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**DESIGN OF THE RADIATION SHIELDING AROUND THE BTF TARGET**

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**Abstract**

This report describes the design of the radiation shield around the energy degrader target at the beginning of the BTF transfer line, successfully installed in May 2008. In particular, the results of Monte Carlo code (Fluka) simulations have been discussed, while the processing of the dose measurements, before and after the installation, is still in progress and will be discussed in a next work.

## 1 Installation of a Radiation Shield around the BTF Target

At the DAΦNE-BTF the reduction of the particle multiplicity is achieved in the following way: first the LINAC beam is intercepted by a (variable depth) copper target in order to degrade the beam energy, then the outcoming particles are energy selected by means of a bending magnet and slit system. The degrader target is shaped in such a way that three different radiation lengths (1.7, 2 and 2.3 $X_0$ respectively) can be selected by inserting it at different depths into the beam-pipe.

Because of the interaction of the impinging $e^+/e^-$ beam in the copper target, this one becomes a source of secondary radiation: gamma rays, secondary electrons and positrons (essentially bremsstrtrahlung and pair production, Compton scattering and ionization) as well as hadrons produced by electromagnetic cascade such as neutrons, pions, protons (mainly due to photonuclear reactions).

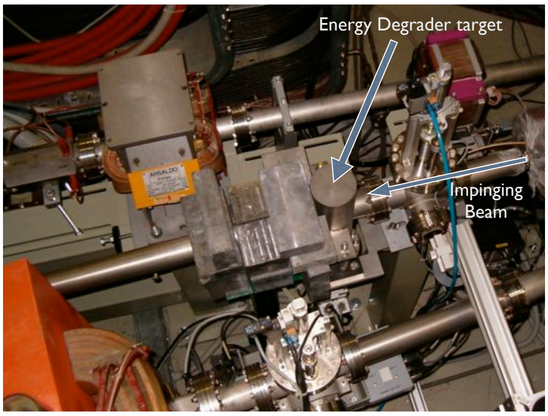


Figure 1: *Energy Degrader Target collocation on the BTF transfer line.*


Figure 2: *BTF copper target: in this picture it is completely kept away from the beam pipe.*

## 2 Radiation Source Term Calculation

The estimation of the secondary particles produced in the BTF copper target has been obtained by the Monte Carlo FLUKA code[2], considering the following beam data: the particles impinging on the target are electrons having energy equal to 0.510 GeV (nominal DAFNE energy), momentum spread equal to 0.0051 GeV/c, divergence equal to 1 mrad, beam width in transversal direction equal to 0.2355 cm.

In figure 3 the histogram gives the overall number of secondaries produced per unit beam particle in the BTF target.

The corresponding energy spectra is reported in terms of particle fluence per unit energy and unit particle in figure 4.

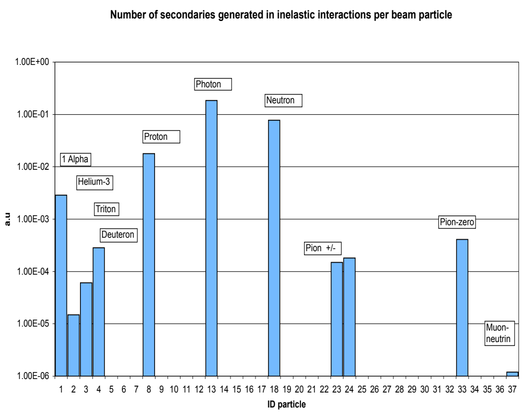


Figure 3: *Number of secondaries produced per beam particle.*

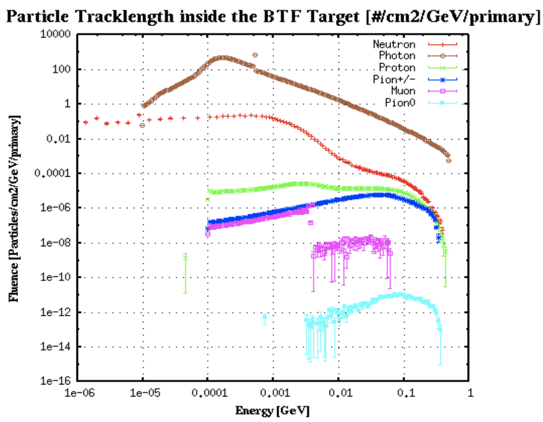


Figure 4: *Energy spectra of secondaries produced in the BTF Target.*

In the BTF target case, the energy loss by ionization can be neglected with respect to the radiative energy loss (Bremsstrahlung).

