[1]Radiation safety and dose control department
Clinical Hospital “Feofaniya”

[2]National technical university of Ukraine
“Igor Sikorsky Kyiv Polytechnic Institute”

Enhancement of shielding properties of the maze for 10 MV linear accelerator

B. M. Bondar[1,2], Ye.V. Kudriashova[3], D.O. Bielykh[3], V.I. Teslenko[4]

in collaboration with

[3]State scientific and technical center for nuclear and radiation safety, Kyiv, Ukraine

[4]Limited liability company «Research and production company «ANALITTEHTCENTR», Kyiv, Ukraine

Shielding Aspects of Accelerators, Targets and Irradiation Facility, SATIF-16, May 28-31, 2024

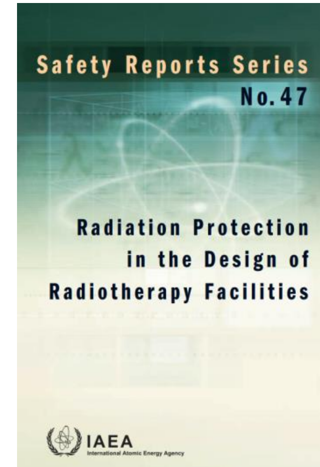
Outlines

- **Motivation: LA facility and bunker design**
- **Experimental measurements**
- **MCNP simulations**
- **Shielding design, verification and installation**
- **Conclusions and prospects**

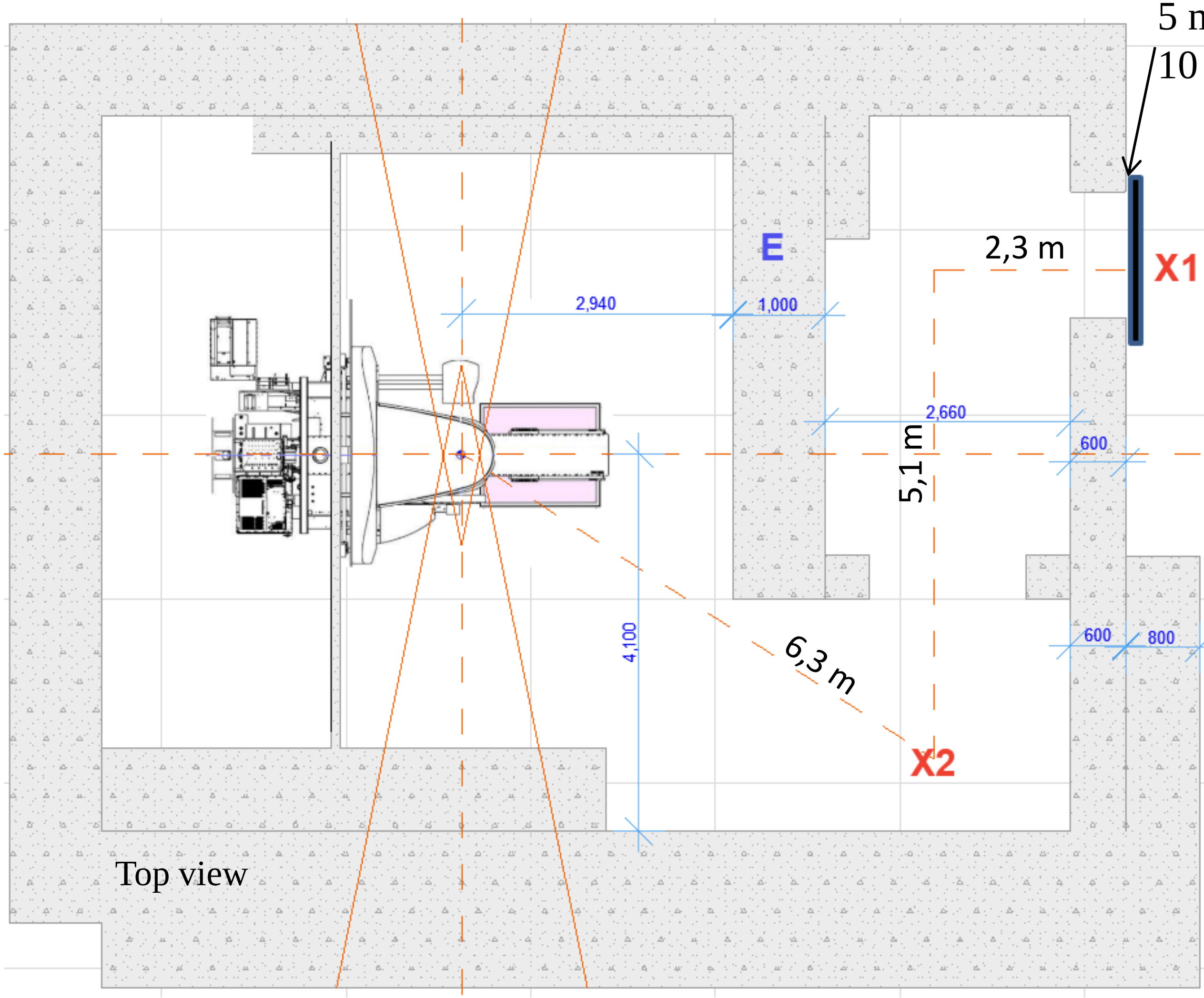
Motivation: LA facility and bunker design

06/2023 – Elekta Infinity (10 MV, 600 MU/min)

Designed without neutrons consideration ⟶ can be acceptable [1]



