PROFILE MEASUREMENTS OF BREMSSTRAHLUNG GAMMA-RAYS FROM TUNGSTEN PLATES FOR RADIOACTIVE ISOTOPE PRODUCTION VIA PHOTONUCLEAR REACTION USING A 60 MeV ELECTRON LINAC

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Abstract

Radioactive isotopes have been produced via photonuclear reaction using a 60 MeV high-power electron linac for research fields of nuclear chemistry and radioactive analysis at Research Center for Electron Photon Science (ELPH), Tohoku University. The electron beam with an average current more than 100 μA is transported to an electron-bremsstrahlung gamma-ray converter of 2 mm thickness platinum or tungsten plate at the irradiation station. A target of 10 mm diameter is placed 3 cm behind a converter. It is enclosed with a quartz glass in the water cooling system and is irradiated for photonuclear reaction. Since the correlation between the spatial profile of bremsstrahlung gamma-rays at the target position and accelerator parameters is of our primary interest, nickel thin films are irradiated and the profiles of bremsstrahlung gamma-rays are measured by intensity distribution measurements of ^{57}Ni radioactivity using the phosphorus imaging plate. In the meantime, the beam emittance and Twiss parameters are measured.

60 MeV ELECTRON LINAC

The Great East Japan Earthquake caused serious damage on the accelerator facility in ELPH. A 300 MeV electron linac was hardly recovered, and the previous accelerating component of the high energy part was completely disintegrated. Only low energy part was salvaged refining high voltage pulse unit for Gun and the components of the transport section (Fig. 1). The electron gun employs Ba impregnated tungsten dispenser cathode. Two S-band 25 MW klystrons input the power to eight one meter accelerating structures and two buncher cavities as well. The average current is 120 μA with 60 MeV. After 90 degree beam bending, it is transported straight to the converter at the target irradiation station.

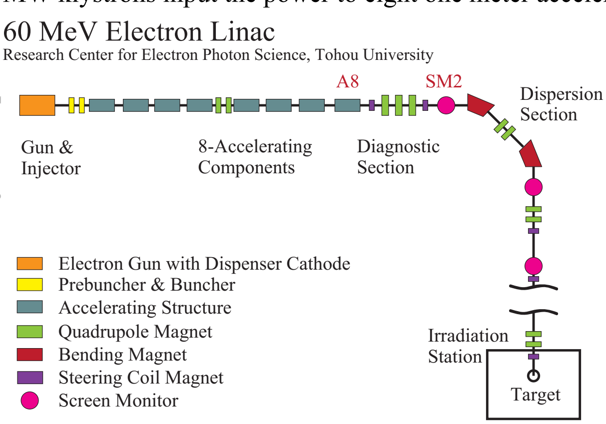

Figure 1: Schematic view of 60-MeV linac.

BEAM CHARACTERISTICS

Emittance and Twiss parameter of the beam from 60 MeV linac are measured by the quadrupole scanning method.

Quadrupole Scanning Method

The configuration of the quadrupole scanning is shown (Fig. 2). Setting initial beam emittance and Twiss parameters at the entrance of the quadrupole as ε_0, β_0, α_0, γ_0, the quadrupole strength k, the transfer matrix in the quadrupole as $Q(k)$, and ones of the free space as S, overall transfer matrix can be express as $T(k) = SQ(k)$. Twiss parameters β, α, and γ at the screen can be written as

$$\begin{pmatrix}\beta\\ \alpha\\ \gamma\end{pmatrix} = \begin{pmatrix} T_{11}^2 & -2T_{11}T_{12} & T_{12}^2 \\ -T_{11}T_{21} & T_{11}T_{22}+T_{12}T_{21} & -T_{12}T_{22} \\ T_{21}^2 & -2T_{21}T_{22} & T_{22}^2 \end{pmatrix}\begin{pmatrix}\beta_0\\ \alpha_0\\ \gamma_0\end{pmatrix}, \quad (1)$$

[1]. RMS beam size σ can be written as

$$\begin{aligned}\sigma &= \sqrt{\varepsilon\beta} \\ &= \sqrt{\varepsilon\beta_0 T_{11(k)}^{\ \ 2} - 2\varepsilon\alpha_0 T_{11(k)}T_{12(k)} + \varepsilon\gamma_0 T_{12(k)}^{\ \ 2}}\end{aligned}, \quad (2)$$

