Neutron Irradiation Based Radioisotopes Production Chance using Secondary Neutron Irradiation in DECY-13 Cyclotron

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Abstract. The research of neutron-based radioisotopes that is using research reactor as irradiation facility still popular in Indonesia. However, the scarcity from Uranium Fuel is a problem that will be faced in future. The proposed solution is used the accelerators to produce radioisotope. DECY-13 is a cyclotron type accelerator that accelerates Proton to 13 MEV. To produced neutron, the accelerated Proton must be interacted with particles that can induce neutrons such as lithium, beryllium, or titanium which is named secondary neutron. Monte Carlo method on PHITS program was used to simulate the result of secondary neutron. DECY-13 cyclotron was able to produced secondary neutron from induced reaction of lithium, beryllium, or titanium. The neutron flux results were 1.463×10^{12}, 4.023×10^{12}, 3.638×10^{12} neutron.cm^{-2}.s^{-1}, respectively. The secondary neutron result from DECY-13 was lowest than Indonesian research reactor, it's made the radioactivity result less optimal than using research reactor. In conclusion, the secondary neutron induced by 13 MeV proton in DECY-13 cyclotron was not feasible to produced common radioisotopes like ^{99m}Tc, ^{131}I, and ^{32}P. However, there was an opportunity to make radioisotopes with high neutron cross section for industrial purpose like Scandium-46.

1. Introduction

The research of neutron-based radioisotopes that is using research reactor as irradiation facility still popular in Indonesia [1]. However, the scarcity from Uranium Fuel is a problem that will be faced in future [2]. The one of proposed solution is used the accelerators to produce radioisotope. To overcome this problem, Indonesia began to initiate the development of a cyclotron type accelerator with code name DECY-13 which is abbreviation for Development of Experimental Cyclotron in Yogyakarta-13 MeV.

DECY-13 should accelerate Proton to 13 MeV with proton beam 50 µA [3]. Because of dependence on neutron-based radioisotope still high, it is necessary to do research to observe opportunity to produce neutron-based radioisotopes in proton cyclotron. Theoretically, to inducing neutron in cyclotron, which is named secondary neutron [4], the accelerated Proton must be interacted with particles that following proton-neutron reaction. The light materials such as lithium and beryllium or transition metals like titanium do the proton-neutron reaction and possible to do a neutron source in DECY-13.

$$^{7}Li + p \longrightarrow \ ^{7}Be + n$$

$$^{9}Be + p \longrightarrow \ ^{9}B + n$$

$$^{48}Ti + p \longrightarrow \ ^{48}V + n$$

The prelamination research of proton induced neutron reaction should simulated using Monte Carlo methods. Monte Carlo was a probabilistic-based simulation method that involved randomly dispersing a generated number across a space. PHITS which is the free Monte Carlo simulation software will be simulated bombardment process between proton particles and the target on DECY-13 [5].

2. Methods

2.1. Target preparation

The irradiation target was used Lithium metal (Li), Beryllium metal (Be), and Titanium metal (Ti) with density were 0.53 [6]; 1.58 [7]; 4.50 [8] g.cm^{-3}, respectively. The targets were placed in target chamber with diameter ϕ = 2 cm. The thickness of the target will be sought to determine the optimum thickness so that the interaction of secondary neutron is not moderated by the target.

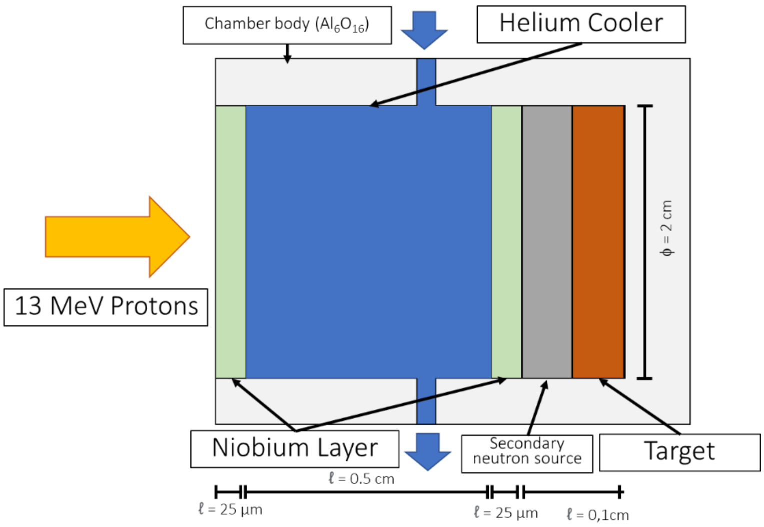

Figure 1. Schematic irradiation target system.