5 mm Pb +
10 mm Steel



n ~7 µSv/h

g ~9 µSv/h

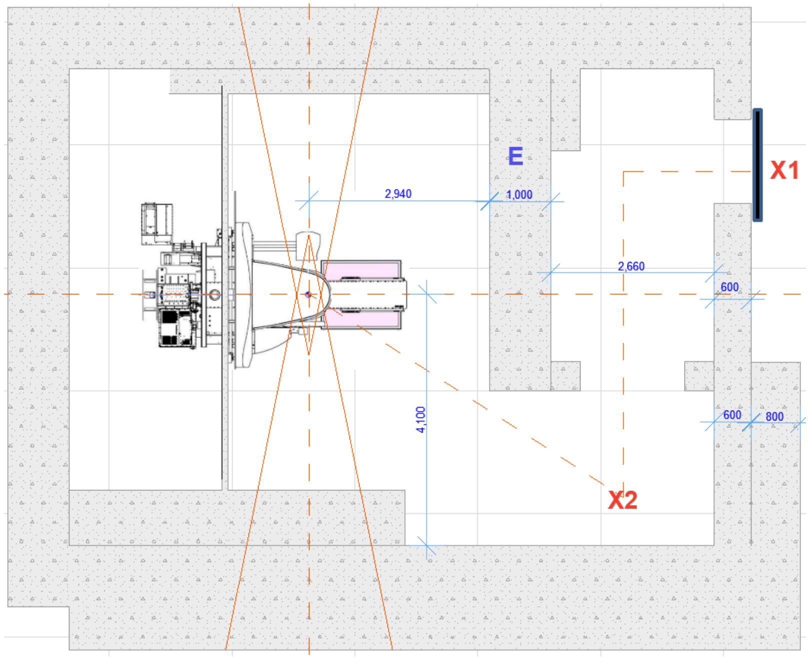
sum prescribed limit

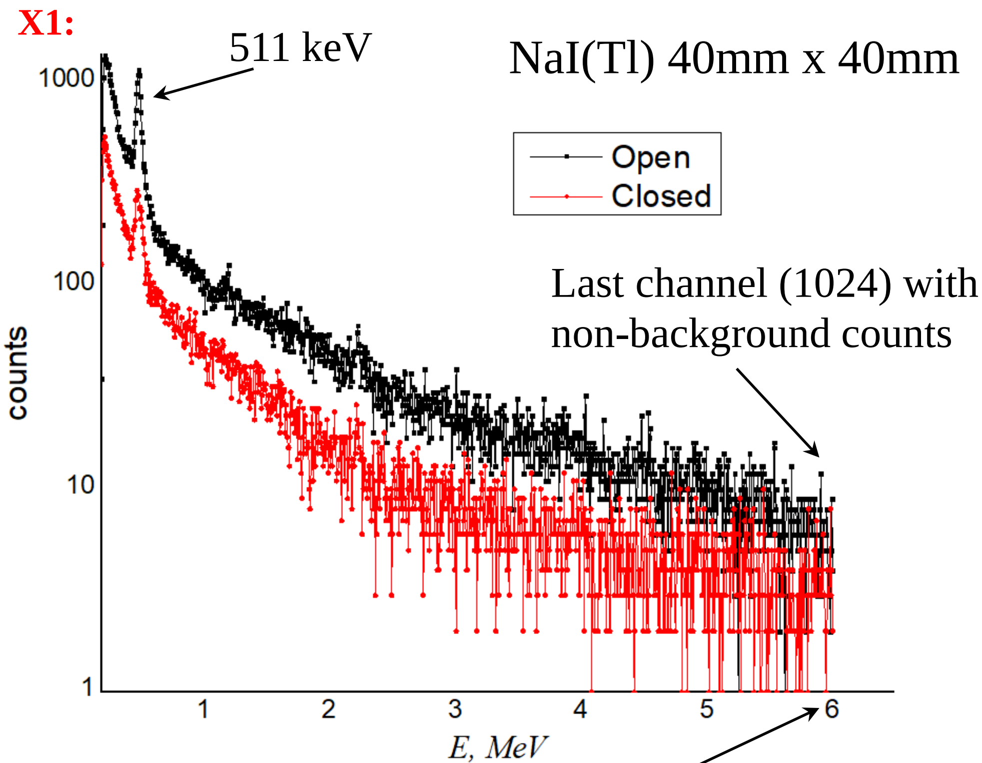
16 µSv/h > 13,3 µSv/h

Maze (~3,5 m) appeared
to be too short

[1] Radiation Protection in the Design of Radiotherapy Facilities. IAEA Safety Reports Series №47, Vienna, 2007.

Experimental measurements of radiation fields





Annihilation → $E_\gamma > 2$ MeV

10 MV leakage and primary scattered ≤ 2 MeV of E_γ [2], that is **up to 6 MeV**

Capture gammas[3]:

$^{nat}Si(n,x\gamma) \rightarrow E_{\gamma max} = 10,5$ MeV

$^{27}Al(n,x\gamma) \rightarrow E_{\gamma max} = 7,7$ MeV

$^{nat}Fe(n,x\gamma) \rightarrow E_{\gamma max} = 7,6$ MeV

$^{nat}Ca(n,x\gamma) \rightarrow E_{\gamma max} = 6,4$ MeV

$^{12}C(n,x\gamma) \rightarrow E_{\gamma max} = 4,4$ MeV

Dose rate (plastic scintillator)

$D_n = 7$ μSv/h

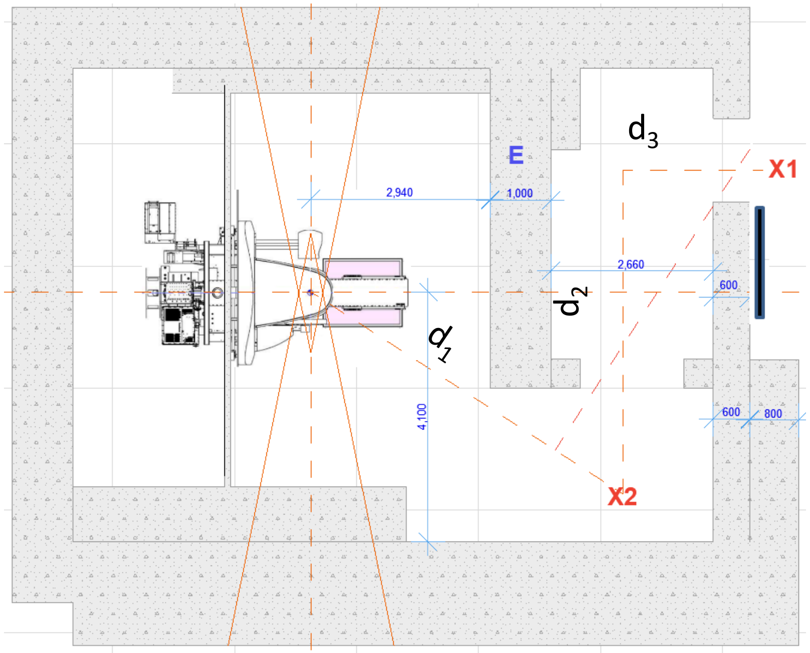
Flux (He-3, NRD-H2, ThermoScientific)

$\varphi_n = 17,8$ n/sec/cm^2

[2] K.Polaczek-Grelik et al. Gamma radiation in the vicinity of the entrance to linac radiotherapy room. Use of gamma radiation techniques, chapter 10, 2019.

