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Study on the Change of Magnetic Field Intensity According to the Activation of Bending Magnet in Medical LINAC

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When the high-energy electromagnetic radiation of the medical linear accelerator is irradiated in high capacity, there is a nuclide transformation due to the radio-activation. Especially for the magnet core of the bending magnet, the magnetic field strength is changed due to the nuclide transformation, and this change in the magnetic field strength is shown as the change in flux of the electromagnetic radiation. Therefore, the effect of radio-activation on the change in flux of the electromagnetic radiation according to the electromagnetic radiation dose is to be evaluated. Subjected to 7 medical linear accelerators planned for disposal, the total dosage, nuclide analysis using the spectrometer of the magnet core, flatness using the water phantom & ion chamber, and the change amount of symmetry were evaluated. As a result, the relationship of change rate in flux according to the dosage is shown in 4 % error per 1,000 Gy. As a result of applying the 1 % threshold limit by the American Association of Physicists in Medicine, TG-142 Report, the tolerated dose is 250Gy. Therefore, on the use of medical linear accelerator in the future, it is recommended to perform the flux evaluation according to the magnet core radio-activation for each 250Gy along with the existing periodical quality control.

Keywords : activation, magnet core, medical LINAC

1. Introduction

The medical linear accelerator is a treatment machine used on cancer patients to irradiate high-energy electromagnetic radiation to cut the DNA chain for killing the cancer cells [1, 2]. For these medical linear accelerators, the energy of the electromagnetic radiation is distributed from a minimum of 4 MV to a maximum of 18 MV [3]. In addition, most of the medical linear accelerators recently installed are for electromagnetic radiation of 10 MV or more, and the distribution ratio is also 10 MV or higher [4-6]. As for the high-energy electromagnetic radiation, when it is 10 MV or higher, photonuclear reaction is occurred by the interaction with the exposed medium, and photo-neutrons and photo-protons are released by the photonuclear reaction [7-9]. And the medium exposed by the photonuclear reaction is radio-activated, and the radio-activated medium releases the radiation independently [10-14]. Radio-activation refers to when high-energy corpuscular ray or electromagnetic radiation is irradiated to the stable nuclide, nuclide transformation is occurred by the nucleon transfer of the nuclide or change in stable state, and the radiation is released independently [15, 16]. The radio-activation has higher possibility of transformation by the irradiation of baryonic ray than the electromagnetic radiation, and the possibility of transformation is increased according to the dosage [17, 18]. However, the medical linear accelerator uses only the electromagnetic radiation and lightly charged particle, so the possibility of radio-activation is relatively low [19]. But, if the dosage is accumulated for long-period of time through the high-energy electromagnetic radiation of the medical linear accelerator, the transformation of radio-activation may be possible, and there may be a difference for each treatment machine, but the radio-activated parts can be verified on disposal according to the deterioration [20]. As the use of medical linear accelerator is progressed for long-period of time, the change in nuclide on various parts located on the irradiated head part is radio-activated as shown in Table 1 by Thatcher's study using

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Table 1. Classification of Neutron Activation from a High Energy LINAC.

