The objective of the work is to study the neutron and gamma ray backgrounds in the FNPB npdgamma experiment to develop an optimized shielding when a supermirror polarizer has been used. Recent estimates [Sha08] of a considerable Co-activation in a FeCoV supermirror bender polarizer for the FNPB cold neutron guide of SNS [Alle07], have prompted reconsideration of the type of a supermirror polarizer to be used. A FeSi coated multi-plate polarizer can be another choice [Gree08]. We modeled gamma ray energy spectrum from such a polarizer and estimated an upper limit of a possible Fe-activation. After reconsidering the npdgamma experiment geometry and shielding we modeled the total background of the npdGamma CsI detectors including a weak contribution from the FeSi polarizer.

1 FeSi supermirror polarizers

The first FeSi supermirrors appeared in 2002 [Stah02], however, the FeSi supermirror multiplate polarizers deployed on the neutrons beams are unknown for authors of this report. The FeSi polarizers are used presently in a form of long mirrors [Stah04,Hol08]. A potential problem with SM FeSi is anisotropic stress in the Fe layers which, if not reduce, can bend substrate or even to peel supermirror layers [Stah04]. For SM with $m = 3$ one expects 599 layers (about 3 $\mu k$) on one site of the sustrate. For multiplate polarizer, as opposite to the mirror polarizer, one have to sputter layers on both sites of substrates, which is more challenging in a case of FeSi. A long mirror coated with SM FeSi is now in use at one of the beams of the FRM-II reactor (Munich) which has the cold neutron flux density value of $4.5 \times 10^7$ cm$^{-2}$s$^{-1}$. The authors of this instrument preferred the FeSi polarizer over FeCoV, since their beam intensity would lead to a considerable Co-activation (see also [Sha08]) of the polarizer setup.
2 Fe-activation in FeSi multi-plate polarizer

With all the ‘radiological’ superiority of FeSi over FeCoV it worthwhile to estimate a possible Fe-activation. One of the iron isotope, namely $^{54}$Fe (5.8% concentration in natural Fe) is activated by neutrons with life time of 2.7 years but with no subsequent $\gamma$ quanta (100% $\beta$-s). However the rare isotope $^{58}$Fe (0.3%) is known to have the activation cross section of $\sigma=3$ b for cold neutrons and the half life of $T=44.6$ days. The neutron capture product nucleus $^{59}$Fe beta-decays to excited levels of $^{59}$Co producing two gamma quanta, 1.10 MeV(56.5%) and 1.29 MeV(43.2%). In this case, the saturated activation, $A_s$, as the number of decays per second after the irradiation time $t > 5 \times T$ is

$$A_s = N_{tot} \Phi \sigma,$$

(1)

where $N_{tot}$ (the dimensionless quantity) is the total number of the $^{58}$Fe nuclei in the device. With an upper estimate of about 50 g of Iron present in FeSi multi-plate polarizer, after 10 days running time in the cold neutron flux $\Phi = 10^9$ cm$^{-2}$s$^{-1}$ the whole polarizer will emit $\approx 10^8$ quanta/sec, which is acceptable, especially with some shielding.

3 Gamma ray spectrum from FeSi polarizer

The production of $\gamma$-rays in the FeSi multi-plate SM, considered presently to be a better choice [Gree08] for the FNPB polarizer was modeled by the MCNP5 code using the lattice geometry as in [Sha08]. The FeSi polarizer parameters were: the length $l = 50$ cm, $n = 40$ channels, the substrate thickness $d = 0.3$ mm, and the cross section 10x12 cm$^2$. The sizes and composition of material coatings of a $m = 3$ FeSi SM were taken as described in Section 1. An amount of boron in substrates was the same as for the FeCoV SM [Sha08].

The MCNP source of the 5-meV neutrons was distributed uniformly inside the polarizer channels and biased to the forward (below 2 deg) angles to produce about 20% of neutron intensity at the polarizer exit. The result for the total number of the emitted $\gamma$ quanta was 0.74 per one incident neutron. The boron $E_\gamma = 480$ keV gamma rays contributed 98.8% to the whole spectrum. Therefore, the hard energy component (1.2%) was reduced drastically as compared with the FeCoV polarizer (30%). The produced hard gamma ray component of the spectrum, shown in Fig 1, has a typical shape of the the gamma-ray spectrum after the neutron capture by Iron.
The FeSi polarizer will have a magnetic cage designed to provide the required field of about 400 gauss. To adapt it to the npdgamma magnetic guide field the polarizer is planned to be placed at twice the distance from the detector in the design with the FeCoV polarizer. Such a change itself makes the gamma-background from the FeSi polarizer less than for the calculated case [Sha08] of FeCoV geometry. We performed two options of the detector background modeling for new geometry with the FeSi polarizer at 140 cm distance from the edge of the first ring of CsI crystals. The first ring is the most vulnerable to gamma-rays from FeSi and it screens the next ring. The general geometry view of MCNP5 modeling is shown in 2. In the first option without any shield but weakly effective spool of the spin flipper the background in the first ring was 6% higher than the background without any polarizer. In the second option we placed a 5-cm thick Pb disk of 40-cm outer diameter and of a 10x12 cm$^2$ opening just after the polarizer. The additional (due gamma-rays from FeSi polarizer) background was only 1.5% in this option which can be neglected. Therefore the detector background with the FeSi polarizer and external cylindrical $^6$Li-plastic shield is expected to be as calculated in [Sha08], Fig.3, where results for the CsI-absorbed gamma energy without background and for the total absorbed energy ("effect" plus "background") are shown. A larger relative contribution of the background in the detector first ring is due to the closeness of the Al-entry window and a lesser value of the effective solid angle subtended by the first ring.

The use of a supermirror polarizer enhances the neutron flux but at a price in beam divergence. The divergence of neutron trajectories is characterized by angular deviation from an ideal parallel directions. We took the divergence of 2 deg (35 mrad), the beam area 10x12 cm$^2$ at the FeSi exit and we looked for the beam profile at the father end of the Spin Flipper with the use of co-centrical tally rings of the 1-cm step in the radius. The result is shown in Fig 4. This is an azimuthally average profile over the subsequent rings. It reveals the full beam size of a 22-cm diameter (the present internal diameter of the Spin Flipper spool is 23.2 cm). Therefore one have to make an appropriate change in the size of the $^6$Li-plastic diaphragm inside the LH2 cryostat (the $^6$Li diaphragm diameter was 17 cm in the LANL npdgamma experiment).

A last concern in the background modeling was an amount of neutron scattering by the air on an extended way from the polarizer to the LH2 cryostat inside the detector. It was demonstrated that 11% of the cold neutron beam was scattered in the geometry of Fig.2, that is, in an opened 140-cm flight path. This is not acceptable and should be dealt with, e.g. by the use of He4 gas replacing the air.
References


Fig. 1. Gamma ray spectrum from FeSi polarizer, excluding the boron 480 keV line. This spectrum is normalized to 1. The intensity of this spectrum amounts to 1.2% of the total (including 480 keV) gamma ray intensity, which is $0.8 \times 10^{11}$ quanta/s.
Fig. 2. Geometry of the npdGamma background modeling for the FNPB with FeSi polarizer.
Fig. 3. Total energy absorbed by the npdgamma detector rings per one cold neutron incident on the liquid hydrogen target: thin red curve - without any background, thick green curve - with modeled background.

Fig. 4. Azimuthally averaged beam profile along the radius in geometry with FeSi polarizer. F is the relative value of the neutron flux density at a given radius $R$. 