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Neutron yield from 113 and 256 MeV proton beams on thick targets

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Outline

- Motivation
- Geometry and Physics list
- Neutron yields
- Conclusions

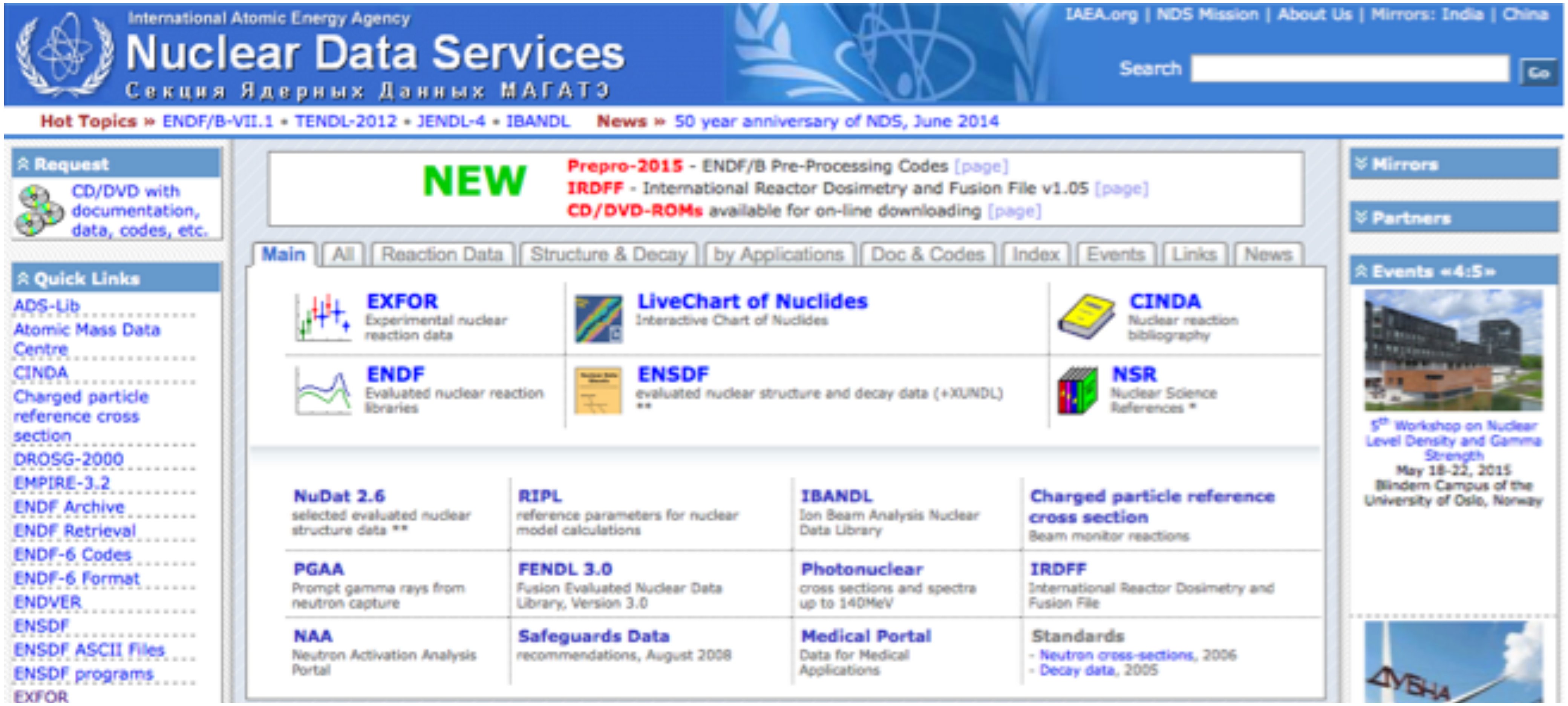
Motivation

- Stray radiation deposit dose far away the treatment target (~80% of the effective dose from stray radiation).
- Internal secondary neutron also contribute to the dose (~20% of the effective dose from stray radiation)
- Secondary neutrons show a high relative biological effectiveness. For carcinogenesis may be ~25%.

- In proton therapy, neutrons are created initially at the treatment nozzle and at the patient by non-elastic nuclear interactions starting from ~20 MeV.
- Thus, we evaluated the neutron yield from thick targets made of Aluminum, Carbon and Iron for proton energies within the therapeutic range.

Brenner and Hall "Secondary neutrons in clinical proton therapy: a charged issue", Radiother Oncol, 86(2) 165-170, 2008.

Reference data



Hot Topics » ENDF/B-VII.1 • TENDL-2012 • JENDL-4 • IBANDL **News** » 50 year anniversary of NDS, June 2014

CD/DVD with documentation, data, codes, etc.

NEW

Prepro-2015 - ENDF/B Pre-Processing Codes [page]
IRDFF - International Reactor Dosimetry and Fusion File v1.05 [page]
CD/DVD-ROMs available for on-line downloading [page]

EXFOR Experimental nuclear reaction data

LiveChart of Nuclides Interactive Chart of Nuclides

CINDA Nuclear reaction bibliography

ENDF Evaluated nuclear reaction libraries

ENSDF evaluated nuclear structure and decay data (+XUNDL) **

NSR Nuclear Science References *

NuDat 2.6 selected evaluated nuclear structure data **	**RIPL** reference parameters for nuclear model calculations	**IBANDL** Ion Beam Analysis Nuclear Data Library	**Charged particle reference cross section** Beam monitor reactions
PGAA Prompt gamma rays from neutron capture	**FENDL 3.0** Fusion Evaluated Nuclear Data Library, Version 3.0	**Photonuclear** cross sections and spectra up to 140MeV	**IRDFF** International Reactor Dosimetry and Fusion File
NAA Neutron Activation Analysis Portal	**Safeguards Data** recommendations, August 2008	**Medical Portal** Data for Medical Applications	**Standards** - Neutron cross-sections, 2006 - Decay data, 2005

