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Assessment for bulk shielding of 600MeV proton beam

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1. Introduction

Muon spin spectroscopy, in acronym μSR, is used widely because of its usefulness in magnetic force and superconductivity field. To get the muon particle, particle accelerator generating high energy beam is needed. In this study, particle type of beam that escapes from the accelerator is proton and energy of beam used is 600MeV. That proton beam with high energy is forced to interact with carbon cylinder target and can make the neutrons with various energy which ranges from very low energy to very large energy. So they may interact with concrete which functions as shielding material or other materials used in the beam lines. During these procedures, radioactive nuclides that may affect workers are produced. So we should estimate how much radionuclides are produced and decide whether workers can work in working space or not.

The first step to get the doses of workers is to decide how thick concrete wall is needed which plays a role as bulk shielding.

So the purpose of this study is whether local shielding is essential or not.

2. Methods and Results

In this study, MCNPX 2.7 version was used to get the neutron energy spectrum induced by 600MeV proton beam.

This study is divided into two steps. First step is to select appropriate physics model for calculation of MCNPX code. Second step is the assessment for bulk shielding thickness to meet the legal limit of annual effective dose.

2.1 Physics Model Selection

There are several usable physics models in MCNPX code. Because of extremely high energy of incident beam, physics model should cover for nuclear data table at specific energy region where nuclear data table is not usable. It is essential process to select appropriate models for conservative results.

Figure1 shows the target shape used in this report. Target is made up of carbon and its shape is cylinder with 12cm thickness and 50cm radius. There is a sphere large enough to surround the target and neutron energy spectrum is obtained on its surface by each solid angle.

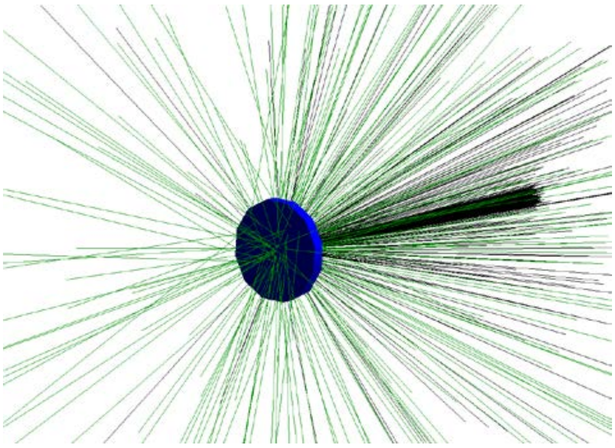

Fig. 1. Secondary neutrons produced by 600MeV protons

The most probable direction of neutron particles with high energy is the interesting region for this study. Proper physics model can be decided from these data.

2.2 Assessment of Shielding Thickness

Second step is to assess the dose at the concrete wall by using the most conservative physics model. μSR facility is surrounded by concrete wall with 10m thickness. The wall is divided into 20 slices so that each slice has 50cm thickness and doses are calculated at each surface of concrete slices. Operation time of μSR facility is assumed 5 months annually for calculation of annual effective dose. Beam current is 0.6mA and maximum effective dose conversion factor is selected to get the conservative results.

In addition, the 600MeV proton beams rarely attenuate in the carbon target because of its high energy. Therefore secondary neutron may be produced at beam dump, but it is assumed that proton beams entering the beam dump are perfectly shielded in the beam dump region. So only secondary neutrons produced in the target material are considered in this study.

Figure2 shows the simple geometry of the target, shielding wall and interesting tally regions. Regulatory concrete was used for shielding material [1].

