SATIF-16 May 28-31, 2024

SATIF-16 Shielding aspects of Accelerators, Targets and Irradiation Facilities

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

Session 5: Induced Radioactivity and Decommissioning
Thursday, May 30, 12.30 – 13.50 h
Contribution #81

Gonzalo Felipe García Fernández[1*], Nuria García Herranz[1], Óscar Cabellos de Francisco[1], Eduardo Gallego[1]

[1]Nuclear Engineering Area, Industrial Engineers Faculty (ETSII), Technical University of Madrid (UPM), Spain

POLITÉCNICA

INDUSTRIALES ETSII | UPM

Scope

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

Session 5: Induced Radioactivity and Decommissioning

Thursday, May 30, 12.30 – 12.50 h
Contribution #81

- Motivation and context: Proton therapy around the world and Spain
- Purpose: Assessment of activation in shielding of proton centers
- Methodology
- Main results
- Summary

Faculty Disclosure

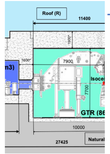
X	No, nothing to disclose
	Yes, please specify:

Company Name	*Honoraria/ Expenses*	*Consulting/ Advisory Board*	*Funded Research*	*Royalties/ Patent*	*Stock Options*	*Ownership/ Equity Position*	*Employee*	*Other (please specify)*

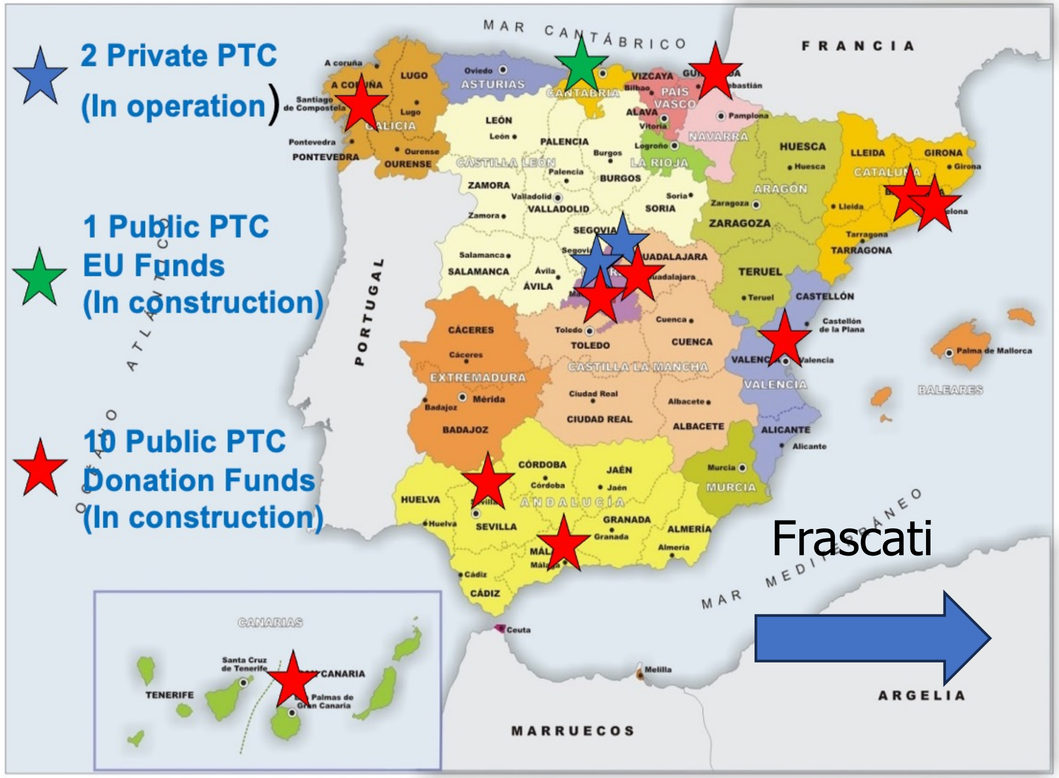
Motivation: Proton therapy Centers (PTC) around the World and Spain

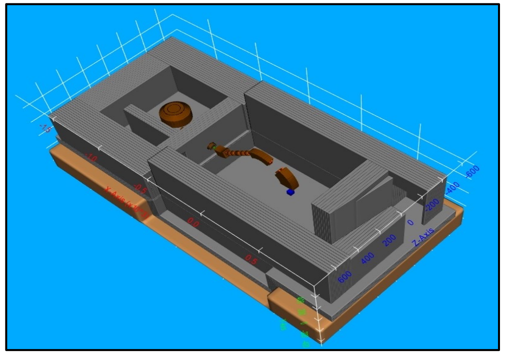
108 PTC in operation

38 PTC in building



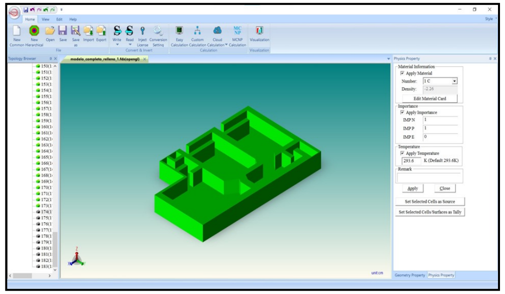
33 PTC in planning



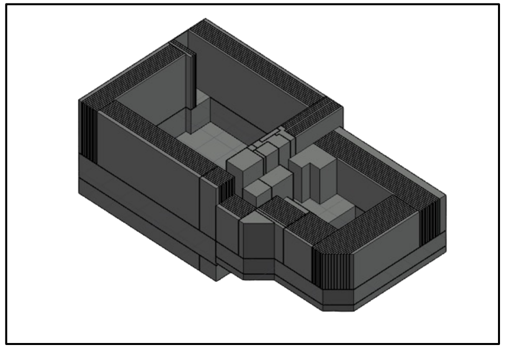


11 (Belgium)
SC
Synchrocyclotron

10 + 1

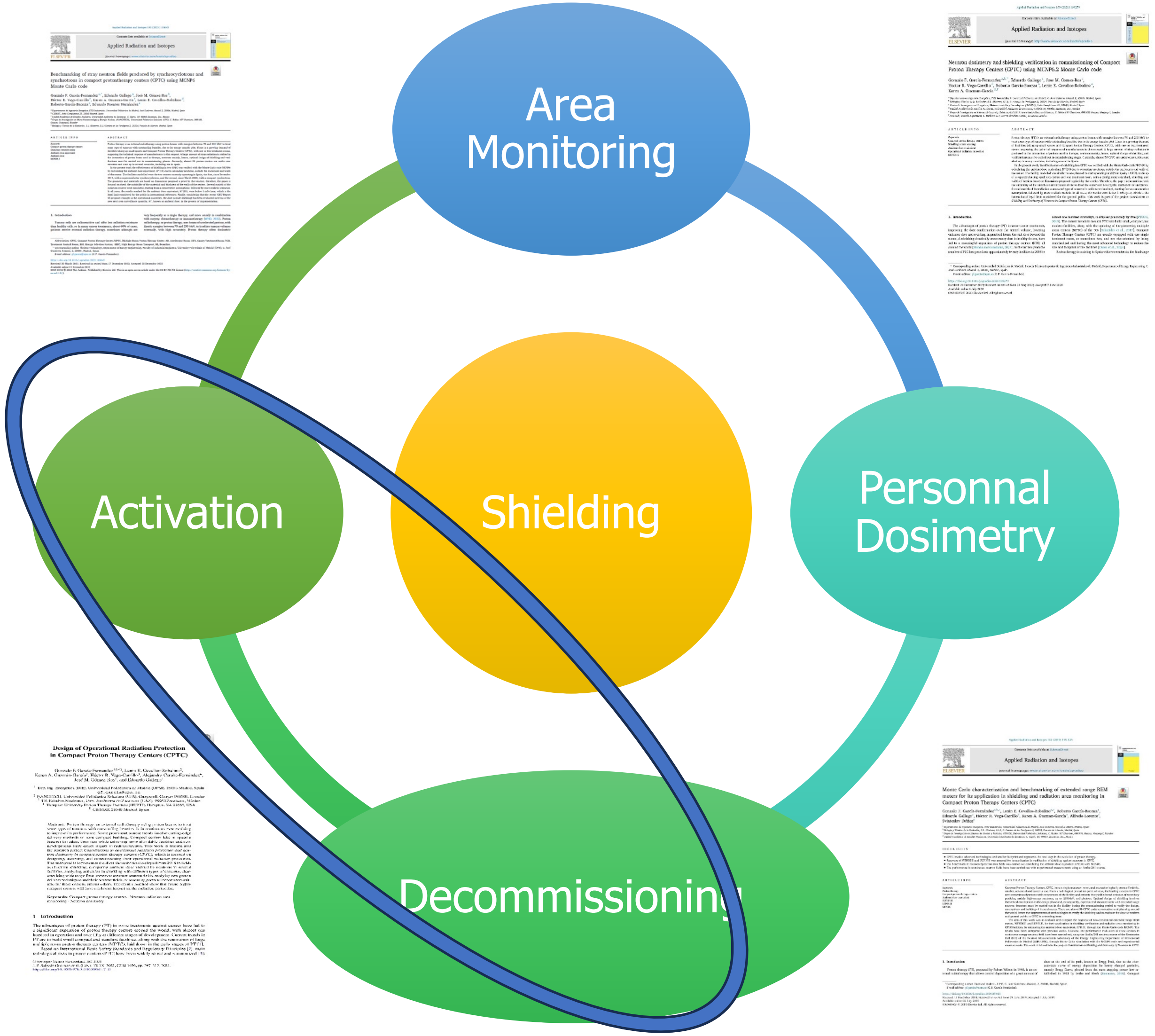


1 (Japan)
Synchrotron



1 (USA)?
Isocyclotron?

Motivation: Operational Radiation Protection in proton therapy centers



Radioactive Facility Operation Authorization
Article 20. Application (2nd category)

The application for the exploitation authorization must be accompanied by the following documents, which will update, where appropriate, the content of those presented when requesting the construction authorization:

a)..

…

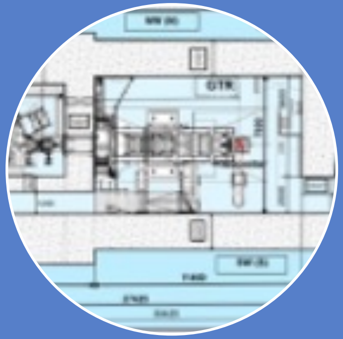
…

…

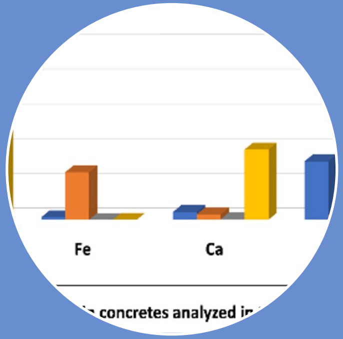
j) ***Dismantling and closure plan****, where the planned final disposal of the waste generated will be set out and will include the study of the cost and the economic and financial forecasts to guarantee closure.*

Purpose

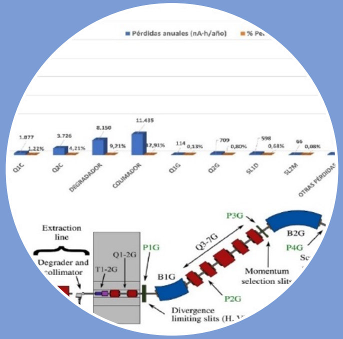
Comparing neutron activation in shielding of compact proton therapy centers (CPTC), depending on the type of concrete in the barriers, using Monte Carlo codes



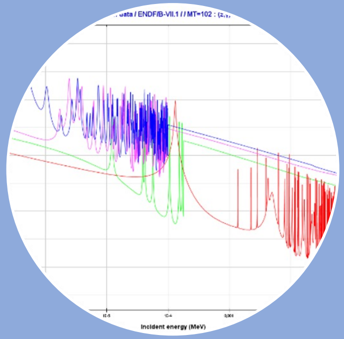
Compact proton therapy centers:
- 11 synchrocyclotron
- 1 synchrotron
- 1 isocyclotron



