ISTITUTO NAZIONALE DI FISICA NUCLEARE
Laboratori Nazionali di Frascati

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1. - INTRODUCTION

The Gran Sasso laboratories of the INFN are located underground, in galleries which have been excavated under the Gran Sasso mountain range. The minimum rock thickness covering the laboratories is about 1400 m of rock of average density 2,8 g cm^{-3} corresponding to a thickness of some 4000 m of water equivalent. The laboratories are located at about 1000 m above sea level. Fig. 1 shows a cross section of the mountain range.

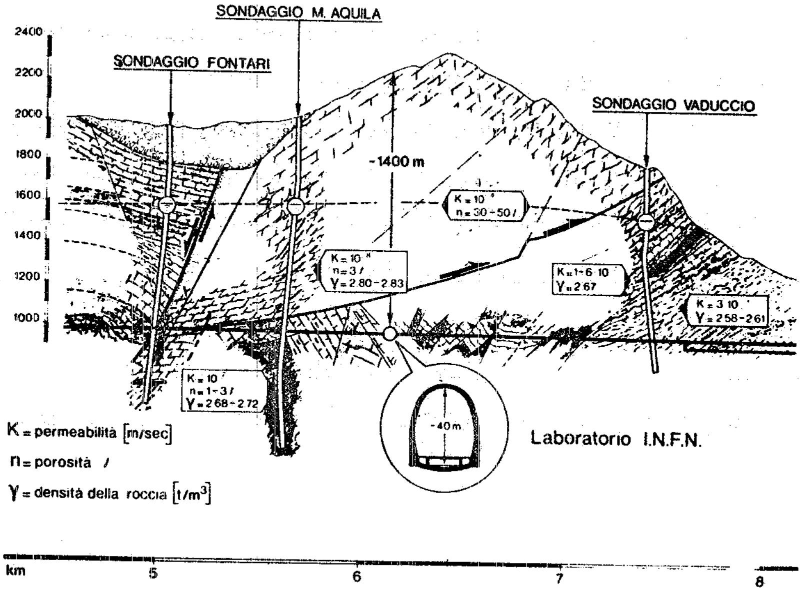

Fig. 1 - A vertical cross section of the Gran Sasso mountain range showing the location of the laboratories.

As the cosmic ray particles penetrate into the rock, the electron and strongly interacting particle components are quickly absorbed: at a depth of about 10 meters, only the muon component is left(4,5). However, the very high energy muons do produce secondary electrons by knock-on processes and by decay such that further electromagnetic and nuclear cascades are initiated underground. As a consequence, neutrons from cosmic ray origin are expected to be found even at great depth underground.

Like for atmospheric neutrons, one expects the energy spectrum of these underground cosmic neutrons to be more populated in the evaporation energy range and down, i.e. the significative part of the spectrum shall range from thermal to some tens of MeV.

In addition, one expects to find in the underground laboratories neutrons produced by spontaneous fission of the ^{238}U and ^{232}Th present in the rocks. This component may even overwhelm the cosmic component, depending on the quality of the rock surrounding the laboratory. Their energy will range from the fission maximum (a few MeV) down.

We are trying to measure as precisely as possible the neutron flux from thermal up to some 10 MeV in the different laboratories of the Gran Sasso facility.

Some preliminary calculations and measurements(1,2,3,4) show that the expected flux may range from some 10^{-7} n cm^{-2} s^{-1} to some 10^{-6} n cm^{-2} s^{-1}.

2. - THE INSTRUMENTATION

It is not easy to detect with good statistical accuracy such low fluxes(6); the only reasonable approach, up to now, has been to use large volumes of BF_3 or ^3He filled proportional counters.

For reducing the intrinsic and electronic background of the measuring system, it is advisable to perform pulse spectrometry rather than threshold measurements.

Tests performed in our laboratory with an AmB neutron source have shown that, for the same neutron efficiency, the spectral resolution of the pulses from the ^3He filled counters is much higher than that from BF_3. In addition, the much lower operating voltage requested for ^3He filled proportional counters reduces the problems related to leakage in the connectors and in the HV supply.

