Design study of Compact Neutron Target with 13 MeV Cyclotron

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1. Introduction

There are some methods to generate neutron, such as nuclear reactor, accelerator, isotope. Neutron has a lot of applications like imaging, therapy and material analysis etc. That's why we need to study about compact neutron source.

In the Pusan National University, there is cyclotron facility, which can accelerate the proton until 13MeV, called KIRAMS-13, Fig.1. It was developed by KAERI and KIRAMS in Korea. Detail specifications of KIRAMS-13 is demonstrated in below Table I.

In this paper, we designed target for compact neutron source with low energy proton beam, which consists of target layer, cooling layer, metal layer and moderator. We found suitable material, thickness and cooling system.

Fig. 1. Cyclotron KIRAMS-13 in Pusan National University

Table I: Specifications of KIRAMS-13

Parameters	Values
Height	1.08 m
Weight	20 Tons
Particle	Proton
Beam Energy	13 MeV
Beam Current	0.05 mA
Beam Type	CW

2. Target Design Process

2.1 Material

In low energy based compact neutron generator, they mainly choose ^{7}Li and ^{9}Be for target material.

In order to make neutron with 13MeV proton beam, ^{9}Be is proper material. The reaction (1) is mainly occurring, during neutron generating process. In general, this reaction has threshold energy, 2.057MeV. If incident energy of proton is below 3MeV, Li target is better than Be. Usually, BeO is used for compound.

$$^{9}\text{Be} + \text{proton} \rightarrow \text{n} + {}^{9}\text{B} - 1.850\ \text{MeV (Q-Value)} \quad (1)$$

2.2 Thickness

In order to deciding proper thickness of target, we calculated by stopping power with PSTAR table in NIST. We can find required thickness from stopping power table. We took this approach from Dr. Yamagata, RIKEN, Japan.

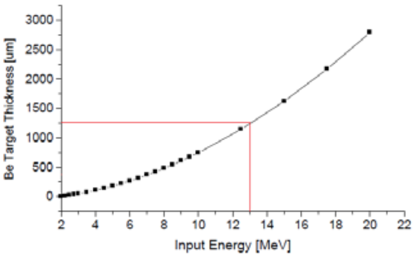

Fig. 2. Required thickness depending on Input proton Energy

2.3 Cooling system

When accelerated-proton beam hit the Be-target, it generates lots of heat. That's why this target needs cooling system. We selected water cooling system for removing heat effectively, which has to be concerned about water's neutron absorption cross section. Additionally, we can control water flow rate and heat transfer efficiency. The melting point of solid Be is 1280℃.

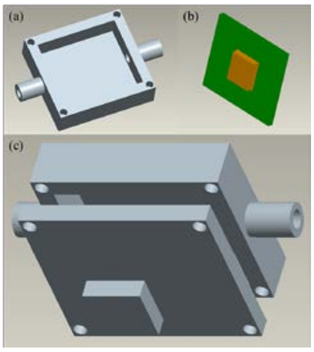

Fig. 3. 3D modeling with Pro/Engineer wildfire4.0

2.4 Metal Layer

After proton passing through target, hydrogen ion continued to pile up in the material. Because of hydrogen, material gets brittle. It is related with life time of target. For solving this problem, we found material, which has high hydrogen diffusion coefficient and short half-life isotope after activating with neutron. They have to solder by lead or weld together. Additionally, we have to concern melting point, thermal conductivity and yield strength. For all conditions, vanadium is suitable for this system.

Table II: Properties of Vanadium

Parameters	Values
Atomic number	23
Half-life of Activated product (^{52}V)	3.7 m
Hydrogen diffusion coefficient at 25℃	$5*10^{-9}$ m^2/s
Yield Strength	80 MPa
Thermal conductivity	30.7 Wm^{-1}K^{-1}
Melting Point	1910 ℃

3. Simulation of Generation neutron

3.1 Source

We tried to make neutron with designed target by using Monte Carlo simulation code, Geant4 (CERN). We used Geant4 10.0 version, and QGSP_BERT_HP 3.0 for physics engine, which is powerful physics model in Geant4 tool. For proton sources, we assumed output beam that it has Gaussian profile and square shape the number of particle is $312.5*10^9$ea.

3.2 Geometry

First of all, we got rid of air in the chamber, and set up the Be-reflector, which includes square tube. It has Beryllium target (green), vanadium metal layer (sky blue) and water moderator (deep blue). Dimension of chamber is 50*50*50 cm^3 and 300cm for distance of target to detector. After proton passing through the target, there is detector that detected the number of neutron and kinetic energy with 20*20 cm^2 for detector size.

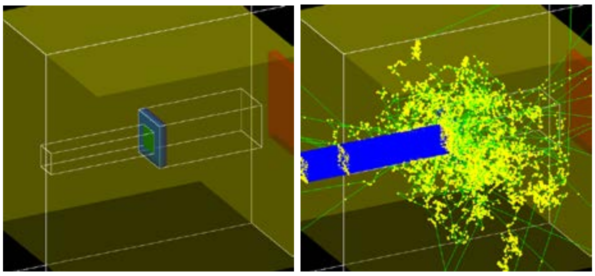

Fig. 3. Monte-carlo (Geant4, CERN) Simulation

4. Conclusion

In this paper, we could find a huge opportunity about compact neutron source by using cyclotron. After Monte Carlo simulation, we got a variety of different energy range neutron source and we could see high neutron flux, $2*10^8$n/cm^{2}s and energy profile, below Fig.4 and Fig.5. If we control proton energy and moderator, we are able to get neutron beam energy we require. As you know, Monte Carlo code is not almighty, so we need to refer to this data. We found out the result that we can control neutron energy with target and moderator.

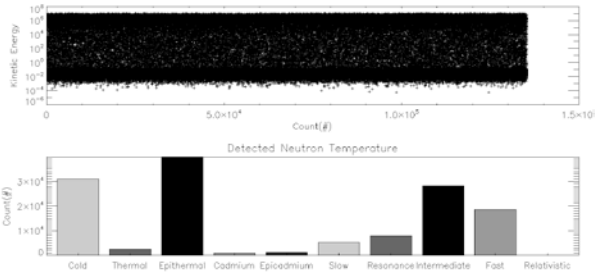

Fig. 4. Detected Neutron Energy and Range

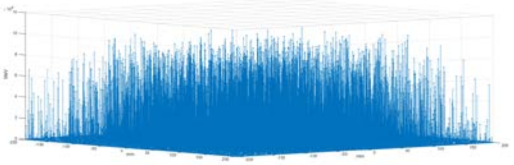

Fig. 5. Energy Profile of Detected Neutron

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