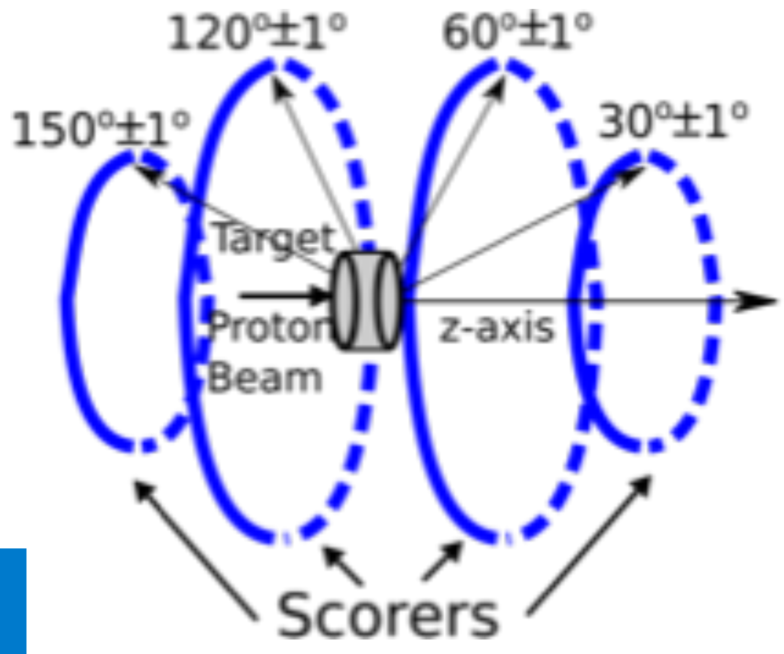
5th Workshop on Nuclear Level Density and Gamma Strength
May 18-22, 2015
Blindern Campus of the University of Oslo, Norway

1. Meier, *et. Al.* "Differential neutron production cross sections and neutron yields from stopping-length targets for 113-MeV protons" Nuclear Science and Engineering, Vol.102, p.310 (1989)
2. Meier, *et. Al.* "Neutron yields from stopping-length targets for 256-MeV protons" Nuclear Science and Engineering, Vol.104, p.339 (1990)
3. www-nds.iaea.org

Geometry and physics list

Modular physics list (for proton dose calculations)

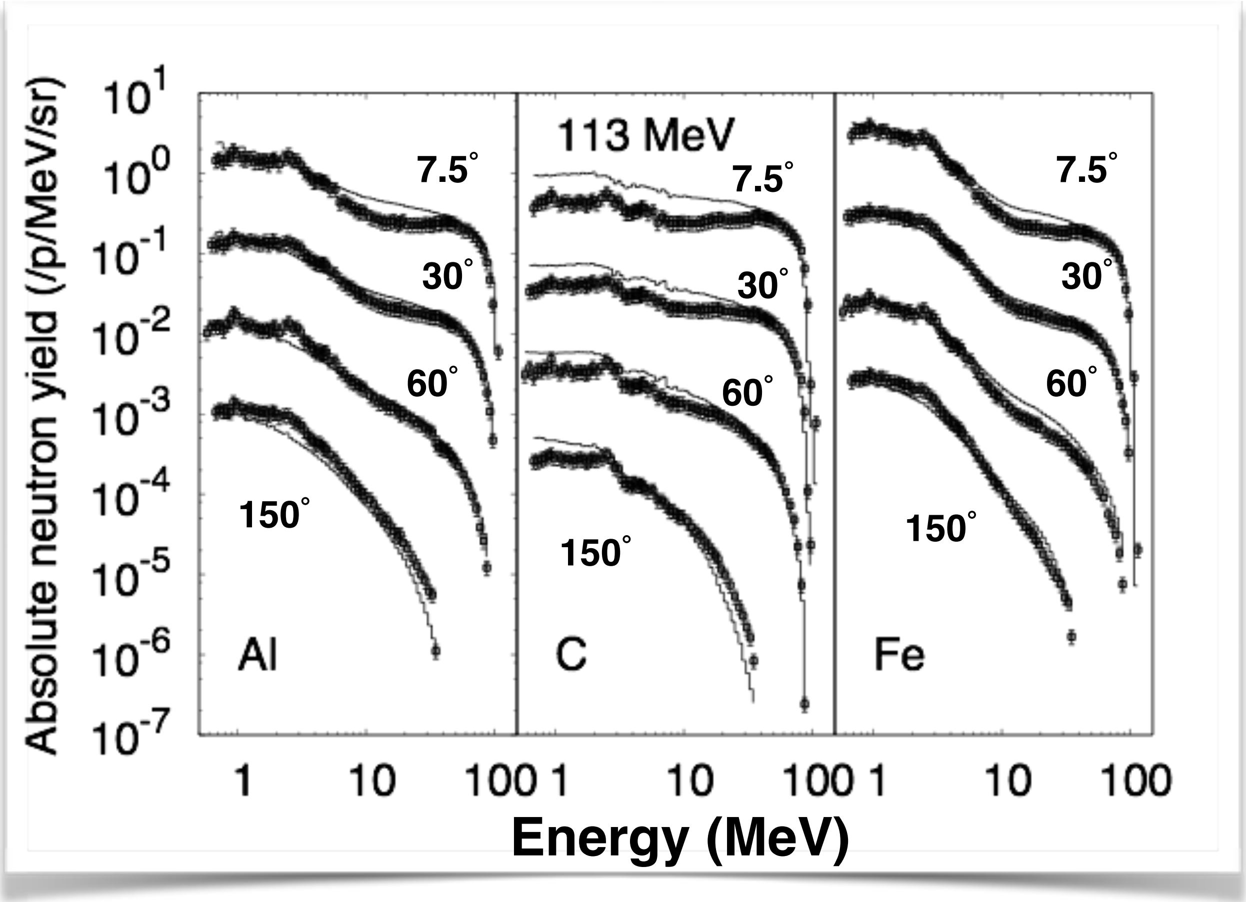
- G4EmStandardPhysics_option4
- G4HadronPhysicsQGSP_BIC_HP
- G4IonBinaryCascadePhysics
- G4HadronElasticPhysicsHP
- G4StoppingPhysics
- G4RadioactiveDecayPhysics



