# Initial Estimation of the Radionuclides in the Soil around the 100 MeV Proton Accelerator Facility of PEFP

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## 1. Introduction

The Proton Engineering Frontier Project (PEFP) has designed a proton linear accelerator facility with 100 MeV – 20 mA. While the accelerator is being operated, several spallation reactions or thermal neutron capture reactions occur between escaped neutrons from the facility and components of a soil. These reactions induce various radionuclides in the soil around the facility. Therefore, a quantitative estimation of the induced radionuclides is essential from the radiation safety aspect. According to this necessity, this study estimated the production rates and migration of radionuclides in the soil around the 100 MeV accelerator tunnel.

## 2. Calculations

### *2.1 Methods*

This calculation was implemented using MCNPX which is the most widely used Monte Carlo particle transport simulation code. Figure 1 shows the neutron spectrum in the 100 MeV accelerator tunnel [1].

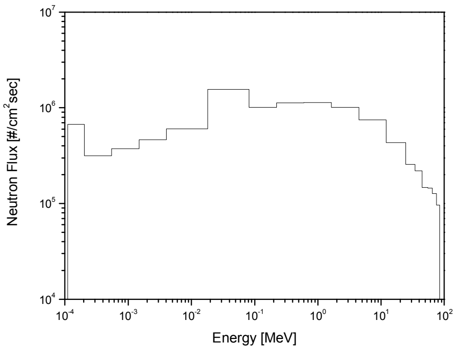


Figure 1. The neutron spectrum in the 100 MeV accelerator tunnel.

The MCNPX modeled the accelerator tunnel building with a 90 cm-thick concrete shielding wall. And the accelerator facility will be constructed above a 5 m soil layer, thus, 5 × 5 × 1 $m^3$ soil layer around the accelerator tunnel building was also modeled. The calculation is performed over a region of 5 m in depth from the accelerator tunnel that covers overall soil layer. The relative density of the soil was determined as 1.5 $g/cm^3$, and the chemical composition and mass fractions of a general soil were applied to this calculation.

### *2.2 Estimation of the Production Rates of Radionuclides in the Soil*

The neutrons from accelerator tunnel induce over one hundred kinds of radionuclide in the soil. This study calculated the production rates of important radionuclides from the radiation safety aspect (10 h < $T_{1/2}$ < 100 y). Figure 2 shows the production rates of the radionuclides when the accelerator was operated for 1 day. As shown in the result, $^{55}Fe$ has the highest production rate ( = 28.6 Bq/1d). Generally, $^{3}H$, $^{7}Be$, and $^{22}Na$ are interesting radionuclides in high energy accelerator facilities. However, $^{3}H$ is not produced in the soil around our accelerator facility since the energies of protons are not sufficiently high enough to induce spallation reactions for producing $^{3}H$.

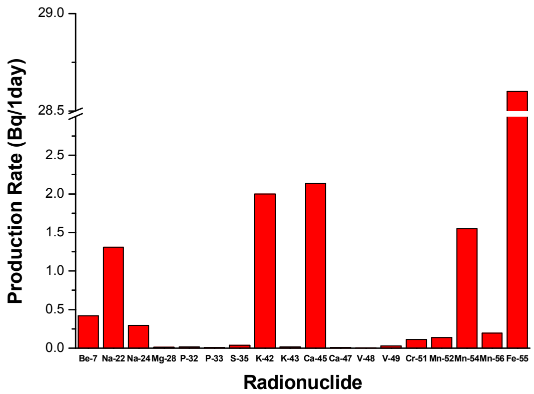


Figure 2. The production rates of radionuclide in the soil.

### *2.3 Estimation of the Soil Activation by induced Radionuclides*

The soil activation was estimated over a 25 $m^3$ region for the radionuclides which have relatively long half-lives and high production rates. It is assumed that the accelerator is operated for 6000 hours and stopped for 2760 hours per 1 year [2]. The decommissioning of the accelerator facility will be executed about 30 years after a shut-down. Therefore, this study estimated the soil activation for a period of 30 years after a shut-down. The saturation was reached when the accelerator was operated for 10 years. Table 1 shows that $^{37}Ar$, $^{45}Ca$, $^{54}Mn$, and $^{55}Fe$ remarkably contribute to the total activity while the accelerator is under an operation. $^{55}Fe$ and $^{22}Na$ dominate in the total activity until 30 years after a shut-down. However, $^{37}Ar$, $^{45}Ca$, and $^{54}Mn$ can not contribute to the total activity due to their short half-lives. At 30 years after a shut-down, the total activity was reduced to 0.1 % in a comparison with the point of saturation.

| Radionuclide | Activity (Bq) | | | |
|---|---|---|---|---|
| | Saturation | 1-yr after shut-down | 10-yr after shut-down | 30-yr after shut-down |
| $^{7}Be$ (12.3 y) | 1.05E-06 | 8.52E-09 | - | - |
| $^{22}Na$ (2.6 y) | 9.27E-06 | 7.10E-06 | 6.46E-07 | 3.14E-09 |
| $^{37}Ar$ (35.0 d) | 1.09E-05 | 8.0E-09 | - | - |
| $^{45}Ca$ (162.6 d) | 1.25E-05 | 2.64E-06 | 2.12E-12 | - |
| $^{51}Cr$ (27.7 d) | 7.40E-08 | 8.19E-12 | - | - |
| $^{52}Mn$ (5.6 d) | 1.03E-12 | - | - | - |
| $^{54}Mn$ (312.3 d) | 1.06E-05 | 4.70E-06 | 3.21E-09 | 2.94E-16 |
| $^{55}Fe$ (2.7 y) | 2.00E-04 | 1.56E-04 | 1.58E-05 | 9.83E-08 |
| **Total Activity** | **2.44E-04** | **1.7E-04** | **1.64E-05** | **1.01E-07** |

Table 1. The activity of various radionuclides in the 25 $m^3$ region of the soil around accelerator tunnel.

### *2.4 Estimation of the Migration of Radionuclides in the Soil*

Most induced radionuclides will undergo β-decay reactions, so that they are important in an internal exposure estimation. Therefore, the migration of radionuclides into a groundwater is evaluated in many accelerator facilities. This study estimated the velocities of radionuclides through the soil using the following equation [3].

$$\frac{v_i}{v_w} = \frac{1}{1 + K(\rho / P)} \quad \text{(Eq. 1)}$$

Where,
$v_i$: velocity of i-th ion in soil
$v_w$: velocity of the water in soil
K: distributin coefficient
ρ: bulk density of the soil
P: porosity of the soil

As shown in previous studies, only $^{22}Na$ significantly contributes to the activation of the groundwater and needs to be considered [4-5]. In the result, $^{22}Na$ will move at a 60 % velocity of that of the water in the soil. However, it is not possible that the groundwater to be used as a public water-supply around our accelerator facility. Therefore, an additional estimation about a radioactivity concentration in the groundwater will not be necessary.

## 3. Conclusion

This study estimates the production rates and migration of radionuclides in the soil around the 100 MeV accelerator tunnel using MCNPX. The results show that the escaped neutrons produced various radionuclides in the soil around the facility. These radionuclides induced the soil activation of about 2.44 $\times$ $10^{-4}$ Bq at the point of the saturation. At 30 years after a shut-down, only $^{55}Fe$ and $^{22}Na$ contribute to the soil activation. And the total activity at this time was reduced to 0.1 % in the comparison with the point of saturation. Therefore, the soil activation will not be a problem after a shut-down. These results will be fundamental information for an estimation of environmental radioactivity in the 100 MeV accelerator facility.

## REFERENCES

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