Activated Radioisotope	Decay mechanism	Half life	Activation process
^{15}O	β^+, EC	2.04m	$^{16}O(\beta, n)\,^{15}O$
^{22}Na	β^+, EC	2.6y	$^{23}Na(\gamma, n)\,^{22}Na$
^{24}Na	IT, β^-	15h	$^{23}Na(n, \gamma)\,^{24}Na$
^{27}Mg	β^-	9.46m	$^{27}Al(n, p)\,^{27}Mg$
^{28}Al	β^-	2.3m	$^{27}Al(n, \gamma)\,^{28}Al$
^{34m}Cl	β^+, EC, IT	32m	$^{35}Cl(\gamma, n)\,^{34m}Cl$
^{38}Cl	β^-	37.24m	$^{37}Cl(n, \gamma)\,^{38}Cl$
^{51}Cr	EC	27.7d	$^{50}Cr(n, \gamma)\,^{51}Cr$
^{52}Mn	β^+, EC	5.59d	$^{54}Fe(\gamma, np)\,^{52}Mn$
^{54}Mn	β^+, β^-. EC	312.3d	$^{56}Fe(\gamma, np)\,^{54}Mn$
^{56}Mn	β^-	2.58h	$^{55}Mn(n, \gamma)\,^{56}Mn$
^{53}Fe	β^+, EC	8.51m	$^{54}Fe(\gamma, n)\,^{53}Fe$
^{59}Fe	β^-	44.5d	$^{59}Co(n,p)\,^{59}Fe$
^{57}Co	β^+	271.8d	$^{59}Co(\gamma, 2n)\,^{57}Co$ $^{58}Ni(\gamma, p)\,^{57}Co$
^{58}Co	β^+, EC	70.78d	$^{59}Co(\gamma, n)\,^{58}Co$ $^{60}Ni(\gamma, np)\,^{58}Co$
^{60}Co	β^-	5.3y	$^{61}Ni(\gamma, p)\,^{60}Co$ $^{59}Co(n, \gamma)\,^{60}Co$
^{57}Ni	β^+, EC	35.6h	$^{58}Ni(\gamma, n)\,^{57}Ni$
^{62}Cu	β^+, EC	9.74m	$^{63}Cu(\gamma, n)\,^{62}Cu$ $^{64}Zn(\gamma, np)\,^{62}Cu$
^{64}Cu	β^+, β^-. EC	12.7h	$^{65}Cu(\gamma, n)\,^{64}Cu$
^{63}Zn	β^+, EC	38.4m	$^{64}Zn(\gamma, n)\,^{63}Zn$
^{65}Zn	β^+	244.3d	$^{66}Zn(\gamma, n)\,^{65}Zn$
^{82}Br	β^-	35.34h	$^{81}Br(n, \gamma)\,^{82}Br$
^{99}Mo	β^+	66.0h	$^{100}Mo(\gamma, n)\,^{99}Mo$
^{120}Sb	β^+, EC	15.9m	$^{121}Sb(\gamma, n)\,^{120}Sb$
^{122}Sb	β^+, β^-. EC	2.7d	$^{121}Sb(n, \gamma)\,^{122}Sb$
^{124}Sb	β^-	60.3d	$^{123}Sb(n, \gamma)\,^{124}Sb$
^{184}Re	β^+	38.0d	$^{185}Re(\gamma, n)\,^{184}Re$
^{187}W	β^-	23.72h	$^{186}W(n, \gamma)\,^{187}W$
^{196}Au	β^+	6.2d	$^{197}Au(\gamma, n)\,^{196}Au$
^{203}Pb	β^+	51.9h	$^{204}Pb(\gamma, n)\,^{203}Pb$

gamma spectroscopy, and there are also changes occurred on the function. Especially for the magnet core in the bending magnet located on the Gantry head part, the influence must be evaluated [21]. As shown in Figure 1, the bending magnet releases the intended energy range of radiation from the accelerating tube of the medical linear accelerator through the electron flux direction conversion and energy filtering. If there is nuclide transformation on the magnet core due to the radio-activation of the bending magnet to cause the change in the magnetic field, there are changes in the role of directional change & energy filter. Therefore, the functional change of the medical linear accelerator according to the radio-activation must be considered. Hence, in this study, the functional reduction of the medical linear accelerator according to the radio-activation of the magnet core was evaluated to provide the standard in use depending on the use amount.

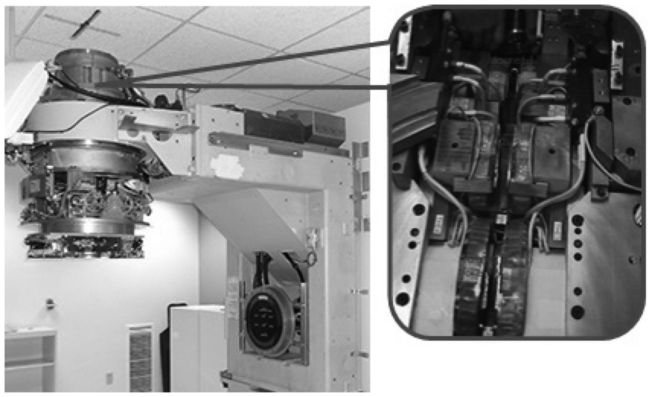


Fig. 1. Bending magnet in LINAC.