[3] Database of prompt gamma rays from slow neutron capture for elemental analysis. IAEA, 2007, Vienna

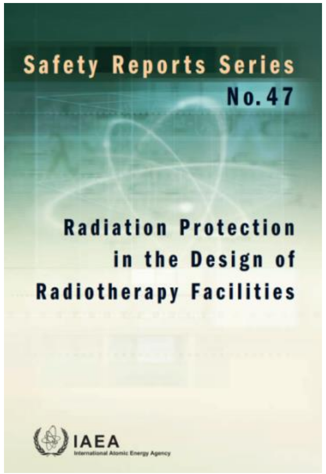
Data at reference points



$$\varphi_n = \frac{Q_n}{4\pi d_1^2} + \frac{5{,}4Q_n}{2\pi S} + \frac{1{,}26Q_n}{2\pi S}, \qquad Q_n = 0{,}06 \cdot 10^{12}\ \frac{n}{Gy}$$

Reference point	φ_n, sec^{-1}cm^{-2}	
	calculated	measured
X2	$4{,}73 \cdot 10^3$	$4{,}74 \cdot 10^3$

Excellent agreement (< 2%)!



$$D_n = H \frac{A}{S_M} \frac{1}{d_1^2} 10^{-\left(\frac{d_2}{5}\right)} 10^{-\left(\frac{d_3}{5}\right)} \frac{1}{3}, \qquad H = 0{,}08\ \frac{mSv}{Gy}$$

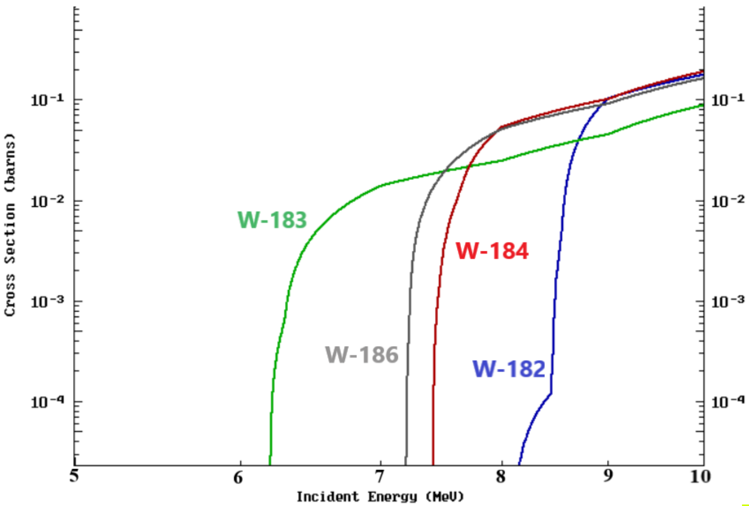
Reference point	D_n, µSv/h	
	calculated	measured
X1 (door open)	7,6	56,8

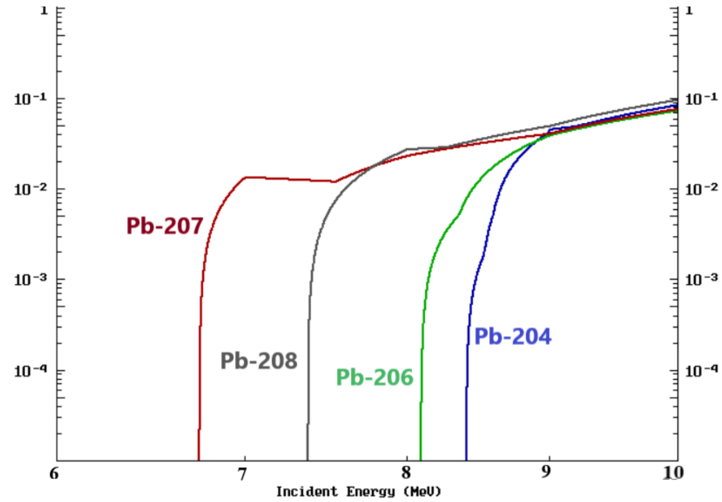
Measured > 7 times higher than calculated – direct visibility

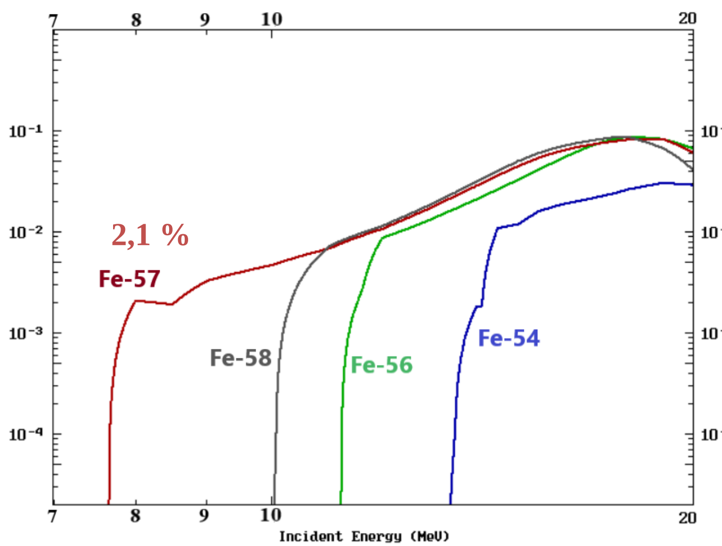
[1] Radiation Protection in the Design of Radiotherapy Facilities. IAEA Safety Reports Series №47, Vienna

MCNP simulations[4]. Gantry construction components

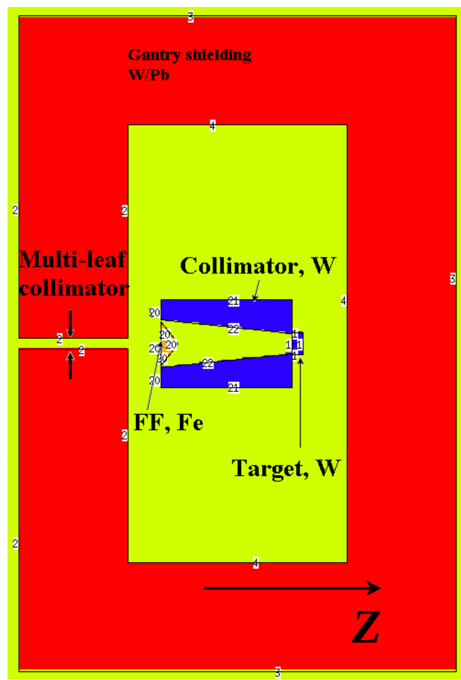
Photo-neutron production on Pb, W and Fe [5]