Four types different concrete for shielding:
- POR
- MAG
- COL
- SLA



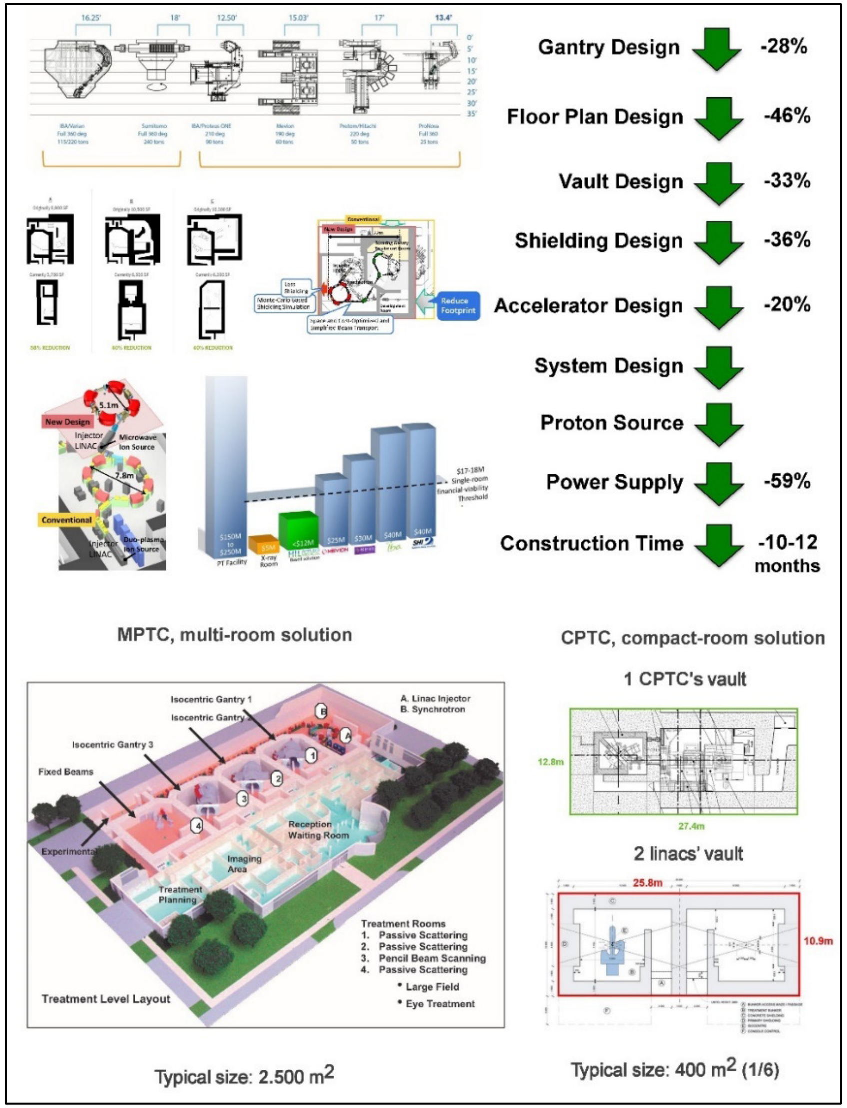
Center workload losses and spectra in the different rooms:
- AR
- GTR
- TCR