For the present measurements we used two ^3He filled proportional counters Thomson LMT type 150 NH 100 in parallel, which have the following characteristics, as given by the manufacturer:

Sensitive lenght	: 100 cm
Diameter	: 2.5 cm
^3He filling pressure	: 300 cm Hg
Thermal neutron sensitivity	: 150 c n-1cm^2
FWHM at the peak	: ≈ 7%
HV supply	: 950 V

The two counters were connected each to its own HV filter, preamplifier and amplifier. However, both the two HV filters were connected to a single HV supply for minimizing the effects of possible HV jitter or drift. The pulse spectra from the two counters were made to superpose by adjusting the gain of the amplifiers. Figs. 2 and 3 show a schematic of the electronics used.

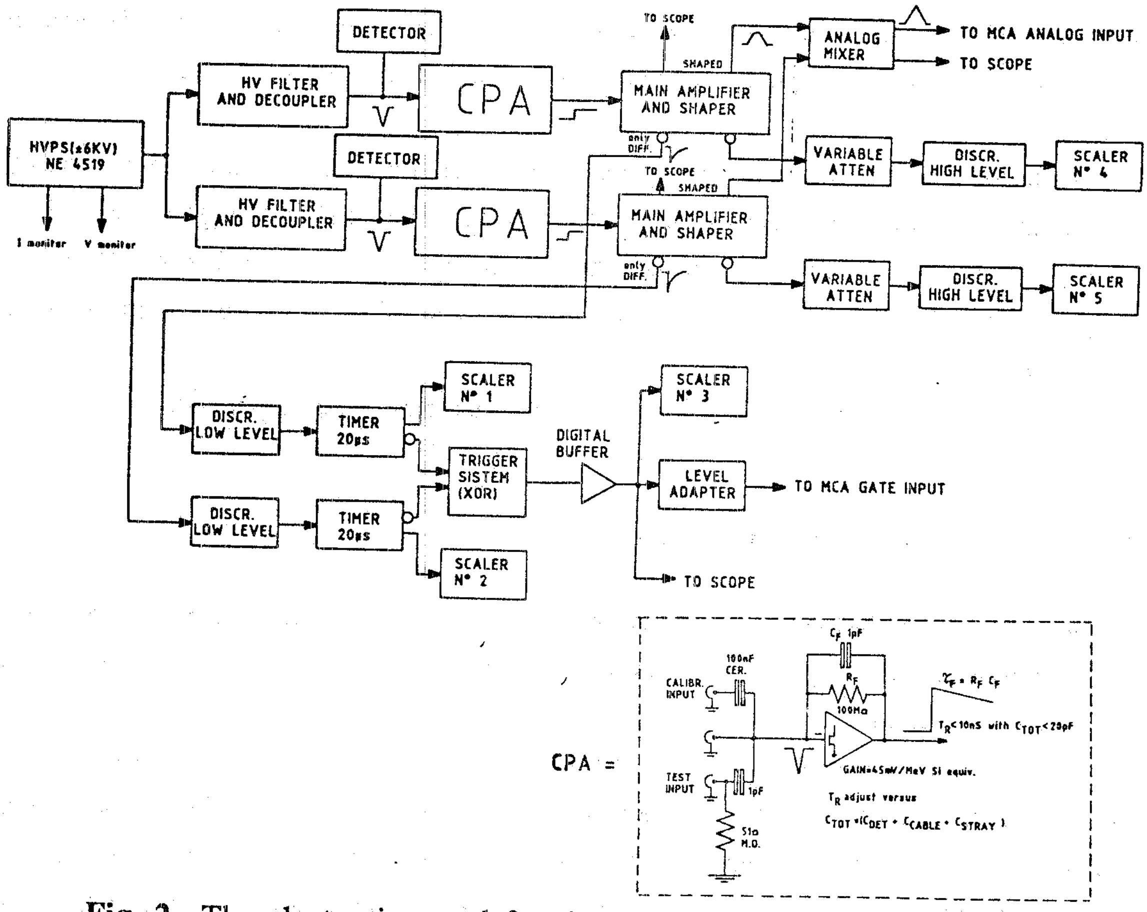

Fig. 2 - The electronics used for the measurements with two ^{3}He detectors in parallel. In the insert is shown a diagram of the charge preamplifier.

