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Validity of generic concrete shielding parameters for different concrete recipes

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Background

High-energy neutrons with energies above 50 MeV are the main radiation hazard at particle therapy centers due to a very low high-energy inelastic reaction cross section. At almost all centers concrete is used as the main shielding material because concrete is an efficient neutron shielding material, is relatively cheap, and has very good structural properties.

Shielding calculations at the Danish Center for Particle Therapy (DCPT) are performed with an analytical line-of-sight model for the ambient dose equivalent [1,

$$H = \frac{H_0(E_p,\theta)}{r^2} exp\left(-\frac{d}{\lambda(E_p,\theta)}\right)$$

E_p: Proton energy

r: Distance from the source to the point of interest

θ: Angle between the proton beam and the line-of-sight from the source to the point of interest

H_0: Source term

d: Wall thickness (g/cm²)

λ: Attenuation length of shielding material (g/cm²).

The present work evaluates the attenuation data (H_0 and λ) for different concrete recipes.

Materials and methods

The elemental compositions (weight %) of TSF-5.5 concrete [1], DCPT concrete, and a special low-activation marble concrete (used in the vicinity of the DCPT degrader) are shown in table 1. Values of H_0 and λ are calculated for all concrete types using MCNPX Monte Carlo simulations [3] of a spherical concrete geometry with a radius of 90 m. Also values of λ are calculated for different water contents of TSF-5.5 concrete.

	TSF-5.5 concrete	DCPT concrete	Marble concrete
Density (g/cm³)	2.31	2.25	2.30
Avg. atomic mass	24.2	22.9	27.7
Element	**Content (weight %)**		
H	0.6 %	0.1 %	<0.1 %
C	17.4 %	7.6 %	10.4 %
O	40.8 %	51.1 %	37.4 %
Na		0.8 %	<0.2 %
Mg	3.2 %	0.1 %	0.2 %
Al	1.2 %	2.4 %	0.6 %
Si	3.4 %	21.8 %	2.3 %
S		0.3 %	0.2 %
K		0.9 %	0.2 %
Ca	32.5 %	13.4 %	47.3 %
Ti		0.1 %	<0.2 %
Fe	0.8 %	1.5 %	0.9 %
Ni		0.2 %	<0.2 %

Table 1: The elemental composition (weight %) of TSF-5.5 concrete [1], DCPT concrete, and low-activation marble concrete.

Results and discussion

The differences of H_0 and λ for DCPT concrete and marble concrete with respect to that of TSF-5.5 concrete for various target materials, proton energies, and angles are shown in figure 1. In addition, in figure 2 λ is plotted versus the water content of TSF-5.5 concrete. The maximum observed change of λ for a significant change of the concrete recipe and the water content is 3.2 % (marble concrete, 0-10°), corresponding to a dose increase of about 20 % or an extra wall thickness of 6.4 cm for a 2-m thick wall. This is insignificant in comparison with the uncertainty of the line-of-sight model and the safety factor of 10 used for the DCPT shielding design.

In figure 1 λ is observed to increase only 0.8 % per extra average atomic number in good agreement with the slowly decreasing total high-energy inelastic neutron reaction cross section per unit mass in figure 3.

For all configurations in figure 1, the calculated values of H_0 and λ for TSF-5.5 concrete is in good agreement with those of Sheu [1] with a maximum deviation of 36 % for H_0 and 3.4 %