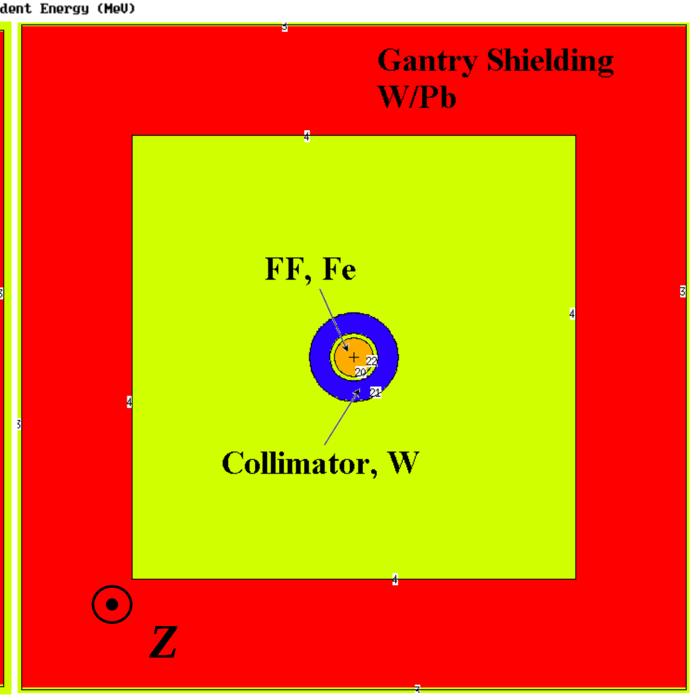






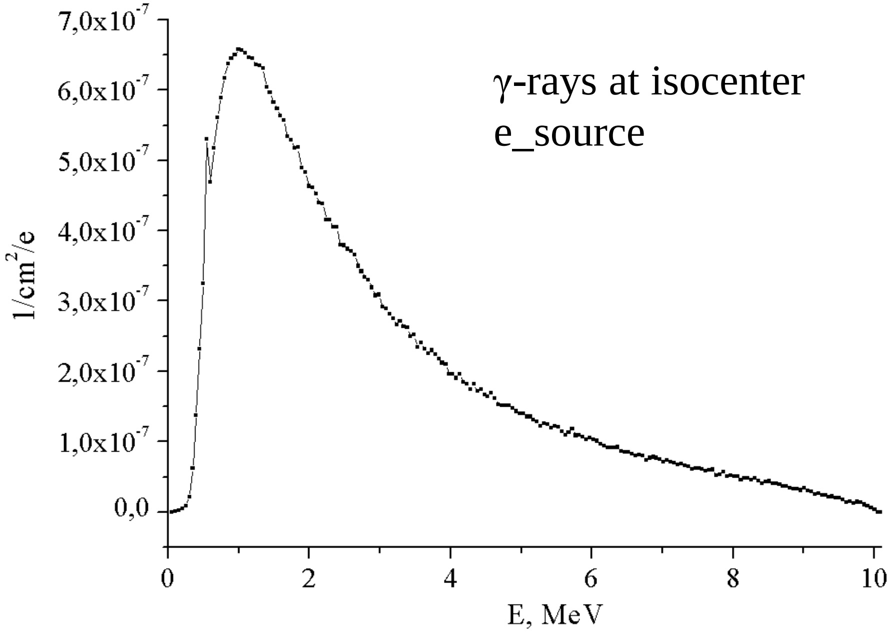
Field 5x5 mm

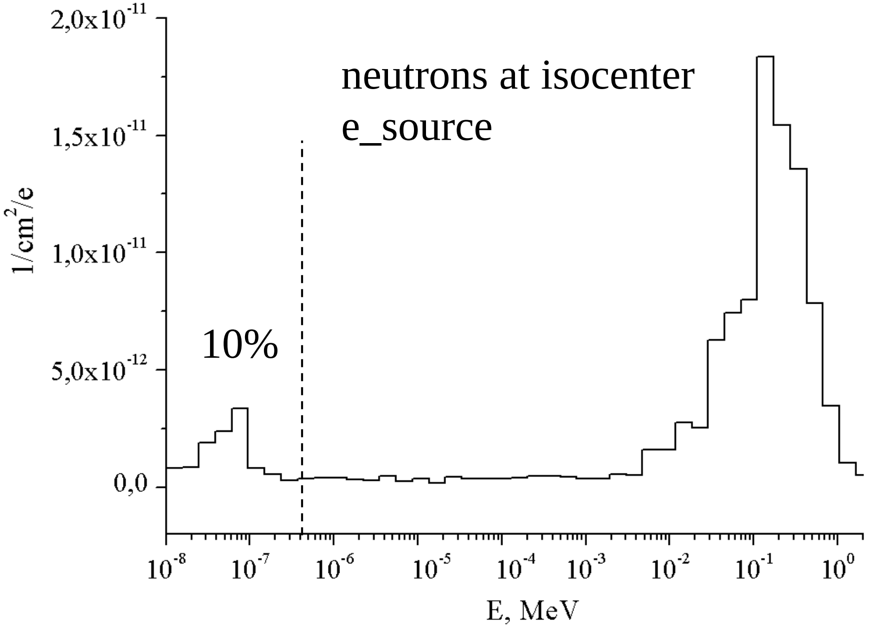


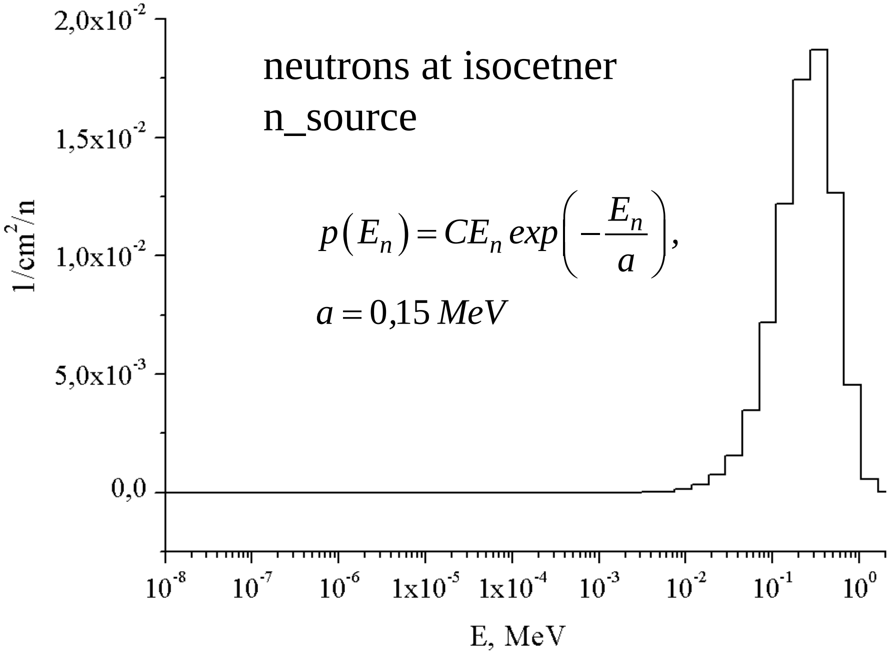