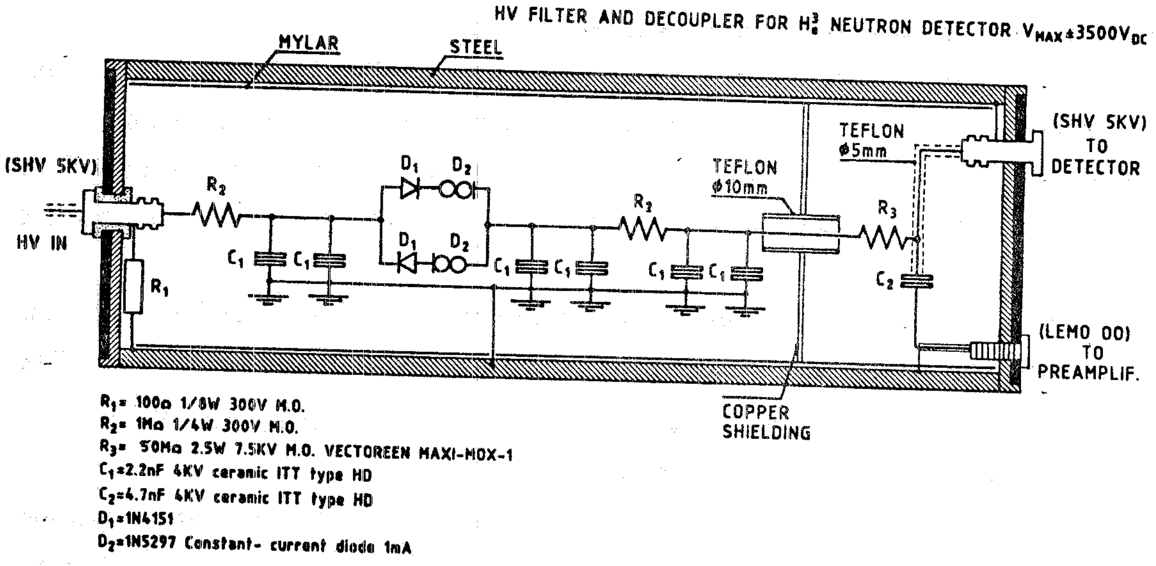

Fig. 3 - The scheme of the HV filter.

The preamplifiers and amplifiers were designed and mounted in our laboratory. The aim of the design was to have a fast low- noise JFET input charge preamplifier (e_n typically 2 nV /√Hz, i_n negligible for shaping time of the order of 2 μs) and very good performance on the burst noise (< 1 count every 2.5 x 10^5 s in the region of interest of the pulse spectrum, with HV on) from all the electronic components employed: in particular from FETs input, npn RF buffer transistor, pnp grounded base, 50 Ω driver, HV decoupling capacitors, 50 MΩ low voltage feedback resistor, 1pF polystirene feedback capacitor, 50 MΩ high voltage polarization resistor etc.

They showed to be suited for our purposes better than any charge preamplifier presently on the market. The computed total noise of the system (Preamplifier + shaping amplifier + detector + HV filter) with the HV at the operating value is of the order of 200 e^- RMS. This value agrees with the experimental line width of less than 1500 e^- FWHM found using an external pulser.

The preamplifier and shaping amplifier will be described in a next report (7).

3. - THE CALIBRATION OF THE COUNTERS

The measurement of the fast neutron component of the field is performed by introducing the two ^{3}He counter into a polyethylene moderator, a cylinder of 30 cm diameter and 120 cm long (about 12 cm of moderating thickness).

The precise calibration of such a large neutron counter is a rather difficult problem.

The moderated counter is a very anisotropic fast neutron detector and the classical simple "inverse square law" calibration method with a point neutron source is not suitable for it.

On the other hand, the dimensions of the counters make it impossible to surround them with a moderator with a spherical simmetry such as to build a fast neutron isotropic detector.

It is very difficult to build a large calibration facility which simulates correctly the measurement field where to introduce the moderated counter.

The very low flux that we are trying to detect does not allow us to evidence in the measurements on the field small variations due to the counter orientation or other factors.

We are performing a thorough study of the calibration of such a large counter which will be described in a next report. We just report here some of the assumptions which are used in the study.

a) The thermal and fast neutron field inside the tunnel is isotropic. This may be true for the neutrons generated by the walls when the detector is located at the centre of the tunnel. The neutrons produced by the cosmic rays may be preferentially coming from the roof. We shall try in future measurements to check this assumption.

b) Because of the anisotropy of the detectors, we shall use as sensitivity to thermal and fast neutrons a weighted average of sensitivities measured with a point source for different orientations of the detectors.

c) We assume that our moderator-counters system behaves like a "long counter", i.e. its sensitivity to neutrons is constant for energies between a few hundred KeV and some ten MeV.

