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PROTON INDUCED BACKGROUND IN THE INTEGRAL SPECTROMETER (SPI) GERMANIUM DETECTORS

N. Diallo[1], **M. Collin**[2], **O. Bersillon**[2], **B. Cordier**[1], **P. Morel**[2], **J. Fréhaut**[2]

[1]CEA/DSM/DAPNIA/Service d'Astrophysique
CEA Saclay, 91191 Gif sur Yvette Cedex, France

[2]CEA Bruyères-le-Châtel, Service de Physique Nucléaire
BP 12, 91180 Bruyères-le-Châtel, France

ABSTRACT

Radioactivity induced in detectors by protons and secondary neutrons is the major background source of gamma-ray telescopes, which limits the sensivity of the detectors. In general the hadronic interactions triggered by energetic cosmic rays in the detector are very difficult to simulate with good accuracy. Now however, the TIERCE code developped at CEA Bruyères-le-Châtel enables us to make these computations with a good accuracy. It is indeed a Monte Carlo code which transport hadrons, electrons and gammas. In that sense, it is one of the few available codes able to simulate correctly the spallation reactions. We have then used this code to simulate the cosmic ray (CR) particles transport in the telescope, evaluate the neutron and proton fluences induced and compute the activation products in the detectors and others surrounding materials.

Keywords: *INTEGRAL*, Gamma-Ray Instruments, Induced Radioactivity, Monte-Carlo Code, Spallation Reactions.

1. INTRODUCTION

The scientific goals of the *INTEGRAL* mission are addressed through the use of high resolution imaging and spectroscopy in gamma-ray astronomy. In order to achieve these requirements, it is important to decrease the background. In fact many materials become radioactive when irradiated by the cosmic ray protons. These primary particles also produce secondary neutrons that activate some materials and produce unstable nuclides. The unwanted signal is due to the β particles and gamma-rays, the decays are not prompt having half-lives ranging from less than a second to a few months and years.

In this work we do not calculate the delayed background, we attempt to do this study in a near future. However we present the spectra of neutron and proton induced by cosmic ray protons inside the different materials of the SPI. We follow the decay of the created nuclides in the Ge and we compute the five most important β decay background contributors at different times for a CR proton.

2. COMPONENTS OF THE CALCULATION

2.1. The cosmic ray spectrum

The orbits proposed for the *INTEGRAL* mission are both Highly Eccentric. In the case of a Russian rocket, the satellite will not cross the active fraction of radiation belts, and in the absence of solar flare accelerated particles, the background photons which will contribute chiefly of the trigger rate of the SPI Ge detector will be induced by interactions of CR (mainly protons in the 500 MeV to few GeV range) with the satellite material (including the Ge detector itself). The incident CR proton spectrum used in our simulations is given by Meyer[1] and the calculations are performed for an isotropic flux at the solar maximum (2 p s^{-1} cm^2). The proton distribution is shown in the Figure 1.

2.2. The TIERCE code

In general, the hadronic interactions triggered by energetic cosmic rays in the detector are very difficult to simulate with good accuracy due to the complexity and the vast number of nuclear processes involved combined with the incompleteness of the tabulated nuclear data. Now however the TIERCE code developped at CEA Bruyères-le-Châtel enables us to make these computations with a good accuracy. It is indeed a Monte Carlo code which transport hadrons, electrons and gammas; it is one of the few available

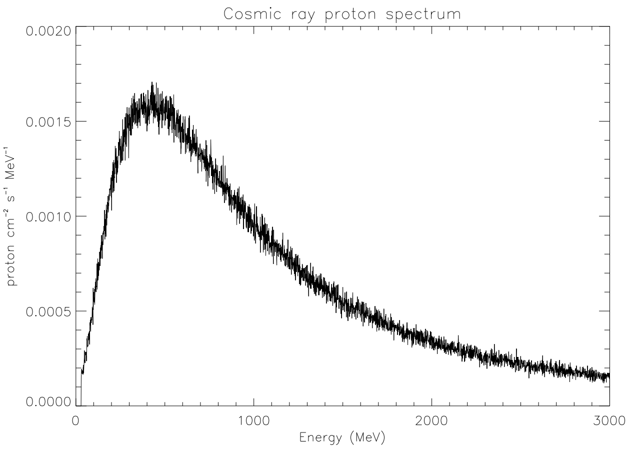

Figure 1: Cosmic ray proton spectrum used in our simulations

codes able to simulate correctly the spallation reactions. TIERCE includes the High Energy Transport Code (HETC) for energetic hadrons and the Monte Carlo N-Particle MCNP code for neutrons of less than 20 MeV and gamma. HETC is a nucleon/meson transport code which uses an intranuclear cascade and evaporation model to simulate the nuclear interactions. MCNP can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, it utilizes multigroup scattering and absorption cross-section data[2]. A physical description of the TIERCE code is presented beside (Figure 2).