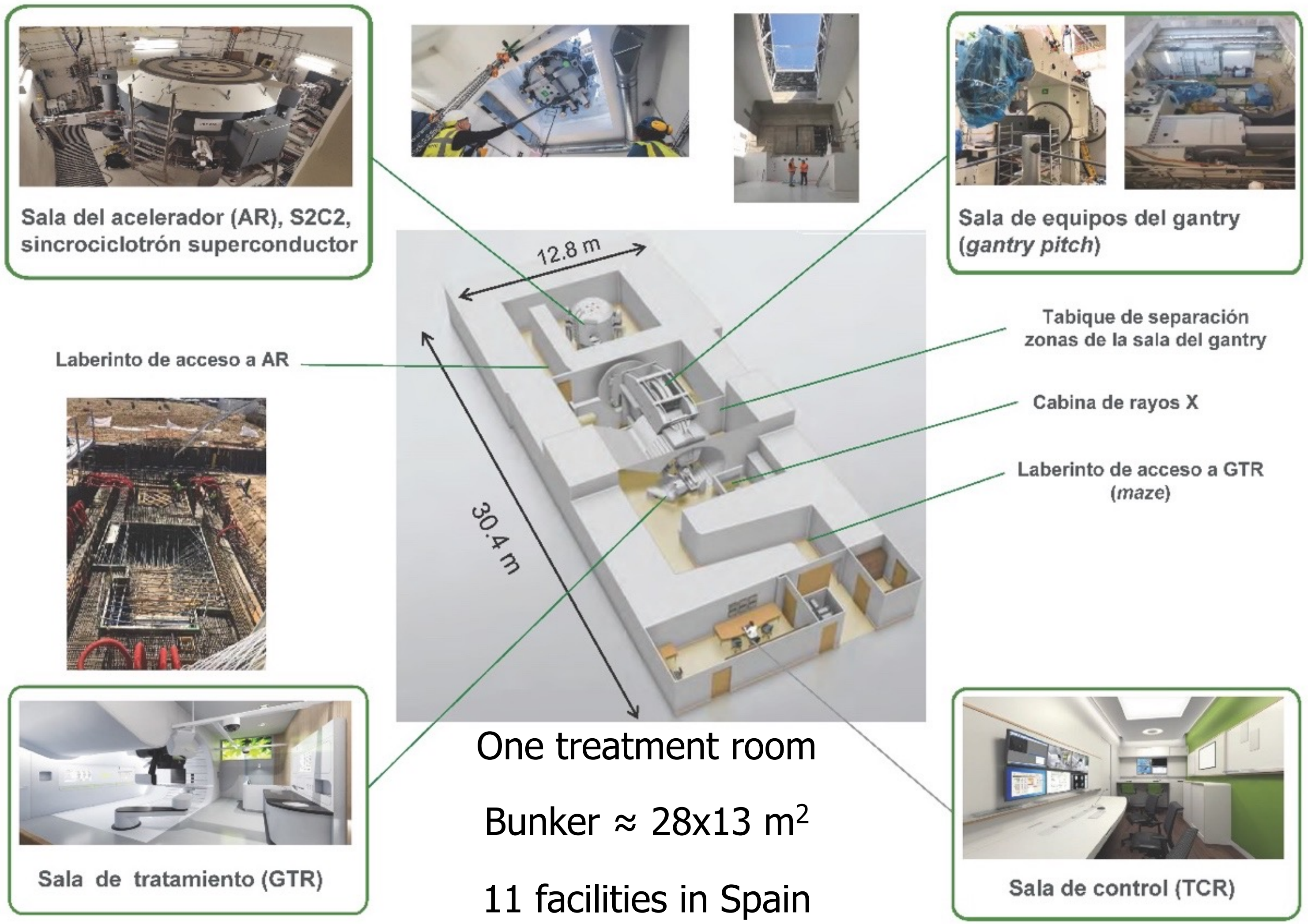


Nuclear data and nuclear physic models:
- ENDF
- JEFF
- TENDL
- JENDL

Monte Carlo codes:
- MCNP
- PHITS

Model of compact proton center
Synchrocyclotron



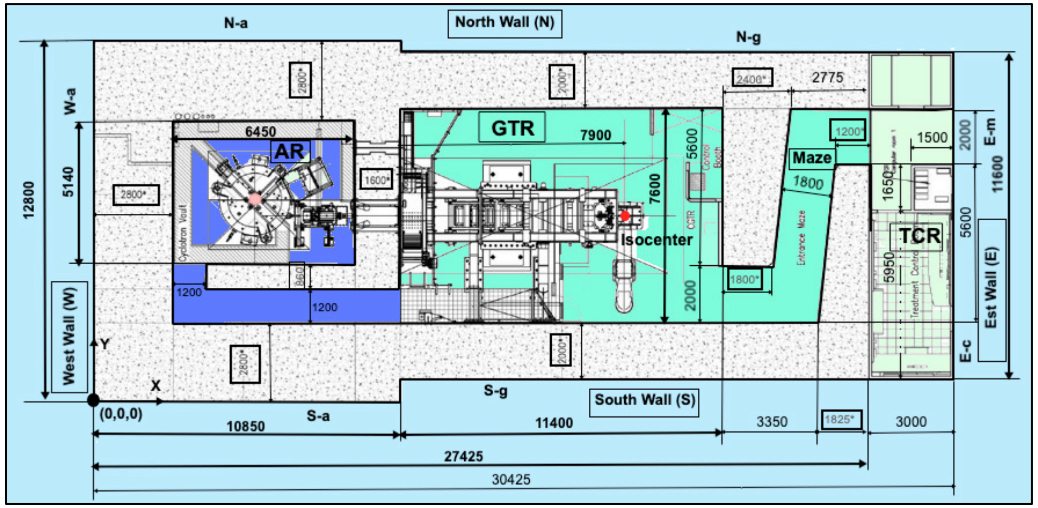


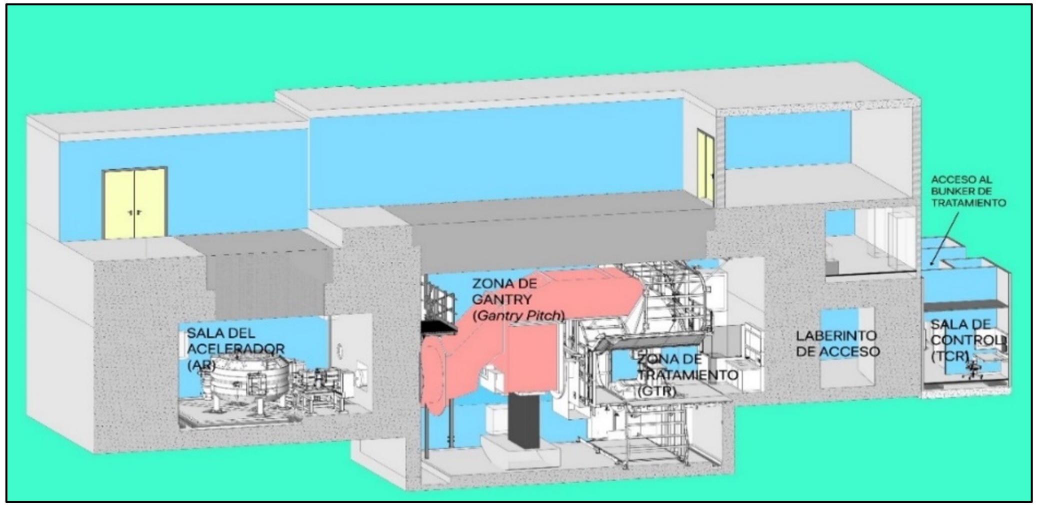
One treatment room

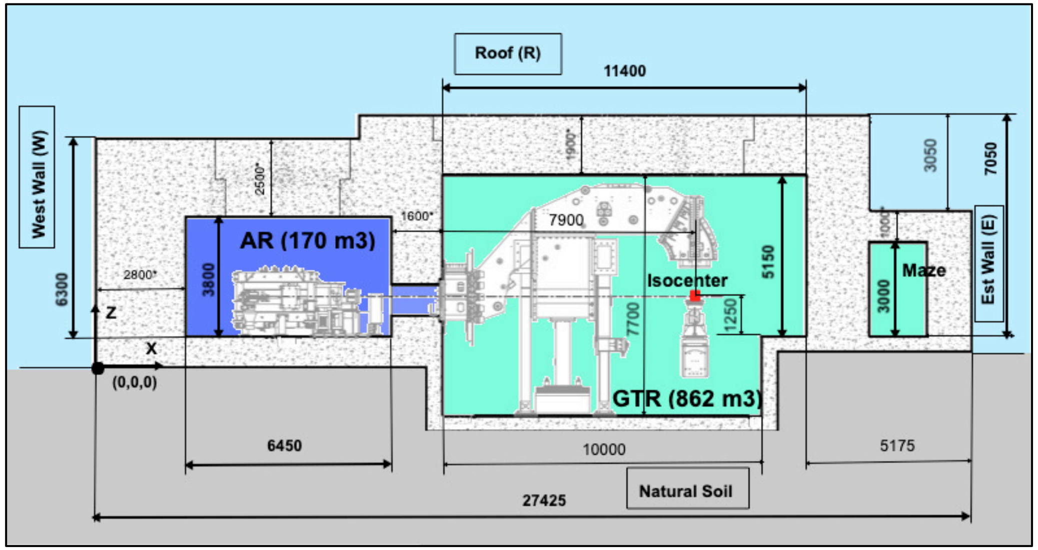
Bunker ≈ $28x13\ m^2$

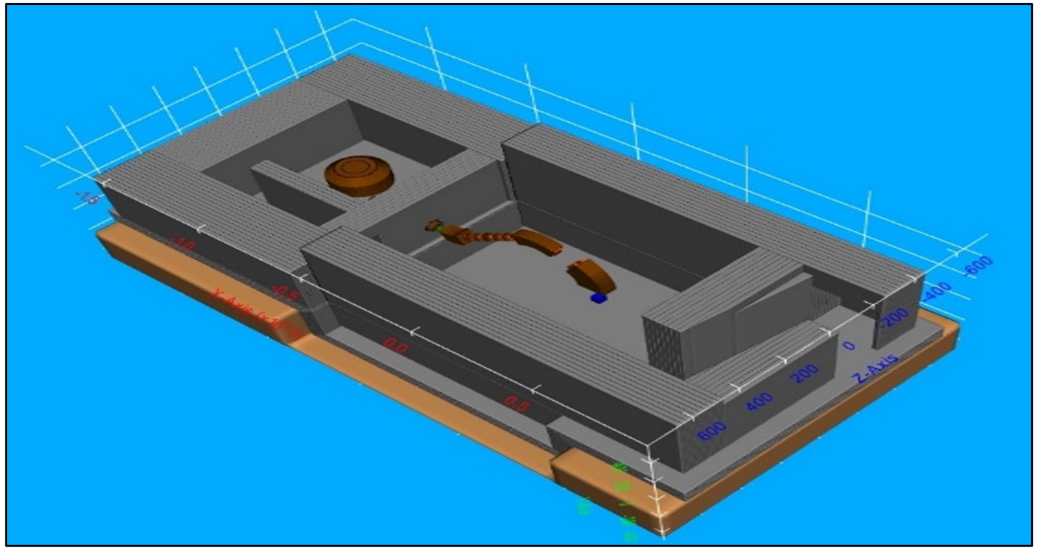
11 facilities in Spain

Model of compact proton center Synchrocyclotron

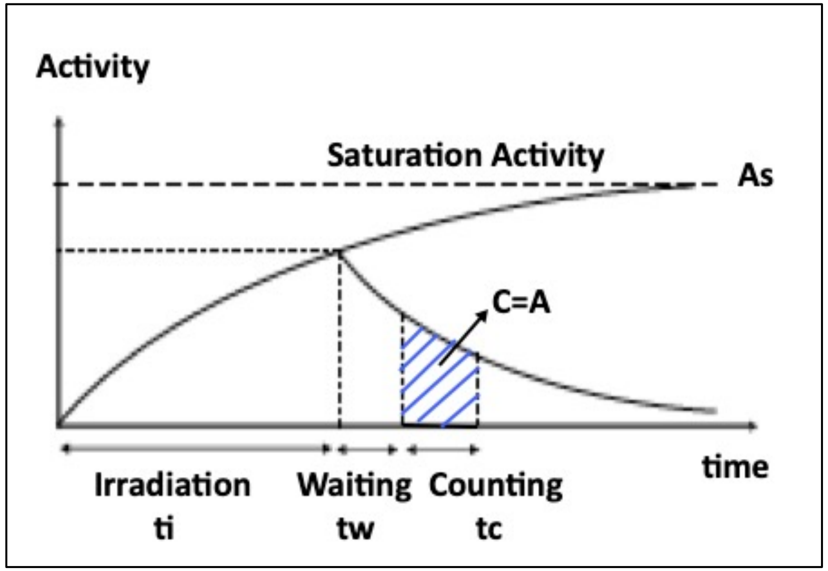








Activation process

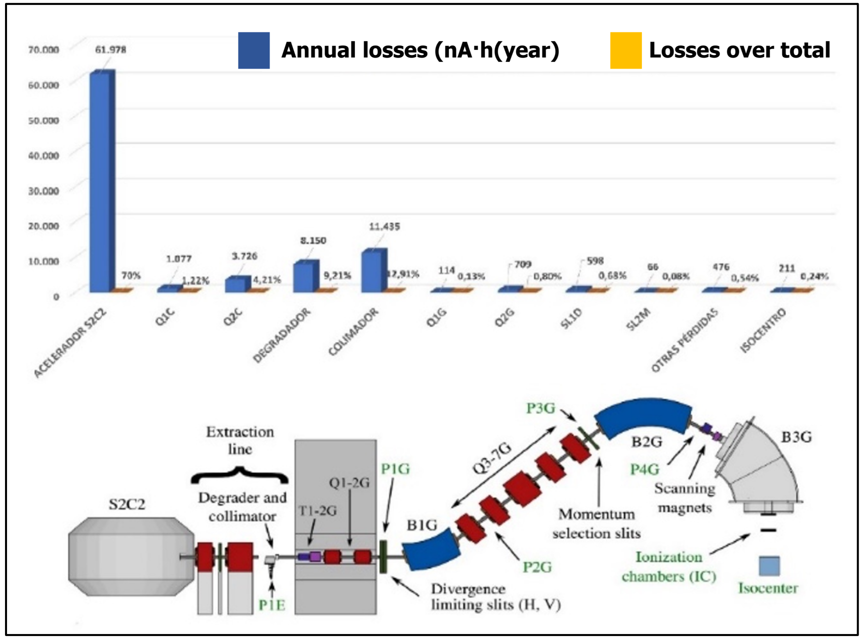


$$\frac{dN_i(t)}{dt} = N \cdot \phi'(E) \cdot \sigma(E) - \lambda \cdot N_i(t)$$

$$A(t) = \phi' \sigma \cdot N \cdot \left(1 - e^{-\lambda \cdot t_{irr}}\right)$$

$$A_{sat} = A(t \to \infty) = \phi' \cdot \sigma \cdot N$$

$$CI = \sum_i^n \frac{a_i}{(CL)_i} \leq 1$$ *Clearance Index*

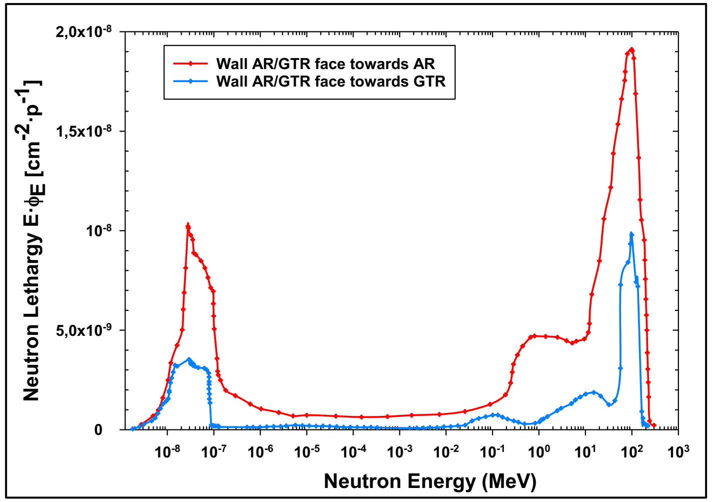


Irradiation time:

t=20 years

No cooling

Tiempo de irradiación en número de periodos de semidesintegración	1	2	3	4	5	6	7	8	9	10
Valor del factor de saturación en % de la actividad de saturación	50	75	87,5	93,75	96,87	98,44	99,1	99,61	99,80	99,90



Neutron fluence: ϕ

Monte Carlo codes

Annual Workload: *3,19·10^8 nC/year*

I=10,1 nA

I=6,31·10^10 p/s

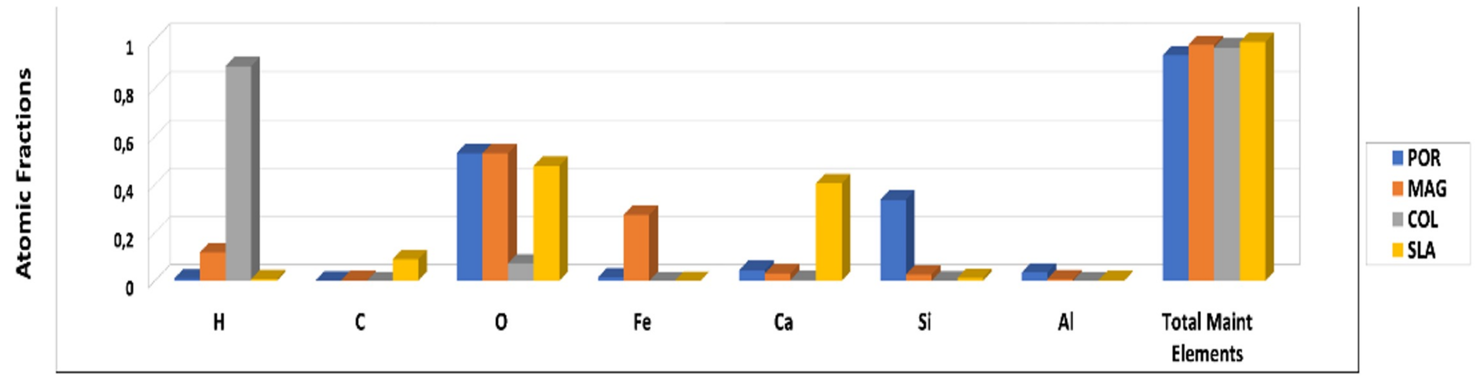
Fluence Rate, $\phi' = \phi \cdot I$

SATIF-16
May 28-31, 2024

Types of concrete

Element	Portland (POR)	Magnetite (MAG)	Colemanite (COL)	Special Low Activation (SLA)
H	0.01	0.118	0.891	0.0072
C	0.001	0.0016	0.0003	0.089
O	0.53	0.5292	0.0727	0.4776
Fe	0.014	0.2736	0.00005	0.0006
Ca	0.044	0.0309	0.0031	0.40492
Si	0.337	0.0263	0.0011	0.012
Al	0.034	0.007	0.0003	0.0027
Mg	0.002	0.007	0.0006	0.0024
Na	0.016	0	0	0.0008
B	0	0	0.029703	0
K	0.011	0.0013	0.00008	0.0003
Mn	0	0.0001	0	0
Ti	0	0.0009	0	0
V	0	0.0002	0	0
S	0	0.0007	0.000008	0.0009
P	0	0.0022	0	0
Sr	0	0	0.000041	0.0003
N	0	0	0.000018	0
Cu	0	0	0	0.00008
Ru	0	0	0	0.0002
Density (g/cm^3)	**2.30**	**4.10**	**2.12**	**2.18**

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



Maint elements in concretes analyzed in the work

Aggregates
- sand
- gravel

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%, ^{152}Eu, 52%,*

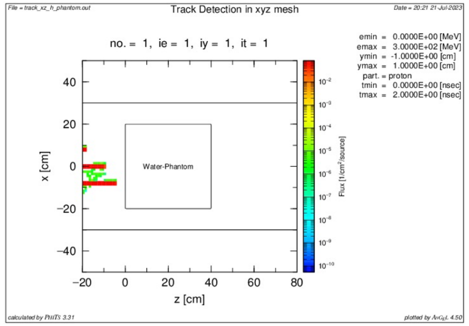
*****Isotopic composition, ^{133}Cs, 100%*

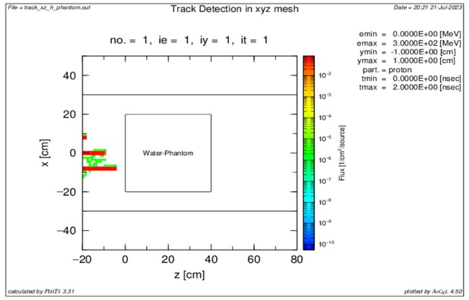
SATIF-16
May 28-31, 2024

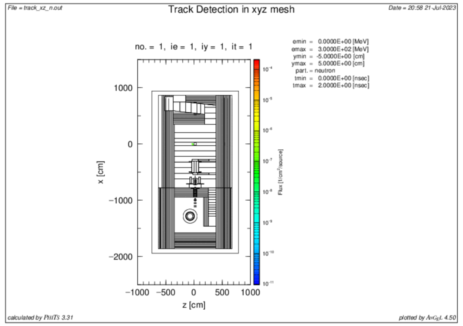
Calculating scenarios
Source term: Neutron yielding

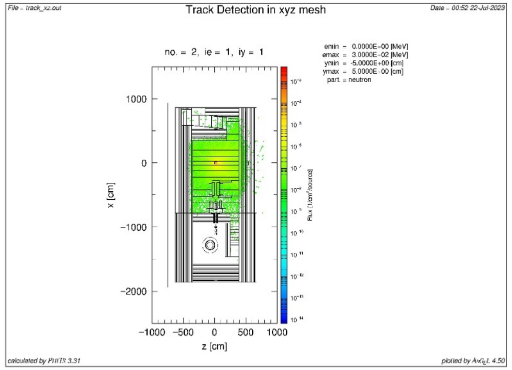
Case	Element	Place	Material	Energy in (*MeV*)	Energy out (*MeV*)	Charge (*nA·h*)	Scenario
1	Accelerator	Circunference of acceleration	Fe + Cu 45 cm	**230**	**230**	22.135	1, 2
2	Accelerator	Extraction	Fe + Cu 30 cm	**230**	**230**	39.843	1, 2
3	Q1C	Entrance Q1C	Fe + Cu 29 cm	**230**	**230**	1076,67	2
4	Q2C	Entrance Q2C	Fe + Cu 49 cm	**230**	**230**	4.802,43	1
5	Q2C	Entrance Q2C	Fe + Cu 49 cm	**230**	**230**	3.725,76	2
6	Degrader	Entrance DEG	Be 19,137 cm	**230**	**70**	3.459,66	1, 2
7	Degrader	Entrance DEG	Be 17,933 cm	**230**	**86**	3.159,38	1, 2
8	Degrader	Entrance DEG	B 15,196 cm	**230**	**116**	1.077,10	1, 2
9	Degrader	Entrance DEG	C 10,054 cm	**230**	**160**	369,03	1, 2
10	Degrader	Entrance DEG	C 4,599 cm	**230**	**200**	83,14	1, 2
11	Degrader	Entrance DEG	Al 19,137 cm	**230**	**230**	2,10	1, 2
12	Collimator	Entrance COL	Ta 4 cm	**70**	**70**	4.192,82	1, 2
13	Collimator	Entrance COL	Ta 4 cm	**86**	**86**	4.021,11	1, 2
14	Collimator	Entrance COL	Ta 4 cm	**116**	**116**	1.649,63	1, 2
15	Collimator	Entrance COL	Ta 4 cm	**160**	**160**	1.006,43	1, 2
16	Collimator	Entrance COL	Ta 4 cm	**200**	**200**	412,16	1, 2
17	Collimator	Entrance COL	Ta 4 cm	**230**	**230**	152,47	1, 2
18-23	Q1G	Entrance Q1G	Fe + Cu 29 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	Values Table 30 for each energy	1, 2