Now, the measured beam size σ_i is the function of k_i, and the beam emittance ε is able to be estimated that χ^2 expressed as

$$\begin{aligned}\chi^2 = \sum_i (\sigma_i \\ - \sqrt{\varepsilon\beta_0 T_{11(k_i)}^{\ \ 2} - 2\varepsilon\alpha_0 T_{11(k_i)}T_{12(k_i)} + \varepsilon\gamma_0 T_{12(k_i)}^{\ \ 2}})\end{aligned}, \quad (3)$$

is minimized.

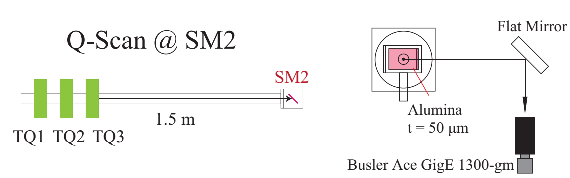

Figure 2: The Quadrupole scanning apparatus.

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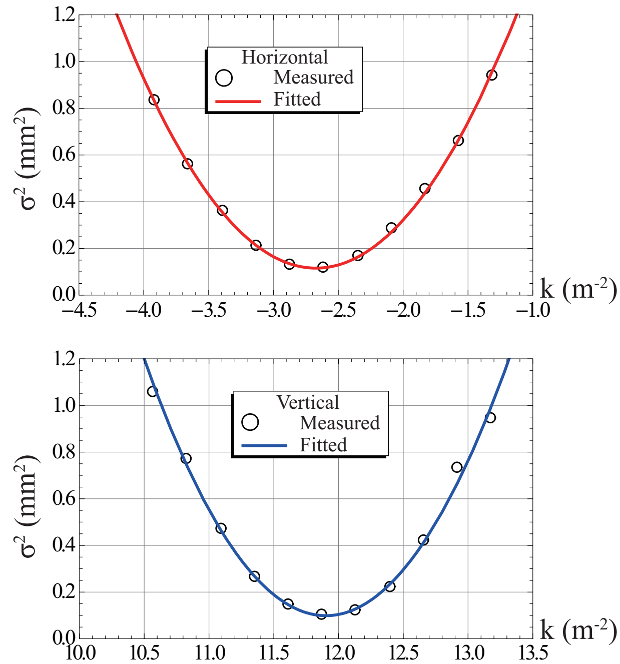

Figure 3: The measured σ and the fitted curve estimated with ε.

Beam Emittance and Twiss Parameters

Quadrupole Scanning of the beam profile has done at SM2 profile monitor 1.5 meter downstream of a quadrupole-triple (Fig. 2). A 50-μm-thick Alumina plate screen was employed. Polarity of those quadrupole is DFD. Quadrupole strengths, *k*–value, were chosen to have beam size is at minima in the concave curve, and Fig. 3 shows measured σ at SM2 as a function of k. Normalized emittances of the 50 MeV electron beam that makes χ^2 minima are estimated as 70.6 and 78.1 (π mm mrad) for horizontal and vertical, respectively.

Inverting a transfer matrix in Eq. (1) from the scanning quadrupole to A8, Twiss parameters at the end of beam acceleration have been estimated with the estimated emittance by the quadrupole scanning (Table 1).

Table 1: Beam Emittance and Twiss Parameters at A8

	Horizontal	Vertical
ε	70.6 ± 1.6 (π mm mrad)	78.1 ± 3.8 (π mm mrad)
β	9.7 ± 0.1	8.5 ± 0.2
α	-2.66 ± 0.03	-2.79 ± 0.07
γ	0.8	1.0

NICKEL FILM IRRADIATION

Three Ni films are placed along the beam axis to profile the bremsstrahlung gamma-ray (Fig. 4). Two tungsten converters with thickness of 1 mm are cooled with blowing air. Films of 10 μm thickness were irradiated for 15 minutes by 50 MeV electron beam with average current of 40 μA.

