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EXPERIMENTAL TESTS OF NEUTRON SHIELDING IN THE ATLAS FORWARD REGION

S.Pospíšil, I.Štekl, T.Čechák, J.Jakůbek, J.Klusoň, J.Koníček, V.Linhart, M.Šiňor
Faculty of Nuclear Sciences and Physical Engineering
Czech Technical University, Prague
C.Leroy
University of Montreal, Montreal
Z.Doležal, R.Leitner, G.Lukhanin
Nuclear Center, Faculty of Mathematics and Physics
Charles University, Prague
M.Lokajíček, S.Němeček
Institute of Physics
Academy of Sciences of the Czech Republic, Prague
J.Palla, J.Sodomka
Faculty of Transportation Sciences
Czech Technical University, Prague

Abstract

Experimental tests devoted to the optimization of the neutron shielding in the ATLAS forward region were performed at the CERN-PS with a 4 GeV proton beam. Spectra of fast neutrons, slow neutrons and gamma rays escaping of a block of iron ($40\times40\times80$ cm^3) shielded with different types of neutron and gamma shields (pure polyethylene - PE, borated polyethylene - BPE, lithium filled polyethylene - LiPE, lead, iron) were measured by means of liquid scintillators, plastic scintillators, Bonner spheres spectrometer and HPGe, BGO detectors. The main aim of the test was to demonstrate the advantage of LiPE against BPE when considering the suppression of the gamma rays yield. Using LiPE offers also the advantage to avoid additional outer layer of lead against the gamma rays accompanying neutron absorption. The first experimental results obtained with a neutron - gamma shield are presented. The idea of a segmented outer layer shielding (iron, BPE, iron, LiPE) is proposed.

Keywords: fast neutrons, thermal neutrons, neutron shielding, neutron reactions, radiative capture, boron, lithium, polyethylene, lead, iron, gamma shielding, gamma radiation, hadron cascade, protons, 4 GeV

1 Introduction

The shielding against fast neutrons in the forward region of the ATLAS experiment has a vital importance for the whole apparatus. The fast neutrons contribute mostly to the radiation hard environment inside the detector. Moreover, they contribute together with the gamma rays accompanying interaction of fast and slow neutrons to the unwanted background signal production.

High-energy particles from the interaction point begin to shower when entering material. If the material is thick, the shower development will continue until most of the charged particles have been absorbed. The remnants are mostly neutrons and associated photons. Electromagnetic showers are absorbed very rapidly, while neutrons will travel long distance, losing their energy gradually. Nuclear capture, in particular of the thermal neutrons, frequently results in the production of photons via (n,γ) reactions. Photons also result from excited-state decay of the spallation products and from fast neutron interactions with atomic nuclei.

The two-step golden rule for construction of a shield against fast neutrons is: i) first moderate, ii) then capture. It has to be noted that ^{3}He and ^{6}Li are the only nuclei where the neutron capture is not accompanied by gamma emission.

The innermost layer of the shielding in the ATLAS forward region acts as an hadron shield [1]. It should have a short hadronic interaction length but should not produce a copious number of secondary neutrons. Iron is used as the main hadron shielding material. The hadron shield is surrounded by a neutron shield made of polyethylene (PE) in which the fast secondary neutrons are effectively moderated and captured through elastic scattering and radiative capture by hydrogen. There is also the proposal in [1] to surround a polyethylene layer with an additional layer of 5 cm of lead to shield against photons from neutron capture.

Another proposal to shield against fast neutrons inside the ATLAS apparatus was based on borated polyethylene (BPE) [2]. Hydrogen is responsible for neutron slowing down while boron is added to capture slowed neutrons. This prevents transport of neutrons and production of highly energetic gamma rays from neutron radiative capture in surrounding materials (e.g. in Fe - 7631 keV, 7645 keV; Cu - 7914 keV, 7637 keV; Si - 4934 keV, 3935 keV) or in PE itself mainly due to the ^{1}H(n,γ)^{2}H (E_γ = 2223 keV), thus suppressing the background. The disadvantage of boron based shield comes from the gamma ray production in the reaction ^{10}B(n,α)^{7}Li$^*\rightarrow^7$Li + γ (E_γ = 478 keV), which is the dominant channel after the neutron absorption. To avoid this disadvantage, it was suggested in [3] to use as a neutron shield lithium doped polyethylene (LiPE) where the reaction responsible for the neutron capture is ^{6}Li(n,α)^{3}H with no gamma ray production. The present work put this idea to the test in a beam environment.