The energy spectrum of the radiated photons ranges from zero to the energy of the incident electrons and the number of photons in a given energy interval is approximately inversely proportional to the photon energy. As we expected for, the calculated bremsstrahlung spectra are noticeably more energetic (i.e "harder") at forward angles (see figure 5) respect to the other directions.

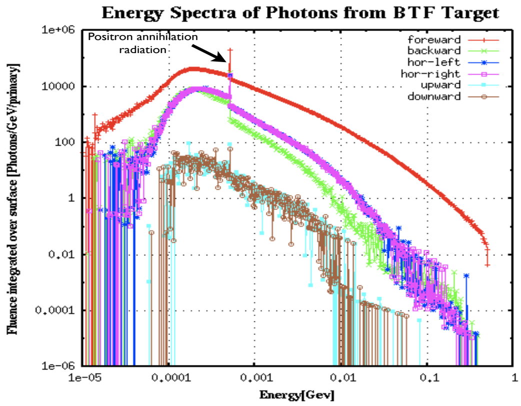


Figure 5: *Spectra of bremsstrahlung photons emerging in various direction from the BTF copper target irradiated by normally inicident monoenergetic electron beams.The arrow indicates the abundant positron annihilation radiation at 0.511 MeV.*

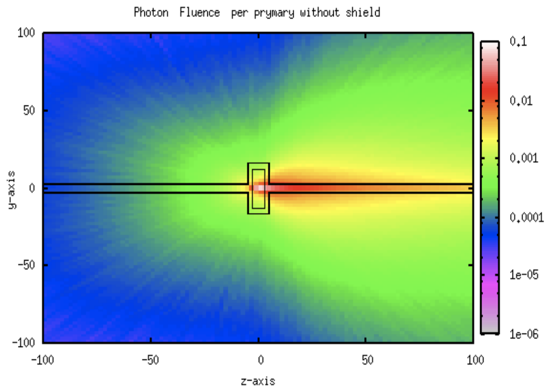


Figure 6: *Spacial distribution of photon fluence from BTF target (The unit on the plot is Photon/cm*$^2$*/primary ). The beam is travelling on z axis (from left to right for the reader), whereas the y axis is the vertical one.*

Neutron production is expected to occur in any material irradiated by electrons in which bremsstrahlung photons above the material-dependent threshold are produced. This threshold varies from 10 to 19 MeV for light nuclei and 4 to 6 MeV for heavy nuclei.The mechanisms of neutron production are only briefly recalled here: Giant Photonuclear Resonance neutrons (the most important source of neutron emission up to approximatively 30 MeV), Quasi-Deuteron neutrons (dominating at energies above the giant resonance), neutrons associated with the production of other particle (neutrons produced by secondary interactions of pions for example). For both Giant Resonance and Quasi-Deuteron process the directionality of the incident electron or photon is lost so that these emissions are isotropic (see figure 8).

As it is shown in figure 7, for energy less than 150 MeV the spectrum is described as a Maxwellian distribution with average energy around 1 MeV. Approaching the higher energies, the Quasi-Deuteron effect adds a tail of higher-energy neutrons to the Giant-Resonance spectrum. The slope becomes steeper as the incident electron energy is approached.

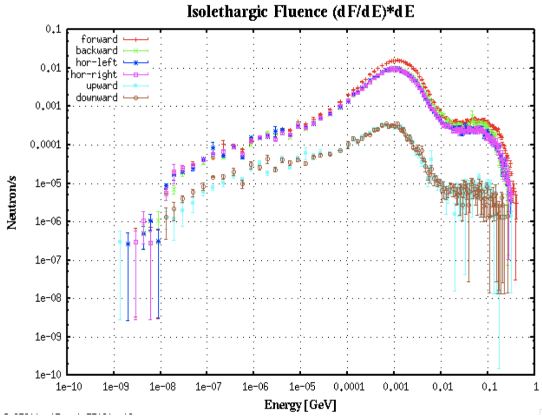


Figure 7: *Spectra of neutrons emerging in various direction from the BTF copper target irradiated by normally inicident monoenergetic electron beams.*