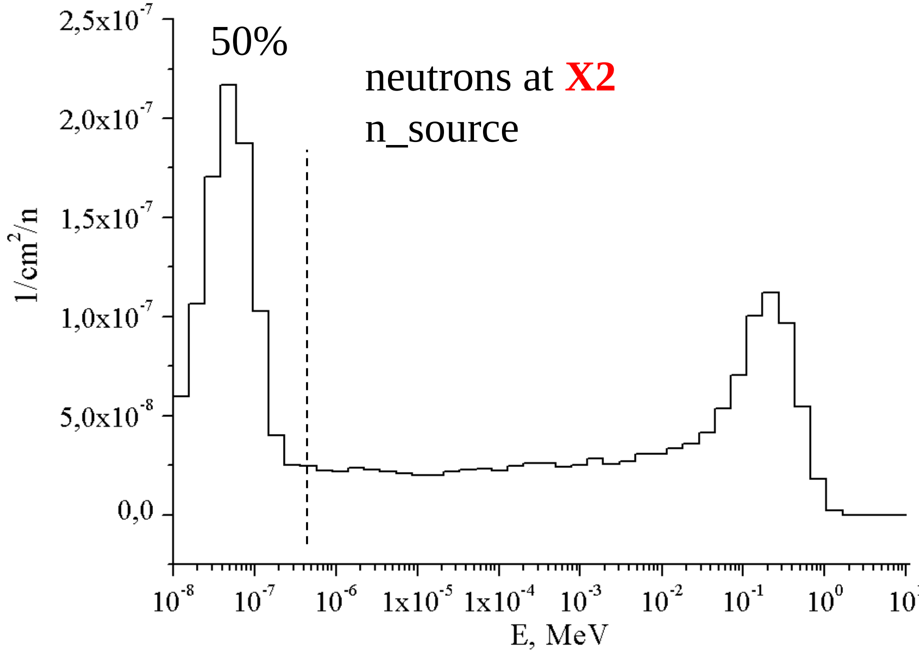
[4] MCNPX User's Manual, Version 2.6.0. Los Alamos National Laboratory report LA-CP-07-1473 (2008)
[5] TENDL-2021