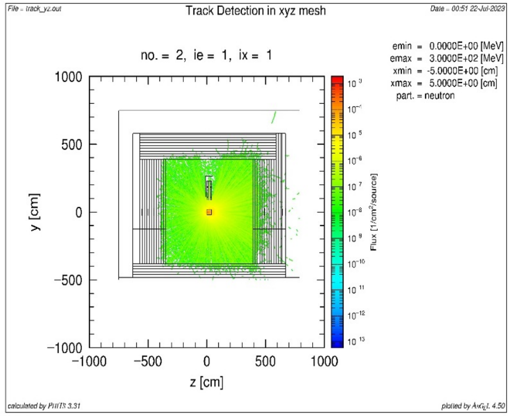
Case	Element	Place	Material	Energy in (*MeV*)	Energy out (*MeV*)	Charge (*nA·h*)	Scenario
24-29	Q1G	Entrance Q1G	Fe + Cu 29 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	10% Values Table 30 for each energy, Other losses	2
30-35	Q2G	Entrance Q2G	Fe + Cu 49 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	Values Table 30 for each energy	1, 2
36-41	Q2G	Entrance Q2G	Fe + Cu 49 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	60% Values Table 30 for each energy, Other losses	1
42-47	Q2G	Entrance Q2G	Fe + Cu 49 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	50% Values Table 30 for each energy, Other losses	2
48-53	SL1G	Entrance SL1G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	Values Table 30 for each energy	1, 2
54-59	SL1G	Entrance SL1G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	20% Values Table 30 for each energy Other losses	1
60-65	SL1G	Entrance SL1G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	17.5% Values Table 30 for each energy Other losses	2
66-71	SL2G	Entrance SL2G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	Values Table 30 for each energy	1, 2
72-77	SL2G	Entrance SL2G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	20% Values Table 30 for each energy Other losses	1
78-83	SL2G	Entrance SL2G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	17.5% Values Table 30 for each energy Other losses	2
84-89	SL3G	Entrance SL3G	Ni 12 cm	**70, 86, 116, 160, 200, 230**	**70, 86, 116, 160, 200, 230**	12.5% Values Table 30 for each energy Other losses	2
90-95	*Phantom*	*Phantom*	Water 40x40x40 cm^3	**70, 86, 116, 160, 200, 230**	-	25% Values Table 30 for each energía	1, 2 Gantry orientation *gantry* 0º
96-101	*Phantom*	*Phantom*	Water 40x40x40 cm^3	**70, 86, 116, 160, 200, 230**	-	50% Valores Tabla 30 para cada energía	1, 2 Gantry Orientation 90º
102-107	*Phantom*	*Phantom*	Water 40x40x40 cm^3	**70, 86, 116, 160, 200, 230**	-	25% Valores Tabla 30 para cada energía	1, 2