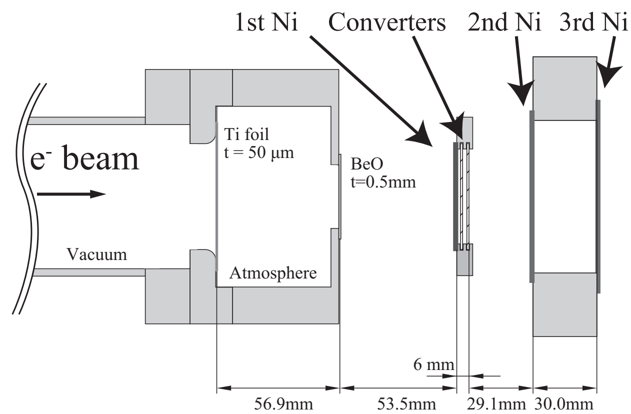

Figure 4: Ni films irradiating configuration.

MEASUREMENTS OF ^{57}Ni ACTIVITY

After the irradiation, the spatial profile of ^{57}Ni radioactivity in films had been taken with phosphor imaging plates, and the radioactivity was measured with Ge (HP) detector. The former are employed to have higher spatial resolution with short measuring time. The latter are for measuring the absolute value of the radioactivity.

Phosphor Imaging Plate (IP)

Phosphor imaging plates of BAS-IP SR 2025 E (IP1) and MS 2040 E (IP2) has been used, and the stored data have been scanned by Typhoon FLA 9500. IP was exposed to the irradiated Ni films packed with plastic wrap for several tens of minutes depending on the intensity of radioactivity.

Ge Detector

Ni film is divided to 1 cm square pieces, and each piece was measured separately with Ge Detector. The γ-ray of 1377 keV from ^{57}Ni was counted. The radioactivity of entire film for each position had been measured as about 20 kBq for1st Ni, and about 350 kBq for 2nd and 3rd Ni.

ANALYSIS OF ^{57}Ni PROFILES

It is regarded that the spatial profile of ^{57}Ni radioactivity in Ni film corresponds to the transverse profile of the electron beam and the bremsstrahlung gamma-ray at the irradiated position. GEANT4 simulation is employed to compare experimental results with analytical results. All components in beam axis are constructed as the experiment. Both profiles of an electron beam and a bremsstrahlung gamma-ray in the simulation is defined as the spatial profile which produces ^{57}Ni. The (γ,n) [2] cross section is included. (*e*,n) cross section is also included as the convolution of virtual photon flux and (γ,n) depending on the energy of electron.

The Profiles at 1st Ni

Since it was expected that the profile at 1st Ni is too small to obtain the distribution by a Ge detector, only IP1 profile is measured (Fig. 5). Although it has some tail in the distribution, fitting with a normal distribution is applied to estimate the initial electron beam size. The size at

ISBN 978-3-95450-147-2

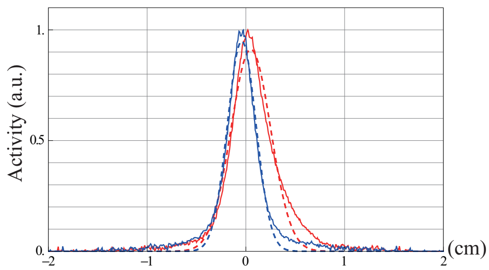

Figure 5: The profile by IP1 for 1st Ni. The horizontal measured profile (Red line), the vertical measured profile (Blue line), and the fitted profiles with normal distribution (Dashed line).

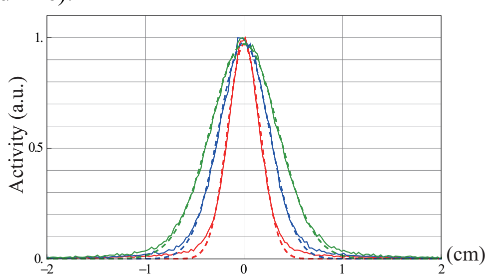

Figure 6: The profile by GEANT4 simulation at 1st Ni. The initial electron beam size σ = 1 mm (Red line), 2 mm (Blue line), and 3 mm (Green line). The fitted profiles with the normal distribution (Dashed line).