2. Materials and Methods

2.1. Equipment and materials

1. Magnet core in medial LINACs :
2. Spectrometer : 400MR-DD2 (Agilent Technologies, USA)
3. Water phantom : Blue Phantom^2 (IBA, Germany)
4. Ionization Chamber : FC23-C (IBA, Germany)
5. Electrometer : DOSE-1 (IBA, Germany)

2.2. Experimental

The beam profile was measured in in-plan and cross-plan within 1 month before disposal subjected to 7 medical linear accelerators disposed in January, 2015~ June, 2017. And, as shown in Fig. 2, the flatness and symmetry of the beam profile for each direction were evaluated 5 times using water phantom and ion chamber each for comparison. In the beam profile measurement, the irradiation condition was as follows: the highest energy among the electromagnetic radiation was selected, the gantry & collimator angle was 0°, the radiation range was 20×20 cm^2, and the source to skin distance was to be 100 cm. The evaluation of flatness was based on the percentage difference between the height of the central axis and the maximum height on both sides. Then the evaluation was applied to the percentage difference of the height of both sides when overlapping based on the central axis. The total dosage of electromagnetic radiation on each medical linear accelerator from initiating the operation to the measurement of the beam profile was acquired for comparison. In addition, the change in the

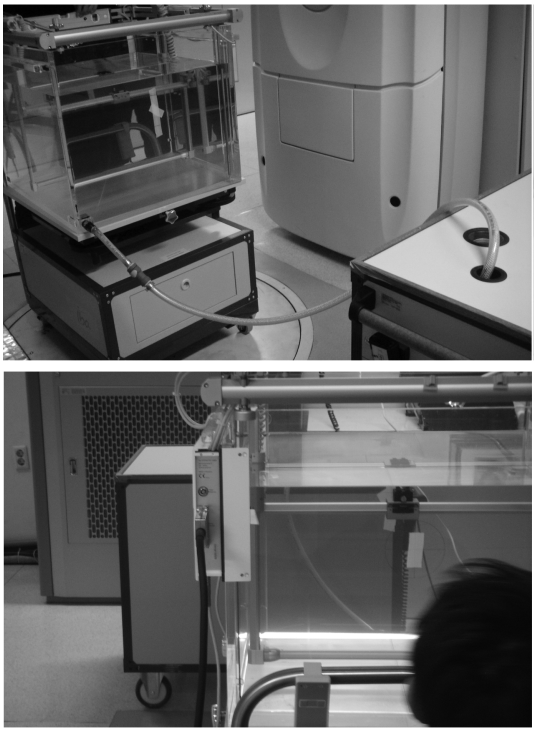


Fig. 2. Measurement of beam profile.

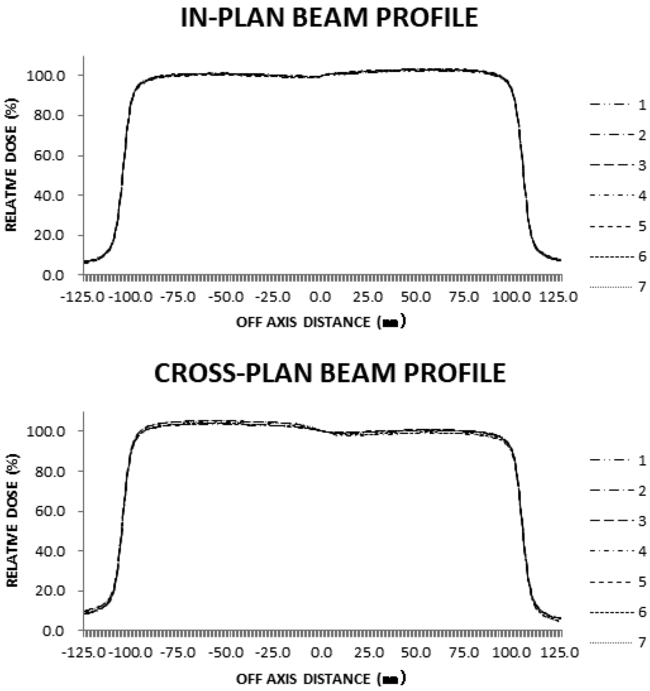


Fig. 3. Result of Beam profile in each LINACs.

