APPENDIX D – STUDIES ON THE 4Π NEUTRON DETECTOR

As described in Appendix C.3, the results of the simulation code concerning both the calculation of detection efficiency values for the 4π neutron detector and the analysis method of pile-up spectra were validated against experimental data taken at NewSUBARU. Therefore, we were able to investigate for optimum detection configurations to be used at ELI-NP using the Geant4 simulation code.

We present here our investigation on a flat detection efficiency configuration of a 4π neutron detector and a study on the pile-up effects given by the time structure of the ELI-NP to the response of this detector.

D.1 FLAT DETECTION EFFICIENCY STUDY

We have investigated various geometric configurations for the 4π neutron detector in search of a flat detection efficiency necessary for (γ,xn) cross section measurements.

We present here four of best developed configurations with characteristics listed in Table D.1. We investigated configurations with up to 32 ^{3}He counters displayed in three concentric rings, as described in Section 3.2.2. In Table D.1 the ring radii, where the radius is defined as the distance between beam line and the center of the counters placed in each ring, the number of counter per each ring and to total number of counters are listed for the four configurations.

Config.	Ring 1		Ring 2		Ring 3		Total
	radius (cm)	# counters	radius (cm)	# counters	radius (cm)	# counters	# counters
1	5.6	4	14	12	16	12	28
2	5.7	4	14	12	16	12	28
3	5.5	4	13	10	16	18	32
4	5.2	3	13	10	16	18	31

Table D.1 Detection configurations investigated for a flat energy dependency neutron detector.

Plots of the detection efficiency values versus energy for the four investigated configurations are listed in Figure D.1.

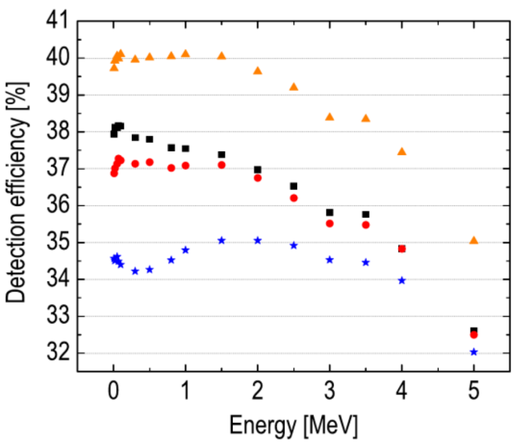


Figure D.1 Total detection efficiency for 4π neutron detectors with the following configurations:

Black – Configuration 1

Red – Configuration 2

Orange – Configuration 3

Blue – Configuration 4.

Characteristics for each configuration are listed in Table

D.1.

We have also investigated for suitable transverse dimension of the polyethylene moderator. We have increased the size of the moderator used for the High efficiency 4π neutron detector from 36 to 56 cm per side. The results on the detection efficiency for Configuration 1 are shown in Figure D.2.

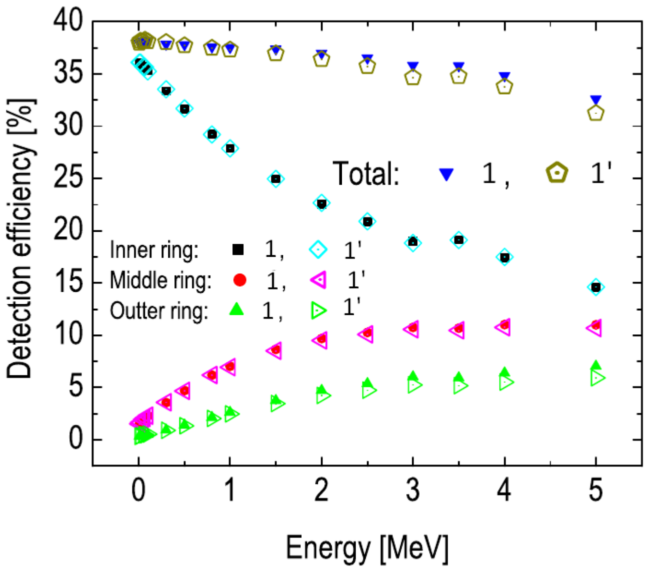


Figure D.2 Neutron detection efficiency for the same configuration of ^{3}He counters embedded in a - configuration 1- 56 × 56 × 50 cm^3 moderator block and in a - configuration 1′ - 36 × 36 × 50 cm^3 moderator block. See Table D.1 for the characteristics of configuration 1.

