beam can be determined in the half of a part. Figures 1 and 2 demonstrate the proton energy variation in the thallium target layer and also the copper substrate.

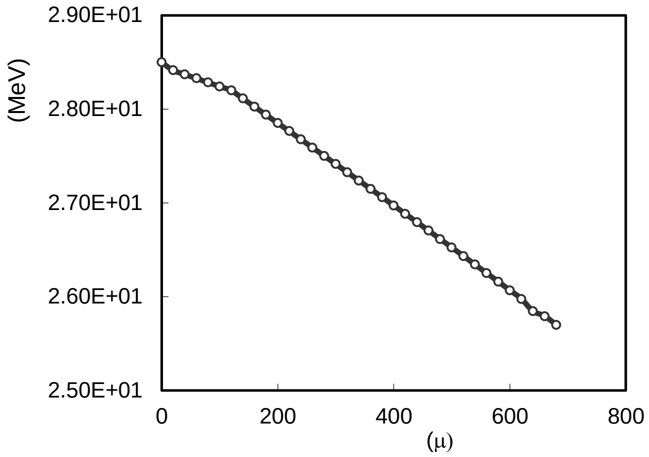


**Figure1.** Incident proton beam energy loss in the thallium target layer

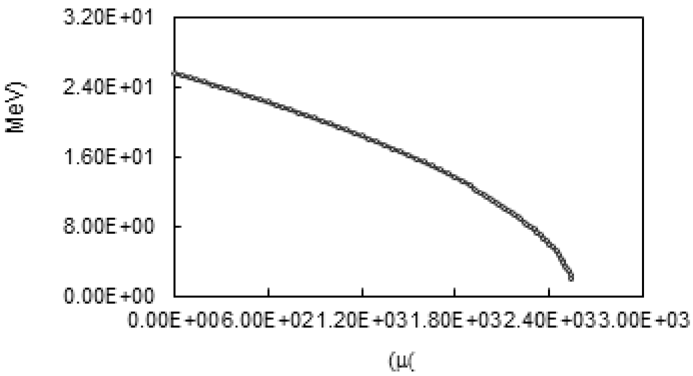


**Figure 2.** Incident proton beam energy loss in the copper layer

## RESULTS

Calculation of produced neutrons numbers after crashing the incident proton beam with the target. One of the most important and practical advantages of Alice code is its capability of calculation of cross section of the radio isotropic materials and also isotropic ones based on the different energy levels of the proton[4],[5]. In this code the total cross section of neutrons by the number of produced neutrons based on the mb.n unit devided by the incident beam energy can be determined for all possible nuclear reactions in the target set which includes a layer of thallium $^{203}Tl$ on a copper layer of $^{63}Cu$ using the incident proton beam energy loss diagrams and replacing the mean energy which is obtained for each substrate of target. The results are depicted in figures 3 and 4[1].

Also the cross section of all neutrons produced by all nuclear reactions in the thallium target layer of its copper substrate is equal to the sum of cross sections of all substrates regarding the incident proto n energy in that substrate. The calculated value for the target set of thallium and copper is equal to the $N_{total}$=204/804b. In order to calculate the total number of neutrons for the target set (thallium and its copper substrate) the following equation can be used[2]:

$$N=\sum_{i=1}^{k}N_i+\sum_{i=1}^{k'}N'_i=\sum_{i=1}^{k}\frac{\rho_i l_i N_\circ J}{M_i e}\sigma_i+\sum_{i=1}^{k'}\frac{\rho'_i l'_i N_\circ J}{M'_i e}\sigma'_i \quad (1)$$

In which:

$N_i$ : the produced neutrons in each thallium layer part (n/sec); $N'_i$ : the produced neutrons in each copper ; substrate part (n/sec); $l_i$ and $l'_i$ : the i'th target part thickness related to the thallium and copper (cm); $\rho_i$ and $\rho'_i$

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: the i'th target part density related to the thallium and copper (gr/cm³); $N_0$ : the Avogadros' number equal to the 6/02*10²³ ; J: beam current of incident proton (A); e : electron load (C); $M_i$ and $M'_i$ : mass number of i'th target part related to the thallium and copper (gr); $\sigma_i$ and $\sigma'_i$ : neutron emission total cross section in the i'th target part related to the thallium and copper; K: the parts number in the thallium layer; $k'$ : the parts number in the copper substrate; N: the total number of neutrons in each second.

