Safety and Analysis of 18 MV Photons Activated Radioisotopes in Siemens Oncor Impression 3D Linac and It's Decommissioning Experience At Klaipeda University Hospital

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1. Background and Goal of the present work

Medical linear accelerators (linacs) are the most used technique to treat cancers in patient by different energies megavoltage photon beams. High-energy photons (>8 MeV – 10 MeV) generated by a linear accelerator may induce photonuclear reactions and activate linac's parts. The activation products cause issues to arise during decommissioning of the machine as workers or additional dose to staff may be exposed to radiation. In this field radiation protection and physical security plays a very important role in safety of ionizing radiation sources.

The aims of this research was to quantify the amount of neutron activation induced radioactivity, identify the remaining radioisotopes present in the Siemens Oncor Impression 3D linac components, discuss decommissioning case and assessed the adequacy of the quality of security measures.

2. Introduction

The linear accelerator head components such as the target, primary collimators, flattening filter, secondary collimator, and multileaf collimators (MLCs) are made of high atomic number materials. When high energy photons interact with high Z material neutrons are generated thorough photonuclear reactions (γ,n). This neutron will travel a distance and will lose energy through interaction with the surrounding material until it undergoes an (n,γ) interaction which results in the activation of a material outside of the initial photon beam.

Activation of the chemical elements leads to unstable isotopes. Most of the activated radioisotopes are decaying with short half-lives, in the range of hours or days, but some other radioisotopes have half-lives of several years.

Table 1. Activation products found in an 18MV Siemens KDS linac

Linac components	Radionuclide	Half-life (days)	Energy (keV)	Estimated activities and uncertainty ($k = 2$) (kBq)
Target	XR Au		65–77	
	^{196}Au	6.2	333.0	7100 ± 710
	^{196}Au		355.7	
	^{196}Au		426.1	
	^{54}Mn	312	834.8	27 ± 8.1
Window wave-guide	^{57}Co	272	122.0	16 ± 1.9
	^{57}Co		136.5	
	^{51}Cr	28	320	11 ± 1.8
	^{196}Au	6.2	333	18 ± 2.2
	^{196}Au		355.7	
	^{196}Au		426.1	
	^{198}Au	2.69	411	
	^{58}Co	70.86	810.7	3 ± 0.3
	^{54}Mn	312	834.8	3 ± 0.4
	^{60}Co	1925	1174	11 ± 1.1
	^{60}Co		1333	1 ± 0.2
Flattening filter	^{57}Co	272	122.0	45 ± 5.4
	^{57}Co		136.5	
	^{51}Cr	28	320.0	37 ± 17.4
	^{54}Mn	312	834.8	40 ± 5.2
Wedge	Only background peaks were identified			

2.1. Decommissioning

Accelerators decommissioning projects started in technical literature and a few detailed decommissioning reports from 1980s was publicated. In 1999 the European Commission issued the report Evaluation of the Radiological and Economic Consequences of Decommissioning Particle Accelerators and In 2020 IAEA published Decommissionig of particle accelerators. This information can be used as the basis of costing for waste and materials management, but predicted activities need to be verified for each of the individual pieces by dismantling the equipment after they have been checked for activation.

The main objectives of waste management within the context of decommissioning of accelerators are to:

1. Minimize the quantities of radioactive waste at all stages of decommissioning;
2. Prevent the combination of waste of different categories (e.g. radioactive waste, hazardous chemical waste);
3. Comply with all applicable regulations in the handling, storage, processing and disposal of the waste.

3. Methods and materials

Linear accelerator Siemens Oncor Impression 3D has been in operation at Klaipeda University Hospital from 2010 until 6/04/ 2021. Photon beam energies used for cancer treatment were 6 and 18 MV. Decommissioning process started with documentation:

1. Preparing final decommissioning plan of the facility according national legislation.
2. Supplementing radiation protection programme and physical security description.
3. Reviewing assessment of the quality and effectiveness of the measure to ensure the physical security system.
4. Preparing linac dismantling plan.
5. Concluding a contract with the radioactive waste manager for radioactive material disposal

According the radiation protection programme received exposure dose was monitored by digital personal radiation dosimeters PM1703MO-I BT. Radiation background, surface contamination, activated components were measured and identified by portable multifunction dosimeter Atomtex AT 1123, contamination monitor CoMo 170 and RadEye B20 dose rate meter (β radiation). Activated linac components were identified included vacuum window of the accelerating wave-guide, bending magnet core, the target and the flattening filter (Fig. 1).