current value of the bending magnet was recorded through the Preventive Maintenance Report. Through this, the change value in the magnetic field according to the dosage was corrected with the change value of the bending magnet current value to be assumed as the change value of the beam profile. And, after the disposal, the magnet core nearest to the target of the bending magnet was separated to perform nuclide analysis with the spectrometer. Through this, the change amount in nuclide according to the dosage and the change value in the beam profile were compared. Besides, the beam profile tolerance value recommended by the American Association of Physicists in Medicine (AAPM), TG-142 report of 1 % was applied to provide the tolerance in the dosage.

Table 2. Total exposure dose in each LINACs.

Number of LINAC	Total Beam on Time	Total exposure dose (Gy)
1	6135.2	1704
2	5889.9	1475
3	5378.7	1460
4	5896.9	1625
5	5880.4	1573
6	6194.6	1837
7	6383.7	1574

Table 3. Flatness and symmetry values of each LINACs.

Number of LINAC	Plan direction	Flatness	Symmetry
1	In	0.32%	0.27%
	Cross	0.75%	0.81%
2	In	0.30%	0.29%
	Cross	0.74%	0.81%
3	In	0.32%	0.31%
	Cross	0.88%	0.92%
4	In	0.32%	0.32%
	Cross	0.90%	0.97%
5	In	0.29%	0.29%
	Cross	0.88%	0.93%
6	In	0.31%	0.29%
	Cross	0.91%	0.95%
7	In	0.31%	0.28%
	Cross	0.94%	0.96%

Table 4. Change of current value for bending magnet.

Number of LINAC	Changing current ratio
1	382.28%
2	421.64%
3	413.82%
4	406.61%
5	452.28%
6	462.26%
7	468.97%

3. Result

An evaluation was performed on the change in magnetic field on the bending magnet according to the dosage of the electromagnetic radiation by the medical linear accelerator. As shown in Table 2, the radiation time & dosage of the electromagnetic radiation by each medical linear accelerator were composed of minimum of 1,460

