Evaluation of decommissioning of proton therapy centers based on the selection of shielding materials at the building stage of the facility

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Public program of proton therapy centers (*PTC*) under development in Spain

MOTIVACIÓN

Proton therapy, radiotherapy with accelerated proton beams, has growing potential in dealing with some tumors, and consequently, in the last decade *proton therapy centers* (*PTC*) are growing across the world, with a forecast that will double by next five years.

Attenuation of prompt radiation from primary proton beams and secondary particles generated (neutrons), is essential to achieve dose limits, but not enough to develop efficient radiation protection in *PTC*. Activation of mechanical elements, environment (air, water, terrain), and the shielding, is another relevant issue, linked to the operational radiation protection of the staff, the future dismantling and management of radioactive waste, and the sustainability of these facilities [**1**].

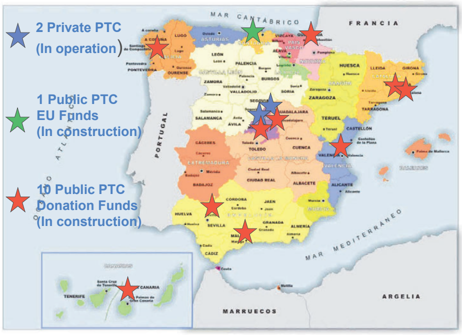
Induced radioactivity remains in the walls for several years, even decades, after their closure, so a study of complete cycle of life and a reliable inventory estimation, depending on the shielding material selected, would be advisable at early stages of projects, to estimate and reduce decommissioning costs, which involve a sensitive part of the total investment [**2**].

PROTON THERAPY IN SPAIN

2019/20
Two private proton centers in Madrid

2025/2026?
One new public proton center in Santander

2026/2030?
Ten new public proton centers around Spain

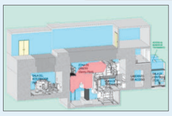


★ **2 Private PTC (In operation)**
★ **1 Public PTC EU Funds (In construction)**
★ **10 Public PTC Donation Funds (In construction)**

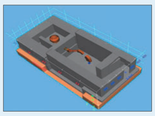
In Spain, two private PCT are working from Dec-2019 and April-2020 (*blue stars*). A third centre, the first of Public System, is under construction (*green star*). Finally, ten new proton therapy room for the Public Health System (*red stars*), are under construction, thanks to a donation of 280 M€ from the Amancio Ortega Foundation [**3**].

MATERIALS AND METHODS

Proton therapy facilities studied



Syncrocyclotron
One treatment room
Bunker ≈ 28x13 m²
11 facilities in Spain

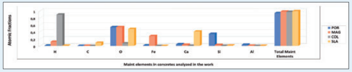


Compact Proton Therapy Centers (CPTC) [3,4]
Reducing cost and footprint
Increasing radioprotection challenges

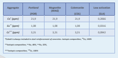
Types of concrete analyzed

1. **POR: Conventional Portland concrete**
2. **MAG: Special concrete with magnetite**
3. **COL: Special concrete with colemanite**
4. **SLA: Special low activation concrete**

Main components



Aggregates

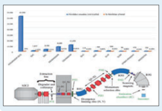


Aggregate	Portland (POR)	Magnetite (MAG)	Colemanite (COL)	Low activation (SLA)
Co* (ppm)	21,9	21,9	21,9	0,2066
Eu** (ppm)	1,08	1,08	1,08	0,0316
Cs*** (ppm)	3,21	3,21	3,21	0,0942

*Cobalt is always included in steel reinforcement of concretes. Isotopic composition, ^{59}Co, 100%
**Isotopic composition, ^{151}Eu, 48%, ^{153}Eu, 52%,
***Isotopic composition, ^{133}Cs, 100%

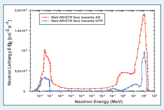
Workload and assumptions in calculations

Losses in beam line



Annual losses
88540 nA·h/y

Neutron Spectrum



Irradiation time
20 years

Workload

Fluence rate, $\phi' = \phi \cdot I$

I=Annual load=$3,19 \cdot 10^{8}$ *nC/y*
$I = 10,1$ nA $= 6,31 \cdot 10^{10}$ p/s

Fluence, ϕ → Monte Carlo calculations

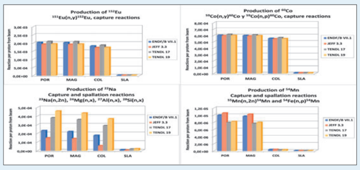
PURPOSE

Assessment of neutron activation in the shielding of proton centers, and the impact in decommissioning and sustainability, comparing four types of concrete, using Monte Carlo codes (MCNP and PHITS).