2.2. Irradiation process

The irradiation simulation was occurred with 10,000 number of particles and 1,000 step of iterations [9] in PHITS 3.24 software. Initially, the Proton was accelerated until 13 MeV energy. However, the energy was decrease to 12.131 MeV after contact with both of 30 µm of niobium foil and 5 mm of helium cooler. The target was irradiated 24 hours also 12 hours cooling. the irradiation result was processed using DCHAIN algorithm [10] to generate dose and radioactivity profile of all isotopes produced.

3. Result and Discussion

The result was discussed in three subsection which was named: the irradiation simulation, the neutron fluxes, and the waste from target source.

3.1. The irradiation simulation

The irradiation simulation was done using PHIT program, the result map of particle showed below:

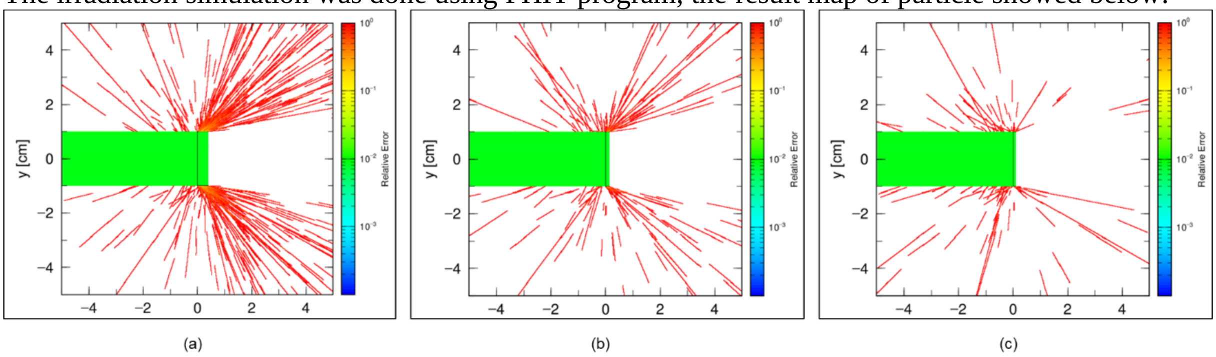

Figure 2. % error maps of proton interaction with: (a) Lithium, (b) Beryllium, and (c) Titanium.

Overall, all of simulation result has been accepted for further discussion. It is because the % error obtained no more than 5% [11]. Increasing the number of iterations should be decreased the % error. However, using number of iterations more than 1000 was not decrease % error significantly [9], [12].

3.2. The neutron fluxes

The interaction between accelerated proton with three materials produced secondary neutron. The secondary neutron flux for Lithium, Beryllium, and Titanium were 1.463×10^{12}, 4.023×10^{12}, 3.638×10^{12} neutron.cm-^{2}.s^{-1}, respectively. Subsequently, the gross neutron flux was rearrangement according to the energy ascending, the graphic was shown below:

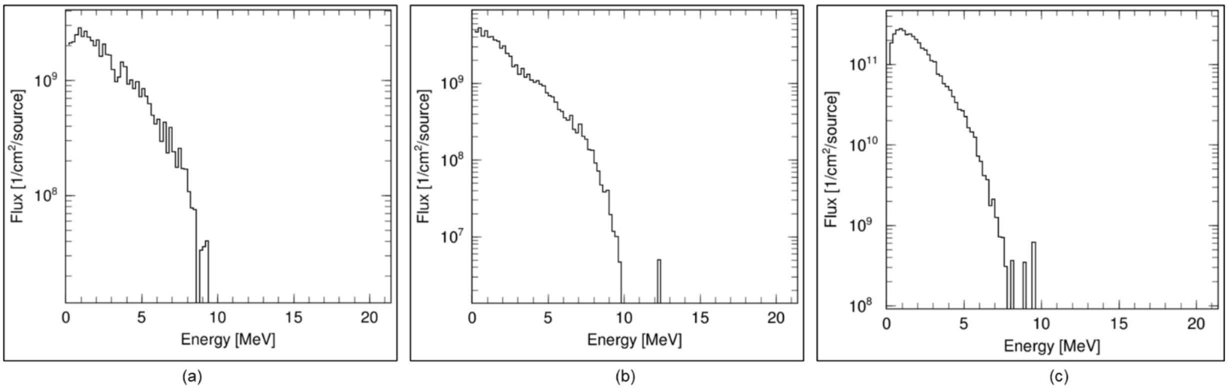

Figure 3. % error maps of proton interaction with: (a) Lithium, (b) Beryllium, and (c) Titanium.