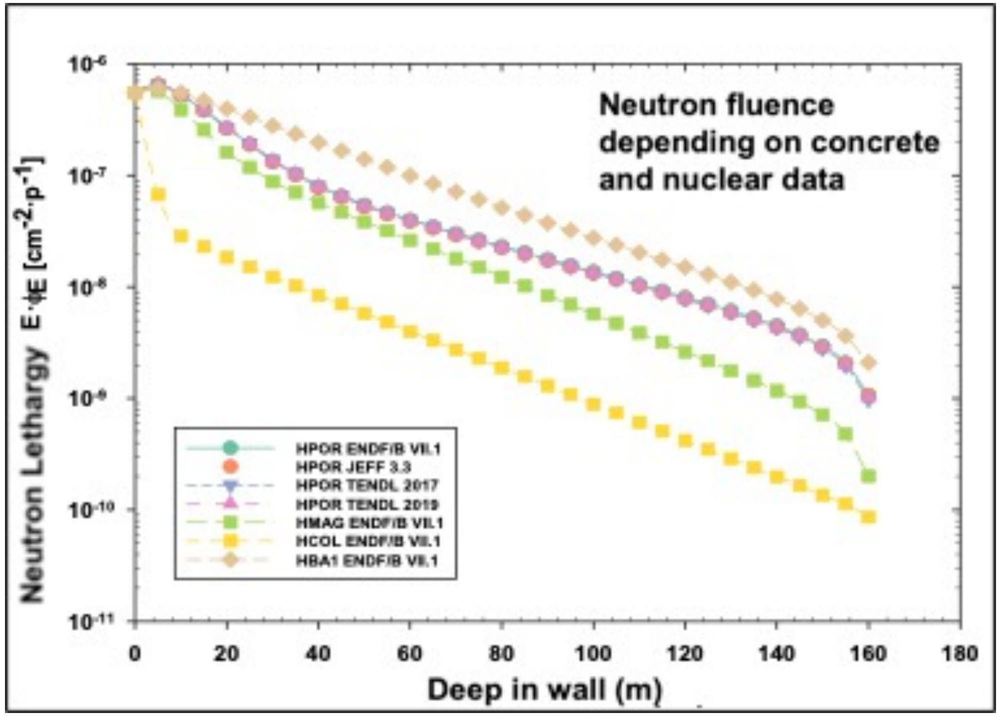


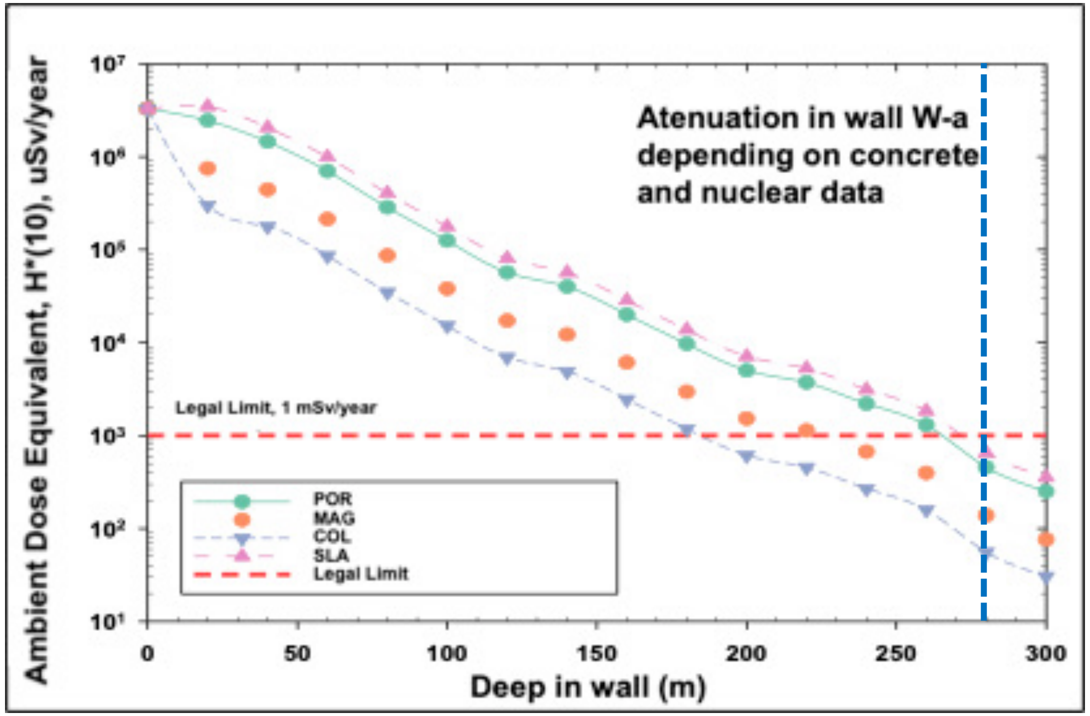


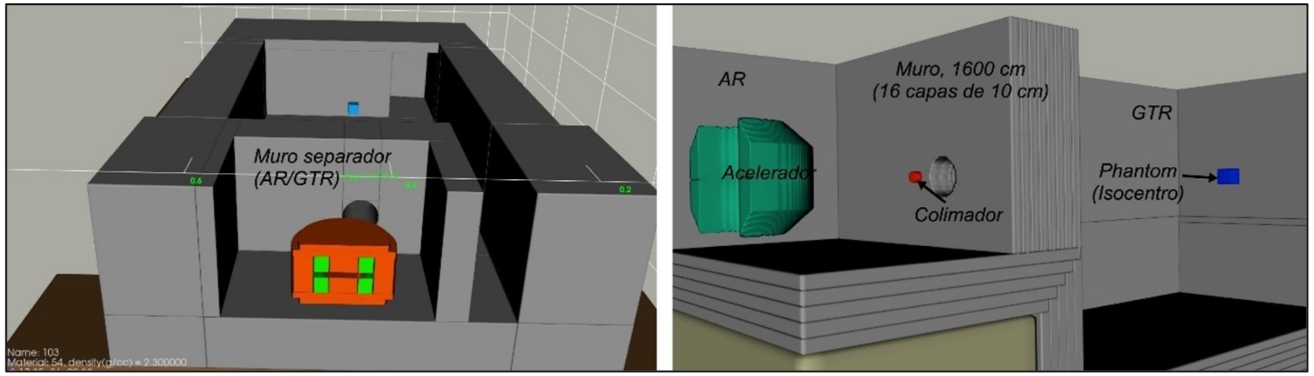




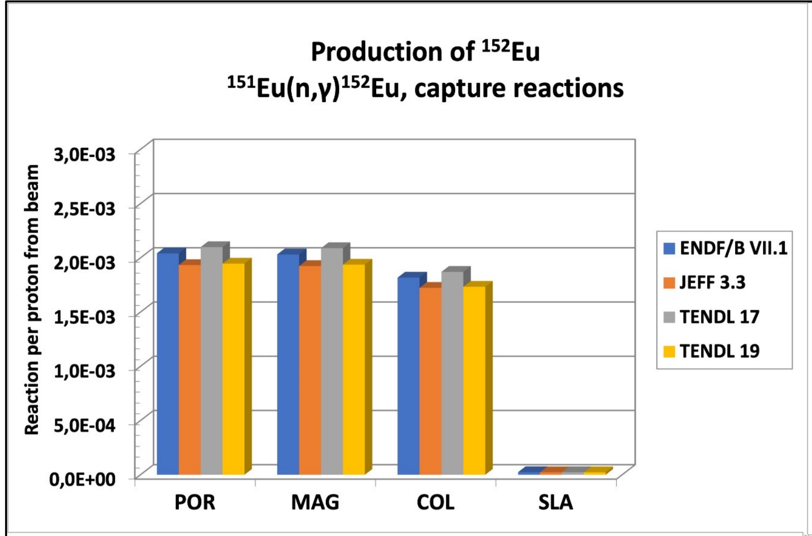
Results: Attenuation plots

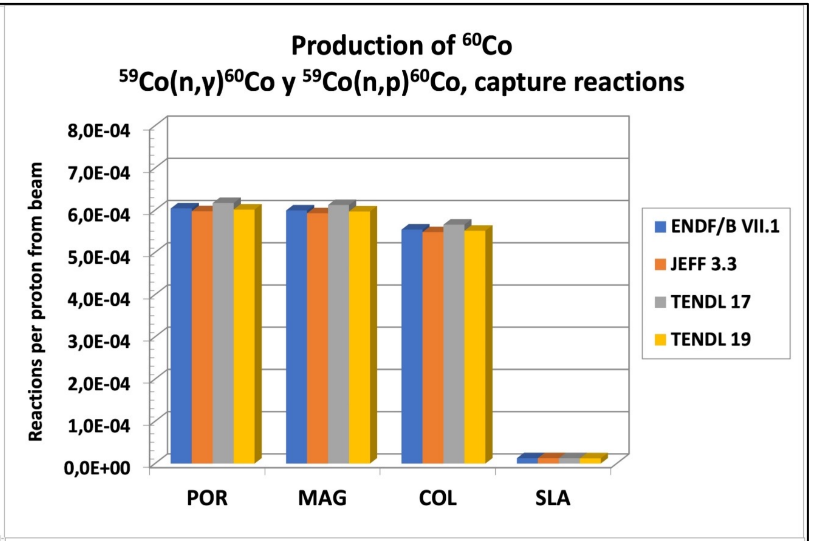


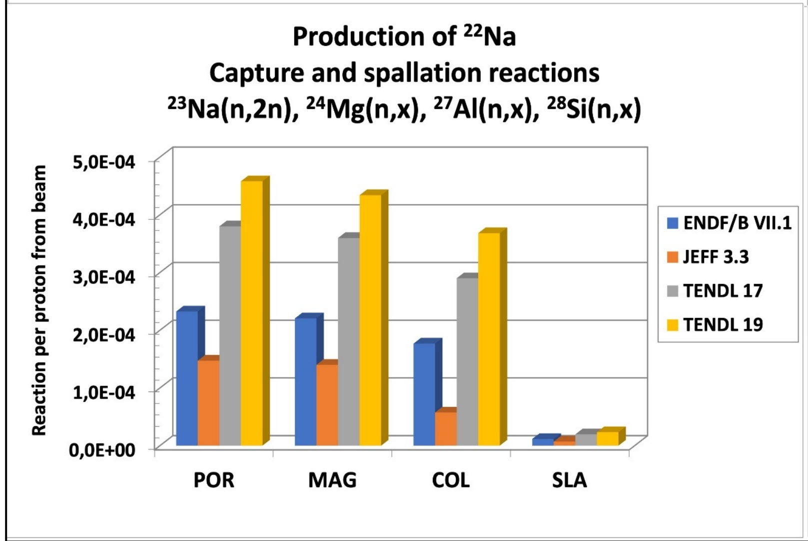


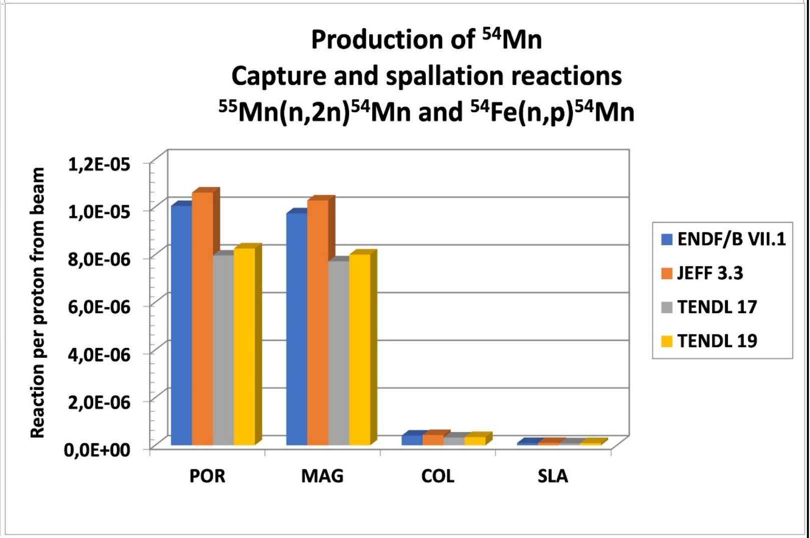


Results: Activation reactions



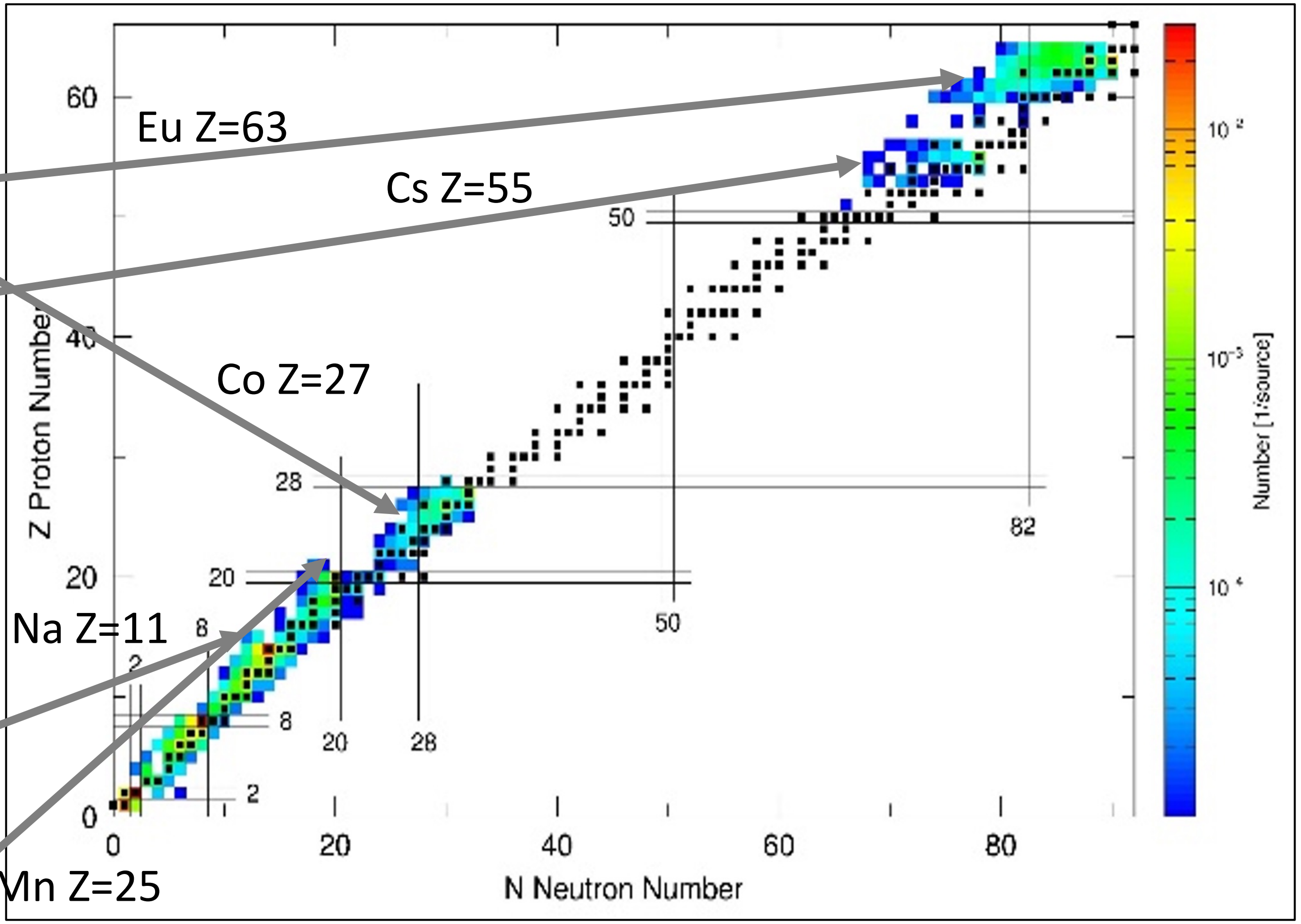




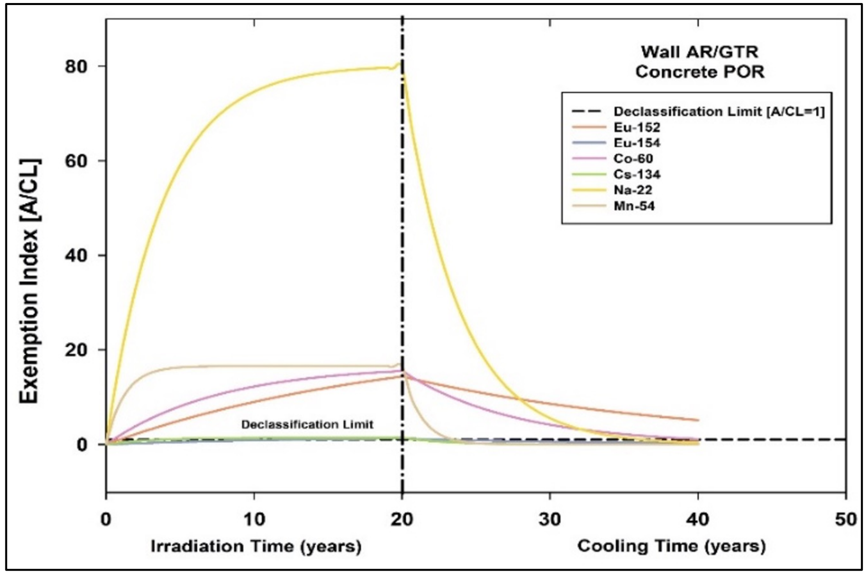


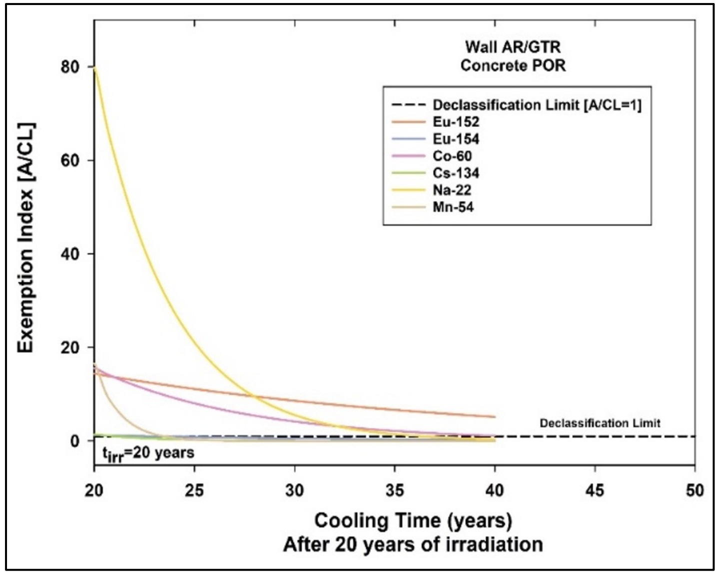
Results: Activation chart

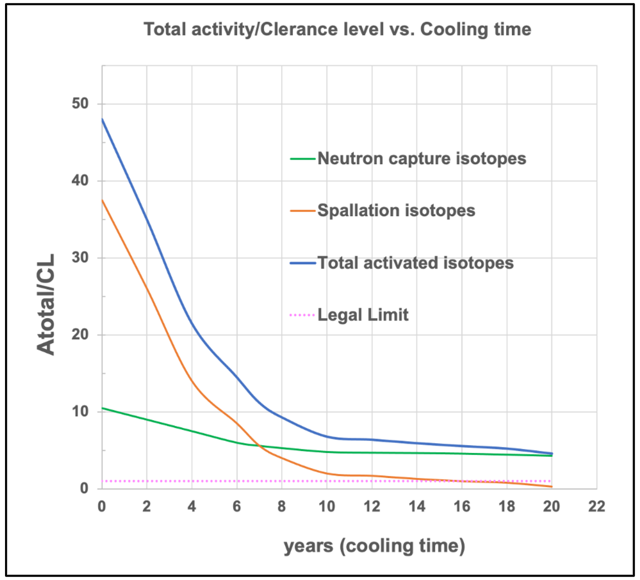
Radionuclide produced	Half life	Maximum energy of gamma rays	Reaction considered	Cross section (b)/abundance (%)	*Clearance Limit, CL, (Bq/g)*
Neutron capture channel					
^{152}Eu	13,3 y	1,41 MeV	^{151}Eu(n,γ)^{152}Eu	9200 b/48%	**0,1**
^{154}Eu	8,8 y	1,28 MeV	^{153}Eu(n,γ)^{154}Eu	320 b/52%	**0,1**
^{60}Co	5,27 y	1,33 MeV	^{59}Co(n,γ)^{60}Co	37 b/100%	**0,1**
^{134}Cs	2,07 y	0,8 MeV	^{133}Cs(n,γ)^{134}Cs	29 b/100%	**0,1**
^{65}Zn	244 d	1,12 MeV	^{64}Zn(n,γ)^{65}Zn	0,78 b/49%	**0,1**
^{46}Sc	0,23 a (84 d)		^{45}Sc(n,γ)^{46}Sc	27 b/100%	**0,1**
^{35}S	0,239 a (87 d)		^{34}S(n,γ)^{35}S		**100**
^{45}Ca	0,445 y		^{44}Ca(n,γ)^{45}Ca	/	**100**
^{55}Fe	2,74 y		^{54}Fe(n,γ)^{55}Fe	/	**100**
^{59}Fe	44,6 d	1,29 MeV	^{58}Fe(n,γ)^{59}Fe	1,15 b/0,31%	**0,1**
Espalation channel					
^{22}Na	2,6 y		^{23}Na(n,2n)^{22}Na ^{24}Mg(n,x)^{22}Na ^{27}Al(n,2p4n)^{22}Na ^{28}Si(n,x)^{22}Na	0,017 b/100% /100% 0,010 b/100% /100%	**0,1**
^{54}Mn	0.855 y (312 d)	0,834 MeV	^{55}Mn(n,2n)^{54}Mn ^{54}Fe(n,p)^{54}Mn	0,79 b/100% 0,39 b/6%	**0,1**

