Evaluation of the Induced Activity in Air by the External Proton Beam in the Target Room of the Proton Accelerator Facility of Proton Engineering Frontier Project

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1. Introduction

One of the radiological concerns is the worker's exposure level and the concentration of the radio-nuclides in the air after shutdown, for the safety analysis on the proton accelerator facility. Although, the primary radiation source is the protons accelerated up to design value, all of the radio-nuclide is produced from the secondary neutron and photon induced reaction in air. Because, the protons don't penetrate the acceleration equipment like the DTL tank wall or BTL wall, secondary neutrons or photons are only in the air in the accelerator tunnel building because of the short range of the proton in the materials. But, for the case of the target rooms, external proton beams are occasionally used in the various experiments. When these external proton beams travel through air from the end of the beam transport line to the target, they interact directly with air and produce activation products from the proton induced reaction.

The external proton beam will be used in the target rooms in the accelerator facility of the Proton Accelerator Frontier Project (PEFP)[1]. In this study, interaction characteristics of the external proton beam with air and induced activity in air from the direct interaction of the proton beam were evaluated.

2. Methods

MCNPX 2.5.f code was used in the proton transport calculation in air with the nuclear data library, LA150, for protons[2]. The acceleration energy of the external proton beams are 20 and 100 MeV. The average beam currents are 4.8 mA for 20 MeV and 1.6 mA for 100 MeV. The composition of air used in this study is shown in Table 1.

3. Calculations & Results

3.1 Distribution of the Proton Beam in Air

The radial distribution of the proton beam is shown in Figure 1. The distribution of the proton beam intensity in air according to the distance in the direction of the beam was calculated and shown in figure 2.

Table 1. Composition of Air

Element	Weight fraction [%]
O2	23.2
N2	75.47
CO2	0.046
H2O	0.00239
Ar	1.28
Ne	0.0012
He	0.00007
Kr	0.0003
Xe	0.00004

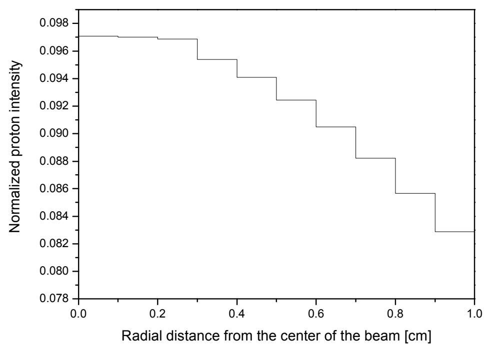

Figure 1. Radial distribution of the proton beam

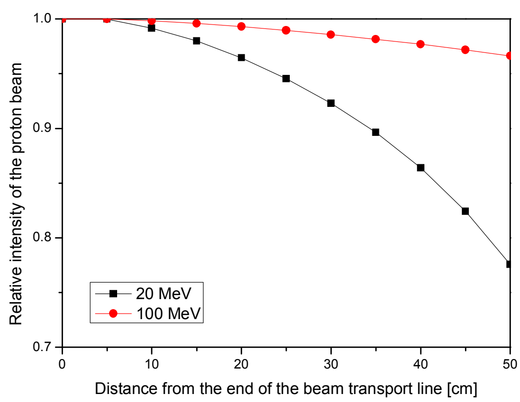

Figure 2. Relative intensity of the proton beam intensity in air according to the distance from the end of the beam transport line

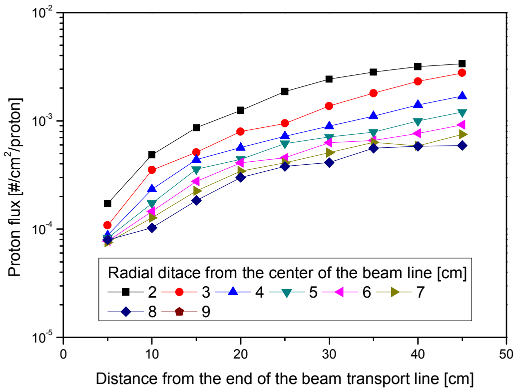

Figure 3. Radial distribution of the proton loss from the beam line

3.2 Induced Activity

Induced activity was estimated for air by using the reaction rate from MCNPX simulation and the equation (1). The value of ϕ for the target room was calculated from MCNPX simulation. The maximum cross section was used in σ for the proton with a energy under 100 MeV. These experimental cross section value were on the references[3], [4] and [5].

$$R = \int_E \frac{\lambda}{(\lambda+\alpha)} N_0 \phi_E \sigma_E \left[1 - e^{-(\lambda+\alpha)t}\right] dE \quad \cdots\cdots\cdots\cdots (1)$$

R : Activity of radionuclide, [Bq/cm^3]
λ : Decay constant, [/hr]
N_o : Number density of the parent nuclide, [#/b·cm^3]
ϕ : Proton flux, [neutrons/cm^2/sec]
σ : Reaction cross-section, [b·cm^2]
t : Irradiation time, [hr]
α : Removal constant, [/hr]

Induced activity and decay after shutdown were evaluated and shown in Table 2. It is well known that ^{7}Be, ^{11}C, ^{13}N, ^{15}O and ^{41}Ar are significant radio-nuclides produced in air for accelerator facility. But ^{3}H, ^{7}Be and ^{11}C was produced only for protons with energy under 100 MeV

4. Conclusion

The beam characteristics of the external proton beam were evaluated for the beam intensity and proton loss in air. Induced activity from proton interaction with air was also evaluated. The concentration of the radio-nuclides was very lower than those from secondary neutrons and photons. Therefore, worker's exposure due to external proton beam is not significant but neutron and photon. And it is not need to set additional equipment like a vacuum chamber for beam line near the targets.

Table 2. Production of radio-nuclides in air from 100 MeV protons

Nuclide	Concentration [Bq/cm^3]
^{11}C	4.07E-8
^{3}H	8.93E-9
^{7}Be	1.58E-9

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