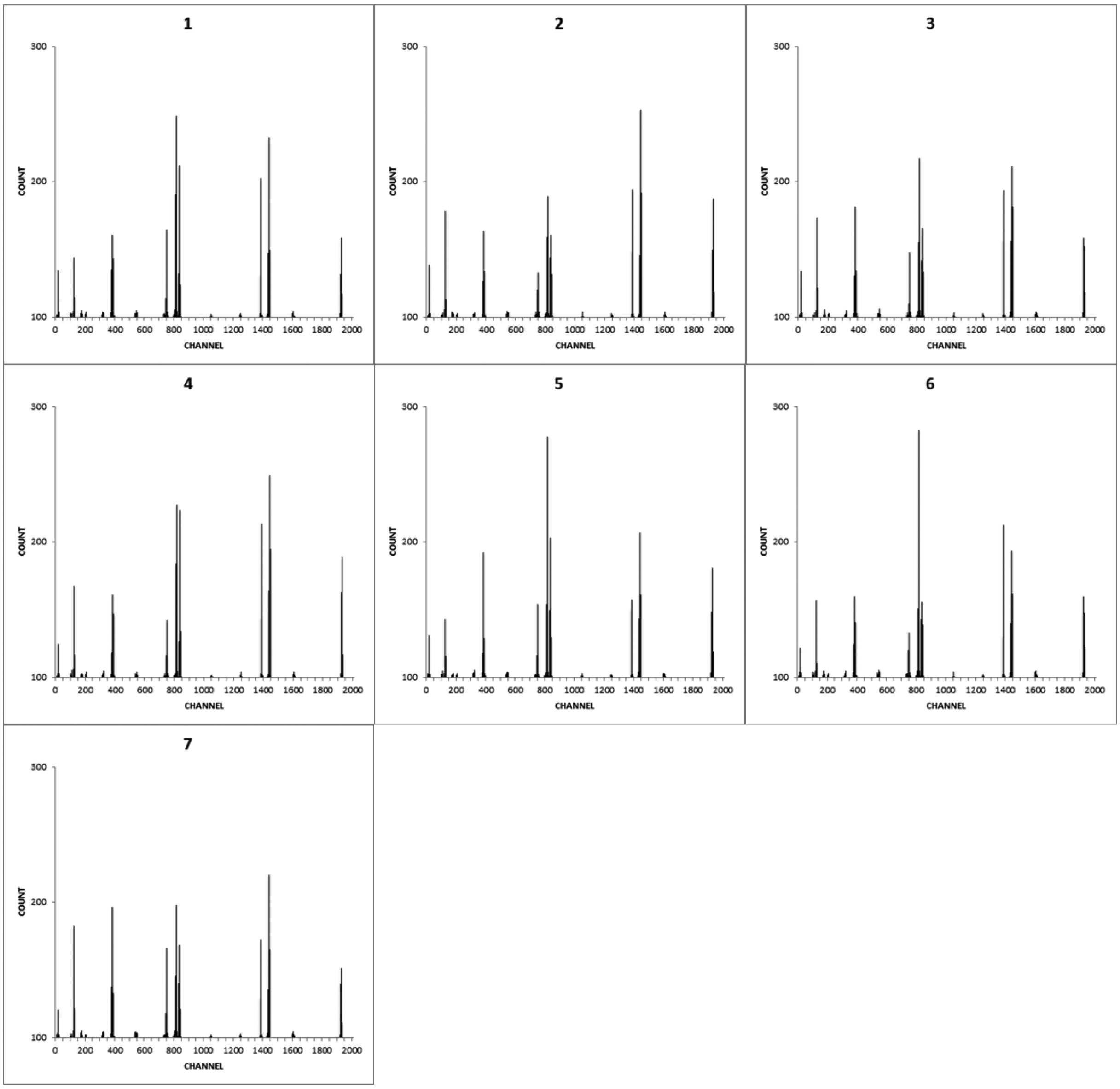


Fig. 4. Result of nuclide analysis in each LINACs.

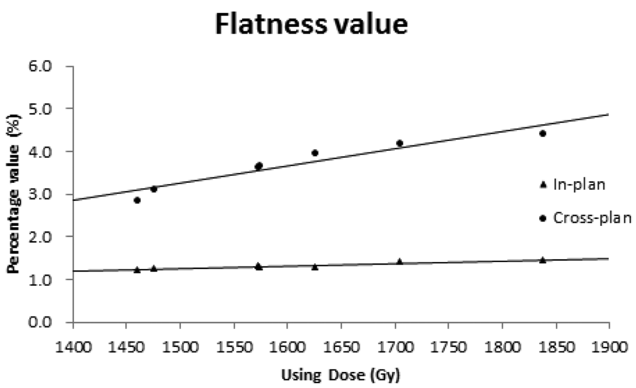
Table 5. Ratio of radioisotope from activation.

Number of LINAC	^{57}Co	^{57}Co	^{53}Fe	^{52}Mn	^{58}Co	^{54}Mn	^{57}Ni	^{52}Mn	^{57}Ni
1	5.32%	5.84%	6.44%	6.72%	9.92%	8.48%	8.16%	5.24%	6.32%
2	4.60%	5.93%	5.40%	4.40%	6.30%	5.33%	6.43%	8.37%	6.27%
3	4.43%	5.73%	6.00%	4.93%	7.23%	5.43%	6.40%	7.00%	5.30%
4	4.17%	5.57%	5.33%	4.73%	7.57%	7.47%	7.10%	8.27%	6.30%
5	4.37%	4.73%	6.40%	5.10%	9.27%	6.73%	5.23%	6.93%	6.03%
6	6.05%	7.85%	7.95%	6.55%	14.15%	7.70%	10.60%	9.60%	7.95%
7	4.14%	6.28%	6.72%	5.76%	6.86%	5.83%	5.90%	7.59%	5.21%