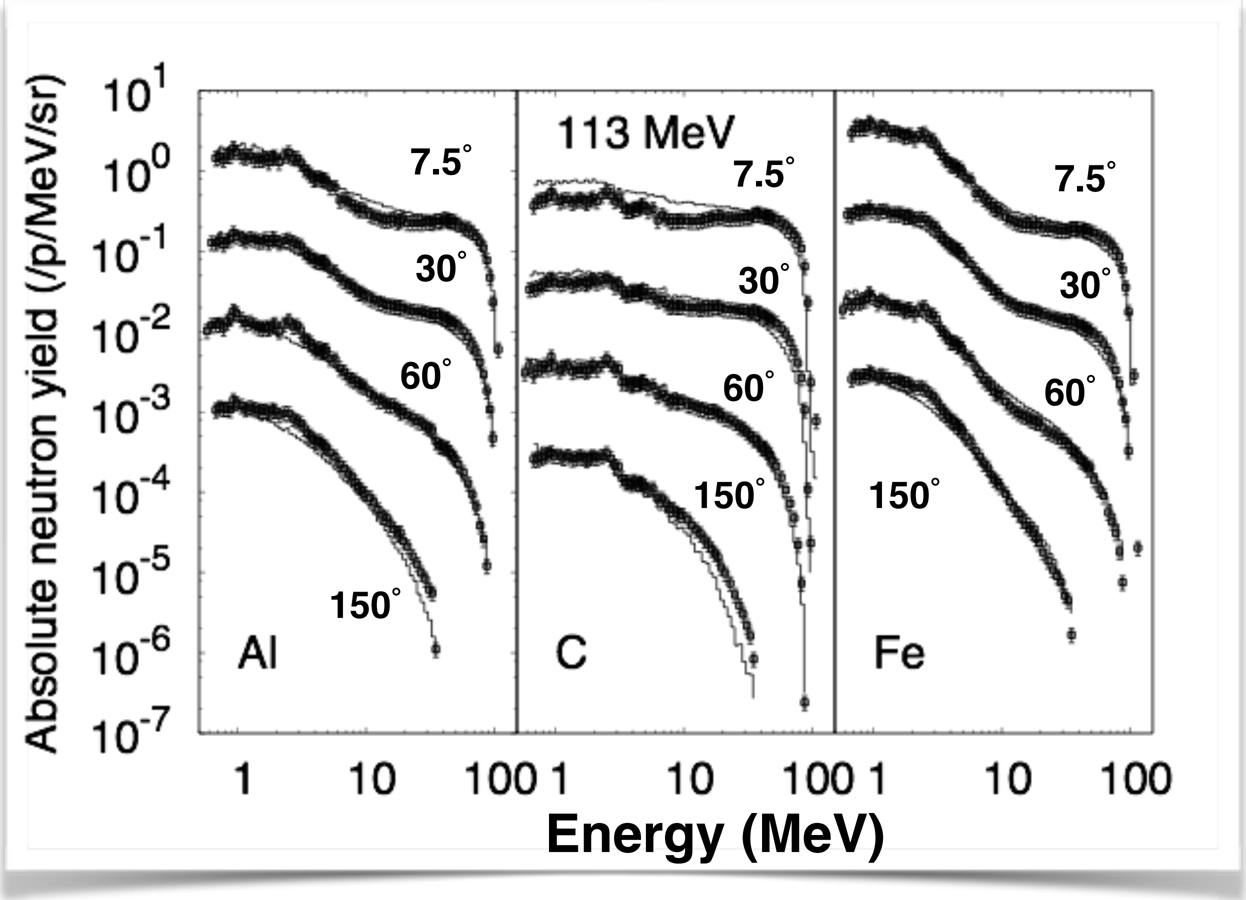
Material	Radius (cm)		Thickness (cm)		Density (g/cm^3)
	113 MeV	256 MeV	113 MeV	256 MeV	
Aluminum	3.65	8.0	4.0	20.0	2.699
Carbon	3.65	8.0	5.83	30.0	1.867
Iron	3.65	8.0	1.57	8.0	7.867

1. Zacharatou J and Paganetti H, "Physics Settings for Using the Geant4 Toolkit in Proton Therapy" *IEEE Trans Nucl Science 55(3)* 1018-1025 (2008)
2. Testa M *et Al.* "Experimental validation of the TOPAS Monte Carlo system for passive scattering proton therapy." *Med Phys* 40(12) 121719 (2013)
3. Faddegon *et Al.* "Experimental depth dose curves of a 67.5 MeV proton beam for benchmarking and validation of Monte Carlo simulation." 42(7) 4199-4210 (2015)