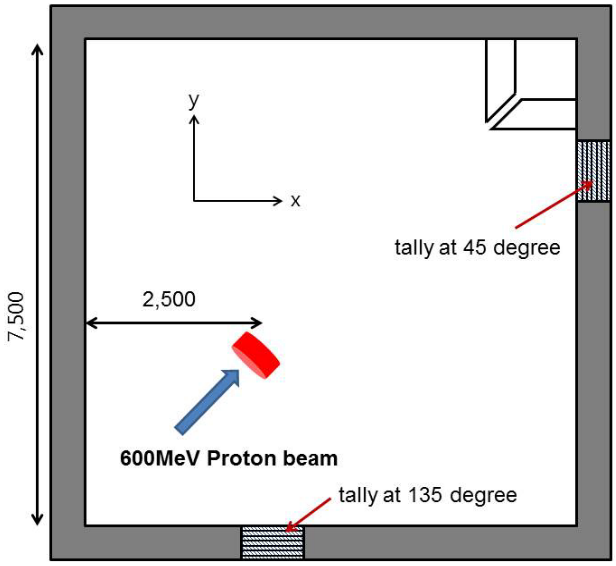

Fig. 2. Tally regions for bulk shielding

Finally, thickness of concrete wall for bulk shielding is determined so that annual effective dose of workers match up to legal limit, 20mSv.

2.3 Bertini Model

As shown in Figure3, Bertini physics model is dominant at high energy region for 0-5 degree. On the other hand, other physics models are almost equal for 15-30 degree, 30-45 degree, 90-120 degree like Figure 4, Figure 5 and Figure 6.