Gy to maximum of 1,837 Gy. In addition, the beam profile results of in-plan and cross-plan for each medical linear accelerator are shown in Fig. 3, and the flatness and symmetry are shown in Table 3 accordingly. Table 4 shows the percentage of change in the bending magnet current value for each accelerator, and the nuclide analysis results of the magnet core nearest to the target are shown in Fig. 4. And, the nuclide transformation rate according to the radio-activation is specified in Table 5. Moreover, the changes in dosage & flux for each accelerator are shown in Table 6, and Fig. 5 shows the correlation graph of the change rate in flux according to the dosage.

Table 6. Value of correctional flatness and symmetry, and total dose in each LINACs.

Number of LINAC	Total dose	In-plan		Cross-plan	
		Flatness	Symmetry	Flatness	Symmetry
1	1704	0.32%	0.27%	0.75%	0.81%
2	1475	0.30%	0.29%	0.74%	0.81%
3	1460	0.32%	0.31%	0.88%	0.92%
4	1625	0.32%	0.32%	0.90%	0.97%
5	1573	0.29%	0.29%	0.88%	0.93%
6	1837	0.31%	0.29%	0.91%	0.95%
7	1574	0.31%	0.28%	0.94%	0.96%



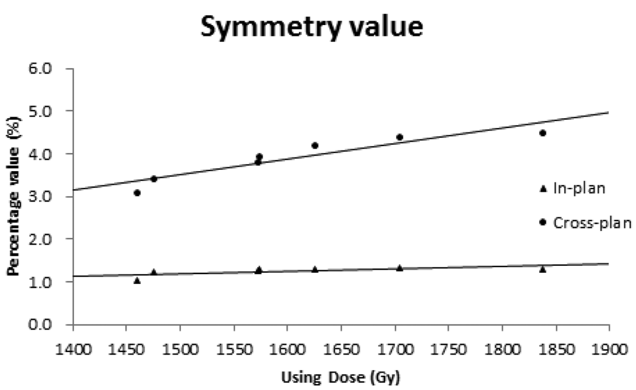


Fig. 5. Correlation graph of dose and rate of changing radiation distribution.

4. Discussion

As the dosage is accumulated in the head part according to the long-term use of the medical linear accelerator, there is a radio-activation occurred on changing the nuclide on various parts. Compared to other parts, the bending magnet is caused with change in the magnetic field strength according to the change in the nuclide, which can result in the flux imbalance of the electromagnetic radiation. Therefore, the nuclide transformation according to the use amount and the flux imbalance are to be measured on the medical linear accelerators before disposal to provide the tolerance on the dosage for the bending magnet. However, in separation of the magnet core for nuclide analysis, there may be vacuum adjustment on reassembly, and few months of operation suspension and high cost from detailed adjustment of the radiation flux, so the study has no choice but to be conducted subjected to medical linear accelerators planned for disposal. Therefore, there is a limitation in the number of subjects. In addition, due to the economic condition of the cost on the nuclide analysis, only the closest to the target among the 3 magnet cores within the bending magnet was used as the subject. There are various advanced studies on the radio-activation by high-energy electromagnetic radiation, but there were no studies subjected to the parts of the medical linear accelerator. Therefore, through this study, it is considered that more studies are required on the analysis of radio-activity subjected to various parts.

5. Conclusion

The change in the magnetic field strength is occurred on the radio-activated magnet core due to the high-energy electromagnetic radiation of the medical linear accelerator. And, as the dosage is increased, the change in the magnetic field strength is also increased to cause the change in flux, and considering the 1% recommended by the American Association of Physicists in Medicine (AAPM), the dosage tolerance is 250 Gy. Therefore, the current value adjustment of the bending magnet must be inspected and readjusted for each 250 Gy. However, there is also a difference in radio-activation according to the energy & temporal integral dose of the electromagnetic radiation along with the adjustment according to the dose of current value on the bending magnet, so it is considered that inspection according to the period is required along with the dose.

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