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Radioprotection shielding for neutrons induced by the reaction (^{2}H (40 MeV), ^{12}C)

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Abstract. In the framework of design studies for SPIRAL2, the simulation of the neutron flux generated by 40 MeV deuterons on a thick ^{12}C target was performed and compared to experimental data. The calculation of the dose rate of these neutrons allowed to compare four materials being considered for radioprotection shielding: barites, gypsum, ordinary concrete and heavy concrete. The simulated map of the neutron dose rate in the production building shows a very high dose rate around the neutron source and in the environment of some of the accelerator equipment.

1 Introduction

SPIRAL2 is a major extension of GANIL. It was designed to produce high quality beams of exotic nuclei for several applications: fundamental nuclear physics (especially far from stability), astrophysics, isotope production for medical imaging and radiotherapy, material properties, and radioactive waste studies [1]. With its high-intensity neutron beams, this new facility will also be ideally suited for applications that require high neutron flux in the range from 1 to 40 MeV. Such studies include the measurement of induced neutron cross sections with different techniques namely time-of-flight, materials irradiation and fission-yield experiments.

SPIRAL2 adds a linear accelerator to the already five existing cyclotrons in use at GANIL. This new high-current accelerator is dedicated to the acceleration of light ions (up to 20 MeV/u) and heavy ions (up to 14.5 MeV/u) [2,3,4]. Irradiated by 40 MeV deuterons with an intensity of 5 mA, a graphite converter will be used as a neutron source of high flux. Located in the production building, the converter is coupled to a uranium carbide target (UC_2) which will produce high rates of fission fragments [5].

Safety studies and the definition of the radiological environment of the new facility require a detailed study in order to quantify the impact of these neutrons and their behaviour in the attenuation of the shielding. We investigated these issues using a simulation of related nuclear reactions and neutrons transport as well as by the modelling of the production building and some of its components.

2 Neutron production

The 40 MeV deuteron beam from the linear accelerator will nominally be stopped in a 4 mm thick graphite converter. After deuteron stripping, neutrons emerge as a continuous spectrum.

A neutron distribution measurement was performed by Lhersonneau et al. at the Physics Department in Jyväskylä, Finland, on behalf of the SPIRAL2 project. In this experiment, several foils (Al, Ni, Co, In and Bi) were used to generate neutron reactions with different thresholds, which allowed the unfolding of the neutron spectra. Figure.1 , taken from Ref. [6], shows the spectra.

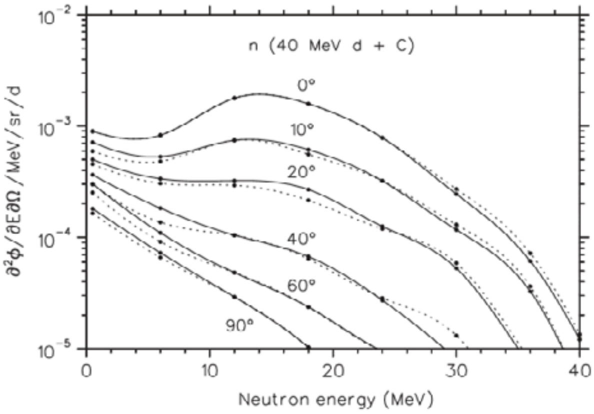

Figure 1: Neutron spectra by activation [6] (solid lines) and TOF measurements [7,8,9] (dotted lines).

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A comparison between these measurements and an MCNP calculation performed by the author of this abstract showed a ratio MCNP/experiment of 1.45 for the neutron yield generated by the interaction of deuterons with the graphite converter within a cone of half-angle of 50° and above 4 MeV (figure 2). The experimental flux is namely 0.0096 per deuteron and the MNCP value 0.0139. We took into account this conclusion in the reconstruction of the neutron source in all MCNP modelling of the shielding studies.

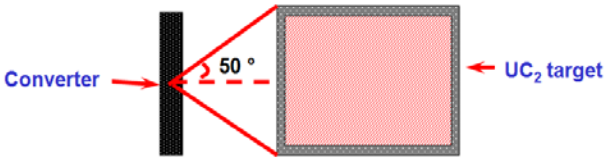

Figure 2: Schematic layout of the converter and the uranium carbide target.

3 Neutron attenuation

3.1. Configuration at 0° angle

Several materials, potentially interesting for our case, were chosen to study the attenuation of these neutrons in the protection shielding: barites, gypsum, ordinary concrete and heavy concrete. The characteristics of these materials are provided in table 1. The calculations were performed with the MCNP code [10].

We calculated the neutron dose rate throughout a shielding protection situated at 300 cm along the beam line axis in the front of the graphite converter and within 300 cm of thickness (figure 3).

We refer to the attenuation factor, μ, as the absolute value of the negative exponential slope ($\Phi(x) = \Phi_0 e^{-\mu x}$) of the curves in figure 3. The μ values in 10^{-2} /cm are 4.5 (barites), 7.6 (gypsum), 6.2 and 7.1 for normal and heavy concretes, respectively. Both gypsum and heavy concrete seem to be excellent materials for the attenuation of neutrons.