Neutron yields: 113 MeV



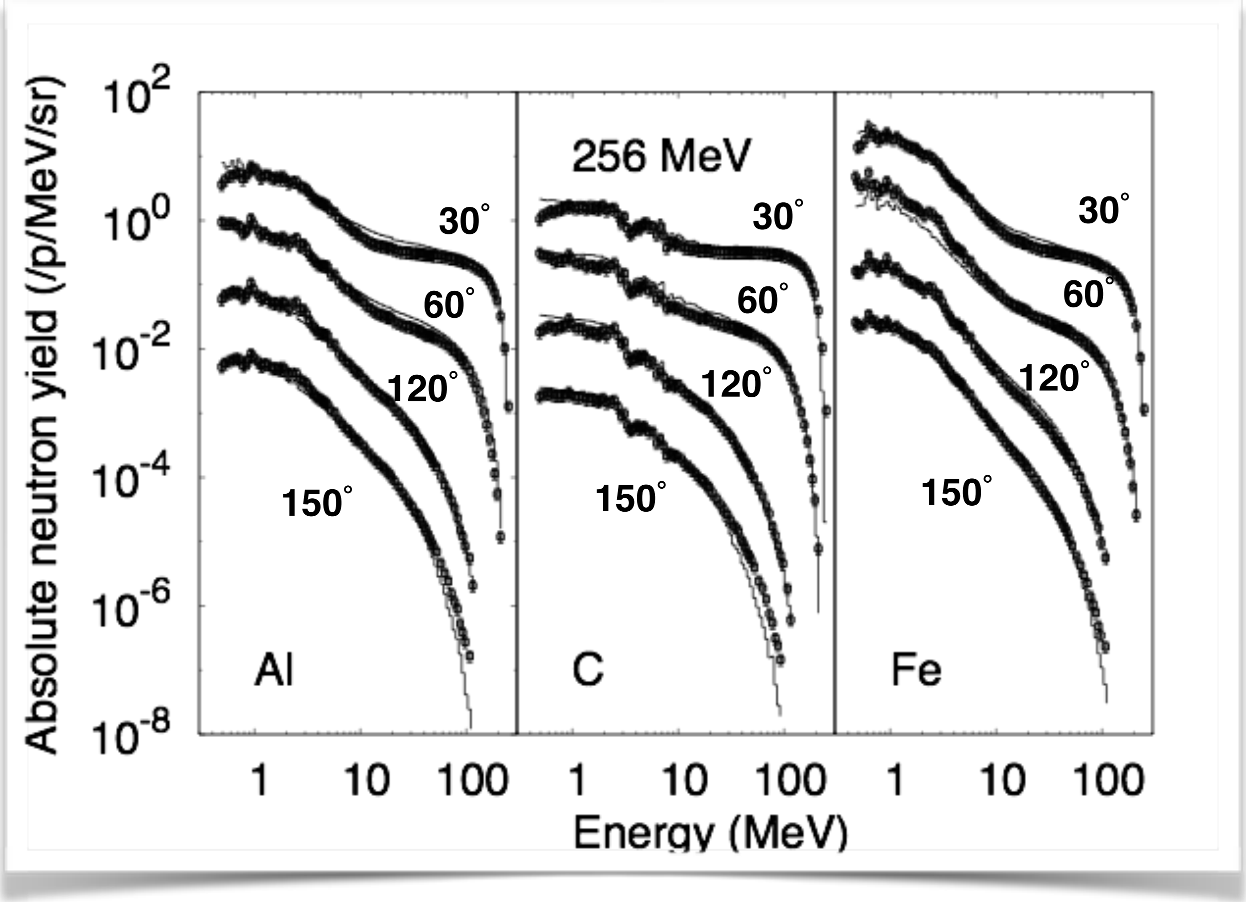
Geant4 v.10.2.p01

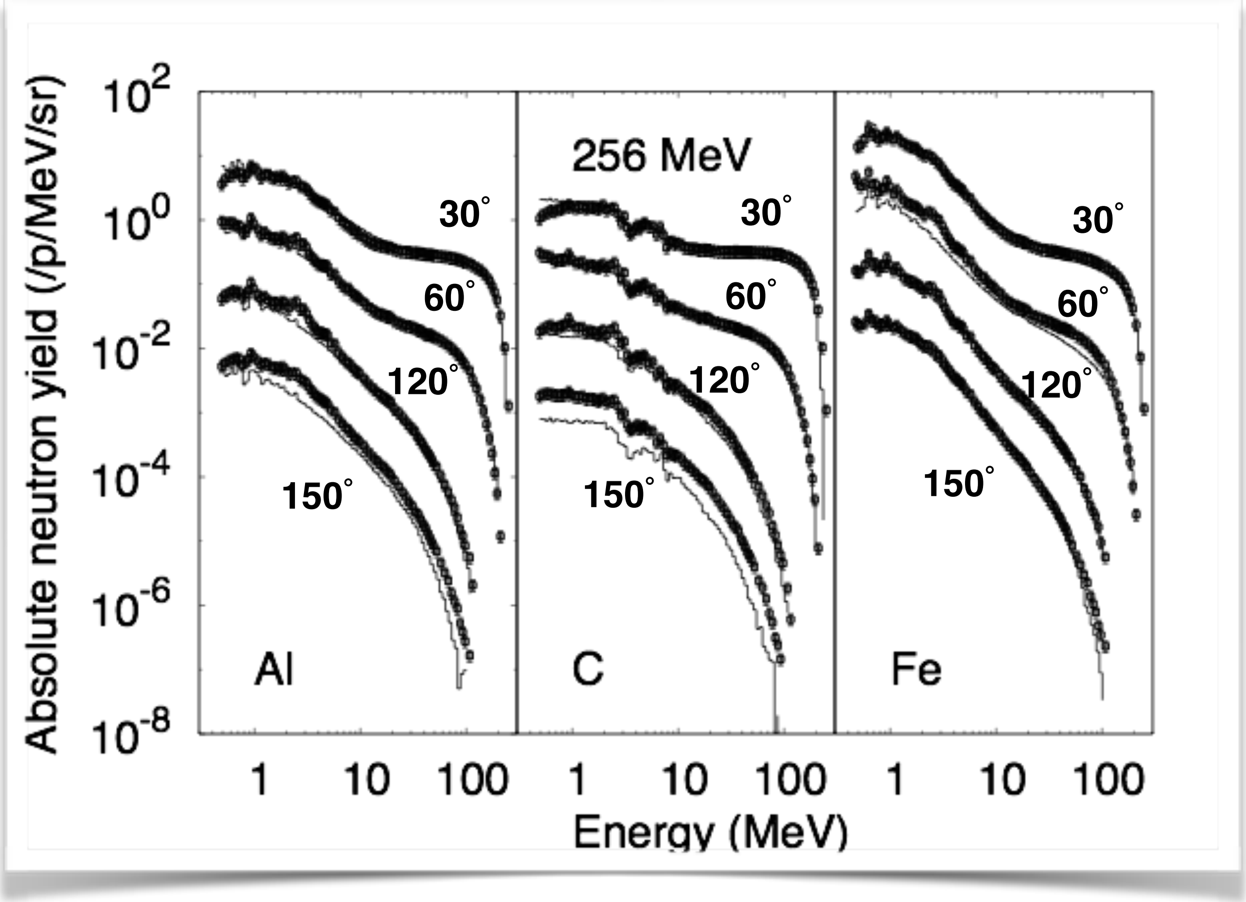


Geant4 v.10.3.b01

Yields are scaled by factors of 1, 10, 100, 1000 for 150°,60°, 30° and 7.5°, respectively

