Neutron Fields around the LNL CN accelerator and the JRC Ispra's Cyclotron measured with BSS

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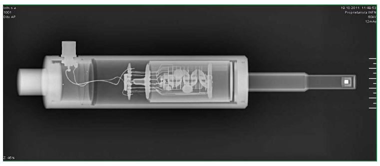
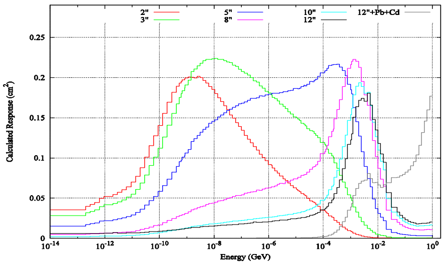
Introduction

Neutron spectrometry based on multispheres' system (**B**onner **S**pheres **S**ystem) is commonly used by many laboratories because of its almost isotropic response, wide energy range and easy operational approach. The LNL Bonner Sphere Spectrometer, based on a ^{6}LiI(Eu) scintillator and 7 moderating spheres, coupled to the unfolding code FRUIT 6.0 [1] (providing response functions calculated with the Monte Carlo code FLUKA [2] and [3]) was used to achieve neutron spectra generated by the interaction of protons of various energies with suitable targets. The CN Van de Graaff accelerator can deliver up to 7 MeV protons meanwhile the JRC Ispra cyclotron covers the range up to 40 MeV. At all irradiations, corrections of the backscattered neutrons were made using appropriate shadow cones. Using the FLUKA code, reference neutron spectra have been obtained in realistic irradiation conditions. These spectra and those obtained by the unfolding procedure have been compared. All spectra are reproduced at 0° angle. Neutron ambient dose equivalent has been evaluated, as well, using FLUKA and FRUIT and also measured using a portable rem counter.

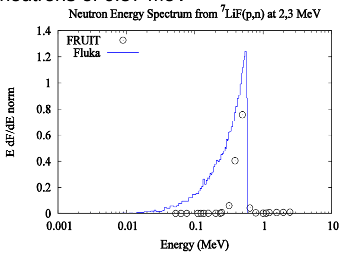


X-Ray radiography of the detector probe for realistic geometry used in FLUKA simulations

FLUKA calculated 120-neutron group responses for the 4 mm ^{6}LiI detector

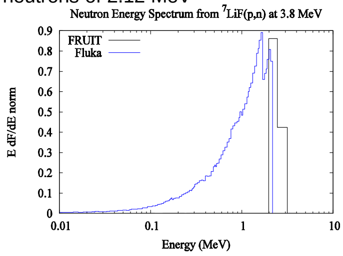


Protons of 2.3 MeV on ^{7}LiF thick target (700 μg/cm^2)
Expected production of monoenergetic neutrons of 0.57 MeV



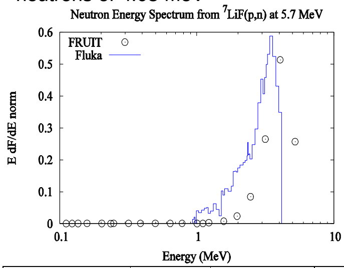
	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	0.04	0.07	0.06

Protons of 3.8 MeV on ^{7}LiF thick target (700 μg/cm^2).
Expected production of monoenergetic neutrons of 2.12 MeV



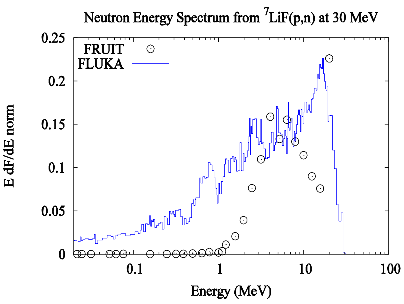
	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	0.4	0.1	0.1

Protons of 5.7 MeV on ^{7}LiF thick target (700 μg/cm^2)
Expected production of monoenergetic neutrons of 4.03 MeV



	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	1.3	0.1	0.1

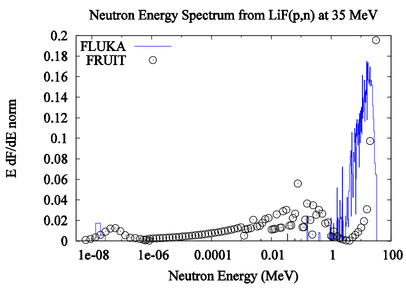
Protons of 30 MeV on 2 mm thick ^{7}LiF target (backing 12 mm graphite).
Expected production of quasi monoenergetic neutrons of 28 MeV.
The interaction of protons with carbon produces spectra edges about 20 MeV lower than the proton energy



	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	31.6	22.3	20.4

Protons of 35 MeV on 2 mm thick ^{7}LiF target (backing 12 mm graphite).
Expected production of quasi monoenergetic neutrons of 33 MeV

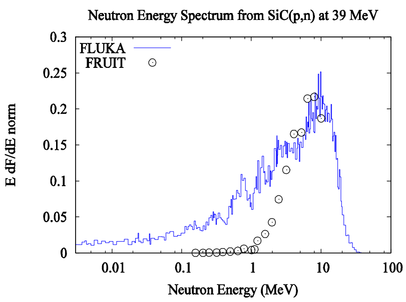
	Reaction Products	Q-Value (MeV)	Threshold (MeV)
p + ^{7}Li	^{7}Be + n	-1.64418	1.88036
p + ^{12}C	^{11}C + n+p	-18.722	20.29438



	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	37.8	53.7	30.4

Protons of 39 MeV on a sintered thick SiC target

	Reaction Products	Q-Value	Threshold
		MeV	
p + ^{28}Si	^{28}P + n	-15.11425	15.65872
	^{27}Si + n + p	-17.17982	17.79870
	^{26}Al + n + 2p	-24.64294	25.53067
	^{24}Al + n + α	-24.64521	25.53302
	^{23}Mg + n + p + α	-26.51657	27,47179
	^{26}Si + n + d	-28.26648	29.28473
p + ^{12}C	^{12}N + n	-18.12058	19.64245
	^{11}C + n + p	-18.72200	20.29438



	FLUKA	FRUIT	Rem Counter
H*(10) (μSv/μC)	18.2	7.5	20.8

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CONCLUSIONS

A BSS using FRUIT, with FLUKA response functions, as unfolding code gives reliable responses for the measurement of workplace spectra aimed at neutron dose assessment. The neutron spectra obtained unfolding the sphere's readings, in particular with monoenergetic neutrons, is in good agreement with those obtained with FLUKA, which simulated the real experimental set up. Both reproduce quite well the expected spectra. Neutron H*(10) comparison shows -up to 30 MeV proton energy- a very good agreement (in the order of 15%) between FRUIT and direct measurement. At higher energies investigated, significant errors probably are due to poor *a priori* information or bad resolution of the response functions.

REFERENCES

[1] R. Bedogni et al., Nucl.Instr. And Meth. A580, 1301 – 1309
[2] A. Fasso` et al.: "Fluka: a multi-particle transport code", CERN-2005-10 (2005), INFN/TC_05/11, SLAC-R-773.
[3] G. Battistoni, et.al.: "The FLUKA code: Description and benchmarking", Proceedings of the Hadronic Shower Simulation Workshop 2006, Fermilab 6--8 September 2006, AIP Conference Proceeding 896, 31-49, (2007).