Evaluation of induced radioactivity over time for medical linear accelerator

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Introduction & Goal

- In recent years, along with demand, the number of replaced and discarded linear accelerator has increased in Korea. As for linear accelerators using a high energy of 8MV or higher, concentration of radionuclides owing to radiation should be considered because of photonuclear reaction radiate the components of the accelerator and materials.
- In Korea, in order to reduce the risk of activation from radioactive materials, disposal/decommissioning must be carried out when clearance level for activity is less than that specified in the regulation.
- However, it is difficult to measure the concentration of radionuclides induced by parts, and it is very difficult to assess the change in radioactive concentration over time.
- In this study, medical linear accelerator equipment was simulated with Monte Carlo codes, and the storage period and disposal/ decommissioning period were confirmed by analyzing the radionuclides and concentrations of each part immediately after the beam was shutdown.

Material & Methods

❖ Monte Carlo simulation

- PHITS code(Ver 3.25) was used for the Monte Carlo simulation[1].
- DCHAIN, which is a decay chain analysis code, was used for the analysis of radioactivity[2].
- The equipment used in this study are Varian Clinac iX, Elekta Agility™, and Siemens Oncor Expression, and major parts such as target, primary collimator, flattening filter, ion chamber, bending magnet, jaw and lead block.
- The beam energy used for simulation were 15MV and 10MV in which photonuclear reactions occur well.
- It assumed that medical linear accelerator was operated for 10 years with an intensity of 80Gy/day and 40Gy/day to check the activity levels, and changes in the concentration of radionuclides and radionuclides for each parts were confirmed after shutdown of the equipment, and it was checked whether it complied with the standard value of 10^3 bq/g for the clearance level for activity.

❖ Flowchart of radiation evaluation System

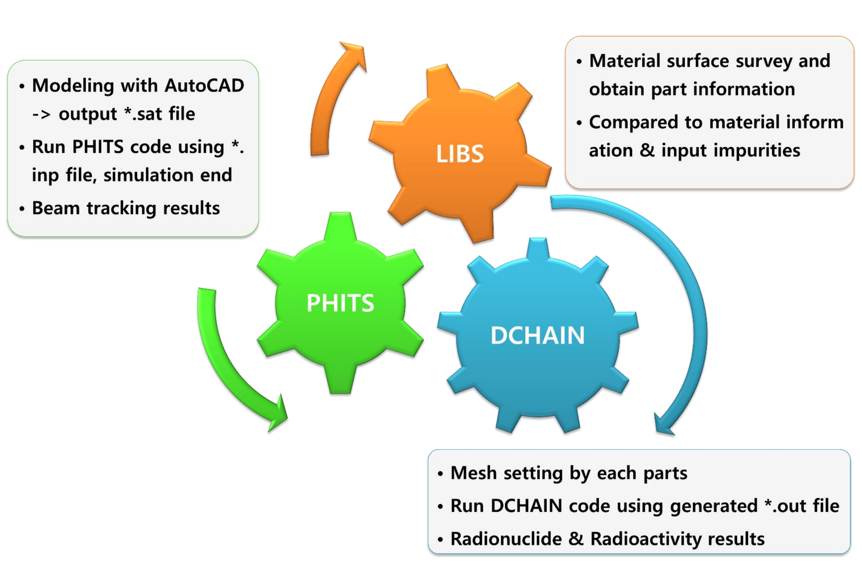

Fig. 1. Flowchart of radiation evaluation System

- Figure 1 shows the flow chart of radiation evaluation System using Monte Carlo code.
- The equipment used for LIBS (laser induced breakdown spectroscopy) was SciAps' Z-300C GEOchemPro (SciAps Inc. Woburn, MA, USA), and impurities were measured in parts of dismantled/disposed lineal accelerator.
- After considering impurities, the element composition ratio of each material was updated.
- DCHAIN code was run through neutron flux obtained as a result of PHITS simulation, and then radionuclides were identified.