2.3. The SPI geometric model

The detector array of the numerical model is composed of 19 hexagonal (6 cm corner to corner $\times$ 7 cm height) Germanium volumes. Each detector is encapsulated in its Be container (the thickness of each capsule is 2 mm around the Ge detector) to avoid contamination. The 19 detector modules are enclosed in a Be cryostat that provides the necessary vacuum and thermal insulation required to maintain them at the operating temperature of 80K. The detector array is surrounded by a 5.5 cm thickness of anticoincidence shield, made of Bismuth Germanate (BGO). The geometrical representation is illustrated in Figure 3. In the numerical simulations we do not model the anticoincidence rings and the mask.

3. RESULTS

We have injected 10^6 cosmic protons isotropically on the geometrical model discussed above and we have calculated the incoming neutron and proton fluences on the various materials. Results of HETC simulations are presented in Table 1; this table gives the number of nuclear interactions induced by high energy protons and neutrons in each material.

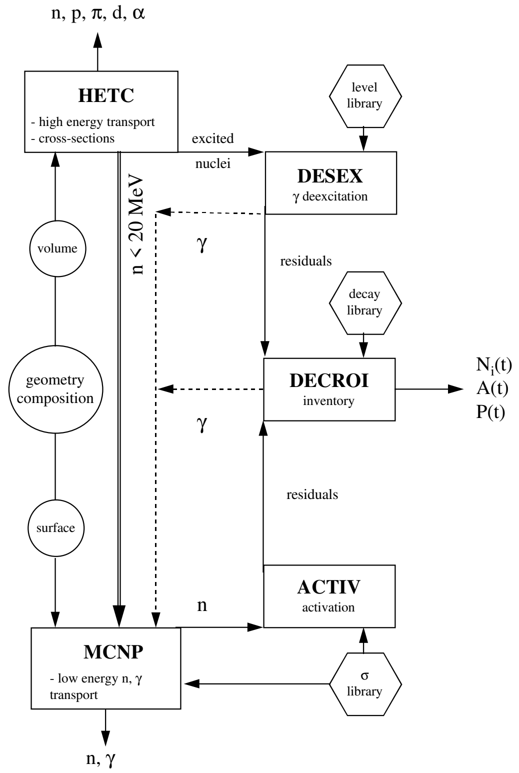

Figure 2: Physical diagram of the TIERCE code

	BGO side	rear BGO shield	Be cryo-stat	Ge detec-tor	Be cap-sule
total	432118	246951	121125	2285	333
primary	177912	102759	46123	793	113
induced protons	231245	132645	63918	1139	164
induced neutrons	185740	105669	52001	1031	154

Table 1 : Simulation of 10^6 cosmic protons by HETC. Number of nuclear interactions induced by high energy ($\geq$ 20 MeV) particles

By using an average cosmic flux of 2 p s^{-1} cm^{-2} and the results of the simulation we can obtain the normalised spectra of the proton and neutron fluxes. These are represented in Figures 4 and 5. We note that the maximum of the proton spectrum inside the shield is shifted to lower energies due to:
-the secondary protons created as a result of the intranuclear cascade process,
-the energy loss of primary protons by ionization.

Also for these spectra, we compute the incoming integrated flux of protons and neutrons in different parts of the telescope.

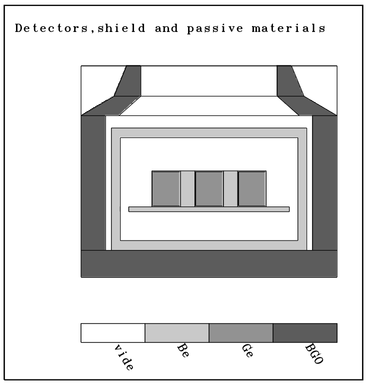

Figure 3: Integral Spectrometer geometry used in our simulations

irradiated surface	incident flux cm^{-2} s^{-1}	
	protons	neutrons
exterior BGO	2	0
exterior cryostat	1.64	14.13
exterior Ge	1.36	27.91

Table 2 : Integrated flux of protons and neutrons in different parts of the telescope

Using the decay program of TIERCE, we calculate the nuclide decay rate at the different times of observation. We note that the large amount of β^+ emitters created in the BGO resulting from spallation products of bismuth. We see also the weak contribution of the residual nuclides created in the Be and hence the strong interest to use Beryllium in the background context. The five most important contributors to the Ge residual nuclides induced by proton and neutron are presented in Tables 3 and 4. We give here the activity rate for different irradiation durations with a cosmic proton flux of 2 p s^{-1} cm^{-2}.

