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MONTE CARLO BENCHMARK OF THE EXPERIMENTAL EVALUATION OF THE ACTIVATION PROCESSES IN AN ELECTRON LINEAR ACCELERATOR FOR RADIOTHERAPY APPLICATIONS

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The Activation Problem

The source: a 15 MeV electron beam source by a VARIAN TRUE-BEAM like device and 600 MU with various jaws opening and irradiation times (orders of 10 min each).

The goal: Properly evaluate the effects of the interaction of the primary beam with the accelerator and the bunker structural materials to estimate the dose that medics and paramedics staff must bear while assisting the patients.

The critical issue: dose for the operators at the end of the patient irradiation session.

The tool: We investigate the activation products and their distribution using both Monte Carlo simulations using the MCNPX/6 codes, to identify the source components, and a detector LaBr3 InSpector™ 1000 Digital Hand-Held Multichannel Analyzer by Canberra.

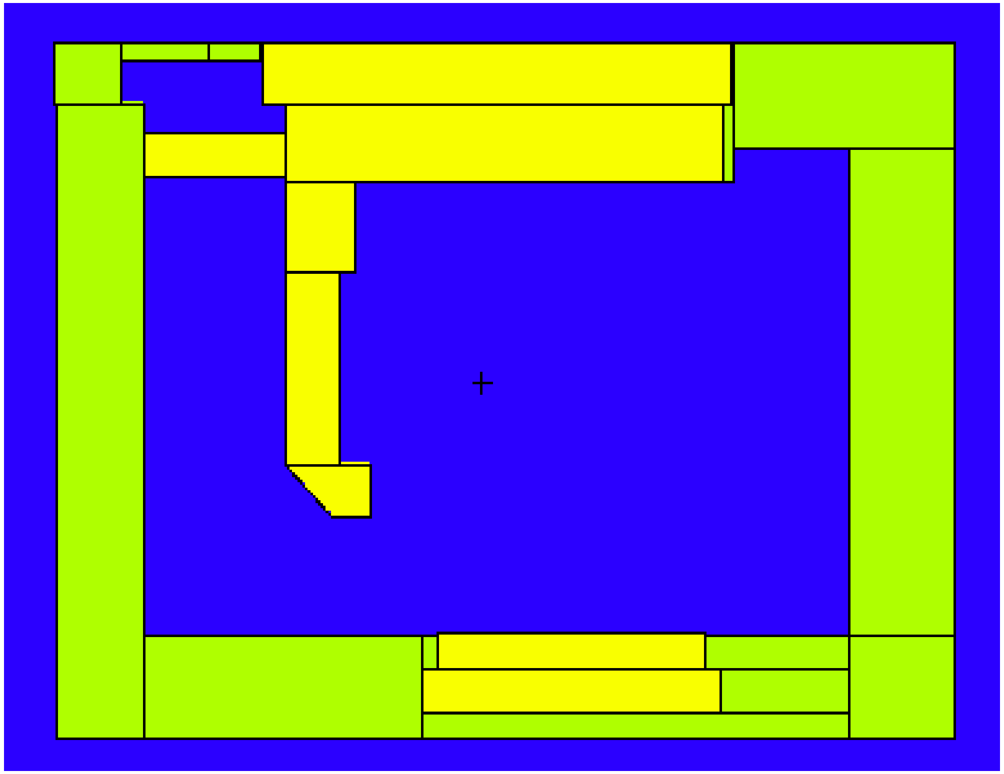
MCNP models were calibrated and able to predict the amount of produced material and where they are generated and obviously doesn't take into account impurities and imperfections (**and unexpected players…**).

The MCNP simulation **results have been scored** thanks to the Residual tally Card.

Some significant portions of the MCNPX simulation input and tallies:

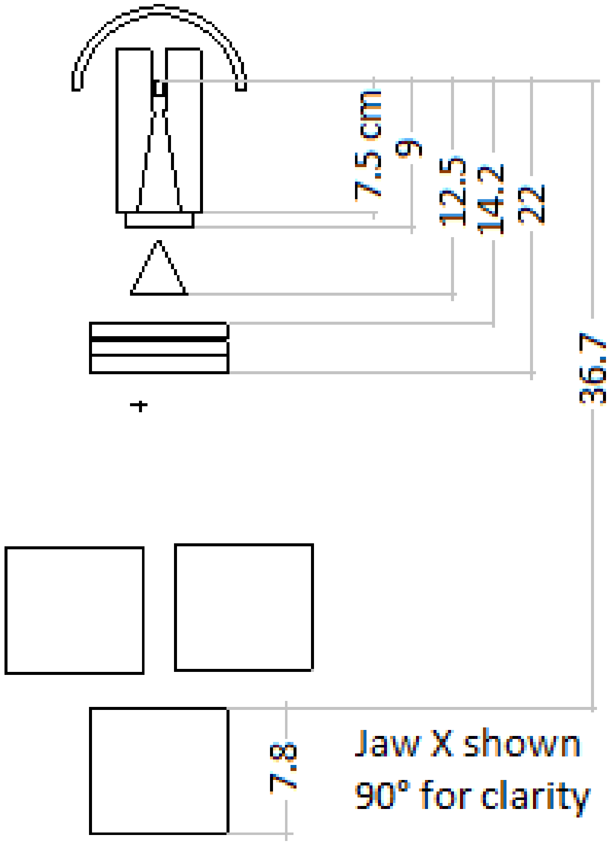
```
PHYS:p  15 0 0 -1 1 j j
PHYS:e  15 0 0 0 0 1 1 1 1 0 0.917
PHYS:n  15 0 0 -1 -1 5
ACT      fission=all nonfiss=all dn=prompt dg=lines thresh=0.95 nap=10
LCA     ielas=2 ipreq=1 iexisa=2 ichoic=0023 jcoul=1 nexite=1  npidk=0 noact=-2 icem=0            ilaq=0
F8:n     1 2 3 4 5 6 7 8 9 10 11 12 13 100
FT8      RES [1 99] $ Heavy-Ion and residual isotopes
```

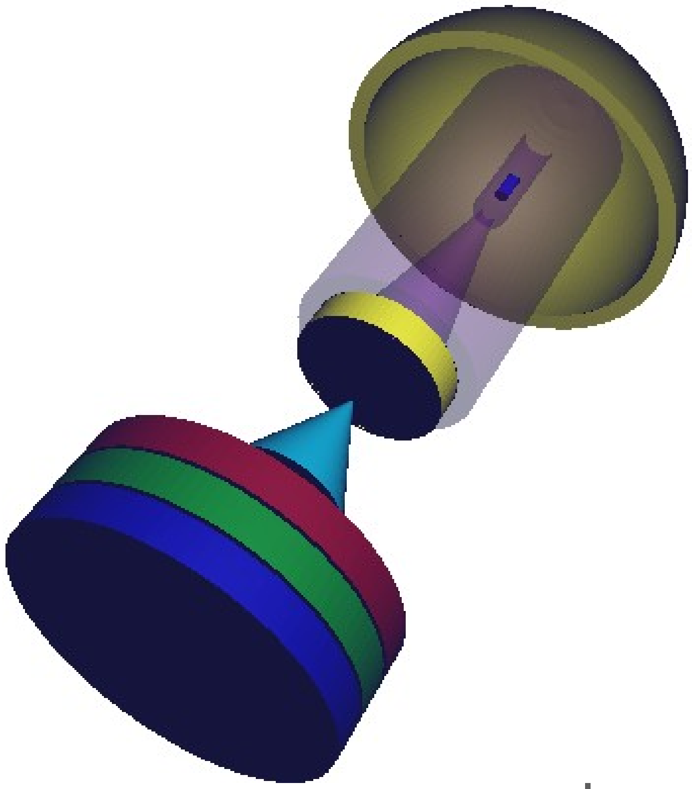
The interaction of high-energy particles with target nuclei causes the production of several residual nuclei. The generated nuclei can be recorded by an F8 tally if used with an FT8 RES special treatment option. The residuals are recorded at each PHYSICS MODEL interaction and at each NEUTRON – NUCLEI interaction as recorded in the library as well.