According to the result the secondary neutron has not feasible to produced radioisotopes, not only the fluxes which below than fluxes on G.A. Siwabesi multi-purpose and Bandung TRIGA 2000 reactor (1×10^{14} and $3{,}4 \times 10^{13}$, respectively) but also the energy was higher. Moreover, the radioisotopes target only need thermal neutron that is energy between 0.025 and 1 eV. Therefore, using DECY-13 to produced popular radioisotopes in Indonesia, such as ^{99m}Tc, ^{131}I, and ^{32}P, was not feasible. However, there was an opportunity to make radioisotopes with high neutron cross section for industrial purpose like Scandium-46.

3.3. The waste from target source

The radioactivity during 24 hours irradiation and 12 hours cooling was showed below:

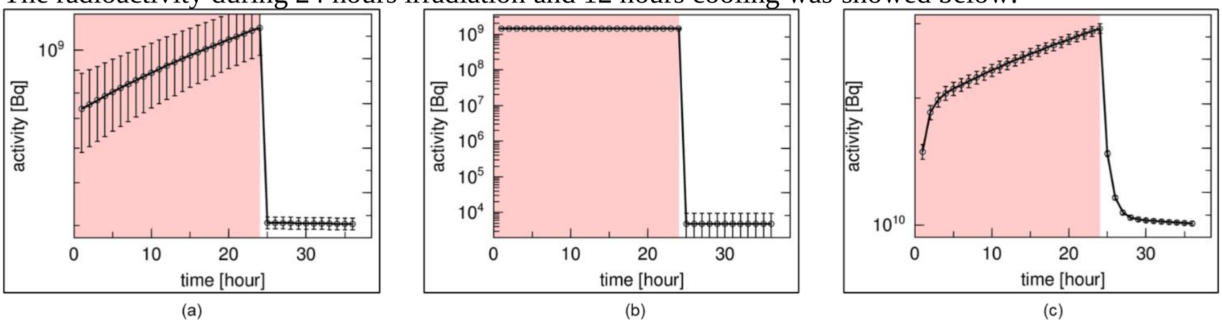

Figure 4. Radioactivity during simulation in: (a) Lithium, (b) Beryllium, and (c) Titanium.

Overall, the radioactivity of three targets was decreased after 24 hours irradiation. Moreover, in Beryllium, it was decay to daughter radioisotopes, such as ^{6}He and ^{8}Be, which have half-live lower than cooling time. The short half-live made the radioactivity extremely decreased.

However, the radioactivity was decreased, At the end of process was still found radioisotopes which 3 higher presented below:

Table 1. Radioactive in three different targets.

Lithium			Beryllium			Titanium		
Name	Radioactivity (Bq)	Half-life	Name	Radioactivity (Bq)	Half-life	Name	Radioactivity (Bq)	Half-life
^{7}Be	3.84×10^{8}	53.22 D	^{3}H	4.81×10^{3}	12.32 Y	^{48}V	9.97×10^{9}	15.97 D
^{3}H	1.88×10^{7}	12.32 Y	^{10}Be	1.18×10^{-1}	1.51×10^{6} Y	^{49}V	4.72×10^{7}	330 D
^{10}Be	1.57×10^{-1}	1.51×10^{6} Y				^{44}Sc	3.03×10^{7}	3.97 H

Generally, all targets generate unnecessary by product radioisotopes that become a waste. Especially on Titanium, the waste radioisotopes which was long half-life was high. It is noticeable when Titanium must avoid to used as target on Proton Induced neutron process.

4. Conclusion

In conclusion, the secondary neutron was induced by 13 MeV proton in DECY-13 cyclotron was not feasible to produced common radioisotopes that was produced in nuclear research reactor like ^{99m}Tc, ^{131}I, and ^{32}P. However, there was an opportunity to make radioisotopes with high neutron cross section for industrial purpose like Scandium-46. Furthermore, supplementary research to find a way to decrease the neutron energy to thermal neutron must conducted.

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