The best configuration current developed is configuration 3, the total efficiency of the neutron detector being 40 - 37.5 % over 0 - 4 MeV and 40 - 35 % over 0 - 5 MeV. The geometrical configuration and the total and rings detection efficiency are shown in Figures D.3 and D.4, respectively.

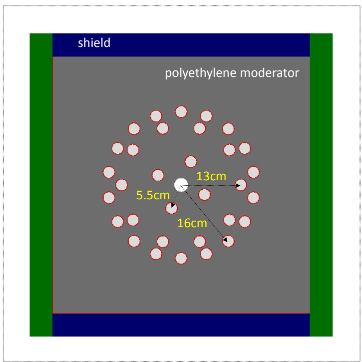


Figure D.3 Cross sectional view of the geometrical configuration of the ELIGANT-TNF.

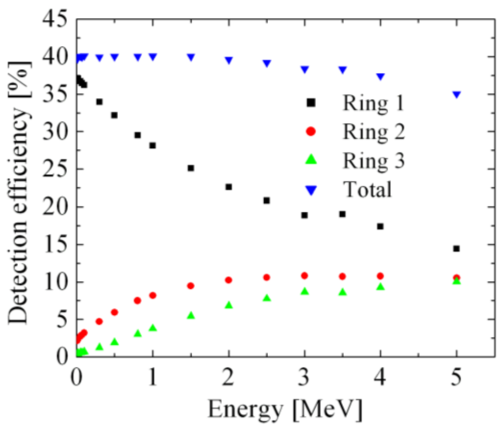
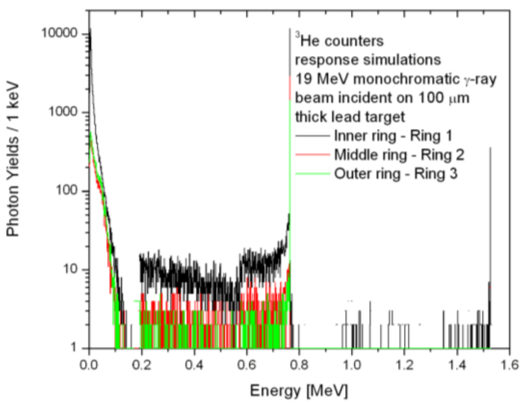


Figure D.4 Total neutron detection efficiency along with efficiencies of Ring 1, Ring 2, and Ring 3 of the ELIGANT-TNF.

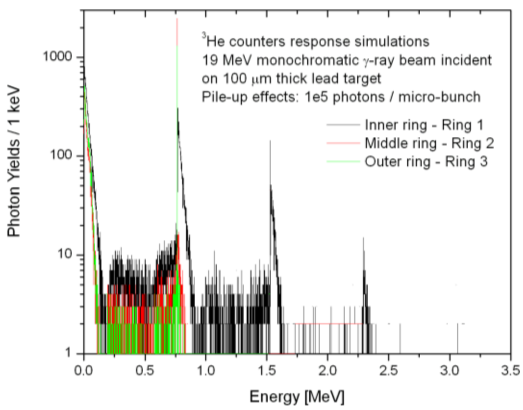
D.2 PILE-UP STUDY ON THE 4Π NEUTRON DETECTOR

The irradiation of a 100 μm thick lead target placed in the center of the ELIGANT-TNF detection system with 19 MeV γ-rays produced by the pencil-like γ-ray source was simulated. We present both total single spectra (Figure D.5.a) and pile-up spectra (Figures D.5.b and D.5.c) and partial incident spectra and energy deposited spectra constructed for events when a photon or an electron were incident on at least one of the counters from a certain ring (Figure D.6). The detection configuration was presented in the previous section and corresponds to configuration 3 described in Table D.1.

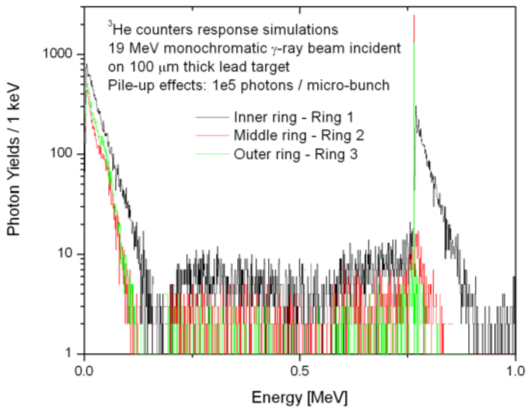
As shown also in Figure C.36, the ^{3}He counters successfully discriminate the energy deposited by photons and electrons from neutron induced events. The plots represented in Figure D.5.a show that even for the inner ring, which has a considerably large component of photon and electron induced counts being placed at only 5.5 cm from the beam line, the neutron – gamma discrimination can be realized by applying an amplitude threshold. 10^9 19 MeV photons incident on the target were simulated for this study.