Table 1: Composition and density of the shielding materials.

material (density)	Composition (Ratio by mass (%))
Barites (2.6)	Ag(3.2e-4);Ba(53.9);Cd(4.0e-4);Ce(2.2e-3);Cu(1.5e-2);Fe(1.4);Mn(4.7e-2);P(2.3e-2);Pb(4.7e-2);S(12.7);Sb(2.6e-3);Si(2.1);Sr(1.2);Ti(1.2e-2);Zn(5.6e-2);O(28.5)
Gypsum (2.5)	H(2.3);O(55.8);S(18.6);Ca(23.3)
Ordinary concrete (2.3)	H(0.5);C(2.2);O(50.9);Na(1.0);Mg(0.5);Al(3.8);Si(26.7);Cl(0.3);K(1.1) ;Ca(10.9) ;Mn(0.03) :Fe(1.8) ;Pb(0.2)
Heavy concrete (3.3)	H(0.2);Na(36.7);Na(0.01);Mg(0.25);Al(2.2);Si(9.5);P(0.64);S(0.15);Cl(0.007);K(0.7);Ca(3.7);Ti(0.2);Mn(0.1);Fe(45.6)

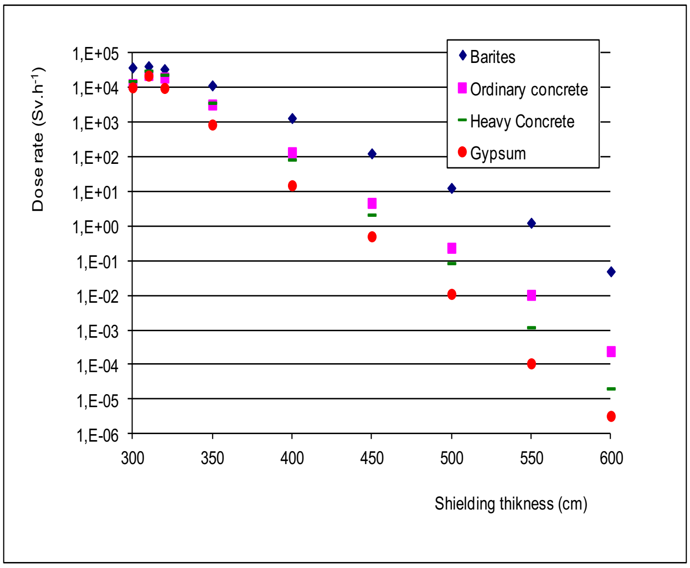

Figure 3: Calculated neutron dose rate and its attenuation within various shielding materials.

3.2 Canal configuration of the production building

A canal configuration was one of the options that were studied for the production building of SPIRAL2 [figure 4]. This building would use primarily ordinary concrete. The MCNP modelling of the building as well as some of its components (quadrupoles, diaphragms, dipole, graphite converter, uranium target) was used to obtain a neutron dose map of the whole building [figure 5].

The results show that canal 1 is the place where the dose reaches its highest rate: ~10^4 Sv.h^{-1} around the neutron source and 6 10^3 Sv.h^{-1} in the middle of the canal. The dose rate in canal 3 is about 10^3 Sv.h^{-1} while it is about 5 10^3 Sv.h^{-1} in canal 2 where some equipment is planned to be installed.

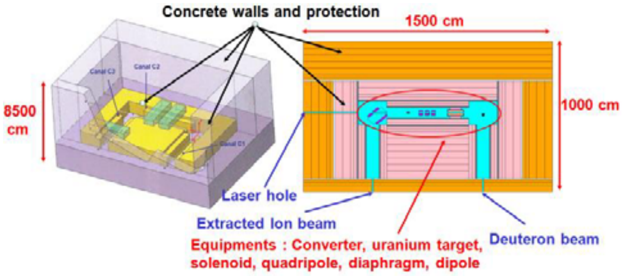

Figure 4: Canal configuration for the production building.

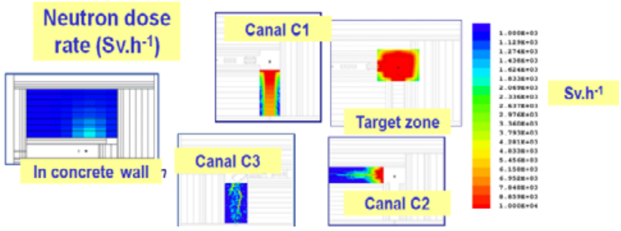

Figure 5: Neutron dose map in the production building

4. Conclusion

The MCNP simulation, together with the experimental neutron spectrum allowed to reconstruct a realistic neutron source based on 40 MeV deuteron stripping on a thick graphite converter target.

The calculated dose rates showed that gypsum and heavy concrete are good materials for attenuation of very fast neutrons.

The simulation of one of the configurations of the production building, the canal configuration, allowed the neutron dose rate to be calculated throughout the building. The dose rate for nominal conditions (5 mA of 40 MeV deuteron) is between 10^3 and 10^4 Sv.h^{-1}.

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