Dose Estimation from Activated Radionuclides at the e^-/e^+ Converter of Linear Accelerator Using QAD Code

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Abstract

The project of synchrotron radiation facility in the University of Tokyo is promoted. The positron storage operation mode is planned and the e^-/e^+ converter is designed in the linear accelerator. The constants of dose equivalent rate per 1cm, Γ, for W and Cu were calculated for the convenient use in the field of radiation protection for accelerators. The calculation was done by using the newest database of ICRP Publ. 74. The amount of activated radionuclides was estimated by using a saturation activity given by W. Swanson. The total amount of induced activity after 20 hrs irradiation was estimated as 1.64 GBq. 1 day after stopping the irradiation, the activity will decrease 4.8 % of the initial activity. The self shielding effect of converter was estimated by using QAD code. The factors of self shielding effect were about 80 for low energy of radionuclides and about 2 for high energy of radionuclides.

1 Introduction

The VSX (VUV and soft X-ray) project, the third-generation synchrotron radiation facility in Kashiwa new campus of the University of Tokyo, is promoted. Our group is taking charge of the investigation for radiation safety of this project [1,2]. The positron storage operation mode is planned for the Light Source Ring and the e^-/e^+ converter is designed in the linear accelerator. Tungsten (W) is thought as for the material of e^-/e^+ converter. Copper (Cu), which has good heat conductivity, is used to cool the converter. W and Cu are activated by the loss of high energy of electron.

In this paper, the following points were investigated as for the activation of the converter:
1) Calculation of constant of dose equivalent rate per 1cm,
2) Estimation of amount of activated radionuclide, and
3) Estimation of self shielding effect of converter.

2 Method for Estimation of Activation

2.1 Accelerator Operation Mode and e^-/e^+ Converter

The synchrotron radiation facility mainly consists of 1) 1GeV linear accelerator (LINAC) as an injector and 2) 1GeV synchrotron as a light source ring. The LINAC operation mode is shown in Table 1. PS mode is used for positron storage. The e^-/e^+ converter is set up around the center of LINAC. The conversion efficiency is estimated from 2×10^{-3} to 3×10^{-3}. The shape of converter is a cylinder of 1cm in the diameter and 1cm in length. The alloy of the tungsten 90% and the copper 10% improves the heat cooling efficiency. The ratio of copper gradually grows, and the extension part of the converter is connected with the cooling device.

Table 1 LINAC operation mode

mode	ope-time [hrs/y]	energy [MeV]	pulse-width [nsec]	current [mA]
ES	245	1,000	1	400
ESL	220	1,000	30	400
EL	4560	400	-	3.75E-2
PS	20	250	1	P;10

ES; electron short pulse mode
ESL; electron semi-long pulse mode
EL; electron long pulse mode
PS; positron short pulse mode

2.2 Calculation of constant of dose equivalent rate per 1cm

The effective dose equivalent, H_E, the weighted sum of the dose equivalents in some organs, was recommended by ICRP (International Commission on Radiological Protection) [3]. H_E is essentially unmeasurable and, as a result, it must be estimated on the basis of dose equivalents determined at appropriate locations in suitable receptors. The deep dose-equivalent index, H_I was used as the alternative of the effective dose equivalent for external exposure corresponding to ICRP Publication 51 [4]. The ambient dose equivalent, H*(10) is the alternative corresponding to ICRP Publication 74 [5]. The deep dose-equivalent index and the ambient dose equivalent at a point in a radiation field express the dose equivalent that would be produced by the corresponding aligned and expanded field in the ICRU sphere at a depth of 1cm on the radius opposing the direction of the aligned field [6]. The dose equivalent rate per 1cm is defined in the Japanese law (The Law Concerning Prevention from Radiation Hazards due to Radioisotopes, etc.) for expressing the deep dose-equivalent index.