Neutron yields: 256 MeV



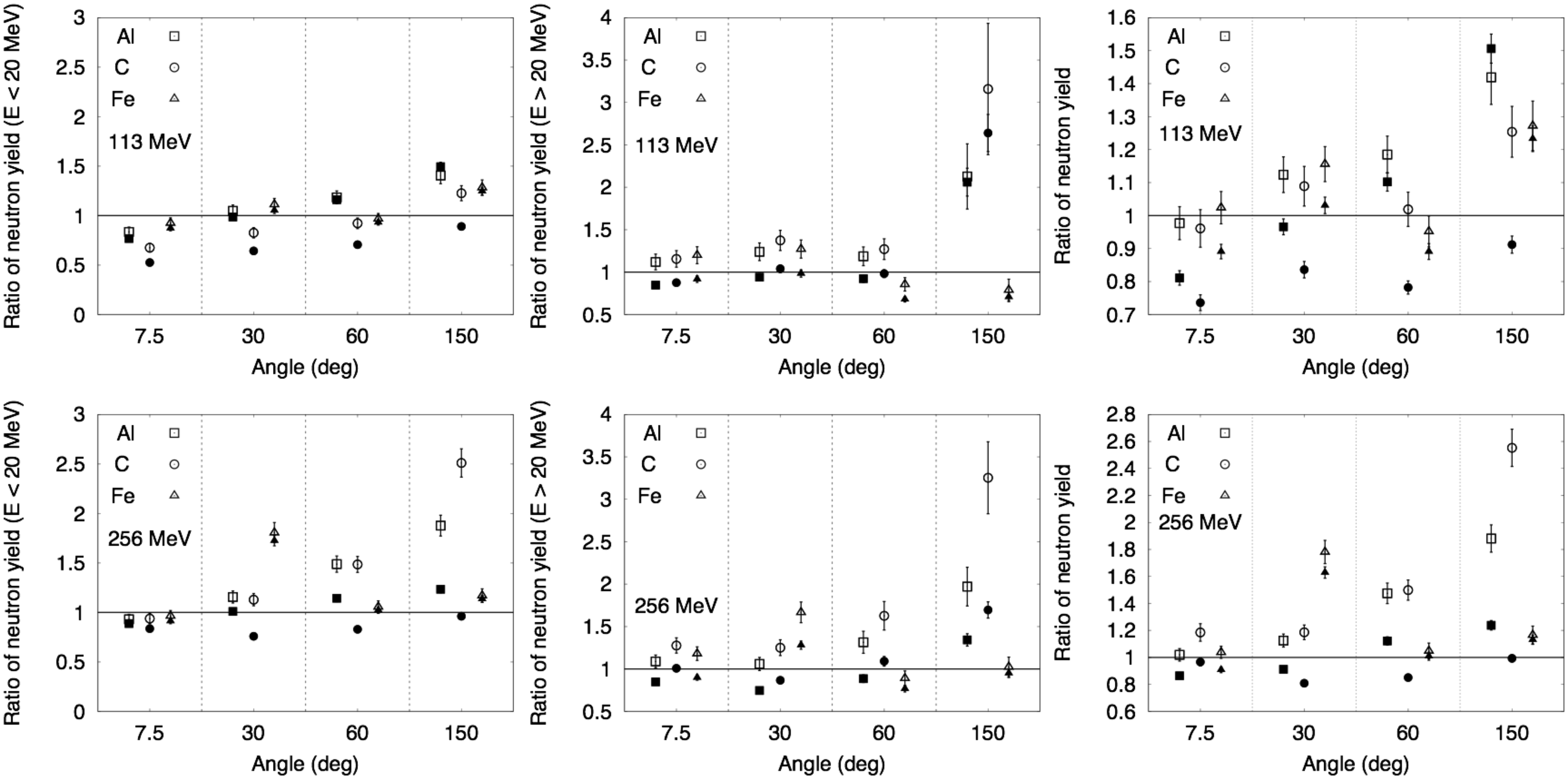


Geant4 v.10.2.p01

Geant4 v.10.3.b01

Yields are scaled by factors of 1,
10, 100, 1000 for 150°,60°, 30°
and 7.5°, respectively