(a)



(b)

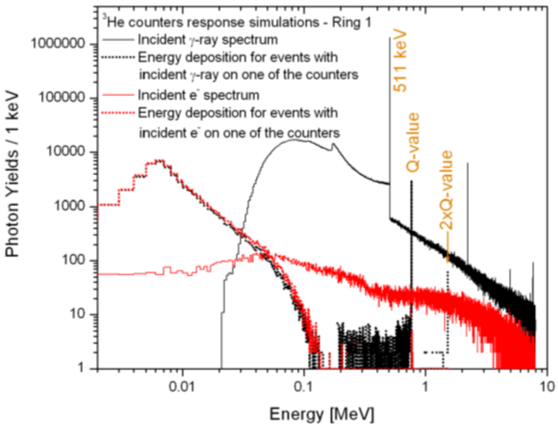


(c)

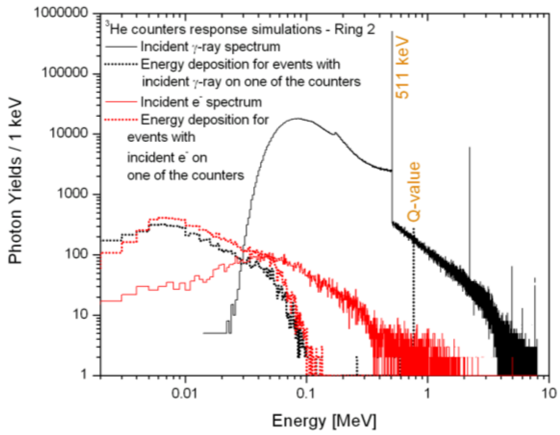
Figure D.5 Single (a) and pile-up (b) and (c) energy spectra of a 100 μm thick lead target was irradiated with a monochromatic 19 MeV γ-ray beam. The target was placed in the center of the ELIGANT-TNF detection system and the spectra correspond to energy depositions in the ^{3}He counters placed on Ring 1(black line), Ring 2 (red line) and Ring 3 (green line). Plot (c) is a close up on plot (b) for better visualization of the energy region below 1 MeV.

For the pile-up study, only the first micro bunch was considered to be implanted on the target, therefore the effects of each consecutive 10^5 events were summed up, where an event is represented by one 19MeV incident on the target. Pile-up of up to three neutrons are observed for this configuration of detector, target and incident beam, as can be observed in Figure D.5.b. A close-up on the energy region below 1 MeV is displayed in Figure D.5.c for an investigation of the possibility of the neutron – gamma discrimination using an amplitude threshold. We observe that even in high energy and high intensity incident γ-ray and electron flux, the neutron – gamma discrimination can be performed applying an amplitude threshold.

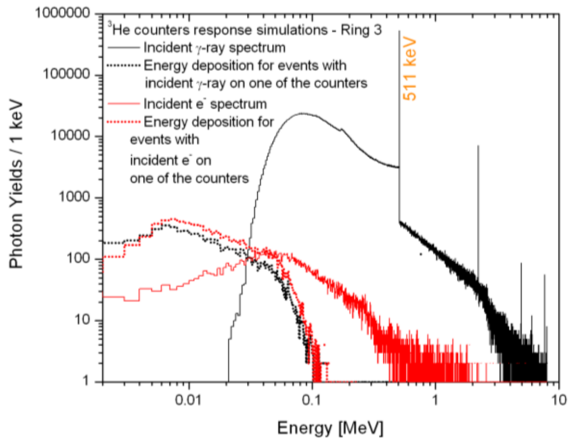
The partial energy spectra was also investigated by applying the following conditions:
- Incident energy of photons incident on counters – black solid line in Figure D.6.
- Energy depositions for the events with one photon incident on at least on of the counters – black dotted line in Figure D.6.
- Incident energy of electrons incident on counters – red solid line in Figure D.6.
- Energy depositions for the events with one electron incident on at least on of the counters – red dotted line in Figure D.6.