The constant of dose equivalent rate per 1cm, Γ (μSv·m^2·MBq^{-1}·hr^{-1}), is shown as following equation:

$$\Gamma = Q/(4\pi d^2)\cdot \Sigma f_i \cdot p_i = 0.000286 \cdot \Sigma f_i \cdot p_i$$

where
Q: source intensity (Bq)
d: distance from source to estimation point (m)
f_i: conversion coefficient for deep dose-equivalent index and ambient dose equivalent from photon fluence (pSv·m^2)
p_i: emission rate per disintegration (%)

It is usual in the calculation of the constant of dose equivalent rate per 1cm to omit the photon, which energy is less than 30 keV and which emission rate is less than 0.01 %. Here we calculated for three energy groups, 1) less than 10 keV, 2) from 10 keV to 30 keV, and 3) more than 30 keV. For major radioisotopes, the list of the constant of dose equivalent rate per 1cm has already prepared. But, for the short-life radioisotopes, which are induced by the activation, the constants are not usually listed. Therefore, we calculated and tabulated the constant of dose equivalent rate per 1cm for the radionuclides, which were induced by the irradiation of W and Cu, for the convenient use in the field of radiation protection for accelerators.

2.3 Estimation of amount of activated radionuclide

The bremsstrahlung produced by the loss of high energy of electron induced the activated radioisotopes. The amount of activated radioisotopes could be estimated by using the saturation activity given in IAEA report No.188 [7].

$$Ss = As \cdot P \cdot \{1-\exp(-\lambda T)\} \cdot \exp(-\lambda T)$$

where

Ss: induced activity ($GBq \cdot hr^{-1}$)
As: saturation activity ($GBq \cdot kW^{-1}$)
P: electron beam power (kW)
λ : decay constant (hr^{-1})
T: irradiation time (hr)

2.4 Estimation of self shielding effect of converter

The dose equivalent rate can be known easily from the information on Γ and induced activity. It brings the overestimation of dose rate because of neglecting the self shielding effect of converter. QAD code [8, 9] was used to estimate the self shielding effect of converter.

QAD code, which was developed at the Los Alamos National Laboratory, is a point kernel code system for neutron and γ -ray shielding calculations. The combinatorial geometry input and GP buildup factor can be used at the version of QAD-CGGP.

3 Results and Discussions

3.1 Constant of dose equivalent rate per 1cm

The constants of dose equivalent rate per 1cm were shown in Table 2 and Table 3. Table 2 is the constants when W is irradiated and Table 3 is for Cu. Γs in the Isotope handbook [10] were listed as a reference. The difference due to the database, namely ICRP Publ. 51 and 74, was not so big. The values of Γ by Publ. 74 were slightly bigger than that by Publ.54. In the calculation by which energy was divided, the Γs of the group including a large range of energy were large as a matter of course but the deference was also small. Ni-63, which was induced by the irradiation of electron beam, was excluded from Table 3 because it is a beta emission nuclide.

3.2 Amount of activated radionuclide

Table 4 shows the induced activity after 20 hrs irradiation and its decay. The total amount of induced activity of 90% W and 10% Cu after 20 hrs irradiation was estimated as 1.64 GBq. 1 day after stopping the irradiation, the activity will decrease 4.8 % of the initial activity.

3.3 Self shielding effect of converter

Table 5 shows the self shielding effect of converter. The values express the dose ratio at 1m from the point source to that from converter taking account of self shielding effects.

Table 2 the constant of dose equivalent rate per 1cm (when W is irradiated)

radionuclide	half-life (hr)	ICRP Publ.74 all energy all photon	ICRP Publ.74 > 10keV > 0.01%	ICRP Publ.74 > 30 keV > 0.01%	ICRP Publ.51 > 30 keV > 0.01 %	Isotope handbook, ver.9
Ta-180m	8.15E+00	1.22E-02	1.19E-02	1.18E-02	1.15E-02	-
Ta-182	2.76E+03	1.90E-01	1.89E-01	1.89E-01	1.87E-01	1.88E-01
Ta-182m	2.64E-01	6.28E-02	6.19E-02	4.92E-02	4.87E-02	-
Ta-183	1.22E+02	5.55E-02	5.48E-02	5.44E-02	5.39E-02	-
Ta-184	8.70E+00	2.55E-01	2.54E-01	2.54E-01	2.51E-01	-
Ta-185	8.17E-01	2.68E-02	2.63E-02	2.61E-02	2.58E-02	-
W-181	2.91E+03	1.04E-02	1.01E-02	9.95E-03	9.76E-03	9.36E-03
W-183	1.43E-03	2.92E-02	2.82E-02	2.76E-02	2.71E02	-
W-185	1.80E+03	1.03E-05	1.02E-05	1.00E-05	9.97E-06	-
W-185m	6.96E-02	4.77E-03	4.71E-03	4.64E-03	4.60E-03	-
W-187	2.37E+01	7.42E-02	7.40E-02	7.36E-02	7.25E-02	7.33E-02