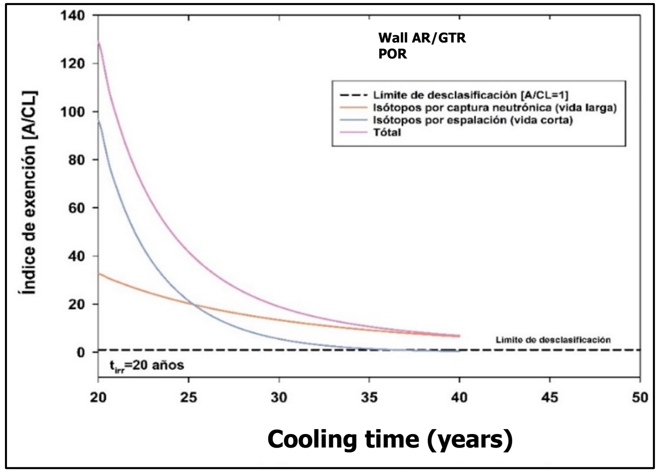


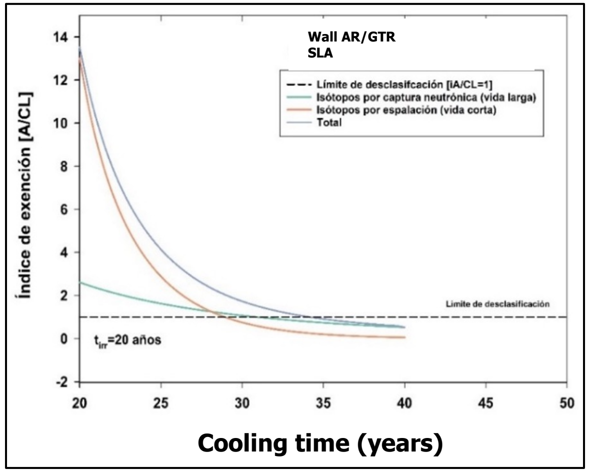
Results: Activation/cooling plots







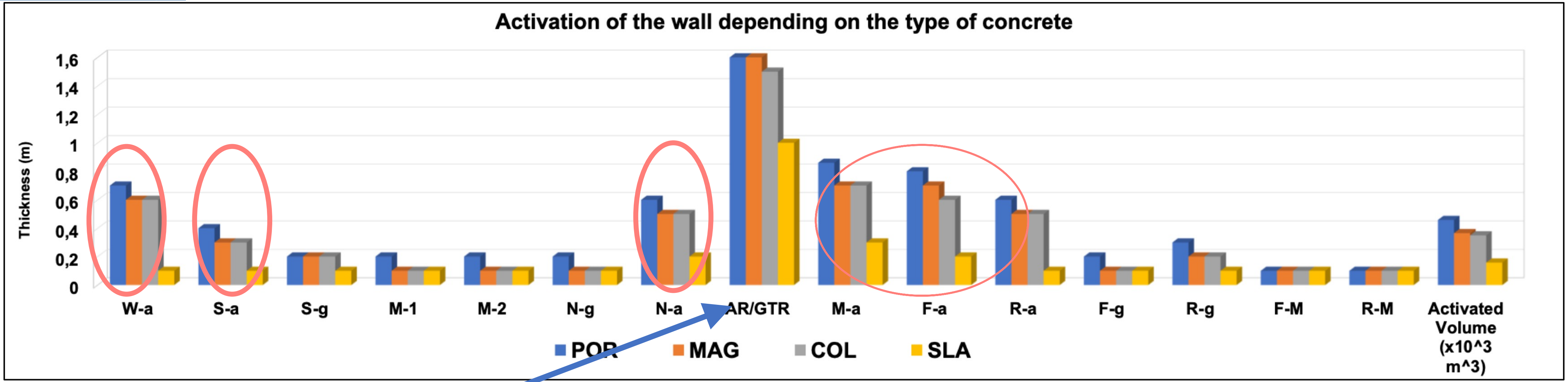


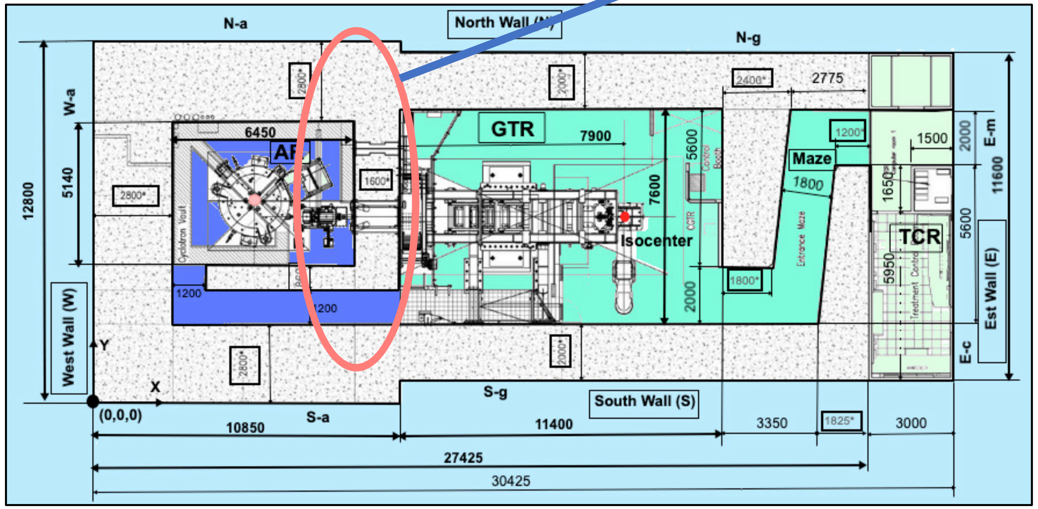


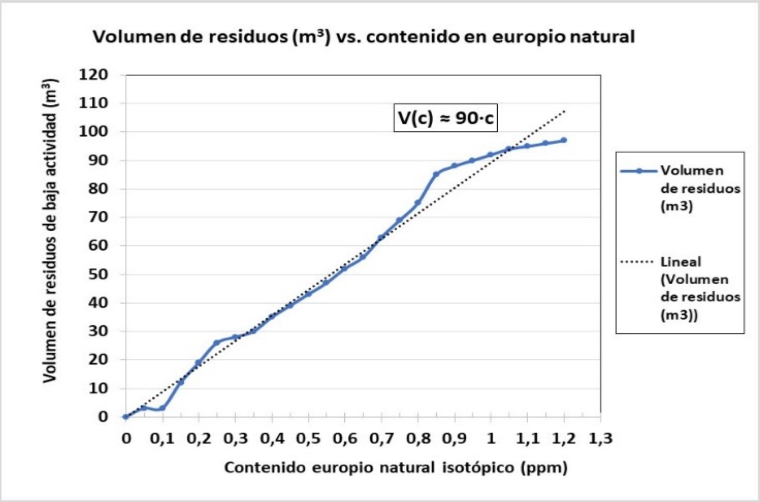
Irradiation time

% Saturation activity

Results: Activation of walls





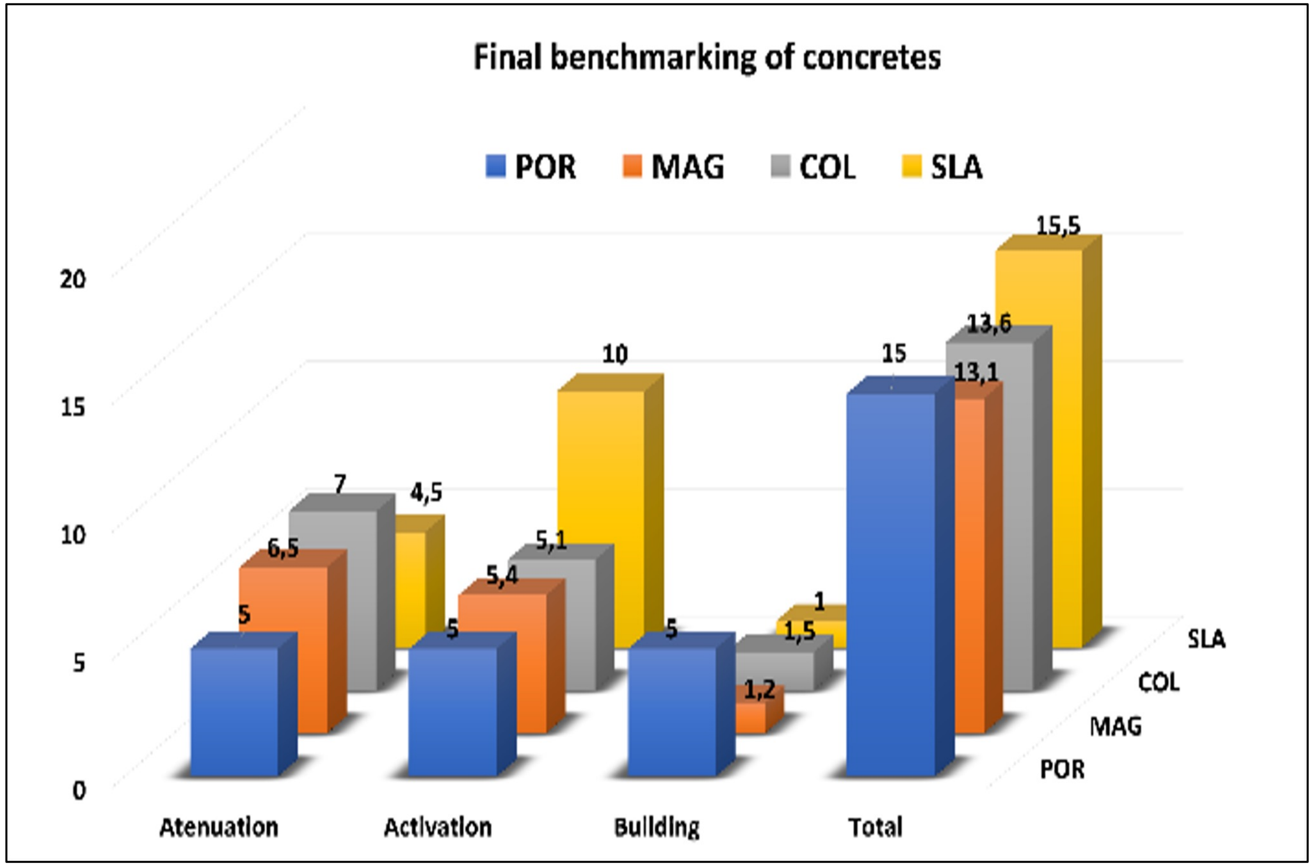


Results: Comparing types of concrete

Building cost

1. POR: 458 m³ 0.18 M€
2. MAG: 365 m³ 0.75 M€
3. COL: 350 m³ 0.6 M€
4. SLA: 158 m³ 1 M€

Based on prices in Spain on Jun 22



Decommissioning costs

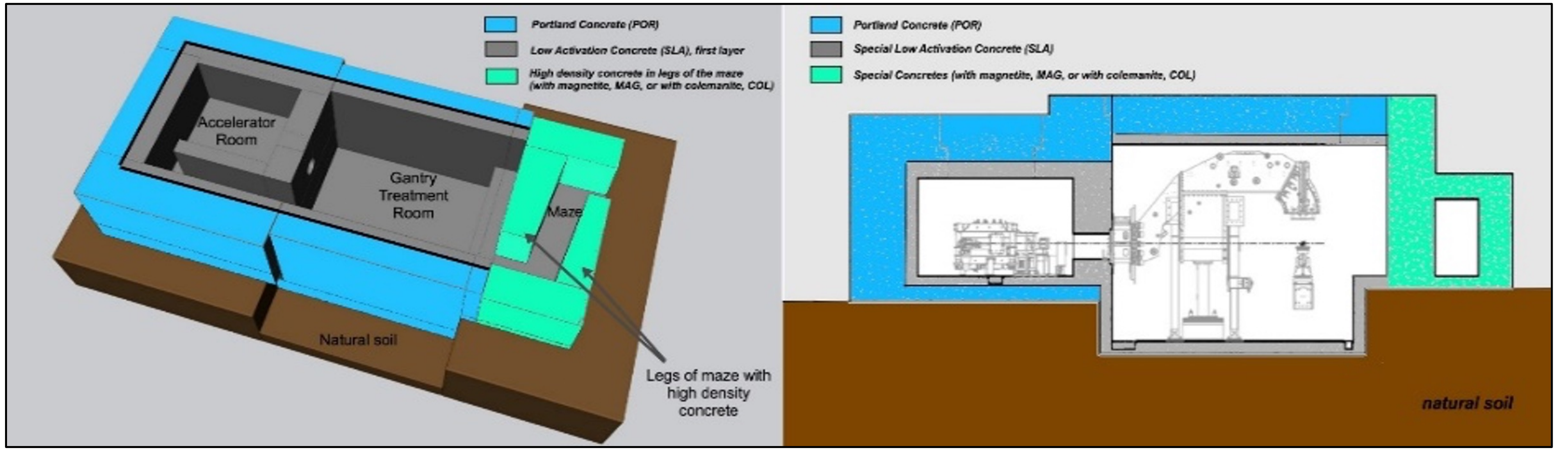
V>200 m ^{3} → €142,000 + €2,710 (V-200)