Integrated neutron yields



Neutron yield from proton beams

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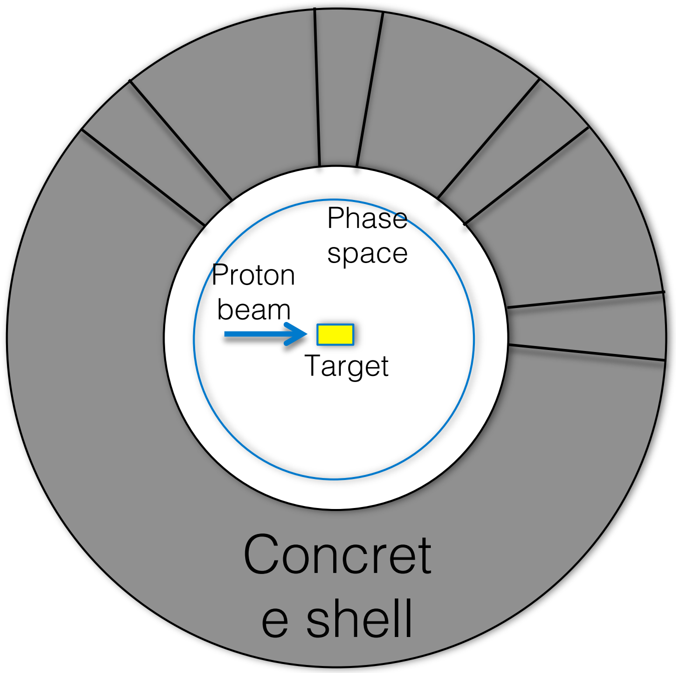
Integrated neutron yields

