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Estimation of air activation in the treatment rooms of proton therapy cyclotrons

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Introduction

Fast neutrons produced during pateint irradiations with energetic protons interact with the oxygen and nitrogen atoms in the air producing short-lived positron emitting radionuclides, ^{15}O, ^{13}N and ^{11}C (Table 1). Consequently, the fast neutrons collide with the gantry room walls, ceiling and floor resulting in slowing down (thermalisation). The thermal neutrons are captured by the ^{40}Ar atoms present in air (~ 3%) via the ^{40}Ar(n,γ)^{41}Ar reaction (Figure 1) producing ^{41}Ar, a beta and gamma emitter (Eγ = 1.3 MeV) of a half-life of 120 min (Table 1). Due to its longer half life radiaoctive ^{41}Ar could reach a longer distance depending on wind flow conditions and cause radiation exposure to public. We have experimenally estimated the ^{41}Ar produtionin the treatment room using superheated emulsion (bubble) detectors and estimated the average activity concentration at the exhaust point.

Accelerator Facility	Effluent	Half Life	Remarks
Proton Therapy Cyclotron (~ 250 MeV)	^{15}O	2 min	e+ emitter
	^{13}N	10 min	e+ emitter
	^{11}C	20 min	e+ emitter
	^{41}Ar	120 min	e- and γ emitter
Medical Cyclotron (15-30 MeV proton)	^{15}O (*)	2 min	e+ emitter
	^{13}N (*)	10 min	e+ emitter
	^{11}C (*)	20 min	e+ emitter
	^{18}F (*)	120 min	e+ emitter
	^{41}Ar	120 min	e- and γ emitter

*Generated as primary PET radionuclide

Table 1: Showing te radioactive effluents produced during the operation of medical cyclotrons.

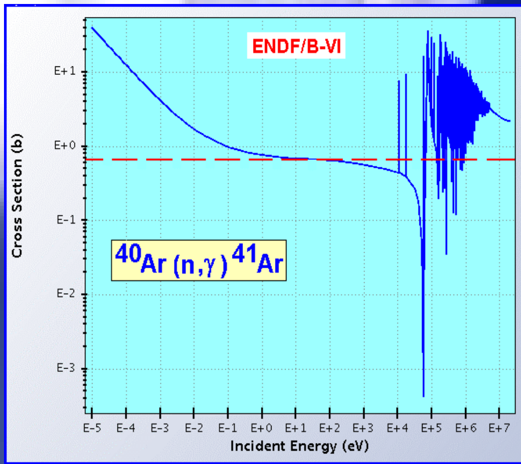


Figure 1: Depicting the excitation function of the production of ^{41}Ar. The average neutron capture cross section evaluated to be 630 mb.

^{41}Ar Concentration Calculation

Elucidated in Figures 2, 3, 4

Figure 3: Bubble dosimetry summary

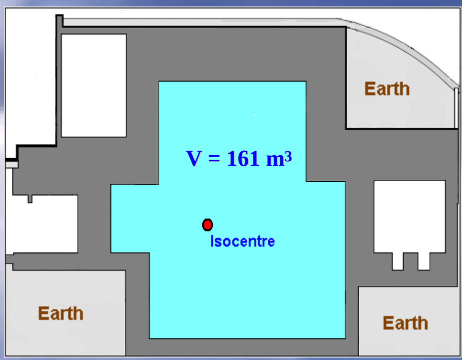


Figure 4: Vertical cross section of gantry room

<u>^{41}Ar activation calculation</u>

$$A = \frac{N \Phi_{th} \sigma \exp(1-\lambda T_b) \exp(-\lambda T_d)}{n V}$$

N = Number of ^{40}Ar atoms in air = 25×10^{22} atoms.m^{-3}

Φ_{th} = Thermal neutron fluence = 1.03×10^{6} cm^{-2}

σ = Neutron capture cross section = 630 mb (6.30×10^{-25} cm^{2})

λ = Decay constant of ^{41}Ar = 0.38 h^{-1}

n = air exchange (ventilation) rate = 8 h^{-1}

V = Treatment room volume = 161 m^{3}

T_b = Irradiation time per dose fraction = 3min (0.05h)

T_d = Delay time following irrradiation = 0 h

<u>A = 34.2 Bqm^{-3} (Regulatory Limit : 200 Bqm^{-3})</u>

Figure 5: ^{41}Ar activity concentration

The pathway : Treatment room (Figure 6) => Plant hall (Figure 7) => Air (^{41}Ar)-monitor (Figure 8) => Effluent exhaust (Figure 9)

Figure 6: One of four WPE treatment rooms

Figure 7: WPE plant (ventilation) hall

Figure 8: Effluent-monitor

Figure 9: Effluent exhaust at WPE rooftop

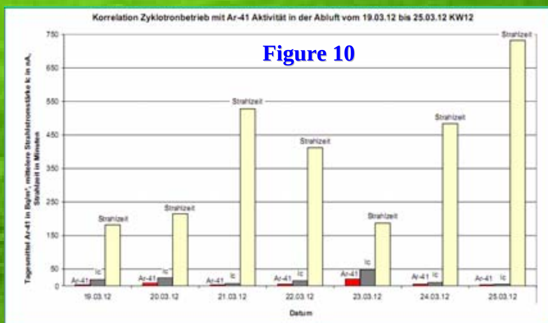
Results and Summary

During routine patient irradiation, radioactive effluents are produced due to neutron activation of the air in the treatment rooms

From Health Physics (public exposure) stand point the radioactive ^{41}Ar ($T_{1/2}$ = 120 min) is most critical, hence, the monitoring of treatment room air becomes mandatory

At WPE the exhaust air from all treatment rooms and cyclotron vault is monitored in real-time using a effleuent (air) monitor located in the plant hall. The daily activity concentration of ^{41}Ar is evaluated and presented in a histogram (Figure 10)

The estimated activity concentration (this work) of ^{41}Ar (34.2 Bqm^{-3}) found to be a factor of 0.17 lower than the regulatory limit (200 Bqm^{-3}) and agrees well with the histogram (Figure 10).



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