(first 200 m ^{3}, €710/m ^{3}, rest €2,710/m ^{3})

Based on Spanish's Regulator Taxes on Jun 22

Some final proposals…

Using layers with different types of concrete



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

Control of the activation of shielding

Matsumura et al. 2022

Paper Radiation Safety Management Vol. 21 (13–25)

Investigation of Concrete Radioactivation in Cyclotron Type Proton Therapy Facilities using in situ ^{24}Na Measurement Method

Hiroshi MATSUMURA[1)*], Go YOSHIDA[1)], Akihiro TOYODA[1)], Kazuyoshi MASUMOTO[1)], Hajime NAKAMURA[1)], Taichi MIURA[1)], Koichi NISHIKAWA[1)], Kotaro BESSHO[1)], Tsunemichi AKITA[2)], Shoichi KATSUTA[2)], Tetsuo AKIMOTO[2)], Yuya SUGAMA[3)], Fumiyoshi NOBUHARA[4)], and Yoko NAGASHIMA[4)]

[1)] High Energy Accelerator Research Organization (KEK), Oho 1-1, Tsukuba, Ibaraki 305-0801, Japan
[2)] National Cancer Center Hospital East, 6-5-1 Kashiwanoha, Kashiwa-shi, Chiba 277-8577, Japan
[3)] Aizawa Hospital Proton Therapy Center, 2-5-1 Honjou, Matsumoto City, Nagano 390-8510, Japan
[4)] Tokyo Nuclear Services Co., Ltd., 1-3-5, Taito, Taito-ku, Tokyo 110-0016, Japan

Received Sep. 9, 2020; accepted May 23, 2022

Ramoiseaux et al. 2023

Ramoisiaux et al. *EPJ Techniques and Instrumentation* (2023) 10:9
https://doi.org/10.1140/epjti/s40485-023-00095-4
EPJ.org
EPJ Techniques and Instrumentation
RESEARCH ARTICLE Open Access

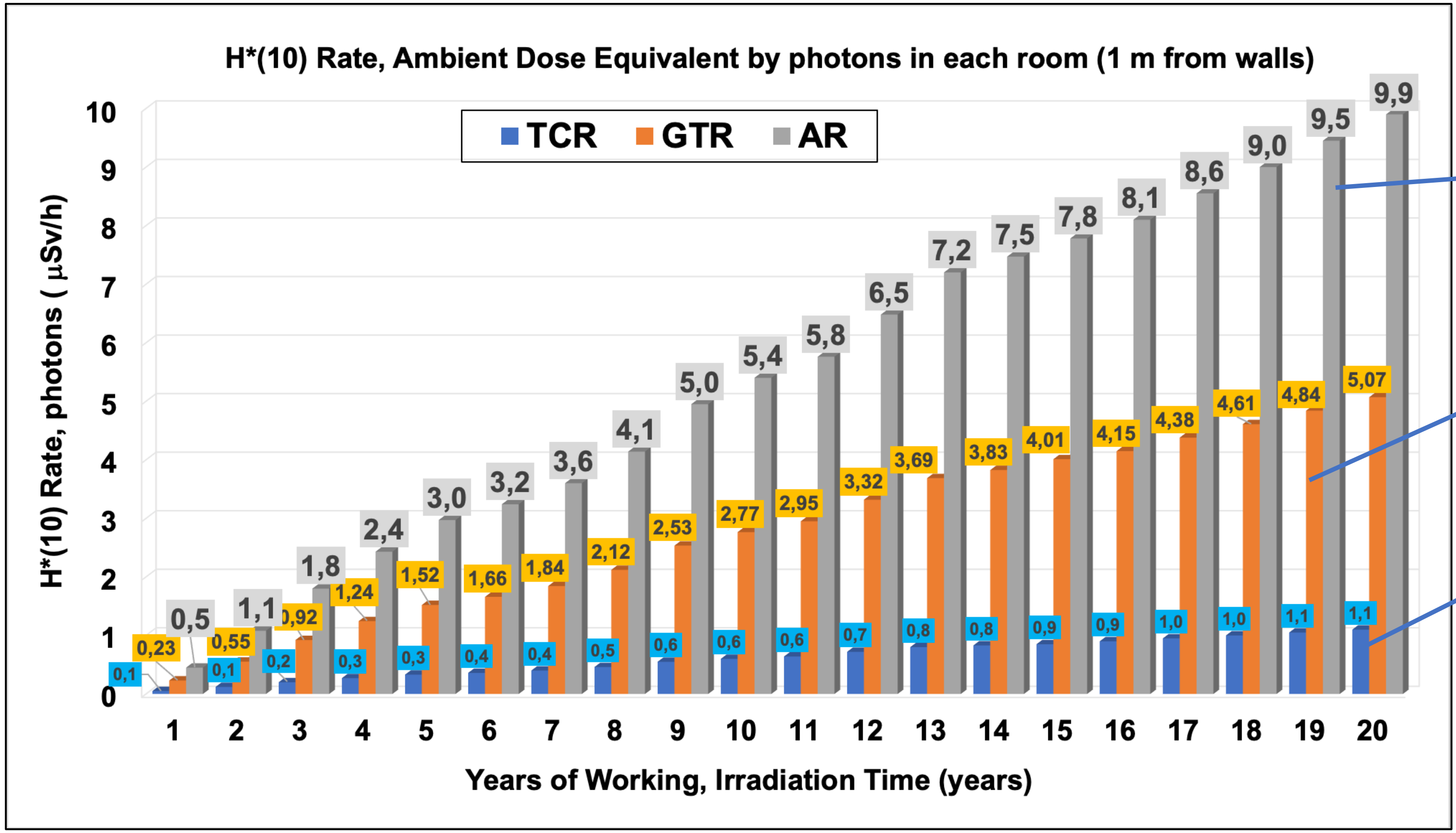
Hybrid monitoring and measurement of concrete shielding activation at the ProtherWal proton therapy centre

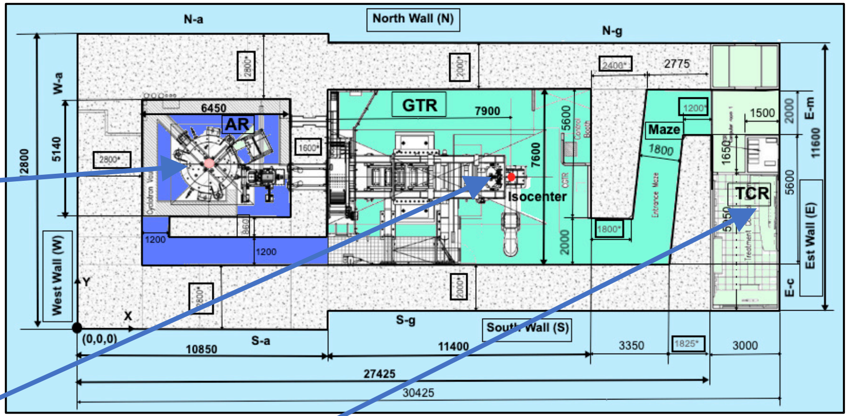
E. Ramoisiaux[1*], C. Hernalsteens[1,2*], R. Tesse[1], E. Gnacadja[1], N. Pauly[1] and F. Stichelbaut[3]

*Correspondence: elliott.ramoisiaux@ulb.be; cedric.hernalsteens@cern.ch
[1] Service de Métrologie Nucléaire, Université libre de Bruxelles, Brussels, Belgium
[2] CERN, European Organization for Nuclear Research, 1211, Geneva, 23, Switzerland
Full list of author information is available at the end of the article

Abstract
Proton therapy systems produce large fluxes of energetic secondary particles when tailoring the beam energy and transverse profile to the specificities of each irradiation plan. A Low Activation Concrete (LAC) mix is foreseen for parts of the shielding of the Ion Beam Applications (IBA) Proteus® One (P1) compact system at the ProtherWal proton therapy centre in Charleroi, Belgium, to limit the long-term activation of the concrete shielding. To experimentally monitor the long-term activation and validate

Coming soon to screens…
Ambient Dose from photons in walls





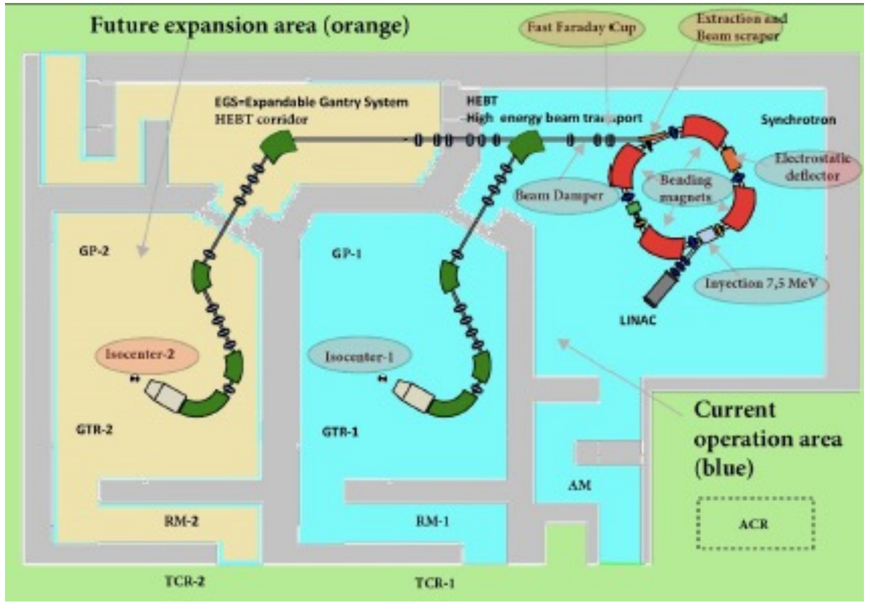
Considering POR concrete as dose reference