The present work is also motivated by the idea of avoiding extensive use of lead in outer layer of forward region shielding. It would made the shielding cheaper and simplify the problem of construction.

2 Experimental

The experimental set-up is schematically shown in Fig 1. The hadron shielding was simulated by an iron block with dimensions of 40 cm$\times$40 cm$\times$80 cm. A collimated beam of 4 GeV protons striked into the block, which was shielded from one side by different types of neutron and/or gamma shields. The distance between the beam and the shielded surface of the iron block was 25 cm. The beam cycle was approximately 14 s with one or two burst each of about 400 ms of duration. The data acqusition system was gated in coincidence with the proton burst (time window $\sim$ 700 ms) to decrease the counting of unwanted background radiation.

The number of protons was monitored by means of a wire chamber and by two scintillating layers standing in front of the block. Independent integral monitoring of the number of hadronic cascades produced in the iron block was done by means of a BGO spectroscopic scintillator positioned on the top of the iron block.

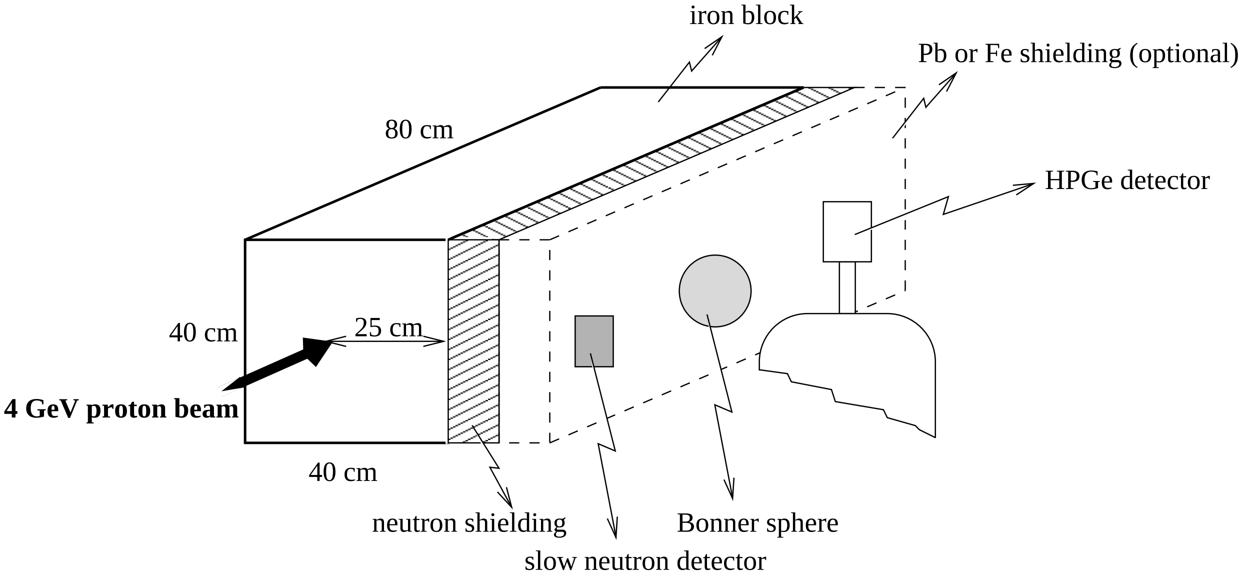

Figure 1: Experimental set-up.

Precise gamma ray spectroscopy performed with a HPGe detector gave exhaustive information about the origin of detected gamma rays. The HPGe detector was covered by a Cd foil 0.5mm thick. The following gamma rays were monitored carefully:

- 478 keV, ^{10}B(n,α)^{7}Li reaction,
- 558 keV, ^{113}Cd(n,γ) reaction,
- 847 keV, ^{56}Fe(n,n'γ) reaction as a measure of inelastic scattering of the fast neutrons in the iron block itself,
- 2223 keV, ^{1}H(n,γ)^{2}H reaction as a measure of the thermal neutrons captured by hydrogen in any types of polyethylene,
- 7631 + 7645 keV doublet from ^{56}Fe(n,γ) as a measure of thermal neutrons captured in the iron block. Thermal neutrons are produced via slowing down of neutrons in the block itself and due to the albedo neutrons scattered from the neutron shield back to the iron block.