Table 3 the constant of dose equivalent rate per 1cm (when Cu is irradiated)

radionuclide	half-life (hr)	ICRP Publ.74 all energy all photon	ICRP Publ.74 > 10keV > 0.01%	ICRP Publ.74 > 30 keV > 0.01%	ICRP Publ.51 > 30 keV > 0.01 %	Isotope hand book, ver.9
Co-58	1.97E-02	1.54E-01	1.53E-01	1.53E-01	1.50E-01	1.51E-01
Co-58m	9.15E+00	2.72E-02	2.67E-02	0.00E+00	0.00E+00	-
Co-60	4.62E+04	3.46E-01	3.46E-01	3.46E-01	3.44E-01	3.47E-01
Cu-61	2.99E+04	1.36E-01	1.36E-01	1.36E-01	1.34E-01	1.34E-01
Cu-62	1.62E-01	1.68E-01	1.68E-01	1.68E-01	1.66E-01	1.66E-01
Cu-64	1.27E+01	3.09E-2	3.06E-02	3.06E-02	3.02E-02	3.02E-02
Cu-66	8.48E-02	1.15E-02	1.15E-02	1.15E-02	1.13E-02	1.14E-02

* Ni-63 is excluded because of beta emission nuclide.

Table 4 the induced activity after 20 hrs irradiation and its decay (GBq)

radionuclides	initial activity	after 1 hr	after 1 day	after 1 week	after 1 month
Ta-180m	3.68E-03	3.38E-03	4.78E-04	2.30E-09	-
Ta-182	1.63E-04	1.63E-04	1.62E-04	1.56E-04	1.35E-04
Ta-182m	3.25E-02	2.35E-03	-	-	-
Ta-183	6.18E-03	6.14E-03	5.39E-03	2.38E-03	9.02E-05
Ta-184	3.59E-03	3.31E-03	5.30E-04	5.53E-09	-
Ta-185	5.25E-02	2.25E-02	-	-	-
W-181	3.92E-03	3.92E-03	3.90E-03	3.77E-03	3.28E-03
W-183	8.00E-01	-	-	-	-
W-185	5.75E-03	5.75E-03	5.70E-03	5.39E-03	4.32E-03
W-185m	7.50E-01	3.55E-05	-	-	-
total for W	1.66E+00	4.75E-02	1.62E-02	1.17E-02	7.83E-03
Co-58	6.00E-02	-	-	-	-
Co-58m	4.68E-02	4.33E-02	7.60E-03	1.39E-07	-
Co-60	1.80E-05	1.80E-05	1.80E-05	1.80E-05	1.78E-05
Cu-61	3.71E-05	3.71E-05	3.71E-05	3.69E-05	3.64E-05
Cu-62	1.03E+00	1.42E-02	-	-	-
Cu-64	3.16E-01	2.99E-01	8.52E-02	3.29E-05	-
total for Cu	1.44E+00	3.56E-01	9.28E-02	8.80E-05	5.42E-05
total activity	1.64E+00	7.84E-02	2.38E-02	1.05E-02	7.05E-03
ratio to initial activity	1	0.048	0.015	0.0064	0.0043

Table 5 Self shielding effect of converter

radionuclides	direction	
	radius	axially
Ta-180m	84.8	456.7
Ta-182	1.8	1.9
Ta-182m	17.3	24.7
Ta-183	8.3	11.1
Ta-184	2.4	2.6
Ta-185	8.9	10.9
W-181	78.2	383.8
W-183	68.0	233.3
W-185	55.4	159.9
W-185m	32.5	57.5
W-187	2.3	2.5
Co-58	1.8	2.0
Co-60	1.5	1.6
Cu-61	2.3	2.6
Cu-62	2.3	2.6
Cu-64	2.3	2.6
Cu-66	1.6	1.7

As shown in Table 4 and 5, a considerable amount of W-181 and W-185 remain even 1 month later and those nuclides have large self shielding effect. This means that the dose estimation without taking into account the self shielding effect will lead overestimation.

4 Conclusion

The induced activity at the e-/e+ converter was estimated taking into account the self shielding effect by using QAD code. Through this estimation, the useful data, such as the constant of dose equivalent rate per 1cm, for the radiation protection in the field of accelerator were arranged and compiled.

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