MCNP simulations. Spectra inside the bunker

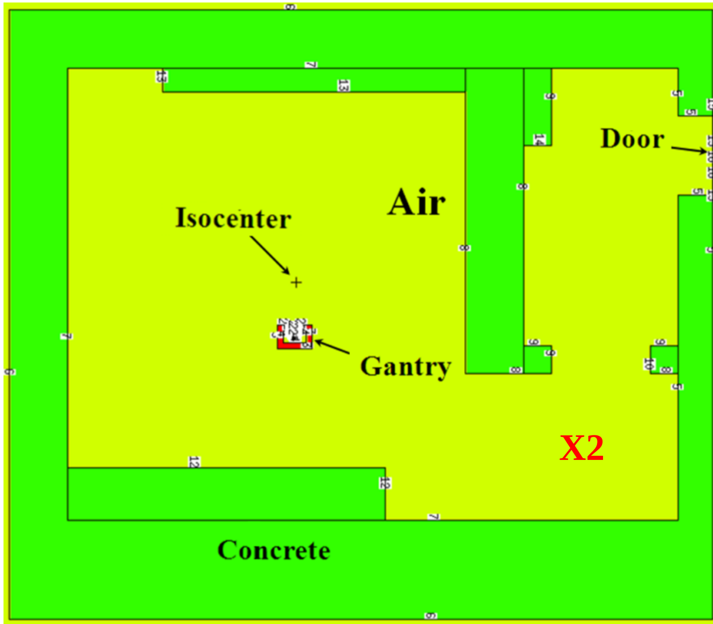


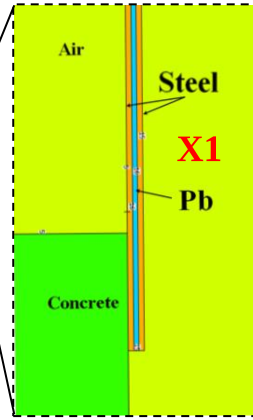






MCNP simulations. Spectra near the door

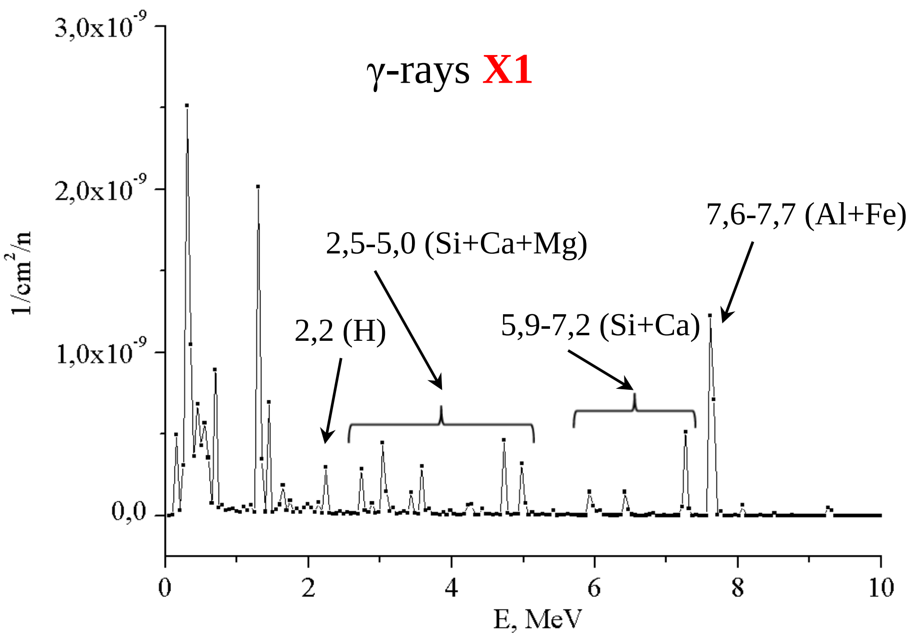


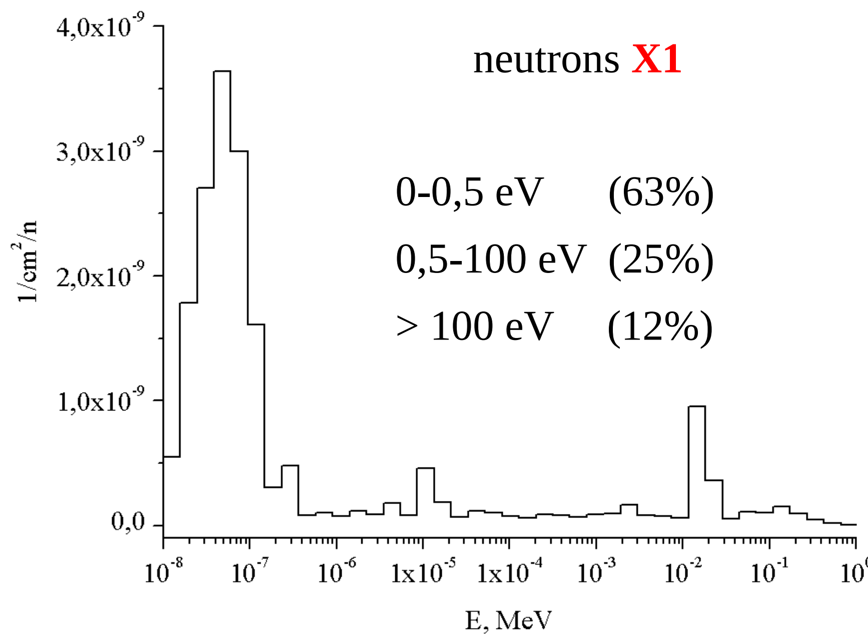


new multilayer door installation?