To ensure safety and security activated linac head parts were packaged in two 3 mm thickness steel transport boxes, in compliance with the regulations, marked with a sign of ionizing radiation and temporary storage in the department specific room with a security alarm, video surveillance system and limited access.

Fig.1 Activated linac parts, vacuum window of the accelerating wave-guide, the target and the flattening filter (a), bending magnet core (b)

Fig.2 Radioactive material transporting boxes

A portable Canberra Falcon 5000 High Purity Germanium (HPGe) detector was used to detect isotopes by the gamma rays emitted from the activated parts. Spectra analysis was performed by Canberra's Genie 2000 and Fitzpeaks spectroscopy software. At the end activated materials were transported from the hospital to Ignalina nuclear power plant for storage decay.

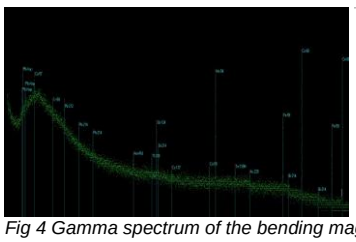
4. Results and discussion

According the radiation dosimeters data accumulated dose to engineers were 2,25 – 3,25 μSv during dismantling period. Dose rate emission levels from activated components have been measured and have been found to be in the range of 0,08–0,24 μSv/h at 5 cm from the linac head and in the range of 0,07–0,1 μSv/h at 100 cm after 3 days in operation. Dose rates measured after dismantling was higher owing to the lack of shielding provided by the head. The highest activation levels were found in target, flattening filter and bending magnet with dose rates up to 6,1 microsieverts per hour at a distance of 5 cm. Also, β dose rate up to 2,58 μSv/h were measured from accelerating wave guide window. Based on results no surface contamination were observed.

Based on gamma – ray spectroscopy measurements a few spectra were obtained (fig.3 and fig.4).

Radio isotope	Activity, MBq	Uncertainty, MBq	Peak energy, keV	Half-life
^{51}Cr	0,11	0,02	320,1	27,7 d
^{54}Mn	0,1	0,01	835	312,3 d
^{57}Co	0,24	0,04	122,1	271,8 d
^{58}Co	0,021	0,002	811	70,8 d
^{60}Co	0,018	0,001	1173,5/ 1332,8	5,3 y
^{181}W	9,8	1,2	EC (56,3 to 67,1)	121,2 d
^{196}Au	0,19	0,01	84,6	6,2 d
^{198}Au	0,0036	0,0001	411,9	2,7 d

Fig 3 Gamma spectrum of the accelerating wave-guide vacuum window, the target and the flattening filter with radioisotopes characteristics



Radio isotope	Activity, MBq	Uncertainty, MBq	Peak energy, keV	Half-life
^{54}Mn	0,015	0,002	835	312,3 d
^{57}Co	0,002	0,001	122,1	271,8 d
^{58}Co	0,0011	0,0004	811	70,8 d
^{60}Co	0,031	0,002	1173,5/ 1332,8	5,3 y
^{124}Sb	0,004	0,001	602,8	60,2 d
^{59}Fe	0,018	0,0001	1099/1 291,6	45 d

Fig 4 Gamma spectrum of the bending magnet core with radioisotopes characteristics

Spectrum analysis revealed dominant radioisotopes ^{51}Cr, ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{181}W, ^{196}Au and ^{59}Fe, where the highest peak of spectrum corresponded to ^{181}W electron capture decay to ^{181}Ta which results x-ray photons. The spectrum showed the annihilation peak at 511 keV as a result of beta plus decay from ^{54}Mn.

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5. Conclusions and Acknowledgements

In the current study linear accelerator Siemens Oncor Impression 3D decommissioning was carried out. Based on occupational doses, gamma and beta dose rate measurements we can assumed that radiation and physical protection was ensured during decommissioning process. According gamma spectra data linac treatment head components and target are the primary source of induced activity. Based on spectrum analysis dominant radioisotopes were ^{54}Mn, ^{57}Co, ^{58}Co, ^{60}Co, ^{181}W and almost all identified isotopes were long-lived, where half-life varies from few days to several years. Total amount of radioactive materials minimized to 158 kg at all stages of decommissioning.