Results

❖ Schematics of Medical linear accelerator using PHITS code

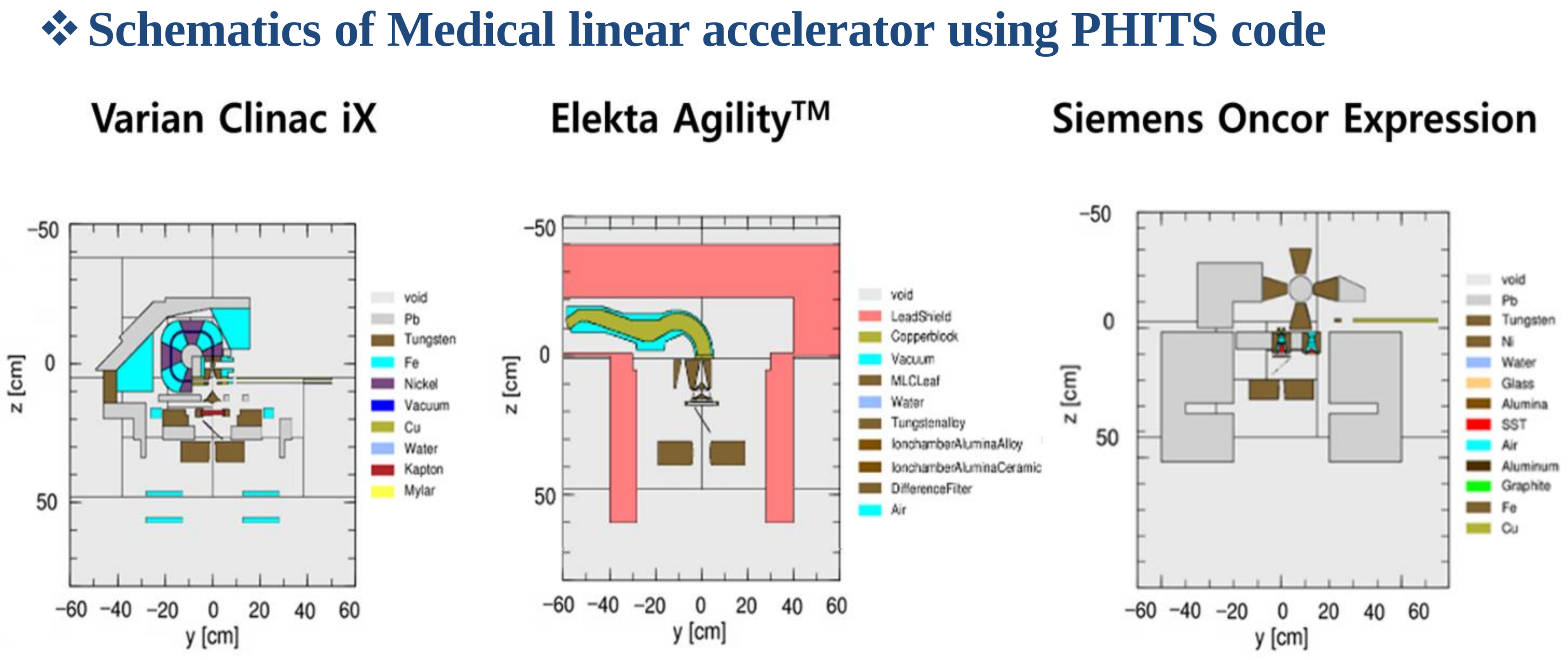

Fig. 2. Medical linear accelerator modeling using Monte Carlo simulation code

- The above pictures were schematics of Linear accelerator. Modeling of Varian Clinac iX (left), Elekta Agility™ (middle), and Siemens Oncor Expression (right) using PHITS code.
- Figure 2 shows the Monte Carlo simulation results of the target, primary collimator, and flattening filter, where major radionuclides could be generated based on drawings reference to dismantled equipment.
- Y-jaw, X-jaw, and MLC were fixed to arrive at a water phantom at the SSD 100 cm, and tracking of 15MV and 10MV photon beams confirmed that no neutrons were generated at 6MV.