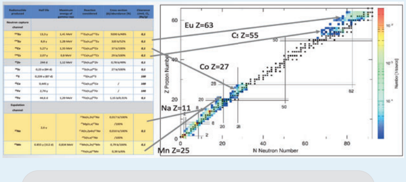
Assessment of wall activation and decommissioning of *PTC* depending on the concrete selected

ACTIVATION PROCESSES

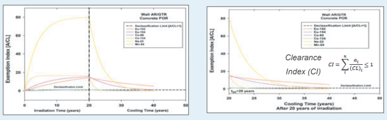
Main reactions of activation



Radioisotopes yielded in concrete



Activation/Desactivation plots



Clearance Index (CI) $CI = \sum_{i}^{n} \frac{a_i}{(CL)_i} \le 1$

$$A_i(t) = N \cdot \phi'(E) \cdot \sigma(E) \cdot \left(1 - e^{-\lambda \cdot t_{irr}}\right)\left(e^{-\lambda \cdot t_{enf}}\right) \quad \left[\frac{Bq}{cm^3}\right] \quad where\ t = t_{irr} + t_{enf}$$

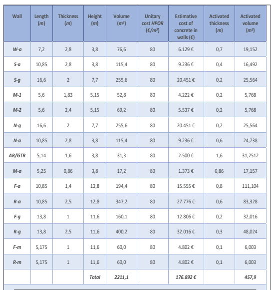
ASSESSMENT OF DIFFERENT CONCRETE

The assessment was carried out comparing three main attributes of concretes: attenuation, activation a cost of building

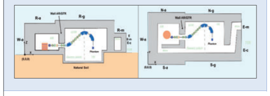
Considering activation, the better concretes are those with lower number of impurities, as SLA. There is a direct relationship between amount of activated concrete and fraction of impurities, as Europium. The channel of activation, and the isotopes yielded, are also important. With low activation concrete, a significant reduction in long-lived isotopes is observed, consequently, in about ten years, both index, corresponding to short-lived and long-lived isotopes, are below the exemption level.

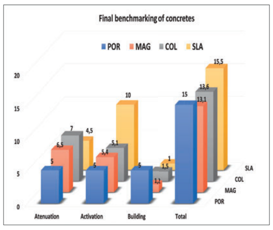
Considering attenuation, although the four concrete largely meet the necessary dose attenuation conditions, the performance of high density materials, with magnetite and colemanite, MAG and COL, is higher.

Conventional Portland concrete, POR, has an intermediate behavior in activation and attenuation, and its building cost is significantly lower, three/four times than MAG and COL, and five/seven than SLA.



Wall	Length (*m*)	Thickness (*m*)	Height (*m*)	Volume (*m³*)	Unitary cost *HPOR* (€/*m³*)	Estimative cost of concrete in walls (€)	Activated thickness (*m*)	Activated volume (*m³*)
W-a	7,2	2,8	3,8	76,6	80	6.129 €	0,7	19,152
S-a	10,85	2,8	3,8	115,4	80	9.236 €	0,4	16,492
S-g	16,6	2	7,7	255,6	80	20.451 €	0,2	25,564
M-1	5,6	1,83	5,15	52,8	80	4.222 €	0,2	5,768
M-2	5,6	2,4	5,15	69,2	80	5.537 €	0,2	5,768
N-g	16,6	2	7,7	255,6	80	20.451 €	0,2	25,564
N-a	10,85	2,8	3,8	115,4	80	9.236 €	0,6	24,738
AR/GTR	5,14	1,6	3,8	31,3	80	2.500 €	1,6	31,2512
M-a	5,25	0,86	3,8	17,2	80	1.373 €	0,86	17,157
F-a	10,85	1,4	12,8	194,4	80	15.555 €	0,8	111,104
R-a	10,85	2,5	12,8	347,2	80	27.776 €	0,6	83,328
F-g	13,8	1	11,6	160,1	80	12.806 €	0,2	32,016
R-g	13,8	2,5	11,6	400,2	80	32.016 €	0,3	48,024
F-m	5,175	1	11,6	60,0	80	4.802 €	0,1	6,003
R-m	5,175	1	11,6	60,0	80	4.802 €	0,1	6,003
			Total	*2211,1*		*176.892 €*		*457,9*





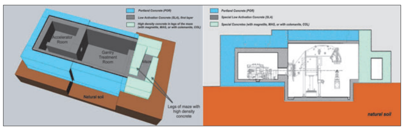
IN SUMMARY

The choice of concrete is a matter of:

1) Attenuating prompt radiation below regulatory limits.
2) Using materials with low activation to reduce the exposure to gamma radiation of the staff and generate as low radioactive waste as possible
3) Optimizing the cost of building.

Neutron flux and spectrum vary significantly in each area of a proton therapy center, therefore, it would be advisable to use different concrete in different areas, optimizing the selection based on, for example, attenuation, activation, and cost of materials, as proposed in this work.

A PROPOSAL AS AN EXAMPLE…



Neutron activation in walls of proton centers, and the impact in decommissioning and sustainability, depend on the type of concrete, and it would be advisable to study the complete cycle of life at the beginning of projects.

REFERENCES

[**1**] IAEA. 2020a. International Atomic Energy Agency. *Regulatory control of the safety of ion radiotherapy facilities*. IAEA-TECDOC-1891. IAEA, Vienna, 2020.

[**2**] IAEA. 2020b. International Atomic Energy Agency. *Decommissioning of particle accelerators*. IAEA, NES. NW-T-2.9, 2020.

[**3**] García-Fernández, G.F. *et al*. *Benchmarking of stray neutron fields produced by synchrocyclotrons and synchrotrons in Compact Protontherapy Centers (CPTC) using MCNP6 Monte Carlo code*. App. Rad. Isot. (2023) Vol 193: 110645.

[**4**] García-Fernández G.F. *et al*. *Neutron dosimetry and shielding verification in commissioning of Compact Proton Therapy Centers (CPTC) using MCNP6.2 Monte Carlo code*. App. Rad. Isot. (2021) Vol 169 : 109279.

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