The study has not yet been completed. For the present measurements we shall use still approximate sensitivities. The fast neutron sensitivity has been calculated by a simple measurement with the counter at a fixed distance from an AmB neutron source. We expect that it may be in error up to a factor of four, at maximum.

For the thermal neutron sensitivity, we used the value provided by the manufacturer. It is just a calculated value, based on the volume of the counter, on the filling gas pressure and on a single value of cross section, usually the cross section of the sensitive element of the gas (^{3}He or ^{10}B) at thermal energy. It has mainly a relative interest, for comparing the sensitivities of various counters. It is also affected by errors and shall be corrected.

The sensitivities that we will use in the present measurements for calculating the fluxes are the following:
thermal neutron sensitivity (the two counters bare) = 300 c n^{-1} cm^2;
fast neutron sensitivity (the two counters inside the moderator) = 54 c n^{-1} cm^2.

4. - THE MEASUREMENTS

The measurements were performed in the bypass N° 12, at 5,6 Km from the tunnel entrance because of the impossibility of entering the laboratories. The rock thickness at the vertical over the bypass is about 1200 m.

Given the situation inside the tunnels, we were not able to perform all the measurements planned i.e. the counters bare, the counters wrapped into a foil of Cd 2 mm thick, the counters into the moderator and the counters wrapped into Cd and inside the moderator. This last measurement shoud give us the value of our "background" produced by electronic noise, internal radioactivity etc. The other measurements should allow us to calculate the thermal, epithermal and fast neutron components of the field.

The results of the measurements are summarized in the following Table:

TABLE

Type of mesurement	Total counting time (h)	Total counts (full spectrum)	Rate (c h^{-1})
Counters bare	73,45	284	3.87 ± 0.23
Counters into moderator	45.15	78	1.73 ± 0.2
Counters wrapped in Cd and into moderator	63.34	73	1.15 ± 0.13

Figs. 4, 5, 6 show the spectra at the MCA.

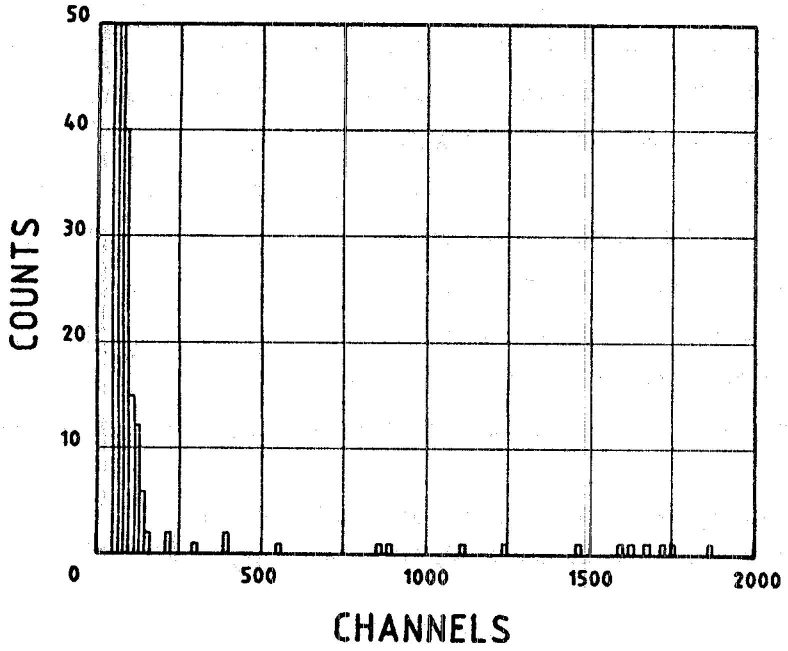

Fig. 4 - The energy spectrum of the pulses from the ^{3}He detectors (background).