Results & Discussion

❖ Radioactivity by parts over time

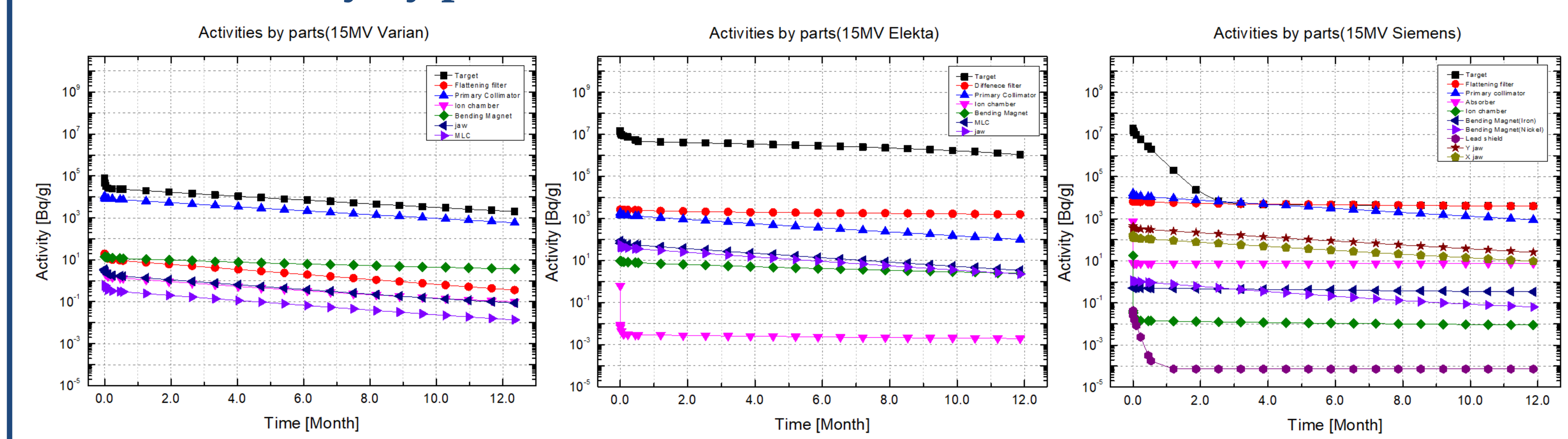

Fig.3. Activities for each component over time for 15MV beam energy. Varian Clinac iX (left), Elekta Agility™ (middle), and Siemens Oncor Expression (right)

- When comparing the workload of 80Gy/s and 40Gy/s, the radioactivity concentration of each parts were about twice as different. The above figure shows the radioactivity concentrations for each parts according to 15MV energies at a workload of 80Gy/s.
- It was confirmed that the concentration of radionuclides in all three components of equipment using 15MV energy, target, primary collimator, and flattening filter remained higher than the permissible concentration of self-disposal after 6 months.
- In particular, it was confirmed that the radioactive concentration of target of the three-equipment using 15MV energy was $1.60*10^3$ to $2.28*10^4$ bq/g even after one year, exceeding the permissible concentration for self-disposal. Typical radionuclides that remain above 1 bq/g after 6 months were identified as ^{51}Cr, ^{54}Mn, ^{55}Fe, ^{57}Co, ^{58}Co, ^{179}Ta, ^{181}W, and ^{185}W.