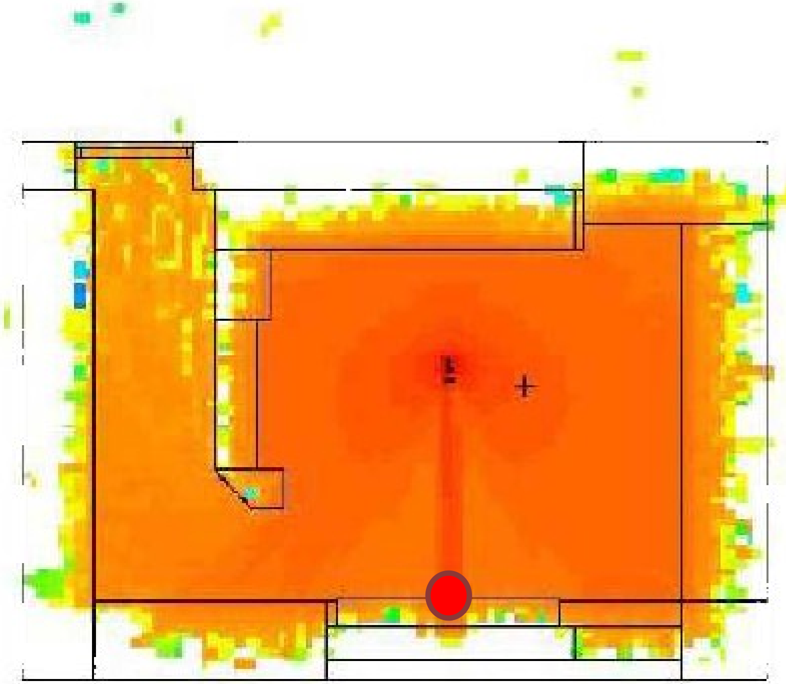


An MCNP x-y view of the bunker hosting the accelerator (the real one)

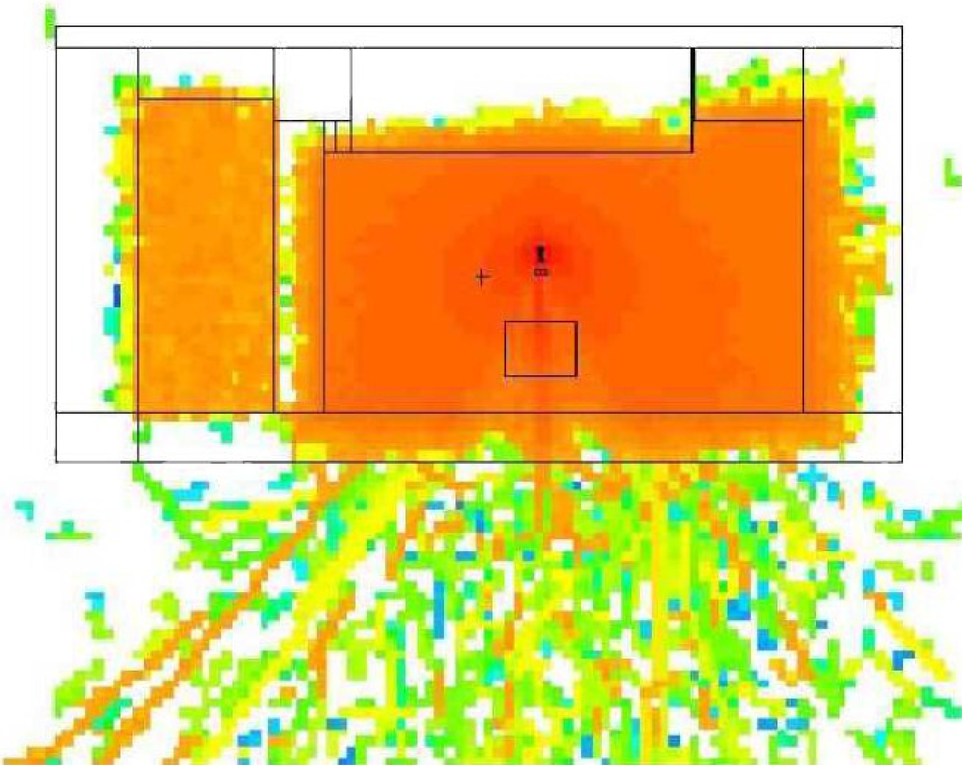
Geometry of the VARIAN True Beam – like accelerator head