Accordingly equation the total number of produced neutrons for the target set of thallium and copper substrate is equal to the sum of number of produced neutrons in each substrate which can be calculated using the equation 1. In this project this value is equal to the n/sec($N_{total}=4.03*10^{13}$). Also using the alice code it is possible to calculate the total intensity of the emitted neutrons for the target set based on the emitted neutron particles energy. The results are demonstrated in figure 5.

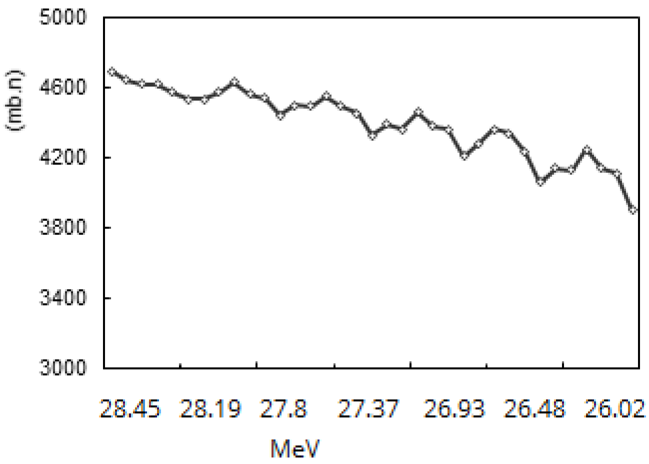


**Figure 3**. The cross section of nuclear reactions (p,xn) for the thallium target

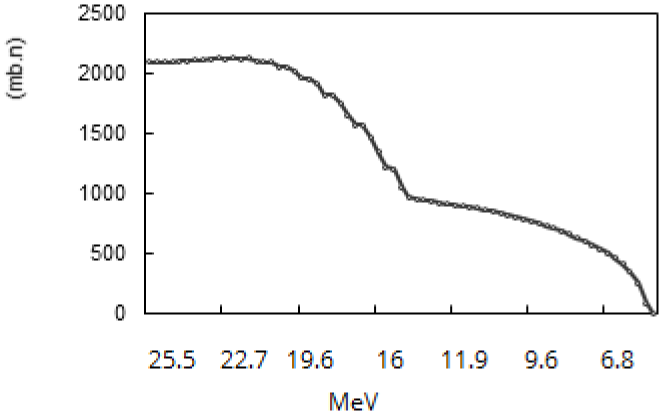


**Figure 4.** The cross section of nuclear reactions (p,xn) for the copper target

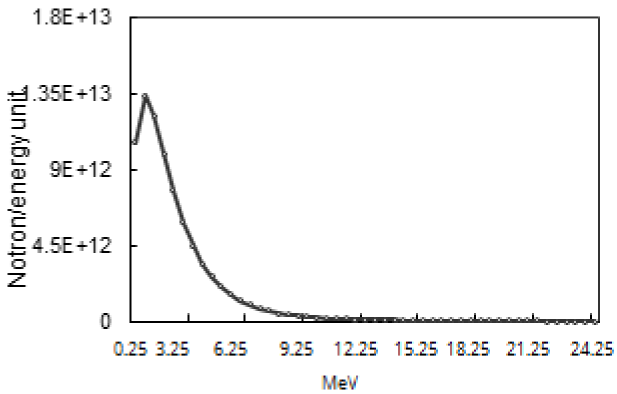


**Figure 5.** Energy spectrum of the emitted neutrons from the target set of thallium and the copper substrate.

## DISCUSSION

Based on the obtained results in this project, the number of produced neutrons from the nuclear reactions of proton with the thallium and its copper substrate target is considerable. So because of the produced neutrons bombardment many of implemented facilities in the target shield are almost activated in a high amount. Also crashing of the neutrons with the concrete wall of the shield causes the nuclear reactions (capturing) with the existing elements in the wall (like Avrvpym, cobalt ,..). Because of the long half-life of the produced radioactive elements the large amount of the activity is accumulated during the time which should be considered and analyzed.

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