(a)



(b)



(c)

Figure D.6 Incident spectra and energy deposition of γ-rays and electrons on the ^{3}He counters placed on Ring 1 (a), Ring 2 (b) and Ring 3 (c) of the ELIGANT-TNF detection system. The radiations are produced by irradiating a 100 μm thick lead target placed in the center of the detector with a monochromatic 19 MeV γ-ray beam.

We have studied the response of a fast neutron detector composed of 20 BF_3 proportional counters embedded in a 36 × 36 × 50 cm^3 polyethylene moderator to the radiation produced by impinging a monochromatic 13 MeV gamma ray beam on lead targets of various thicknesses. The BF_3 counters are placed in three concentric rings of 4, 8, and respectively, 8 counters, in the configuration shown in Figure 3.2.1 The counters contain BF_3 gas 96% enriched in ^{10}B at 1 atmosphere pressure.

For the pile-up study, only the first micro bunch was considered to be implanted on the target, therefore the effects of each consecutive 10^5 events were summed up, where an event is represented by one 13MeV incident on the target. Two different target thickness values were investigated.

For a 120 µm thick lead target, we obtain a maximum of 4 coincident neutrons. We can separate the events when we have 1 recorded neutron from the ones where 2, 3,respectively 4 neutrons were recorded coincidentally. Also, the signals given when other types of radiation but no neutron were detected in coincidence can be easily separated from the neutron events. For this case we had 0.8×10^9 incident gamma rays on target. Figure D.7 shows single and pile-up spectra obtained for a 120 µm lead target. Also pile-up effects given at the irradiation of a 12µm were investigated. The results are displayed in Figure D.8.

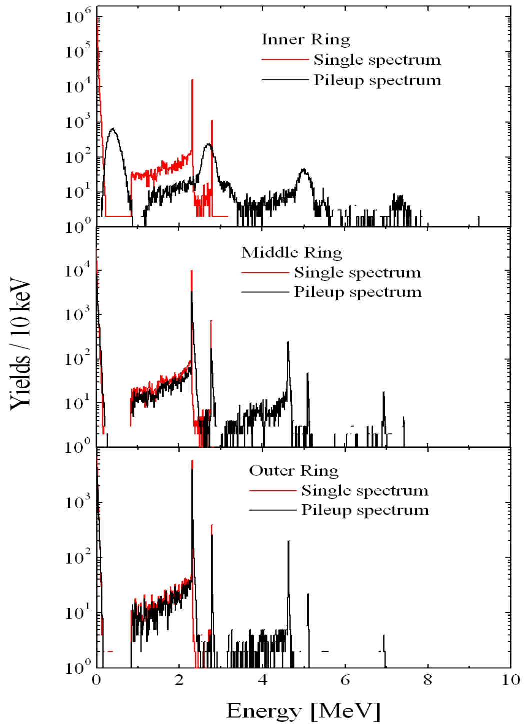


Figure D.7 Single and pile-up spectra recorded with BF_3 counters for a 120 µm thick Pb target.

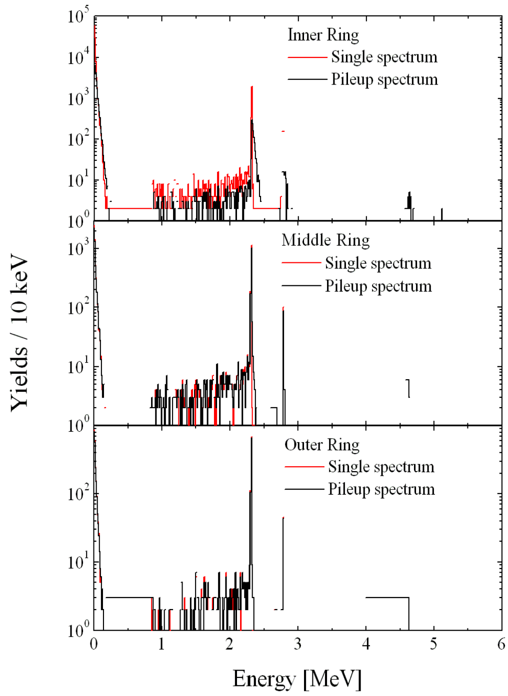


Figure D.8 Single and pile-up spectra recorded with BF_3 counters for a 12 µm thick Pb target.