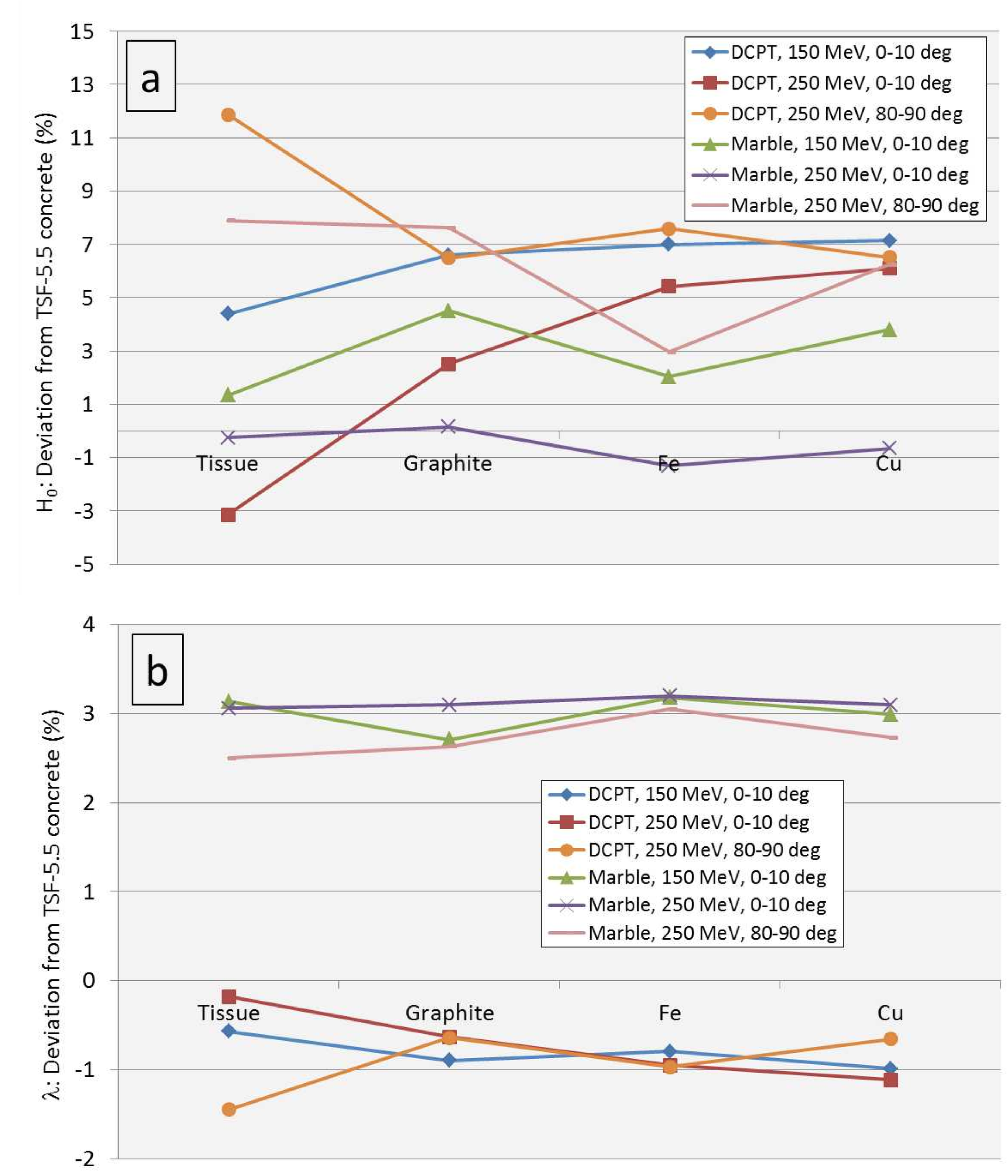

Figure 1: Deviation of H_0 and λ with respect to that of TSF-5.5 concrete for various target materials, proton energies E_p, and angles θ. a) Deviation of H_0. b) Deviation of λ.