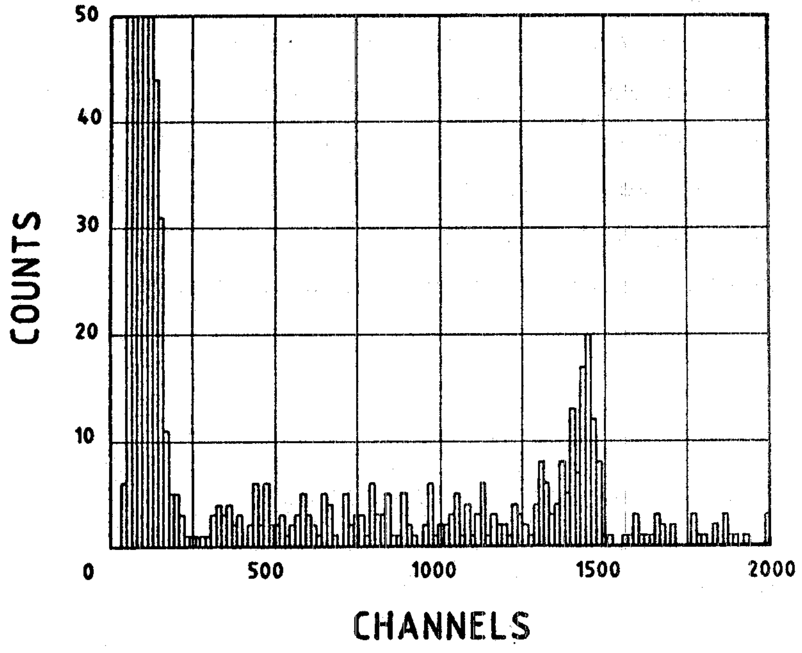

Fig. 5 - The energy spectrum of the pulses from the ^{3}He detectors (counters bare).

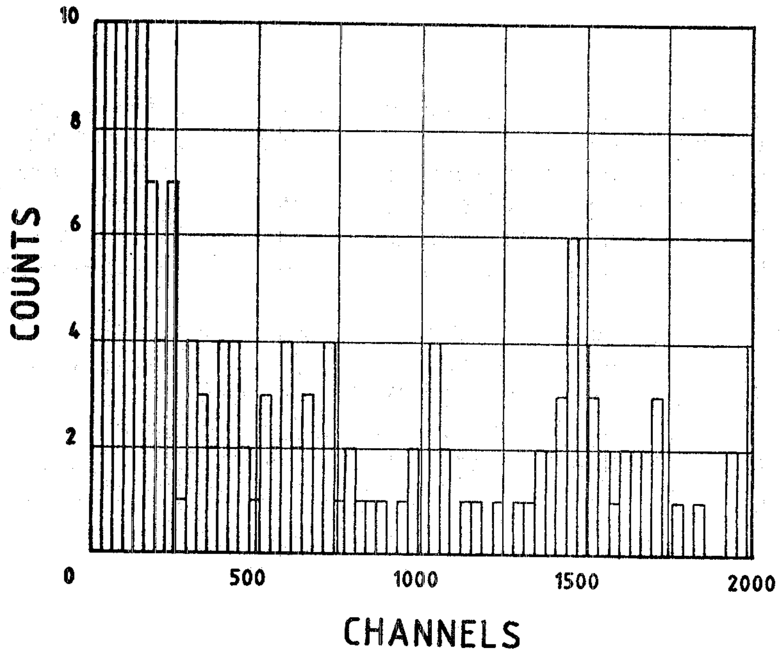

Fig. 6 - The energy spectrum of the pulses from the ^{3}He detectors (counters inside moderator).

From these measurements and the sensitivities indicated in the previous paragraph, one calculates the following fluxes.

Thermal and epithermal component = $(2{,}5 \pm 0{,}2) \times 10^{-6}$ n cm^{-2} s^{-1}

Fast component = $(3.0 \pm 0{,}9)$x 10-6 n cm^{-2} s^{-1}

The errors indicated are one standard deviation errors in the measurement and background compounded, assuming a Poisson distribution of the data. From the considerations in(6) one may expect a statistical error of at least 10%. It is also worth to remind that, due to the calibration uncertainty in the sensitivity of the detector, these values may be wrong up to a factor of four.

5. - CONCLUSIONS

The present measurements are still far from setting a final value of the neutron fluxes inside the Gran Sasso laboratories. One can, however, draw some considerations:

a) The thermal and fast neutron fluxes are not very different from each other;

b) They shall lay around 10^{-6} n cm^{-2} s^{-1}.

Further measurements with more sensitive detectors are planned to:

a) determine the fluxes of the various components with high accuracy;

b) study the variation of the fluxes along the laboratories;

c) separate the walls and the cosmic contributions to the fluxes.

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