Neutrons from rock radioactivity in the new Canfranc underground laboratory

J Amaré, B Bauluz, B Beltrán, J M Carmona, S Cebrián, E García, H Gómez, I G Irastorza, G Luzón, M Martínez, J Morales, A Ortiz de Solórzano, C Pobes, J Puimedón, A Rodríguez, J Ruz, M L Sarsa, L Torres and J A Villar

1 Laboratorio de Física Nuclear, Universidad de Zaragoza, Spain
2 Departamento de Ciencias de la Tierra, Universidad de Zaragoza, Spain
* Paper presented at the conference by J Puimedón

E-mail: puimedon@unizar.es

Abstract. Measurements of radioactivity and composition of rock from the main hall of the new Canfranc underground laboratory are reported. Estimates of neutron production by spontaneous fission and \((\alpha, n)\) reactions are given.

1. Introduction
The aim of this work is to perform a first step for the estimate of the background in a long term ROSEBUD experiment. Since our initial proposal [1] we have done in Canfranc several runs [2,3] of several weeks with bolometers of 50 grams, but more mass and running time are required for dark matter search. In ROSEBUD, the simultaneous measurement of heat and light allows particle discrimination [4,5] and nuclear recoils from neutron scattering are the main background of the experiment. In this work we have measured the radioactivity and composition of the rock of the new Canfranc underground laboratory and we have estimated the neutron production rate per unit mass coming from \((\alpha, n)\) reactions and spontaneous fission. This production rate and the neutron spectrum can eventually be input values in a Monte Carlo code to study the most adequate shielding. Additionally, the information given here can be useful for other experiments.

2. Radioactivity and composition of the rock samples
Spontaneous fissions depend only on rock radioactivity and \((\alpha, n)\) reactions depend also on rock composition. Some years ago, in the first phase of the works concerning the new laboratory, mechanical and structural rock properties were studied and we had access to samples of rock at ground level along the axis of the main hall. We took four of them at 14, 31, 43 and 51 meters from the railway tunnel wall (figure 1). They were chosen attending their regular spacing along the axis and their different visual aspect. All selected points were inside the projected main hall but now, after some changes in the original plan, the 14 m point is outside the already excavated main hall.

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3 Present address: DAPNIA, CEA, Saclay, France.
4 CEE fellow under contract HPRN-CT-2002-00322, presently at the Università di Milano-Bicocca, Italy.

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The rock composition (table 1) and radioactivity (table 2) were obtained by x-ray diffraction and HPGe gamma spectrometry, respectively. The mineral content is different in every sample and the samples at 14 and 51 meters are much more radioactive than those at 31 and 43 meters. As first conclusion we can say that the composition of the Canfranc rock is very heterogeneous.

**Table 1.** Mineral composition of the rock. Measurement precision is about 5%.

|        | 14m | 31m | 43m | 51m |
|--------|-----|-----|-----|-----|
| Quartz | 47% | 14% | 19% | 37% |
| Illite  | 38% | 9%  |     |     |
| Dolomite| 12% | 8%  | 74% |     |
| Feldspar| <5% | <5% |     |     |
| Calcite|     |     | 79% |     |
| Chlorite| 7%  | 37% |     |     |
| Pyrophyllite| 14% |     |     |     |

**Figure 1.** Schematic graph of the Canfranc laboratory. The positions of the four samples are marked in the hall axis.

In figure 2 we compare the Canfranc radioactivity with that of three other European underground laboratories. The more radioactive samples of Canfranc are comparable to hall A of Gran Sasso [6] and the less radioactive ones are comparable to Modane [7]. The halite of Boulby [8] is the best rock, with less than 1 Bq kg\(^{-1}\) of \(^{232}\)Th and \(^{238}\)U. Thorium is more important in Canfranc, uranium is more important at Gran Sasso and both have similar importance in Modane and Boulby.

**Table 2.** Radioactivity of rock (Bq/kg). Only statistical uncertainties are quoted.

|        | 14 m | 31 m | 43 m | 51 m |
|--------|------|------|------|------|
| \(^{238}\)U | 30±3 | 4.5±0.2 | 9.8±0.3 | 31±1 |
| \(^{232}\)Th | 60±6 | 8.5±0.3 | 23±1 | 76±2 |
| \(^{40}\)K | 880±36 | 37±1 | 43±2 | 680±11 |

**Figure 2.** \(^{232}\)Th and \(^{238}\)U in Canfranc, Gran Sasso, Modane and Boulby.

3. Neutrons from the rock

The spontaneous fission of the nuclei of natural chains has been observed in four of them: \(^{238}\)U, \(^{235}\)U, \(^{234}\)U and \(^{230}\)Th with half-lives of 8.2x10\(^{13}\) y, 10\(^{19}\) y, 1.5x10\(^{16}\) y and 10\(^{21}\) y, respectively [9]. Therefore we have only taken into account \(^{238}\)U with 2.2 neutrons per spontaneous fission [10]. We calculated the neutron production coming from (\(\alpha,\)n) reactions with ALPHN program [11], obtained from the Nuclear Energy Agency. It was developed for calculating (\(\alpha,\)n) neutron production in canisters of high-level waste. The decay data and neutron yields of the alpha emitters of \(^{232}\)Th and \(^{238}\)U chains are available. Although ALPHN only calculates the neutron production rate per unit mass and does not calculate the neutron spectrum, it is enough for our first estimate.

The results of our calculations are shown in table 3. All samples are really different, for instance, the neutron production at 51 m is twenty times greater than at 31 m. The figure 3 compares our results...
with those of Gran Sasso [6], Modane [12] and Boulby [8]. The arithmetic mean of Canfranc samples is $1.5 \times 10^4$ neutrons per second per kilogram, 40% less than that of Gran Sasso Hall A. The Canfranc neutron spectrum from rock radioactivity is dominated by ($\alpha$,n) reactions and it will be harder than spectrum of Gran Sasso Hall A, where half of neutrons comes from spontaneous fission. Neutrons in Canfranc are three or four times more abundant than in Gran Sasso Hall C, Modane and Boulby.

### Table 3. Neutron production (n s$^{-1}$ kg$^{-1}$).

| Depth (m) | ($\alpha$,n) | Fission | Total |
|----------|--------------|---------|-------|
| 14       | $1.9 \times 10^{-4}$ | $3.6 \times 10^{-5}$ | $2.3 \times 10^{-4}$ |
| 31       | $1.5 \times 10^{-4}$ | $5.4 \times 10^{-6}$ | $1.5 \times 10^{-5}$ |
| 43       | $7.2 \times 10^{-5}$ | $1.2 \times 10^{-5}$ | $8.4 \times 10^{-5}$ |
| 51       | $2.6 \times 10^{-5}$ | $3.7 \times 10^{-5}$ | $3.0 \times 10^{-4}$ |

**Figure 3.** Neutrons from rock radioactivity in Canfranc, Gran Sasso, Modane and Boulby.

### 4. Conclusions

The composition of the Canfranc rock is very heterogeneous. If our four samples are representative, the neutron production from rock radioactivity is about $1.5 \times 10^4$ neutrons per second per kilogram. The mean energy of neutrons is higher than that corresponding to pure spontaneous fission neutrons because ($\alpha$,n) reactions are dominant in Canfranc. An input value for any estimate can be $10^3$ neutrons per second per kilogram with a factor 3 of uncertainty due to rock heterogeneities. The concrete of the laboratory, provided that it is thick and homogeneous enough, can reduce this uncertainty. In Canfranc a concrete layer of about 50 cm covers the floor and layers of about 20 cm cover walls and ceiling. Measurements of concrete samples are ongoing.

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