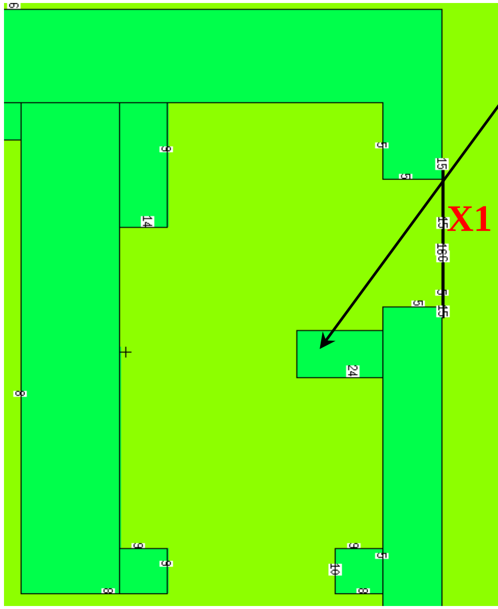
frame interlocks engine electronics

$$k_{MCNP} = \frac{\varphi(X2)_{exp}}{\varphi(X2)_{MCNP}} = 2{,}12 \cdot 10^9$$

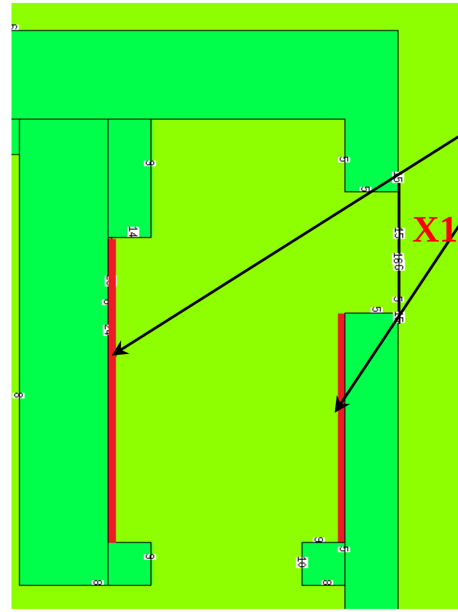




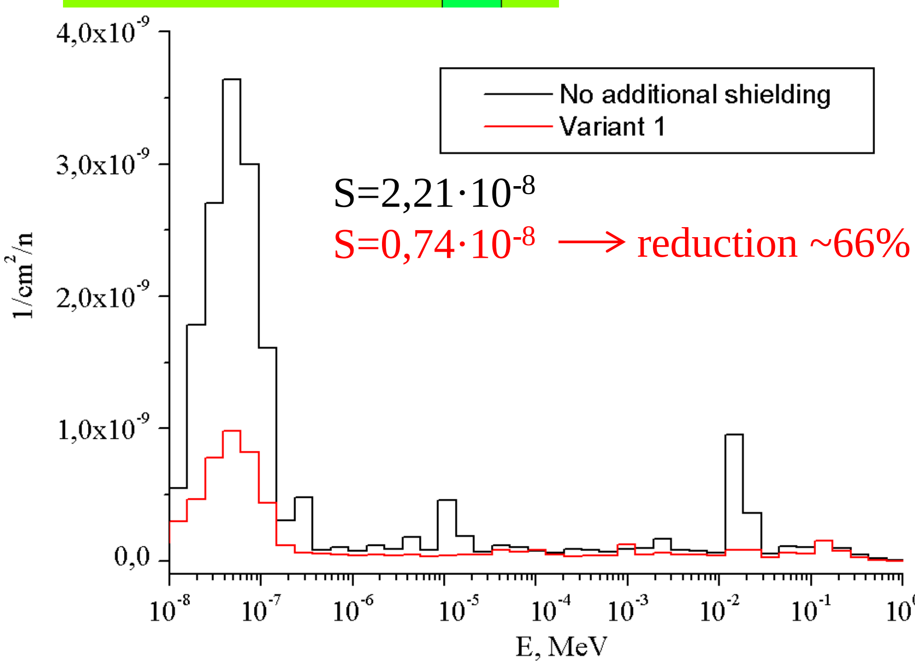
2 variants of additional shielding

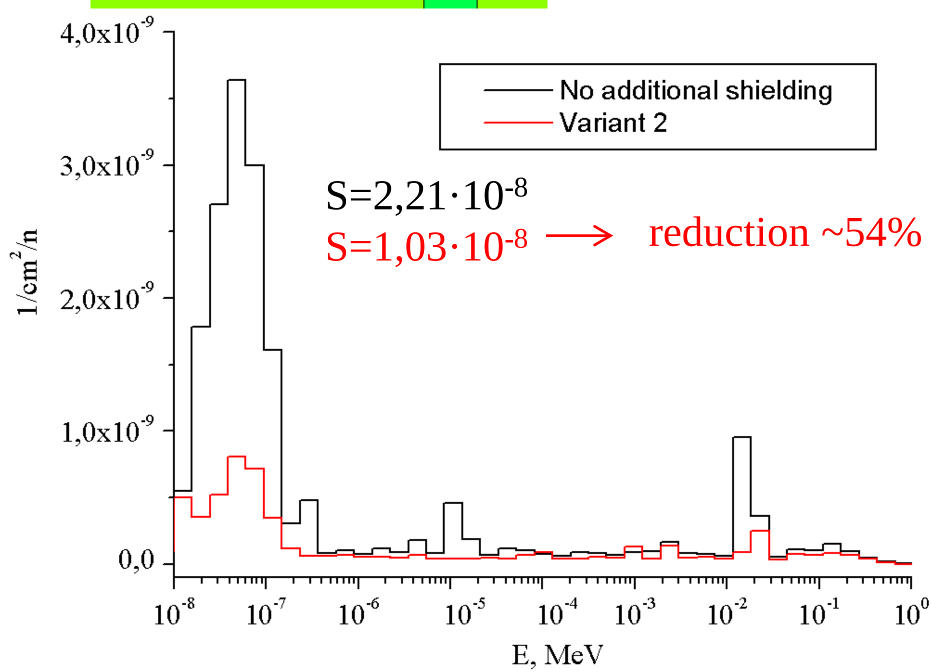


Ledge
Concrete
(2,35g/cm^3)
500 mm x 750 mm



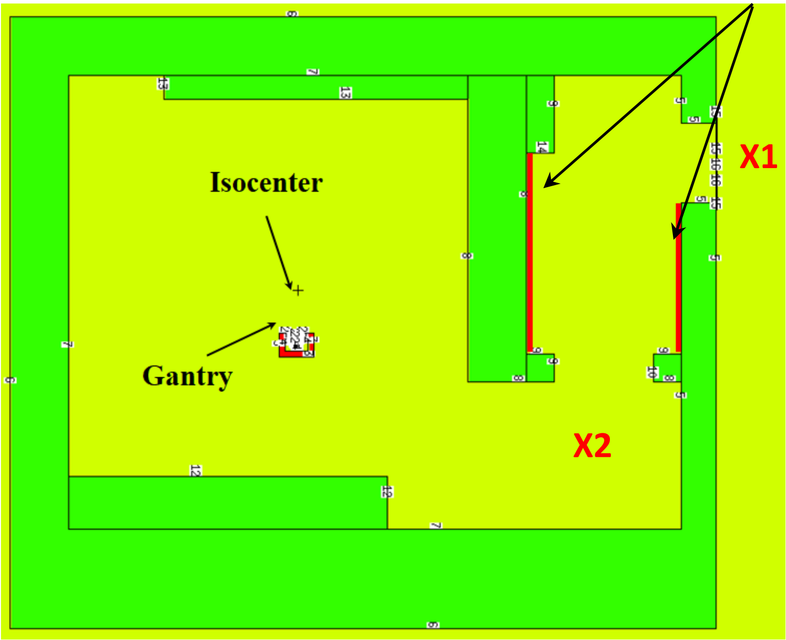
Plates
Borated Paraffin
(5% by weight)
40 mm





Installation and verification

Shielding plates



Reference point	Before		After		Reduction, %
	Flux, $sec^{-1}cm^{-2}$	Dose, μSv/h	Flux, $sec^{-1}cm^{-2}$	Dose, μSv/h	
X1	17,8	6,7	11,1	3,2	52,2
X2	$4{,}74 \cdot 10^3$	-	$2{,}28 \cdot 10^3$	-	51,8