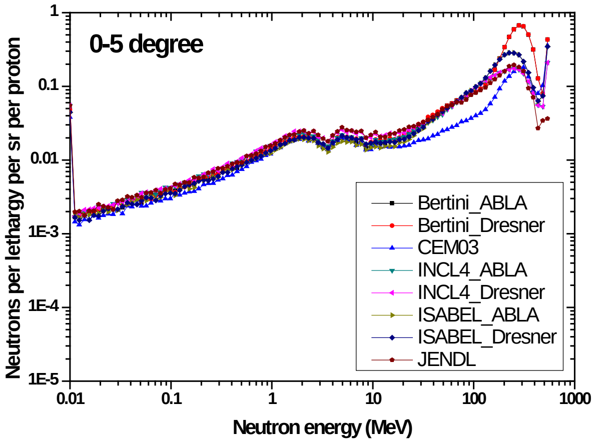

Fig. 3. Neutron energy spectrum in 0-5 degree

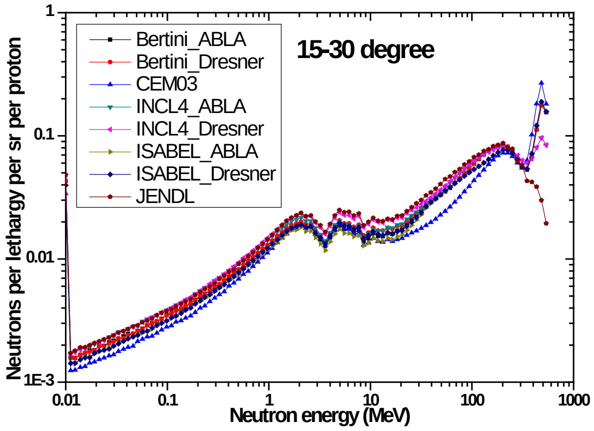

Fig. 4. Neutron energy spectrum in 15-30 degree

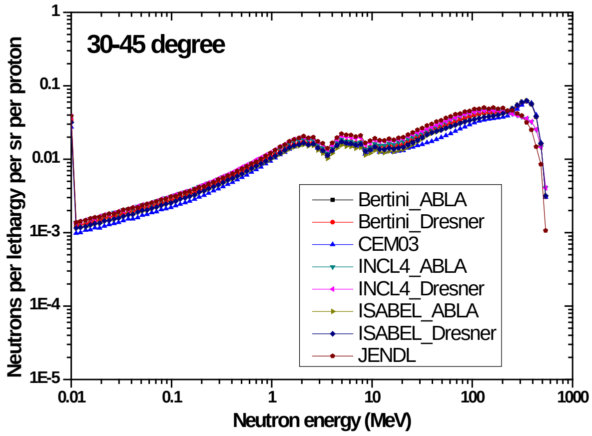

Fig. 5. Neutron energy spectrum in 30-45 degree

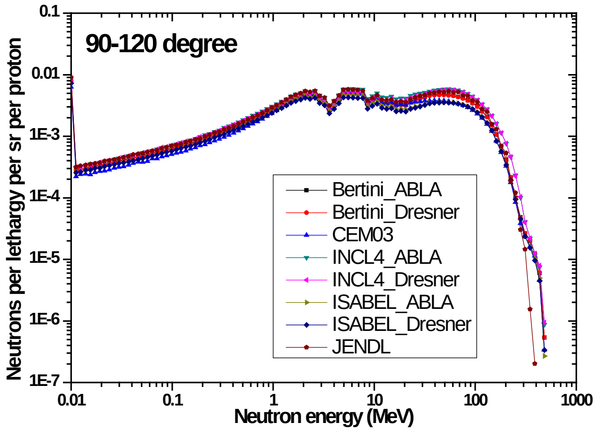

Fig. 6. Neutron energy spectrum in 90-120 degree

It is clear that the number of neutrons is emitted easier in 0-5 degree than other solid angle. In addition, Bertini physics model is similar to other physics models in 15-30 degree, 30-45 degree and 90-120 degree.

Therefore it is proper to select Bertini model as a conservative physics model.

2.4 Shielding thickness to meet 20mSv/year

Second step is to calculate the bulk shielding. As stated above, Bulk shielding calculation was done with Bertini model.

There are three tally regions to be evaluated. One of the tally regions is sliced by x value and its value is shown in Table I. It is located at 45 degree in the direction of the proton beam. Second tally region is sliced by y value and that is shown in Table II. It is located at 135 degree in the direction of the proton beam. The other tally region is the concrete ceiling which is located at 90 degree in the direction of the proton beam and its result is shown in Table III.

Maximum neutron effective dose conversion coefficient which is antero-posterior (AP) direction was selected for evaluating effective dose at each concrete slice [2].

Table Ⅰ: Effective dose at concrete wall located at 45 degree

Thickness of concrete (cm)	Effective Dose(mSv)
700	7.88E+01
750	**2.72E+01**
800	**8.95E+00**
850	4.79E+00

Table Ⅱ: Effective dose at concrete wall located at 135 degree

Thickness of concrete (cm)	Effective Dose(mSv)
400	9.94E+01
450	**3.04E+01**
500	**8.63E+00**
550	2.28E+00

TableⅢ: Effective dose at concrete ceiling

Thickness of concrete (cm)	Effective Dose(mSv)
500	7.78E+01
550	**2.00E+01**
600	7.19E+00
650	2.26E+00

The legal limit of annual effective dose is 20mSv.

According to the Table I, there should be minimum about 7.7m thick concrete wall for 45 degree, 4.8m thick concrete wall for 135 degree and 5.5m thick concrete for ceiling to meet the legal limit of effective dose.

3. Conclusion

It is obvious that the thickness of concrete wall needed for bulk shielding is too unrealistic and huge to construct μSR facility. Then μSR facility costs too much money and loses effectiveness.

As a result from this study, there should be not only bulk shielding but also local shielding.

In this study, there is no consideration for activation in the concrete wall, but we can expect easily that the dose from activated element emitting radiation is not negligible.

Thus further study has to contain the local shielding so that workers get doses below the legal limit of annual effective dose at their working space where activation of shielding materials is under consideration.

REFERENCES

[1] L. M Petrie, P. B. Fox, and K. Lucius, “Standard Composition Library”, ORNL/TM-2005/39, Oak Ridge National Laboratory, 2009.

[2] N. Petoussi-Henss, W.E. Bolch, K.F. Eckerman, A. Endo, N. Hertel, J. Hunt, M. Pelliccioni, H. Schlattl, M. Zankl, “ICRP 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures.” ICRP Publication 116, Ann. ICRP 40(2–5).