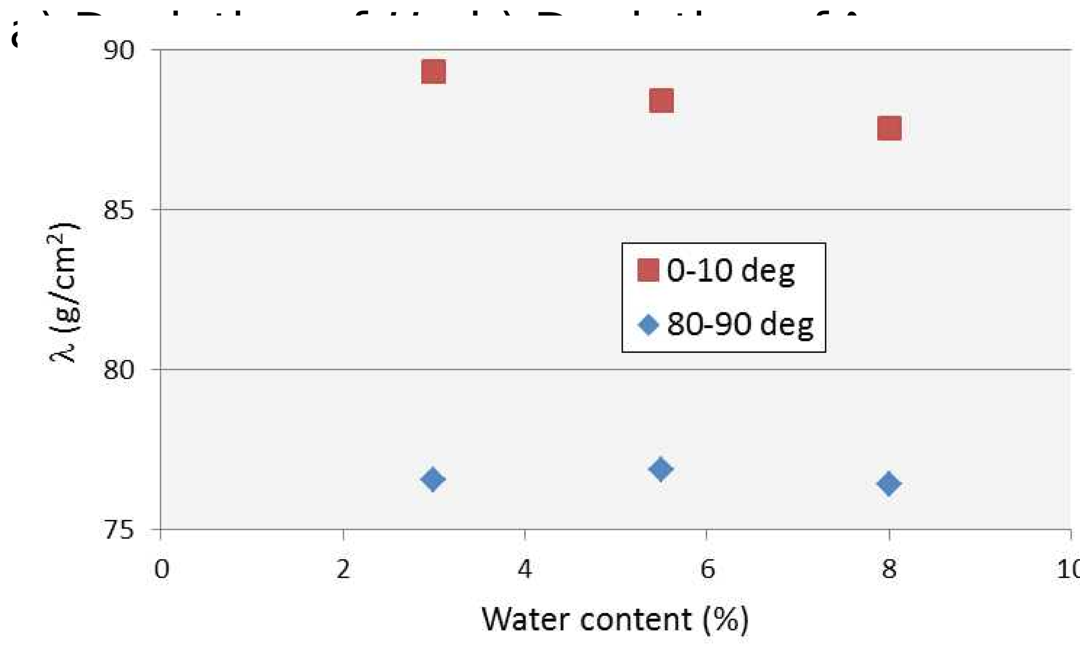

Figure 2: λ versus the water content of TSF-5.5 concrete.

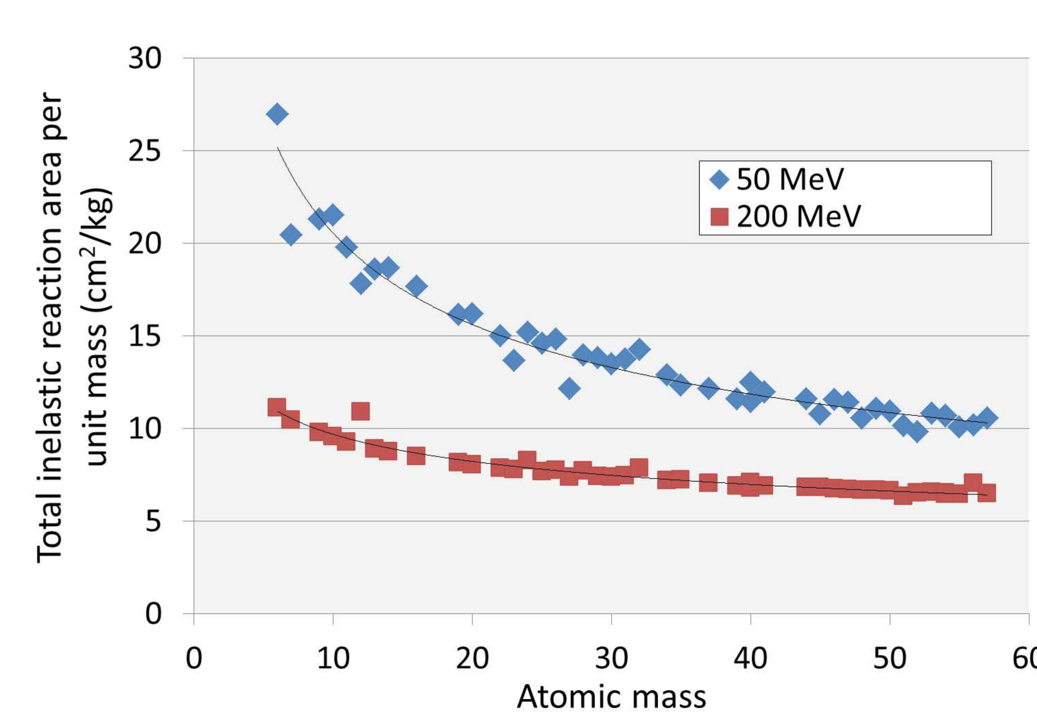

Figure 3: Total high-energy inelastic neutron reaction cross section per unit mass versus atomic mass of the target nucleus [4].

Conclusions

The change of λ with atomic number is slow in good agreement with the slowly decreasing total high-energy inelastic neutron reaction cross section per unit mass. Therefore, for standard-density concrete with an average atomic number in the range 20-30, the use of generic source and attenuation data from literature produces an error which is insignificant in comparison with the uncertainties of shielding calculations

References

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