1st Ni is σ = 2.0 and 1.5 mm for horizontal and vertical, respectively. The irradiation is simulated with the initial beam size with σ = 1, 2, and 3 mm (Fig. 6). The sizes of those profile are σ = 1.7, 2.6, and 3.4 mm as a normal distribution, respectively. Interpolating the size of these simulation, the initial beam size for GEANT simulation is estimated as σ = 1.4 and 0.8 mm respectively from the measured size at 1st Ni.

The Profiles at 3rd Ni

Figure 7 shows projected profile of 1 cm region taken by Ge detector, IP2, and the simulation. All profiles are peak normalized. The profiles by Ge detector and simulation are fitted by the normal distribution although there exits some tail. The size is σ = 6.6 and 6.7 mm for the former, and is σ = 7.0 and 6.9 mm for the latter. The inverted proportion in the transverse spatial size is noticed between them. The simulation has done with the parallel electron beam with no emittance, and the electron beam for this irradiation has 70.6 and 78.1 (π mm mrad) respectively with finite Twiss parameters prior to the converters.

The profile by IP2 has long tail in distribution entirely, and it is clear that it does not fit to the normal distribution. It is assumed IP is counting other incomings under specific condition since the measurement for 1st Ni does not show this feature.

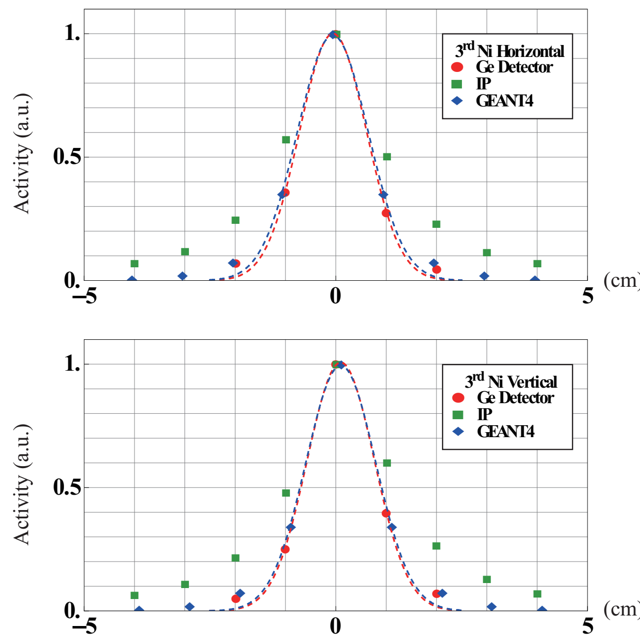

Figure 7: The profile by Ge detector, IP, and GEANT4 simulation at 3rd Ni. Profile is fitted with the normal distribution (Dashed line).

CONCLUSION

The emittance of electron beam from 60 MeV linac has been measured to be 70.8, 78.1 (π mm mrad). Twiss parameters at the end of the accelerating structure were 9.7 and 8.3 m for β, -2.7 and -2.8 for α. Since the correlation between the spatial profile of bremsstrahlung gamma-rays at the target position and accelerator parameters is of our primary interest, the beam optics to a converter is going to be investigated to estimate Twiss parameters.

The spatial profile of bremsstrahlung gamma-ray has been measured by the radioactivity measurements of nickel films irradiated at the beam axis. The spatial distribution of ^{57}Ni radioactivity at the six cm downstream of converters is estimated as σ = 6.6 and 6.7 mm respectively by Ge detector measurement. The GEANT4 simulation shows good agreements in the size of a bremsstrahlung gamma-ray at 3rd Ni. However a discrepancy is found that the proportion of the transverse spatial size is inverted. The simulation may also require the beam emittance and Twiss parameter at the converter to reproduce the experimental results. The profile by IP2 obviously differs to others for 3rd Ni. IP may count other incomings different from the designated area of a source under a certain condition. The profile of a point like radioactive source will be measured to analyse IP response.

REFERENCES

[1] D.C. Carey, "The Optics of Charged Particle Beams", 1992, pp. 114-122.

[2] `http://www.nndc.bnl.gov/exfor/servlet/X4sGetReacTabl?regx=2421&subID=210034003&pointer=`