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Calculation of induced Air Activation in Proton Accelerator

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1. Introduction

Korea Multi-purpose Accelerator Complex (KOMAC) is branched off from Korea Atomic Energy Research Institute (KAERI). The 100 MeV linear proton accelerator as well as the various types of the ion accelerator have been operated and developed in KOMAC. It is well known that the operation of the proton accelerator which is above several tens of MeV energy could produce a secondary radiation as well as activate the surrounding matters. The secondary radiation such as neutron and gamma, produced by the interaction with primary proton beam in the target room, must be shielded in order to protect the worker and public. Another important thing is the induced radioactivity produced in air and the accelerator components. In this paper, FLUKA code [1] was used to compare the degree of air activation according to the distance between beam window and target when protons accelerated in a proton accelerator pass through the air.

2. Calculation of induced radioactivity

The use of an external beam in the proton accelerator generates an additional radio-isotopes since it passes through the air layer until a proton is incident on the target. FLUKA code in the case of 50 cm and 100 air layer was used to calculate a radioactivity, and the case for 0 cm was performed using the analytical method based on semi-empirical formulation described in National Council on Radiation Protection (NCRP)144 report [2].

There are the number of analytical methodologies addressed in the literature[3-4] to estimate the activation of the air inside the proton accelerator vault and the environmental impact. The present study is focused on the estimation of induced radioactivity of air in 20 MeV proton accelerator vault. The short-lived radioactive isotopes produced in air, namely, Ar-41, O-15, N-13 and C-11 were studied in detail but, the production of induced radioactivity of H-3 in air was evaluated as negligible for 20 MeV proton energy.

2.1 Calculation Model for FLUKA

A Monte Carlo code, Fluka(version 2011.2C.6) is used for the simulations to estimate the radiation transport problems. Fluka has a capable of making predictions about time evolution of the radionuclide inventory calculations online. The isotope production and decay as a function of irradiation time and cooling time are calculated using the Bateman equations.

To estimate the neutron yield and energy distribution originated by the 20 MeV protons bombarded in the target material (SiO_2), a pencil proton beam incident on the thick target of a cylindrical shape is modeled as shown in Figure 1.

The induced air activity is estimated, by simulating a pencil beam of protons incidence on a thick target in a target room vault of dimensions 4 m × 4 m × 3 m (48 m^3) filled with dry air. The end position of the beam window is 50 cm and 100 cm from the target in each calculation case. The target position is assumed at the center of the room. The induced air activity is simulated using RESNUCLEI card for 10 min of proton irradiation time.

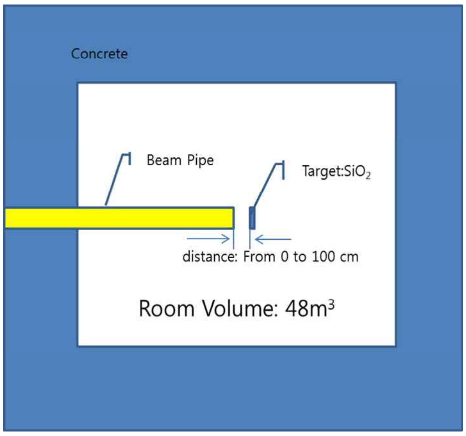

Fig. 1 Calcuation Model for FLUKA

2.2 Analytical calculations

In the case of about 0 cm air layer, such like the target is in vacuum, the activity concentration in the non-ventilated vault is calculated using the method suggested in NCRP 144 report. The activity concentration of Ar-41 in the non-ventilated vault, A_s in Bq/cm^3 is calculated using the following formula:

$$A_s = \phi_{th} \frac{N_A}{A} f_w \rho \sigma \qquad (1)$$

Where N_A is the Avogadro number, A is the atomic weight of element, f_w is the weight fraction composition of argon in air, ρ is the air density and σ is the thermal neutron capture cross-section of 40Ar, which is about 610 mbarns. The thermal neutron fluence, ϕ_{th}, can be calculated by the following formula:

$$\phi_{th} = \frac{1.25Q_F}{S} \quad (2)$$

Where Q_F is the total yield of neutrons, S is the surface area of the enclosure in cm^2. Here, the neutron yield, Q_F for analytical calculations is obtained by the Fluka simulation.

The production activity per unit neutron path length of O-15, N-13, C-11, Be-7 and H-3, A (Bq/m) in the air is calculated by the following formula:

$$A = 100\phi_{HE} \frac{N_A}{A_i} f_w^i \rho \sigma_i \quad (3)$$

Where ϕ_{HE} is the high energy neutron yield above the reaction threshold, N_A is the Avogadro's number, A_i is the mass number of the target atom, f_w^i is the weight fraction of the target nuclide i in air, ρ is the density of air and σ_i is the cross-section of the target nuclide i.

Considering the cross-section is shown table I. The value (2.2E+8 n/sec) of ϕ_{HE} used for this calculation is the high energy neutron yield above the reaction threshold obtained from Monte Carlo simulations. The saturation activity, A_s (Bq/cm^3) is following :

$$A_s = \frac{AL}{V} \quad (4)$$

where L is the path length (m) and V is the volume of the enclosure (cm^3). L is calculated as the radius of the enclosure assuming the 48 m^3 volume of the enclosure as a sphere.

Table I. Parameter for empirical calculation

Radio-nuclide	Target Atom	f_w^i	Cross Section (mbarn)
H-3	Carbon	1.20E-04	10
	Nitrogen	7.55E-01	30
	Oxygen	2.30E-01	30
Be-7	Carbon	1.20E-04	10
	Nitrogen	7.55E-01	10
	Oxygen	2.30E-01	5
C-11	Carbon	1.20E-04	30
	Nitrogen	7.55E-01	10
	Oxygen	2.30E-01	5
N-13	Nitrogen	7.55E-01	10
	Oxygen	2.30E-01	9
O-15	Oxygen	2.30E-01	40
Ar-41	Argon	1.28E-02	610

2.3 Calculation Results

The Ar-41, which is produced by thermal neutrons interaction with Ar-40, is produced almost constantly independent of the distances between the beam window and the target, while other radionuclides are generated proportional according to the distances of protons flight range in the air. Compared with the case where the proton incidences into the target in a vacuum, the proton external beam is more generated radio-activity concentration by 1E6 ~ 7 except the case of Ar-41.

Table II. Induced activity according to the distance from the surface of Beam window to one of the target

radionuclide /half life		Distance from the Beam Window to the Target				
		100 cm		50 cm		0 cm
		(1) [Bq/cc]	Rel.err. (%)	(2) [Bq/cc]	Rel. err. (%)	(3) [Bq/cc]
Ar-41	1.827h	6.2E-04	16.13	5.7E-04	12.36	5.5E-04
O-15	122.2sec	2.9E+00	0.80	2.0E+00	0.79	1.7E-06
N-13	9.97m	5.2E+01	0.14	2.7E+01	0.21	1.0E-06
C-11	20.48m	6.4E+01	0.06	2.8E+01	0.09	6.2E-07
H-3	12.3y	1.4E-07	2.27	7.4E-08	4.78	5.61E-12

3. Conclusions and Future work

The use of an external proton beam, which has more than several tens of MeV, produces more radio-nuclides in the air than case of the proton beam bombarded into the target in a vacuum. And the production amount of H-3 is negligible in any cases. The Monte Carlo simulation and the evaluation methodology suggested by NCRP144 will be directly compared but also compared with the experimental measurement results.

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