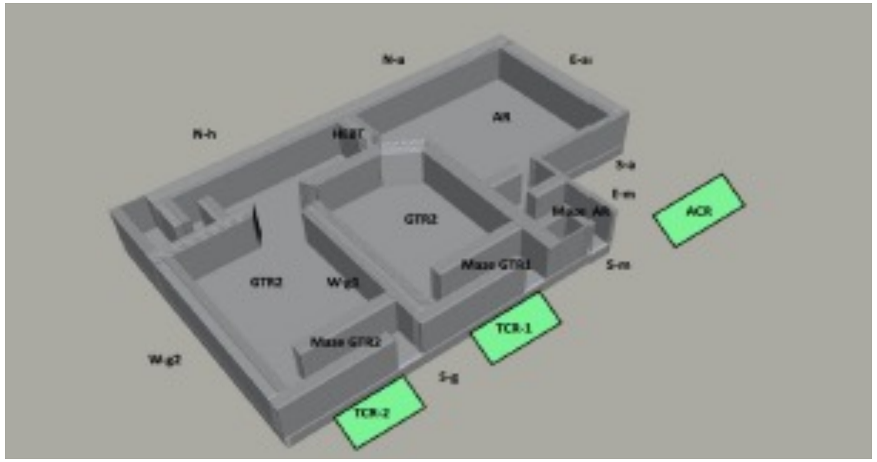
MAG≈0.92

COL≈0.98

SLA≈0.62

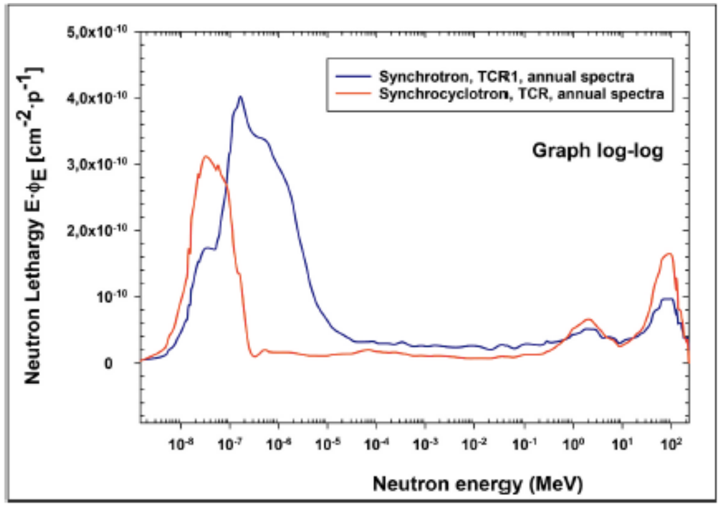
Model: Synchrotron



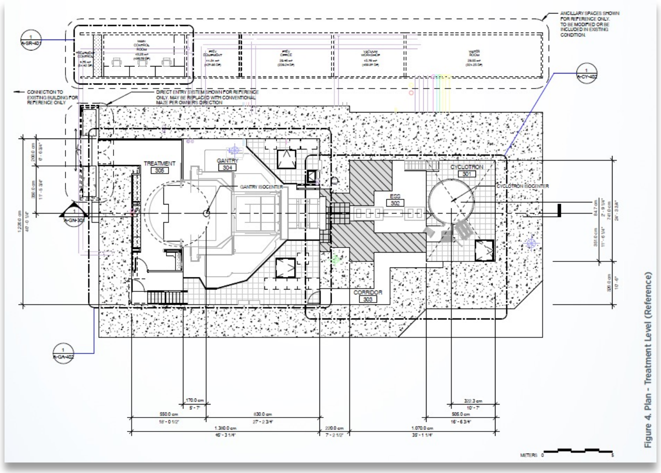


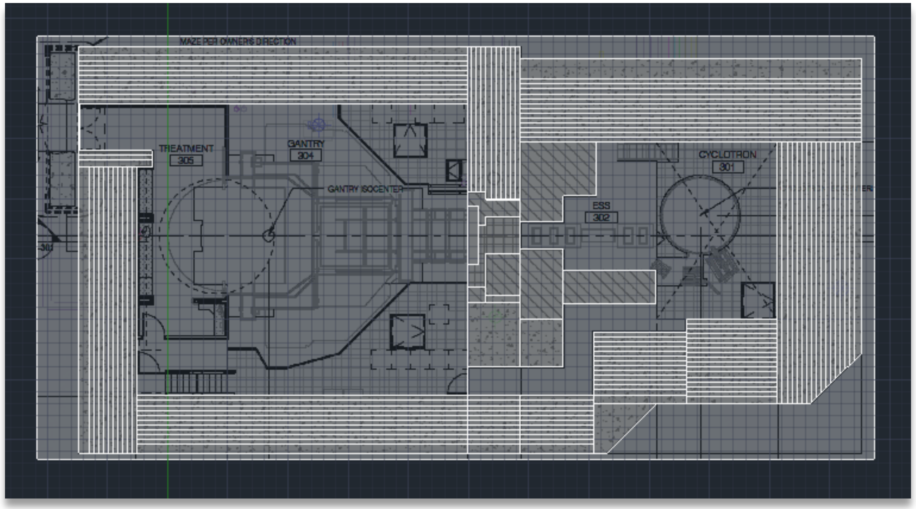
Annual workload considered in a CPCT with synchrotron.

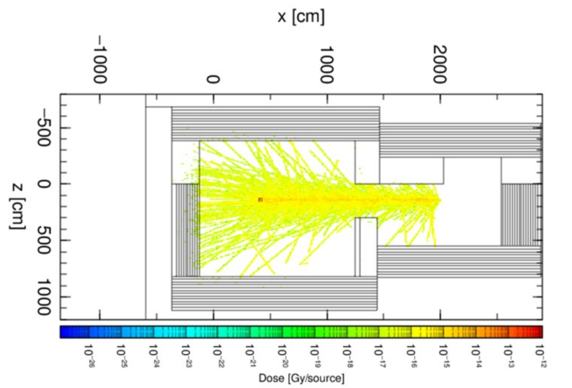
Nominal energy (MeV)	Nominal range (g/cm²)	Proton beam per tretament of 2 Gy (nA)	Annua workload at the phantom in the isocenter (nA·h)/y
170	18.4	0,27	50,65
200	26.0	0,17	105,54
230	32.9	0,13	54,89
Total annual workload at the isocenter, W_{iso} (nA·h)/year			211,08

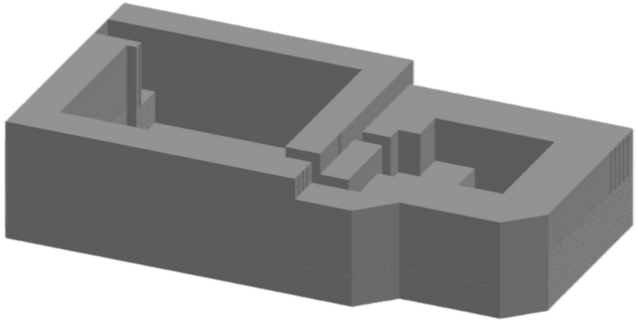


Model: Isocyclotron

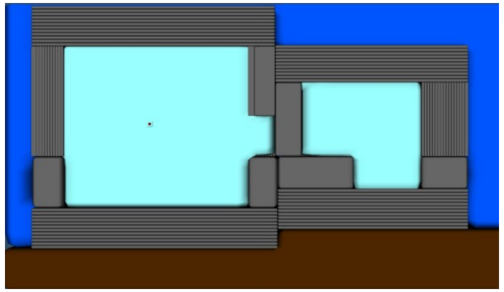


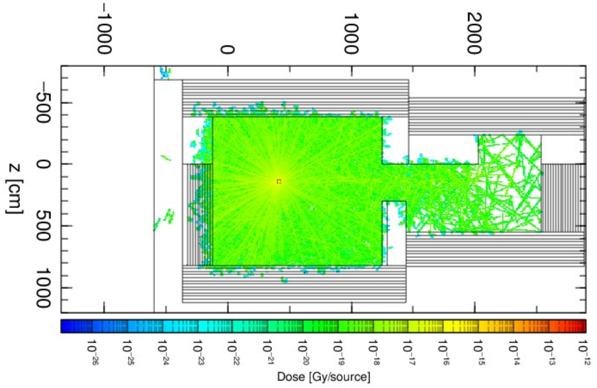






SuperMC





CAD

PHITS

Radiation fields

Summary

Behavior of different types of concrete for shielding in proton therapy centers was assessed

The amount of activated material is relevant, in a first stage, but the type of activation and the isotopes present is very relevant (quality: long and short life)

From the attenuation point of view, the four concretes meet the necessary dose attenuation conditions. Special concretes, MAG and COL, have much superior attenuation properties

From the point of view of activation, the most recommended concretes are those with a lower content of impurities that can be activated and generate radioactive waste. Direct relationship between the amount of activated concrete and the fraction of impurities (Eu)

Considering that the neutron flux and the neutron spectrum vary significantly in each area, it would be advisable to use different concretes, optimizing the selection with criteria based on attenuation, activation, and cost, for example.

References

1. Cossairt, J.D., Quinn, M. *Accelerator radiation physics for personnel and environmental protection*. Boca Raton, FL, CRC Press, Taylor & Francis Group, 2019.
2. Vincke, H., Theis C, Roesler S. *Induced radioactivity in and around high-energy particle accelerators*. Radiation Protection Dosimetry. 2011, 146(4): 434-9.
3. Infantino, A. *Advanced aspects of radiation protection in the use of particle accelerators in the medical field*. TD. Universitá Degli Studi di Bologna (2015).
4. Carbonez, P., La Torre, F.P., Michaud, R., Silari, M. *Residual radioactivity at the CERN 600MeV synchrocyclotron*. Nuc. Inst. Met. (A). Volume 694, 2012, pages 234-245.
5. EC. 1999. European Commission. *Evaluation of the radiological and economic consequences of decommissioning particle accelerators*. Report of European Commission 19151, 1999.
6. EC. 2013. European Commission. *Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom*. Of. J. EU. 13 1–73, 2014.
7. IAEA. 2019. International Atomic Energy Agency. *Methodologies for assessing the induced activation source term for use in decommissioning applications*. SRS, 95, 2019.
8. IAEA. 2020a. International Atomic Energy Agency. *Decommissioning of particle accelerators*. IAEA, NES. NW-T-2.9, 2020.
9. IAEA. 2007. International Atomic Energy Agency*. Application of the concepts of Exclusion, Exemption and Clearance.* Safety Guide. RS-G-1.7. 2007.
10. IAEA. 1988. International Atomic Energy Agency. Thomas, R.H., Stevenson, G.R. *Radiological safety aspects of the operation of proton accelerators*. TRS 283. IAEA.
11. NCRP. 2005. *Radiation Protection for Particle Acceleration Facilities*. Recommendations of the National Council on Radiation Protection and Measurements, Report 144, Rev. 2005.
12. Ipe, N.E. PTCOG. *Shielding Design and Radiation Safety of Charged Particle Therapy Facilities*. PTCOG Report 1, Particle Therapy Cooperative Group (2010).
13. IAEA. 2020b. International Atomic Energy Agency. *Regulatory control of the safety of ion radiotherapy facilities*. IAEA-TECDOC-1891. IAEA, Vienna, 2020.
14. Chadwick, M.B., Herman, M., Obložinský, P., *et al. ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data*. Nuclear Data Sheets, Volume 112, Issue 12, 2011, Pages 2887-2996, ISSN 0090-3752.
15. Plompen, A.J.M., *et al. The joint evaluated fission and fusion nuclear data library, JEFF-3.3*. 2020, The European Physical Journal A. Springer Berlin Heidelberg.
16. Shibata, K, Iwamoto, O, Nakagawa, T., Iwamoto, N., *et al. JENDL-4.0: A New Library for Nuclear Science and Engineering*. J. Nuc. Sc. Tech., Vol. 48, No. 1, p. 1-30, 2011.
17. García-Fernández, G.F., Gallego, E., Gómez-Ros, J.M., Vega-Carrillo, H.R., Cevallos-Robalino, L.E., *et al. Benchmarking of stray neutron fields produced by synchrocyclotrons and synchrotrons in compact proton therapy centers (CPTC) using MCNP6 Monte Carlo code*. Applied Radiation and Isotopes, Vol. 193 (2023), pp. 110645.
18. Werner, C.J. (Ed.), 2017. *MCNP User's Manual - Code Version 6.2, LA-UR-17-29981*. Los Alamos National Laboratories.
19. Sato, T., Iwamoto, Y., Hashimoto, S., Ogawa, T., *et al. Features of Particle and Heavy Ion Transport Code System PHITS Version 3.02*. J. Nucl. Sci. Technol. 55, 684-690 (2018).
20. Silari, M., Stevenson, G.R. *Radiation protection at high energy proton accelerators*. Radiation Protection Dosimetry. Vol. 96, No 4, pp. 311–321 (2001).
21. Carroll, L.R. *Predicting Long-Lived, Neutron-Induced Activation of Concrete in a Cyclotron Vault*. American Institute of Physics, 2001.
22. Ramoisiaux,E., Tesse, R., Hernalsteens, C. *et al. Self-consistent numerical evaluation of concrete shielding activation for proton therapy systems - Application to the proton therapy research centre in Charleroi, Belgium*. Eur. Phys. J. Plus, 137 8 (2022) 889.
23. Vega-Carrillo, H.R., Guzmán-García, K.A., Rodríguez-Rodríguez, J.A., *et al. Photon and neutron shielding features of quarry tuff*. Annals of Nuc. Energy, 2018 (112): 411-417.
24. García-Fernández, G.F., Gallego, E., Gómez-Ros, J.M., Vega-Carrillo, H.R., García-Baonza, R., Cevallos-Robalino, L.E., Guzmán-García, K.A. *Neutron dosimetry and shielding verification in commissioning of Compat Proton Therapy Centers (CPTC) using MCNP6.2 Monte Carlo code*. Applied Radiation and Isotopes, Vol. 163 (2021), pp. 109279.

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

Session 5: Induced Radioactivity abd Decommissioning
Thursday, May 30, 12.50 – 13.10 h
Contribution #81

Gonzalo Felipe García-Fernández[1*], Nuria García Herranz[1,], Óscar Cabellos de Francisco[1], Eduardo Gallego[1]

[1]Nuclear Technology Area, Energy Engineering Department, Industrial Engineers Faculty (ETSII), Technical University of Madrid (UPM), Spaiin

Thank you for your attention

Grazie Mille

Muchas Gracias

Acknowledgment

Pablo Gracia Tolosana (UPM)
Daniel Navarro Hernández (UPM)
Cristina Ratero Talavera (UPM)

Further information? Please contact us:

Gonzalo Felipe García-Fernández
Assistant Professor
gf.garcia@upm.es

Nuclear Technology Area
Industrial Engineers Faculty (ETSII)
Polytechnic University of Madrid (UPM)