β^+ emitters			
1 day		1 month	
nuclide	rate(%)	nuclide	rate(%)
^{68}Ga	19.5	^{68}Ga	13.2
^{62}Cu	13.8	^{62}Cu	9.5
^{66}Ga	7.7	^{69}Ge	6.0
^{61}Cu	5.1	^{66}Ga	6.4
^{63}Zn	4.9	^{61}Cu	3.5
3 months		6 months	
nuclide	rate(%)	nuclide	rate(%)
^{68}Ga	12.7	^{68}Ga	12.3
^{62}Cu	9.0	^{62}Cu	8.8
^{69}Ge	8.7	^{69}Ge	8.4
^{66}Ga	6.1	^{66}Ga	5.5
^{61}Cu	3.4	^{61}Cu	3.3

Table 3: The five most important contributors of β^+ emitters created in the Ge by spallation reactions.

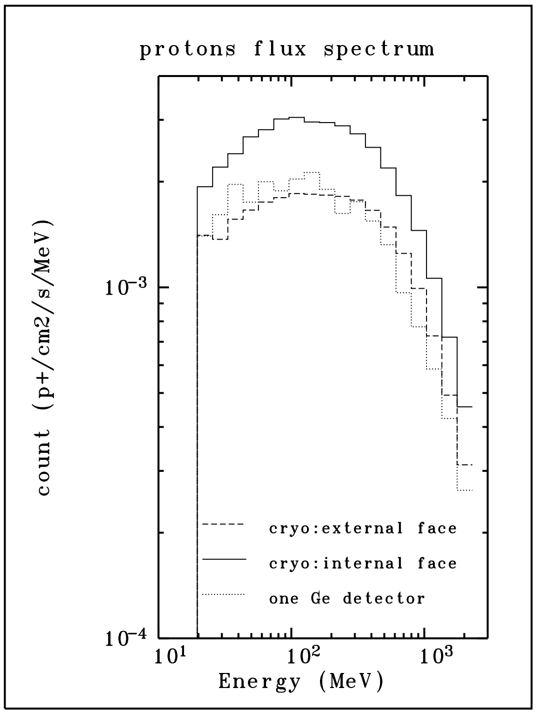

Figure 4: Proton flux spectrum:(dashed) arriving on the external face of the cryostat; (solid) escaping the internal face of the cryostat towards the interior; (dotted) arriving from a Be capsule to a Ge detector.

β^- emitters			
1 day		1 month	
nuclide	rate(%)	nuclide	rate(%)
^{70}Ga	29.5	^{70}Ga	27.1
^{73}Ga	27.7	^{73}Ga	26.3
^{75}Ge	11.7	^{72}Ga	15.6
^{72}Ga	11.3	^{75}Ga	10.8
^{69}Zn	5.4	^{69}Zn	4.9
3 months		6 months	
nuclide	rate(%)	nuclide	rate(%)
^{70}Ga	26.8	^{70}Ga	26.7
^{73}Ga	26.0	^{73}Ga	25.9
^{72}Ga	15.5	^{72}Ga	15.4
^{75}Ga	10.7	^{75}Ga	10.6
^{69}Zn	4.9	^{69}Zn	4.9

Table 4: The five most important contributors of β^- emitters created in the Ge by spallation reactions.

4. CONCLUSIONS

Further studies are needed to improve this model. The next step is the calculation of the delayed background. Then a more accurate representation of SPI with the rings and the mask will allow us to better understand the different background components and to identify and compute the expected background gamma ray lines.

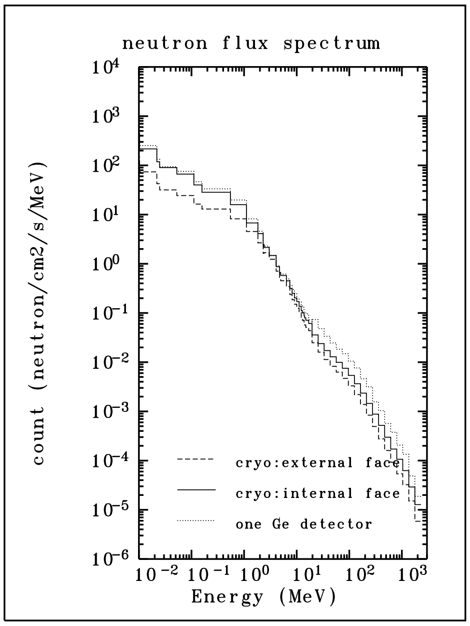

Figure 5: Neutron flux spectrum

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