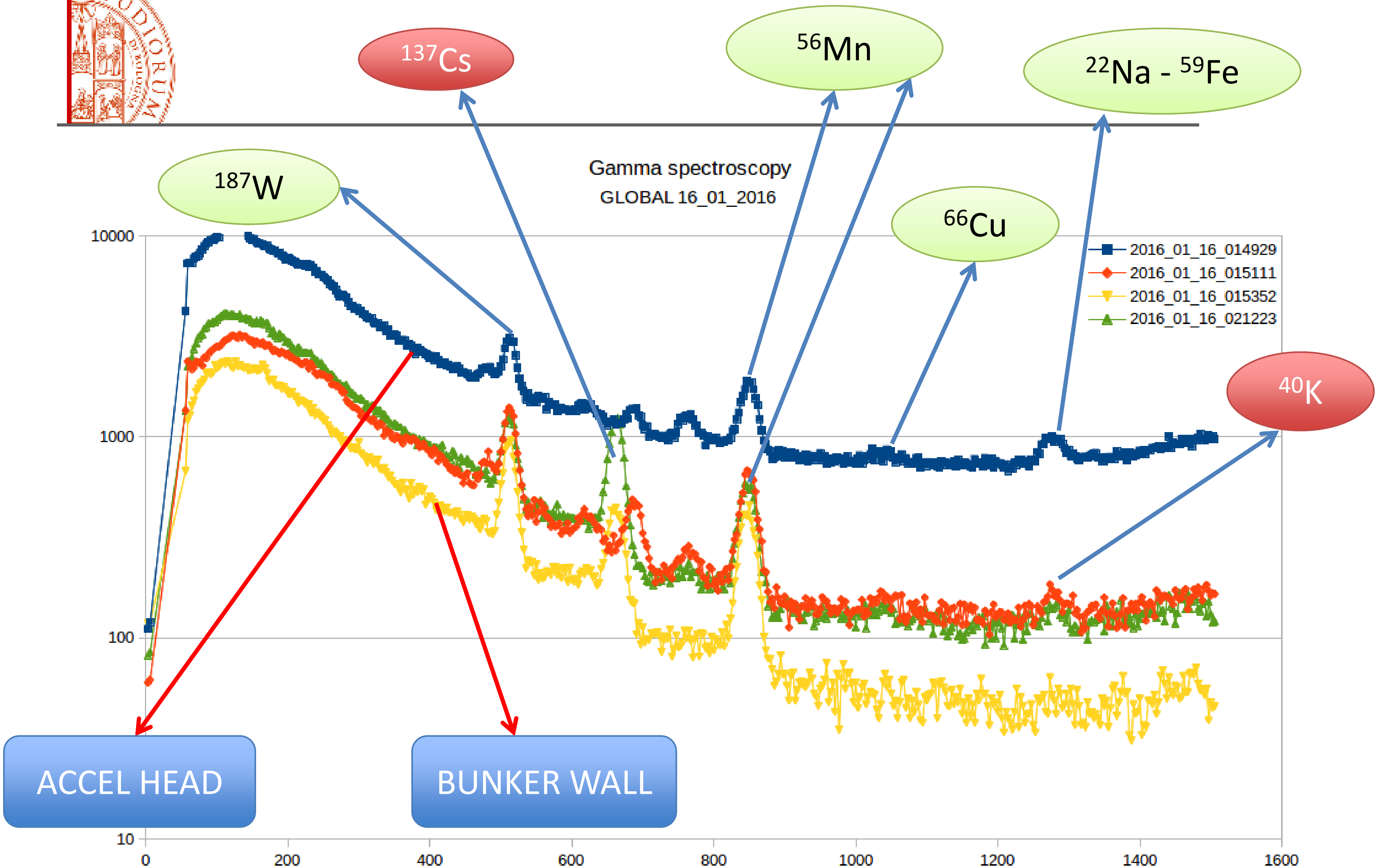




2D X-Y Visualization of the photon flux with primary beam pointed on the bunker wall



2D X-Z Visualization of the photon flux with primary beam pointed on a water phantom in the floor direction



Gamma spectroscopy
GLOBAL 16_01_2016
187W
137Cs
56Mn
22Na - 59Fe
66Cu
40K
2016_01_16_014929
2016_01_16_015111
2016_01_16_015352
2016_01_16_021223
10000
1000
100
10
0
200
400
600
800
1000
1200
1400
1600
ACCEL HEAD
BUNKER WALL

Activation results and Monte Carlo Estimations

ACCELERATOR HEAD		
MATERIAL	COMPONENT	% OF GENERATED PRODUCTS (MCNP)
W	Primary collimator	71.822
	Target	0.177
	Y1 jaw	7.58
	Y2 jaw	7.59
	X1 jaw	3.79
	X2 jaw	3.75
Cu	Target	2.45
	Flattening Filter	2.20
Be	Berillium Vacuum Chamber	0.02
Capton	Capton Disks	0.51
Lead	Lead Cake	0.08

The % amount of produced materials, referred to the accelerator head.