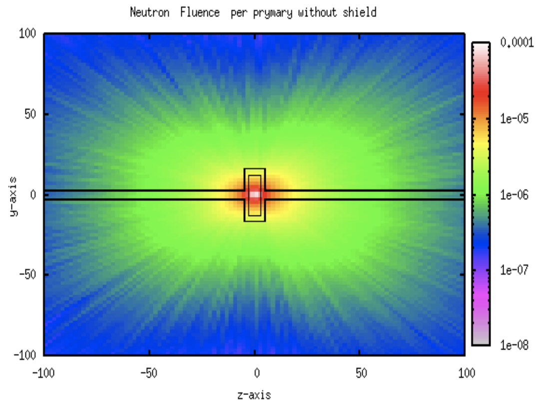


Figure 8: *Spacial distribution of neutron fluence from BTF target (Neutron /cm$^2$/ primary). The beam is travelling on z axis (from left to right for the reader), whereas the y axis is the vertical one.*

## 3 BTF Target Shield Description

The necessity of shielding the energy degrader target of the DAFNE-BTF comes essentially from two exigencies:

1. To reduce the radiation damage of electronic and mechanical instrumentation located just around the BTF target

2. To reduce the background arriving in the BTF hall, where the experiment devices and appartus are placed for data taking

Concerning the second point it is important to stress that the shield around the target is not enough by itself alone to assure a low radiation background in the BTF hall, because the higher energy photon radiation is entering the beam-pipe mainly in the forward direction, so that it is necessary to intercept the radiation in a well suitable point along the transfer line. The complete BTF transfer line simulation by a Geant4 based application (BDSIM[3]) is still under development. At the end of this study we should be able to evaluate the background all around the transfer line, and consequently to determine where to locate other shields and how thick they have to be. Anyway the BTF target shield is the starting point needed to guarantee a reduction of background in the BTF hall in the frame of a complete multiple step shielding design.

The limited room available around the target has been the more stringent boundary condition that we had to take into account in the shield design, in addition to the difficulty of acces in the area in which the target is placed, due to the concentration of many structural and instrumentations apparatus. The shield is composed of layers of different materials in order to create a modular structure that can be easily mounted and moved away around the target, once the support basement has been installed. The major difficulty during the installation was, in fact, mounting the stainless steel plate and columns to support the shield (se figure 9). The technicians of the accelerator division showed a great ability in moving very heavy plates (each one having a mass of about 40 kg), since they couldn't use any load displacer device, during the installation (ended on March 28).

The shield has been designed in order to reduce as much as possible[1], mainly, gamma and neutron fluxes coming from the BTF target, so that appropriate materials have been chosen according the following criteria:

1. High Z heavy materials are suitable for gamma rays shielding.

2. Hydrogenous material are needed for neutron moderation and to attenuate "fast" neutrons.

3. Boron planner sheets are chosen for thermal neutron capture (by means of the $^{10}B(n,\alpha)^7Li$ reaction with cross section for room temperature thermal neutrons of 3837 barns).

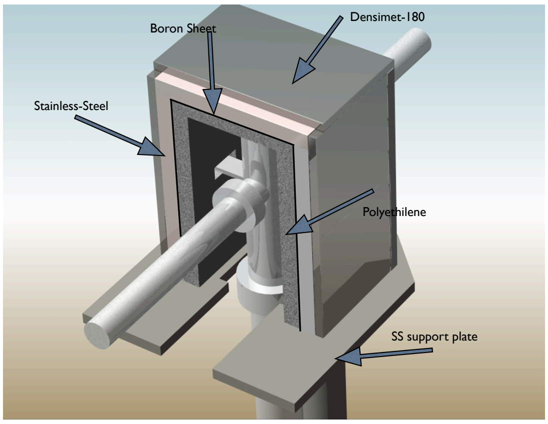


Figure 9: *BTF Target Shield Design: chosen materials (back view).*


Figure 10: *Target Shield installation (frontal view).*

As high Z heavy element a special Tungsten alloy, Densimet-180, has been chosen for the BTF target shield. In table 3 the main characteristics of this material are reported. This choice came from an accurate evaluation of the ratio benefits/coast of using Densimet-180 with respect to an alternative machined lead shield.

The Densimet-180 alloy is only little bit lighter than pure Tungsten (18.0 vs 19 g cm$^{-3}$) , but in spite it offers the main advantage that is as well machinable as a steel. The densimet layer is the external one (see figure 9) and has a thickness of 25 mm.