sum prescribed limit

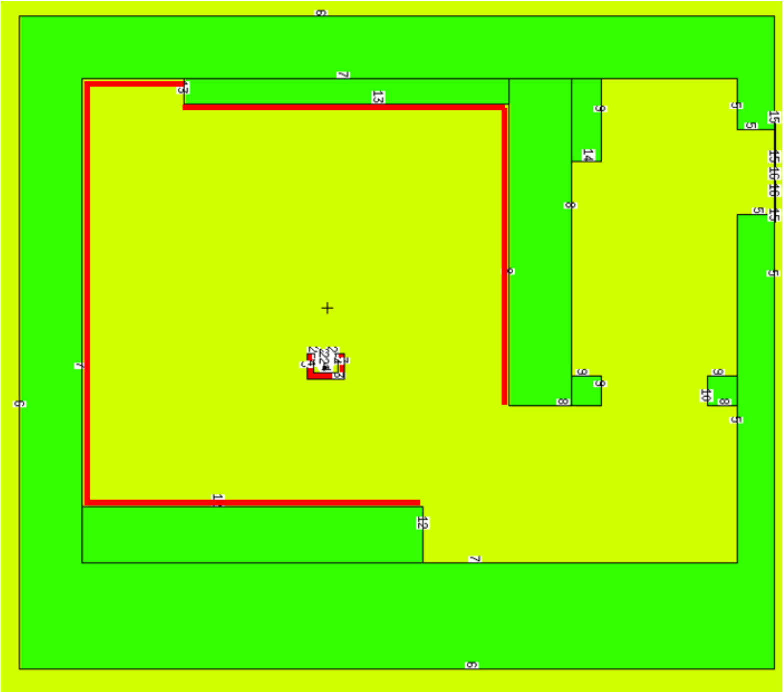
7+3,2=10,3 μSv/h < 13,3 μSv/h

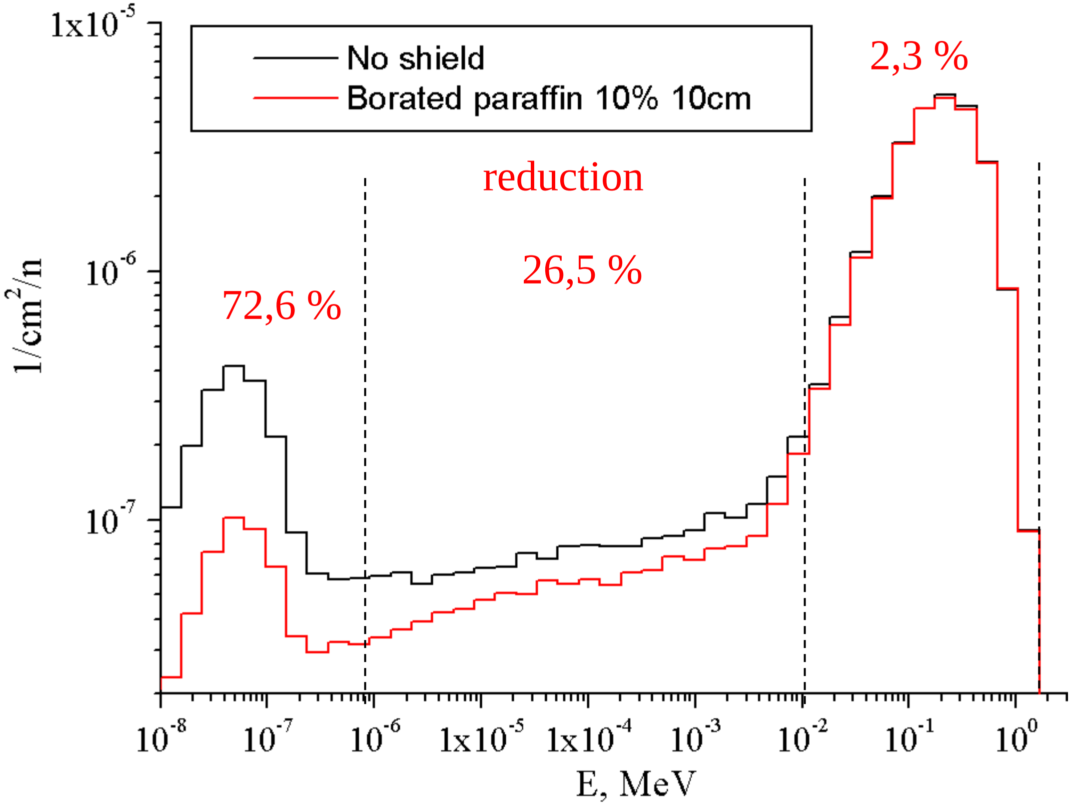
Isocenter – neutrons dose 0,8 – 3,7 mSv/Gy [6,7]

[6] Neutron contamination in radiotherapy processes: a review study, Journal of Radiation Research, Volume 62, Issue 6, November 2021, Pages 947– 954.
[7] Evaluation of photoneutron dose equivalent in 10 MV and 15 MV beams for wedge and open fields in the Elekta Versa HD linac, Applied Radiation and Isotopes, Volume 188, 2022, 110363, ISSN 0969-8043, https://doi.org/10.1016/j.apradiso.2022.110363.

Dose reduction to patient

Neutrons dose at isocenter 0,8 – 3,7 mSv/Gy





Dose from thermal neutrons ~ 0,02 mSv/Gy (0,6% of total dose)[8]

No significant dose reduction → max ~ 6,5 mSv per course of 60 Gy

[8] Ralph H. Thomas Gary H. Zeman Fluence to Dose Equivalent Conversion Coefficients for Evaluation of Accelerator Radiation Environments. https://escholarship.org/content/qt5pd0x47s/qt5pd0x47s_noSplash_c3d44929b9279e73384fada1150dd239.pdf

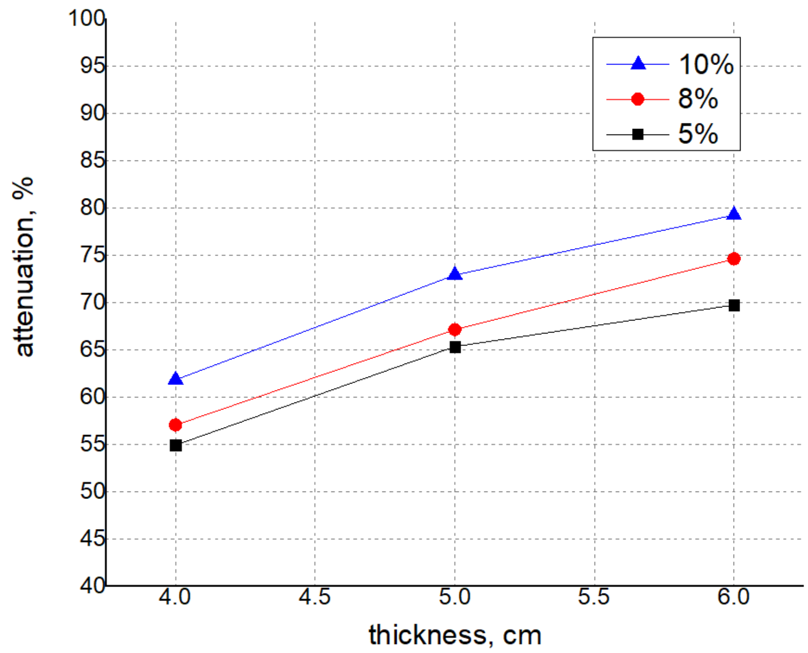
Conclusions

- **It is advisable to consider neutrons for all designs of 10MV accelerators**

- **Experimental measurements showed excellent agreement with calculations at reference point X2 – IAEA 47 Report**

The concrete ledge and borated (5%) paraffin plates ensure similar shielding properties against neutrons

Weak dependence on B% content and thickness – manufacturing dictates the type of shield



- **Plates inside the treatment room – dose reduction to patients only from scattered neutrons (<3%)**

Tank you for attention!