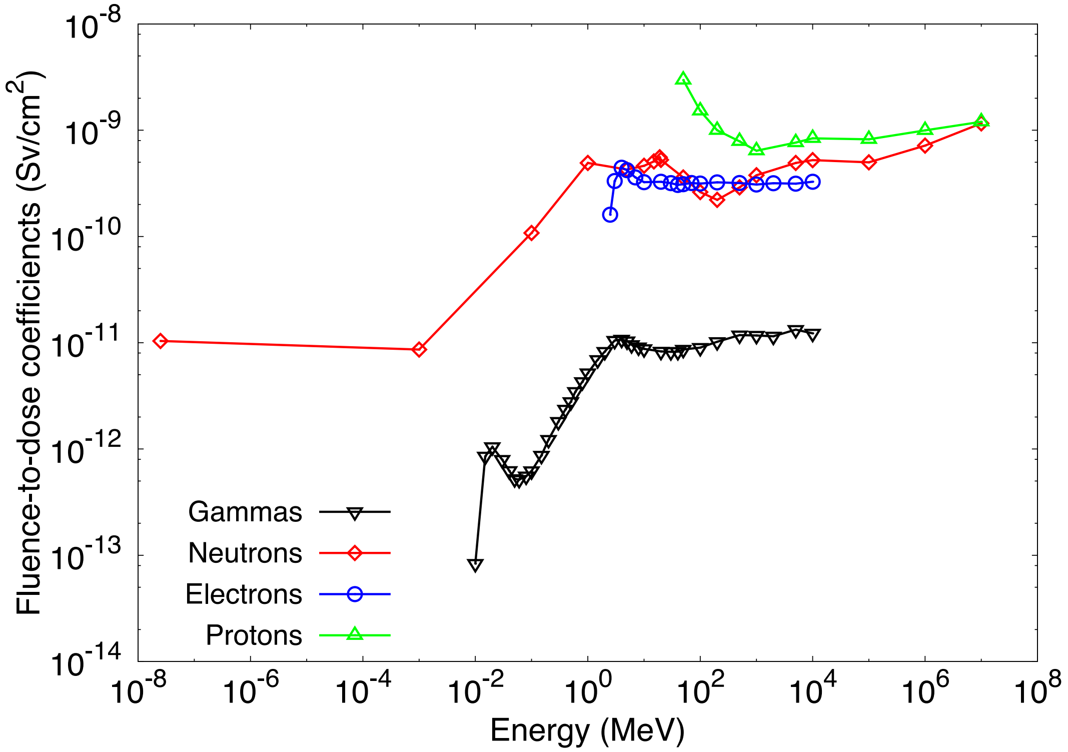


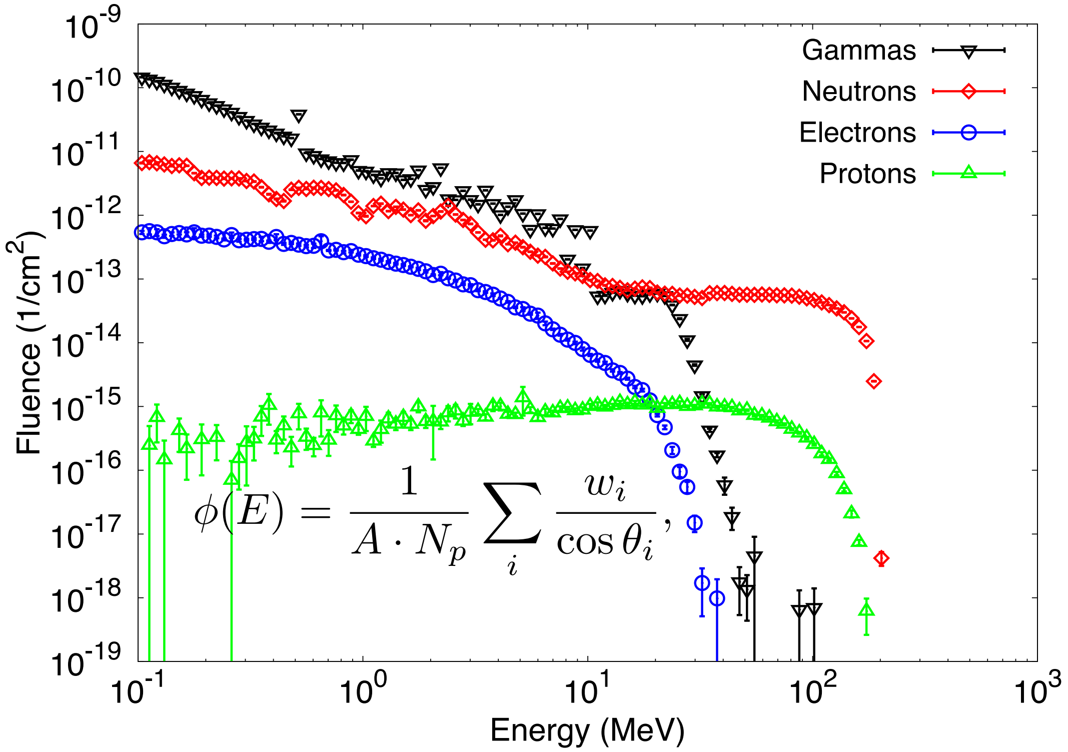
Methodology from Pelliccioni, M. Overview of Fluence-to-Effective Dose and Fluence-to-Ambient Dose Equivalent Conversion Coefficients for High Energy Radiation Calculated Using the FLUKA Code, Radiat. Prot. Dosim. 88(4), 279-297 (2000)

$$H(10) = \sum_i c(E_i)\cdot\phi(E_i)$$

$$H\left(E,\theta,\frac{r}{\lambda}\right) = \frac{H_1(E,\theta)}{r^2}\exp\left[-\frac{d}{\lambda_1(\theta)g(\alpha)}\right] + \frac{H_2(E,\theta)}{r^2}\exp\left[-\frac{d}{\lambda_2(\theta)g(\alpha)}\right]$$

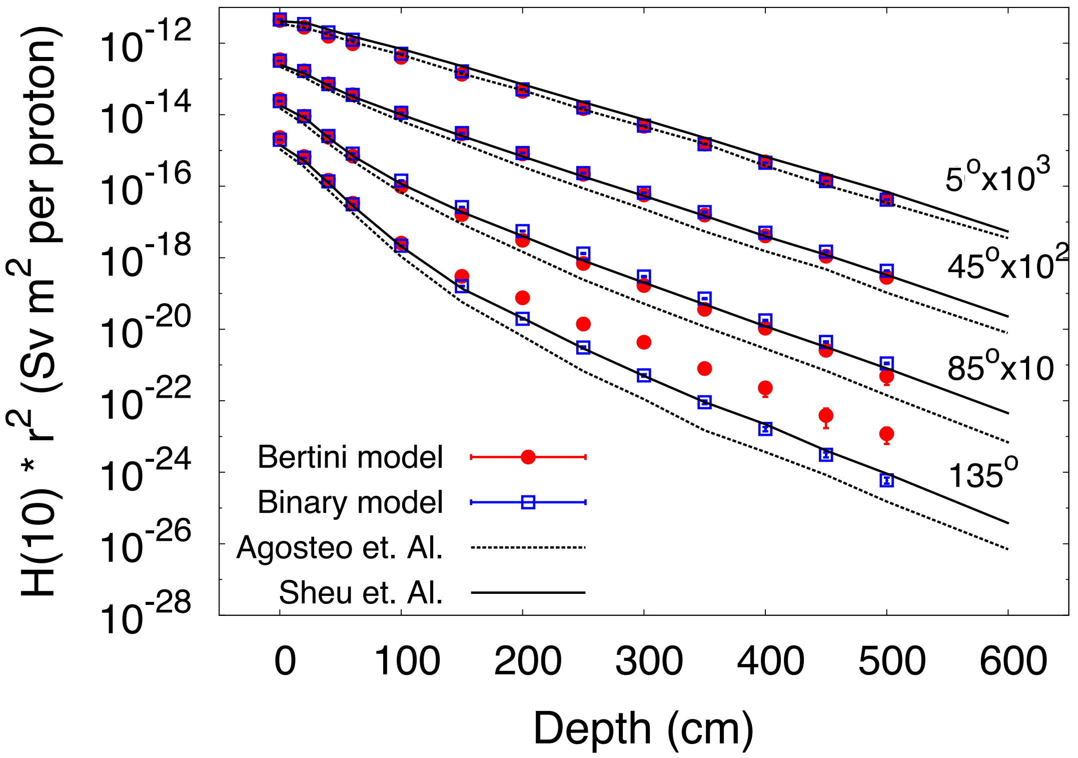
Source terms and attenuation lengths (shielding parameters)