^{187}W	Total # of atoms produced in the head	% Radioisotopes
6.05e-6	2.94e-5	35

MATERIAL	NORMALIZED FRACTION (ON ^{187}W)
Cu	0.30136
Be	4.7e-4
Capton	0.2
Lead	0.111
Total head	4.86

The normalization is done on the global number on atoms of W187 produced, shown in table. This quantity represents the total number (normalized) of atoms of all materials, radioactive and not, produced by the nuclear reactions.

ISOTOPE	$T_{1/2}$	γ Energy	Intensity	Main Reactions	Position
^{187}W	23.7 h	479.531	21.8	$^{186}W(n,\gamma)^{187}W$	1
		551.532	5.08		
		618.361	6.28 14		
		685.774	27.3		
		772.89	4.12		
^{66}Cu	5.1 min	1039.23	9	$^{65}Cu(n,\gamma)^{66}Cu$	1-2
^{124}Sb	60.2 d	1691	0.47	$^{63}Cu(n,\gamma)^{64}Cu$	1
^{59}Fe	44.503 d	1291.59	43.2	$^{58}Fe(n,\gamma)^{59}Fe$	1
^{24}Na	2.31 min	1396	100	$^{23}Na(n,\gamma)^{24}Na$	1
^{22}Na	2.60 y	1274.53	99.9	$^{19}F(\alpha,n)^{22}Na$	1
				$^{24}Mg(d,\alpha)^{22}Na$	
^{56}Mn	2.58 h	846.77	99	$^{55}Mn(n,\gamma)^{56}Mn$	1
^{40}K	1.277E+9 y	1460	11	Naturally occurring	2

Pos. 1: accel head
Pos. 2: bunker wall

Summary of Varian Truebeam-like device referred to the accelerator head. Position 2 is referred to the bunker structure.

Thanks to the experimental setup we were able to find the activity of some radioisotopes and thanks to Monte Carlo code we were able to identify the peaks and even the isotopes invisibles to our instruments but presents in the processes.

The 187W activity were calculated as 0.612 MBq, in the explained measurement condition and 1.57 MBq estimated with MCNP.

MC code suggests to look for other isotopes of interest over the measurement range or invisible to our instruments that will be validated in a future work. It is worth to cite the 28-Al with T 1/2 2.31 min and 1780 keV of energy peak, Intensity equal to 100% produced by 27Al(n,γ)28Al. Also Barium isotopes inside the bunker structure have been found in the simulation.

OTHERS MC ESTIMATED ISOTOPES	$T_{1/2}$	^{187}W NORM	γ Energy	Intensity	Reaction
^{64}Cu	12.8 h	0.158	1345.84	0.473	$^{63}Cu(n,\gamma)^{64}Cu$
^{207m}Pb	0.8 sec	0.002	569.702	97.87	$^{207}(n,n')^{207m}Pb$
			1063.662	88.5	$^{208}Pb(\gamma,n)^{207m}Pb$
					$^{208}Pb(\gamma,n)^{207m}Pb$
^{28}Al	2.31 min	0.673	1780	100	$^{27}Al(n,\gamma)^{28}Al$
^{37}S in bunker structure	5.07 min	3.5E-4	3103	94	$^{36}S(n,\gamma)^{37}S$
^{49}Ca in bunker structure	8.8 min	0.015	3084	92	$^{48}Ca(n,\gamma)^{49}Ca$

The results show a possible general approach to perform spectrometry analysis coupling the experimental measurements with the results of a Monte Carlo estimate to properly identify the peaks, the source components and the materials not directly detectable by the instrumentation.

Our data confirm how it is important that the staff who work with the patients, before getting them from the treatment bed, be able to move away the accelerator head, in front of a measured dose rate equal to 70 µSv/h at contact and 30 µSv/h at 1 meter, fully coherent also with the validating MC simulation outcome.

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2. T. Goorley, "MCNP6.1.1-Beta Release Notes", LA-UR-14-24680(2014).

3. Rohan Ram, Ian Steadman, UOIT, Determination of Activation Products and Resulting Dose Rates for the Varian Truebeam.

4. Pawel Jodlowski, NUKLEONIKA 2006;51(Supplement 2):S21S25, Self-absorption correction in gamma-ray spectrometry of environmental samples; an overview of methods and correction values obtained for the selected geometries

THAN K YOU