# Comparison between simulation and measurement of activation products in high-energy medical linear accelerators

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## Introduction

The general purpose of this study was **to investigate the activation products of a medical x-ray linear accelerator** (linac). Energies up to over 10 MeV are enough to induce photonuclear reactions in which radionuclides are produced. The **activation products** vary according to the materials used in the construction of the linear accelerator and to accessories used in treatment room. Several studies have been devoted to study the typical radionuclides generated by linear accelerators.

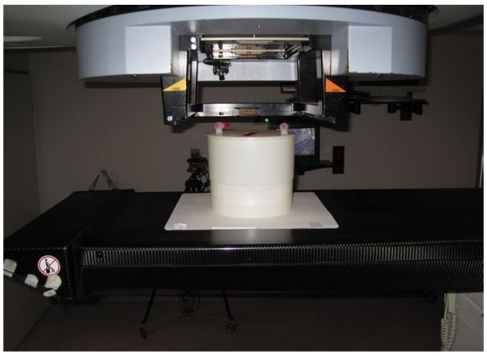

***Figure 1:*** *Gas Marinelli beaker flushed with nitrogen gas and irradiated with 15 MV photons with field size of 40 x 40 cm²*

## Materials and Method

In the present work, the activity of $^{13}N$ and $^{15}O$ per unit volume of air produced by a 15 MV beam (300 MU/min) for field size 40 x 40 cm² has been evaluated at isocenter around Siemens linac at Pius-Hospital Oldenburg using portable gamma detector with 15% relative efficiency (Canberra) and two gas Marinelli beakers, one of them flushed with $N_2$ gas and the other flushed with $O_2$ gas. The type of Marinelli beaker used was G-433N and made from polystyrene material, with height of 180 mm and diameter of 206 mm. The $O_2$ gas Marinelli beaker was irradiated for **5 min** and immediately six $O_2$ spectra were recorded every 60 s. On the other hand, the $N_2$ gas Marinelli beaker was irradiated for **15 min** and seven $N_2$ spectra were recorded every 60 s with one spectrum during 120 s.

The **spectra were analyzed** for the time evolution of the 511 keV positron-electron annihilation peak. For the $N_2$ series, a prominent peak appeared, decaying with a half-life of 10.0 min. This finding indicates contribution from $^{13}N$ ($T_{1/2}$ = 9.96 min). The $O_2$ series showed a slowly decaying small peak, probably due to residual $N_2$ gas in the beaker. No signal contribution in the early spectra from $^{15}O$ ($T_{1/2}$ = 2.05 min) was observed. No other peaks (except lines from natural isotopes like $^{40}K$) could be observed. The $N_2$ series data were analyzed quantitatively assuming that all 511 keV photons were due to $^{15}N$ decay. Detector absolute efficiency was obtained from LabSOCS software (Canberra, Inc.).

## Geant4 Monte Carlo Code

In this work the Geant4 Monte Carlo (**GMC**) code was used to simulate the activation products in the medical linear accelerator. To model the energy degradation of the photo-neutrons travelling inside a treatment room, a model of a treatment room was simulated with a dimensions of 7 × 7 × 5 m³, surrounded by concrete walls and is filled with dry air.

To investigate the air activation products, a model of a gas Marinelli beaker was simulated with height of 180 mm and diameter of 206 mm at the isocenter.

## Results

The evaluation of $N^2$ spectrum using the gas Marinelli beaker method gives 765 ± 37 Bq/l for $^{13}N$. The results of activity for the $^{13}N$ and $^{15}O$ using the mathematical model was found to be 715.41 and 0.839Bq/l respectively.

| No. | H. Fischer *et al* | $T_{1/2}$ | This study (using GMC code) |
|---|---|---|---|
| 1 | $^{24}Na$ | 15.0 h | $^{24}Na$ |
| 2 | $^{28}Al$ | 2.3 m | $^{28}Al$ |
| 3 | $^{51}Cr$ | 27.7 d | **** |
| 4 | $^{54}Mn$ | 312.3 d | $^{54}Mn$ |
| 5 | $^{56}Mn$ | 2.6 h | $^{56}Mn$ |
| 6 | $^{57}Co$ | 271.8 d | **** |
| 7 | $^{57}Ni$ | 36.0 h | **** |
| 8 | $^{58}Co$ | 70.9 d | **** |
| 9 | $^{59}Fe$ | 45.1 d | **** |
| 10 | $^{60}Co$ | 5.3 y | **** |
| 11 | $^{62}Cu$ | 9.7 m | $^{62}Cu$, |
| 12 | $^{64}Cu$ | 12.7 h | $^{64}Cu$ |
| 13 | $^{65}Zn$ | 244.3 d | **** |
| 14 | $^{82}Br$ | 35.5 h | **** |
| 15 | $^{99}Mo$ | 66.0 h | **** |
| 16 | $^{122}Sb$ | 2.7 d | **** |
| 17 | $^{124}Sb$ | 60.2 d | **** |
| 18 | $^{184}Re$ | 38.0 d | **** |
| 19 | $^{187}W$ | 23.7 h | $^{187}W$ |
| 20 | $^{196}Au$ | 6.2 d | **** |
| 21 | $^{203}Pb$ | 51.9 h | **** |

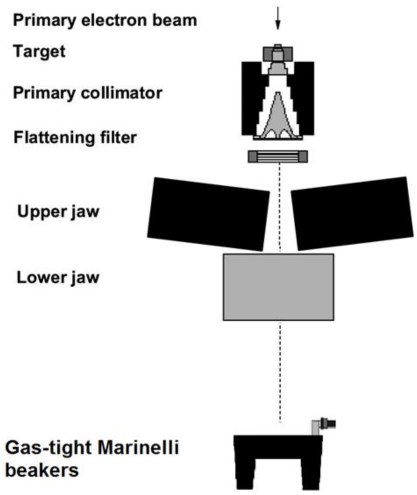


***Figure 2:*** *Geometric representation of the Siemens LINAC's head and gas Marinelli beakers simulating the irradiation field of 15 MV, using Geant4 Monte Calro Code. The room's wall have been made transparent for the reader to better view the modeled geometry.*

## Math. Model

**The activity, A, of Nitrogen and Oxygen in gas Marinelli beaker was calculated using the following equation:**

$$A = m(N_a/M)\sigma[1-e^{-\lambda t}] \text{ (part./s)} \quad [1]$$

$$m = \frac{PV}{RT} x15.99(g/mol) \quad [2]$$

*σ … (ϒ,n) cross section (mbarns)*
*$N_a$ … Avogadro number*
*λ… Decay constant*
*t … irradiation time*
*M … Molar mass of target isotopes*
*m … Mass of gas in Marinelli beaker*
*P … Pressure*
*V … Volume of Marinelli beaker*
*R … Gas constant*
*T … Temperature*

## Conclusions

- The results obtained in this study using the gas Marinelli beaker conclude that $^{13}N$ is the main contributor to air activation in medical linear accelerator .
- The evaluation of $N_2$ spectra gives 765 ± 37 Bq/l for $^{13}N$.
- In this work, the activation products in medical linacs has been analyses using the Monte Carlo code Geant4 and results show good agreement with experimental results of gas Marinelli beaker measurements.

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