In parallel, the gamma rays emitted from the whole configuration (iron block + shielding) were measured by means of a NaI(Tl) crystal.

Fast neutron spectra were measured by two independent spectrometers - Bonner spheres spectrometer and recoil proton spectrometer based on a liquid organic scintillator. Thermal neutron flux from shielding was monitored by means of a Si detector in connection with a ^{6}Li convertor [4] and by a ^{6}Li enriched scintillator.

The measurement was performed with different types (PE, BPE, LiPE) and different thicknesses (8 cm and 16 cm) of neutron shielding. The polyethylene based neutron shielding was also combined with outer Pb gamma shield with thicknesses of 5 cm and 10 cm and with outer Fe gamma shield with a thickness of 5 cm. All kinds of neutron shielding were produced in KOPOS Kolín (Czech Republic). Chemical composition of PE is CH_2, BPE is CH_2 + H_3BO_3 (3 weight % of B) and LiPE is CH_2 + Li_2CO_3 (10 weight % of Li). Measurement with the unshielded iron block was performed to estimate the yield of gamma radiation produced by neutrons in surrounding materials in the experimental hall (concrete, magnets, etc.), both considered to be "background radiation".

thickness [cm]	type of shielding	B (478 keV) peak area [counts]	Fe (847 keV) peak area [counts]	H (2223 keV) peak area [counts]	Fe (7631+7645 keV) area of peaks [counts]
8	PE	27751±1681*	16243±1527	67185±1485	15024±1811
8	BPE	556586±1048	21383±535	4653±326	4230±548
8	BPE+5cm Fe	12956±325	14737±520	1669±271	2763±341
8	LiPE	13601±528 *	16599±651	4581±440	3045±429
16	PE	35331±1680*	8282±1744	86062±1997	10602±1606
16	PE+5cm Pb	8897±217*	2564±384	6993±209	1053±214
16	PE+10cm Pb	3537±202*	1658±323	1442±167	641±200
16	BPE	296838±762	9190±286	2654±155	2559±211
16	LiPE	12154±530*	8766±509	4104±328	2911±351
	background**	23013±482*	15939±577	2354±291	1227±361

Table 1: Relative yields of gamma rays relevant to shield quality assessment (* from boron contained in the surroundings, ** measurement of background only with the iron block without any shielding).

The first results from the measurements are summarized in Table 1. The results clearly display a significant suppression of neutron capture gamma rays (2223 keV, 7631 keV, 7645 keV) for both types of doped PE (BPE, LiPE) compared with pure PE. It is also clearly seen that so effective decrease of the above mentioned gamma rays can be hardly achieved by additional lead shield of about 5 cm thickness. The disadvantage of BPE is illustrated by the huge amount of gamma-rays accompanying neutron absorption by B (column 3 of the Table 1, E_γ = 478 keV), which would also require additional gamma shield (because most of the detectors are very sensitive to this energy). Fortunately, the shielding of that gamma rays is easier and can be done with the help of construction material more convenient than lead, let's say with iron (see third row of Table 1 with 8 cm of BPE + 5 cm of iron).

3 Conclusions

The results obtained from the present experimental tests lead to the following conclusions:

- BPE and LiPE are more effective than PE in decreasing the neutron capture gamma ray production,
- BPE, compared with LiPE, needs additional low energy gamma ray shielding for which lead can be replaced by iron,
- the shielding capabilities of BPE and LiPE can be utilized by combining them, e.g. a segmented shielding made of consecutive layers of iron, BPE, iron, LiPE. This idea will be tested in forthcoming runs planned for the beginning of July 1997.

This report contents only preliminary results. The analyses of direct measurement of neutron emission from the whole set-up is in progress. Final results will be prepared after next run in July 1997 as a ATLAS Technical Note and the authors are intending to publish them in NIM.

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