❖ Clearance level for activity

Table 1. Clearance level for activity of linear accelerator

Radio-nuclide	half-life[s]	Clearance level[Bq/g]	Radio-nuclide	half-life[s]	Clearance level[Bq/g]
^{3}H	$3.89\cdot10^{8}$	100	^{65}Zn	$2.11\cdot10^{7}$	0.1
^{26m}Al	$6.35\cdot10^{0}$	0.1	^{65}Zn	$2.11\cdot10^{7}$	0.1
^{28}Al	$1.35\cdot10^{2}$	0.1	^{93m}Nb	$5.09\cdot10^{8}$	10
^{52}V	$2.25\cdot10^{2}$	0.1	^{99}Mo	$2.37\cdot10^{5}$	10
^{51}Cr	$2.39\cdot10^{6}$	100	^{101}Mo	$8.77\cdot10^{2}$	10
^{54}Mn	$2.67\cdot10^{7}$	0.1	^{99m}Tc	$2.17\cdot10^{4}$	100
^{56}Mn	$9.28\cdot10^{3}$	10	^{110m}Ag	$2.16\cdot10^{7}$	0.1
^{55}Fe	$8.66\cdot10^{7}$	1000	^{125}Sb	$8.71\cdot10^{7}$	0.1
^{57}Co	$2.35\cdot10^{7}$	1	^{179}Ta	$5.74\cdot10^{7}$	0.1
^{58}Co	$6.12\cdot10^{6}$	1	^{181}W	$1.05\cdot10^{7}$	1
^{59}Fe	$3.84\cdot10^{6}$	1	^{181}W	$1.05\cdot10^{7}$	10
^{60}Co	$1.66\cdot10^{8}$	0.1	^{183}W	$3.47\cdot10^{24}$	0.1
^{60m}Co	$6.28\cdot10^{2}$	1000	^{185}W	$6.49\cdot10^{6}$	1000
^{61}Co	$5.94\cdot10^{3}$	100	^{187}W	$8.64\cdot10^{4}$	10
^{57}Ni	$1.28\cdot10^{5}$	0.1	^{196}Au	$5.33\cdot10^{5}$	0.1
^{59}Ni	$2.40\cdot10^{12}$	100	^{196m}Au	8.10	0.1
^{63}Ni	$3.19\cdot10^{9}$	100	^{196n}Au	$3.46\cdot10^{4}$	0.1
^{65}Ni	$9.06\cdot10^{3}$	10	^{198}Au	$2.33\cdot10^{5}$	10
^{62}Cu	$5.80\cdot10^{2}$	0.1	^{203}Pb	$1.87\cdot10^{5}$	10
^{64}Cu	$4.57\cdot10^{4}$	100	^{203}Hg	$4.03\cdot10^{6}$	10
^{65}Zn	$2.11\cdot10^{7}$	0.1	^{209}Pb	$1.87\cdot10^{5}$	0.1
^{66}Cu	$3.07\cdot10^{2}$	0.1			

- According to the notice of regulation for clearance level for activity(Nuclear Safety and Security Commission, No. 2020-6, May 26, 2020) in Korea, radioactive wastes can be disposed when it is less than the allowable concentration of clearance level for activity.
- Table1 shows radionuclides obtained from the simulation with an initial radioactivity concentration of 10^{-5} or more and a half-life of 5 seconds or more.
- In the case of equipment using 15MV energy, radionuclide exceeding the allowable activity after 1 year showed ^{55}Fe, ^{57}Co, ^{54}Mn, ^{181}W, ^{185}W, and ^{179}Ta, whereas in the case of 10MV energy, there was only ^{181}W(Elekta) of radionuclide exceeding the allowed concentration after 6 months.
- Radionuclides maintaining activity of 10^3 Bq/g or more after 6 months were ^{55}Fe in the target(Siemens) and flattening filter(Siemens), and ^{185}W and ^{181}W in the target(Varian, Elekta), and the primary collimator (Varian, Siemens).

Conclusion

- Considering the clearance level for activity specified in the regulation in Korea, the target of the 15MV Varian, Elekta, and Siemens equipment had to be stored for at least 6 months to be disposal, while the same parts of 10MV equipment could be disposed of after 2 months.
- If the activity concentration can be predicted in consideration of the energy and workload used for each medical linear accelerator as described above, it is considered that guidelines for workers to work safely so as not be exposed to radioactive material during decommissioning/ disposal can be presented.

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Reference

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