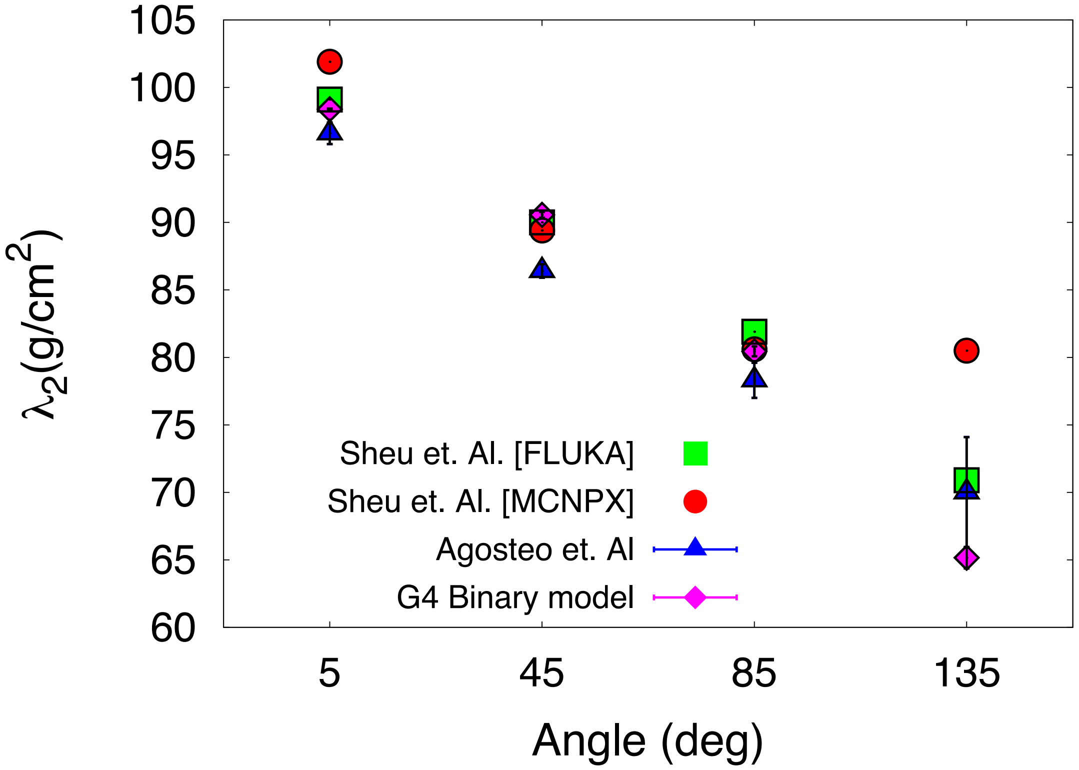




$$\phi(E) = \frac{1}{A\cdot N_p}\sum_i \frac{w_i}{\cos\theta_i},$$

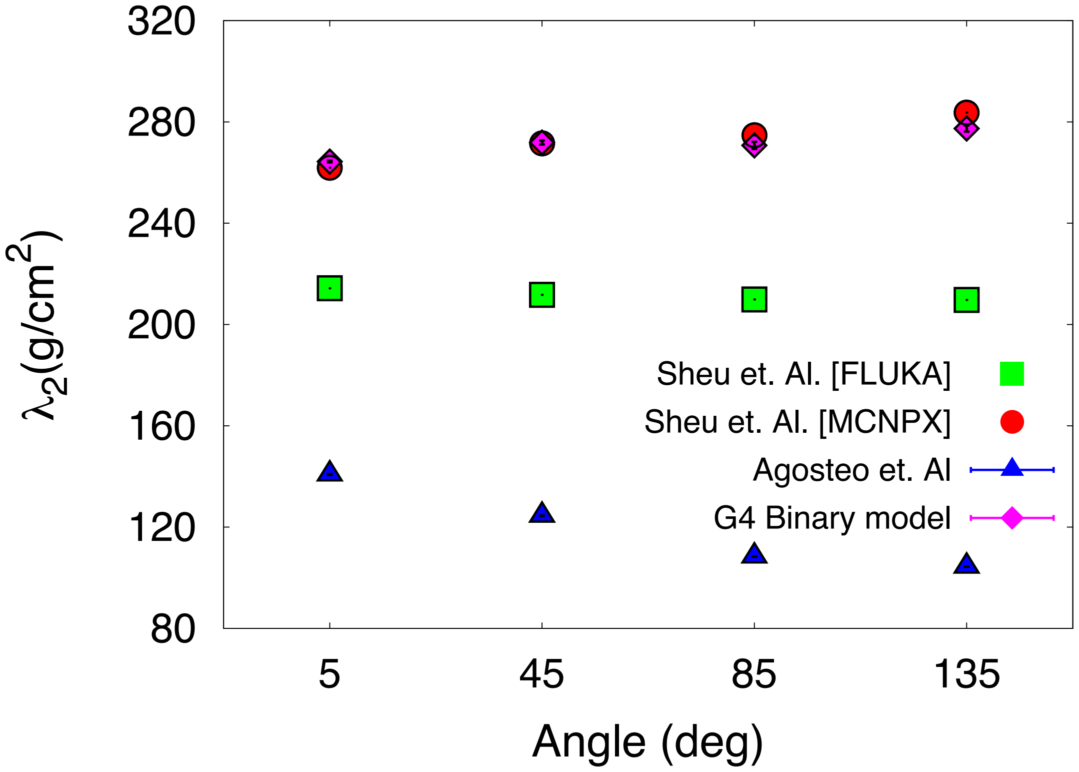
Integrated neutron yields





Data from literature (MCNPX and FLUKA based calculations):

- Sheu et. Al. Deep-penetration calculations in concrete and iron for shielding of proton therapy accelerators. Nucl. Inst. and Meth. Phys. Res. B, 280, 20-17 (2012)
- S. Agosteo, et. Al. Shielding data for 100–250 MeV proton accelerators: double differential neutron distributions and attenuation in concrete, Nucl. Instrum. Methods B 266 (2007) 581–598.
- S. Agosteo, M. Magistris, M. Silari, Z. Zajacova, Shielding data for 100–250 MeV proton accelerators: attenuation of secondary radiation in thick iron and concrete/iron shields, Nucl. Instrum. Methods B 266 (2008) 3406–3416.



Conclusions

- In general, an improvement in the accuracy of integrated total yields was obtained for 113 MeV with the current beta version for all target materials and all angles, compared with v.10.2.p01.
- In the other hand, the 256 MeV energy beams showed lost of accuracy only for 60° and 150° for aluminum and carbon materials.
- Source terms and attenuation parameters can be used for comparison between codes due to the lack of experimental data at these proton energies