Polyethilene,$(CH_2)_n$ has been chosen as hydrogenous material. It is very effective for neutron shielding because of its hydrogen content (14% by weight) and its density (0.92 g cm$^{-3}$). The polyethilene layer consitues the inner layer and has a thickness of 40 mm.

[1]At least a reduction factor 50 in the neutron and photon fluence

| Densimet-180 Alloy | | | |
|---|---|---|---|
| Chemical Composition[%] | | Nominal Density [g cm$^{-3}$] | Modulus of elasticity [GPa] |
| W | Rest | | |
| 90 | Ni, Fe | 18.0 | 380. |

Stainless steel is a relatively high density materials (7.8 g cm$^{-3}$), that thanks to its low cost is an attractive shielding material for gamma rays. Furthermore, iron (the main component of ss) is relatively good for slowing down fast neutrons by inelastic scattering and is a good absorber of thermal neutrons. The knowledge of the elemental composition is important about radioactivation estimation and it has been considered in the FLUKA calculation .

The stainless steel layer in the BTF shield has the double role of shielding material and structural leading structure, being rigidly bolted to the horizontal support plate. The steel layer has a thickness of 35 mm. The inner layer of polyethylene and the outer one of densimet are tighten with screws on the steel layer. Nowadays the polyethylene layer and boron sheets are not yet installed: this will be done soon after having received these materials (foreseen by end of April 2008).

The expected reduction of the photon and neutron are shown in figure 11 and 12 respectively, reported in terms of the fluence in a solid angle of $\pi/2$ around the beam axis in forward direction. The cut at higher energies in the plot of gamma ray spectra is due to the fact that after the target the more energetic gammas escape inside the beam pipe.

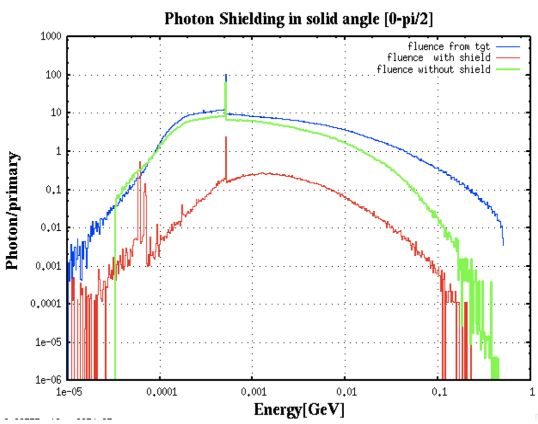


Figure 11: *Photon Shielding.*

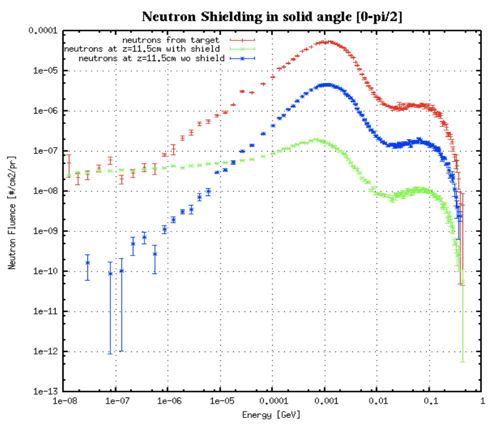


Figure 12: *Neutron Shielding.*

Measurements of the doses due to gamma rays and neutron in a range of 1-2 m around the shielding have been taken during the next BTF runs, allocating 7 dosemeters for gamma rays (Calcium Fluoride thermoluminescence detectors) and 7 particle detectors (Cr-39 detectors) based fast neutron plastic dosemeters, sensitive in the 0.1 - 20 MeV energy interval. These experimental value will be compared with the predictions in order to validate the FLUKA model used for the estimation;

**References**


[1] D. Alesini et al., "*Dafne Upgrade for Siddharta Run*", G-68, 28/11/2006.

[2] A. Fasso et al., "*A multi-particle transport code*", CERN-2005-10 (2005), INFN/TC-05/11, SLAC-R-773.

[3] I. Algapov et al., "*The BDSIM Toolkit*", EUROTeV-Report-2006-014-1.

[4] W.P. Swanson, "*Calculation of Neutron Yields Released by Electrons. Incident on Selected Materials*", SLAC-PUB-2042 November 1977.