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ABSTRACT

We report the measurement of thermal, epithermal and fast neutron flux performed in an underground laboratory excavated under about 2000 m of rock; they are compared with measurements in open air. A set of three large ^{3}He proportional conters in parallel was used.

1. - INTRODUCTION

We have measured the thermal, epithermal and fast neutron flux (up to some 10 MeV) in the Gran Sasso National Laboratories of the INFN which have been excavated at a depth of 2000 meter under the Gran Sasso mountain range in Italy. The vertical thickness of rock over the laboratories is about 3950 m water equivalent; they are located at 42° 27' 09" latitude North and 12° 27' 08" longitude East, at an altitude of about m 1000 a.s.l.

The aim of the measurement is twofold:

1) To assess as precisely as possible the neutron contribution to the total radiation doserate in the laboratories in view of their possible use also for experiments in health physics, radiobiology and medical physics.
2) To evaluate the spurious events and background produced by neutrons in the large detectors that will be installed in the laboratories for experiments in particle physics and astrophysics.

Neutrons in an underground "cavity" originate from two sources:

a) All the high energy nucleons and electrons which feed the hadronic cascade that produces the majority of neutrons in the atmosphere are absorbed by the depth of rock above the cavity. Only muons and neutrinos are expected to penetrate that depth. We then foresee that the neutrons of cosmic origin found underground are produced in the last few meters of rock surrounding the cavity by the electromagnetic cascade initiated by muons (better, by the electrons into which they decay), which develops in an hadronic cascade. Neutrons produced by neutrino interactions may be neglected.

The flux of these neutrons should be related through appropriate multiplicity factor (1) to the muon flux and energy in the last few meters of rock over the cavity; namely, it shall be proportional to $E_\mu^{0.7}(x)$, where $E_\mu(x)$ is the average muon energy at a depth x (2).

b) Spontaneous fission of ^{238}U, ^{235}U, ^{234}U, ^{232}Th, ^{230}Th present in the rock will probably generate the majority of the fast neutrons detected.

One may expect these neutrons to be distributed over an equilibrium energy spectrum similar to that found in open air (the typical $1/E^n$ spectrum with n close to 1) with a knee in the region around 1 MeV due to the fission neutrons.

2. -THE INSTRUMENTATION

As specified in the introduction, our purpose is the measurement of the neutron flux present in the underground laboratories. An approximate calculation of the expected flux gives values of the order of 10^{-6} n cm^{-2} s^{-1}. It is rather difficult to detect such a low flux: even with very sensitive detectors it shall take several days, say weeks, of continuous measurements for achieving an acceptable statistical accuracy (3).

A Simpson pile detector (IGY design) of the type utilized by cosmic ray physicists to evaluate the variation of the cosmic ray intensity through the measurement of neutrons locally produced in a lead radiator does not fit our purposes.

On the other end, the most sensitive detectors for fast neutrons remain the large thermal neutron sensitive proportional counters surrounded by a moderator.

Several trial measurements were performed (4),(5),(6),(7) before reaching the set up used for the present measurement.

The apparatus we built is composed by three ^3He filled proportional counters 100 cm long and 5 cm diameter, filled at a pressure of 228 cm Hg (manufactured by Centronics, England). Each counter has a thermal neutron sensitivity, as stated by the manufacturer, of 433 c n^{-1}cm^2.

We decided to use ^3He filled counters after comparison with BF_3 filled counters. For the same gas volume and pressure, the sensitivities of ^3He and BF_3 counters are comparable; the pulses from neutrons in BF_3 are much higher than in ^3He. However, at normal temperature, the FWHM of the pulses from ^3He is much narrower than for BF_3 and this compensates for the above disadvantages. The narrower the FWHM of the pulses, the smaller is the effect on the measurement of the unavoidable background counts from the counter itself and from the electronics that, as we will show, are rather uniformly distributed over the energy spectrum from about a few hundred KeV.

There exist on the market counters with higher sensitivity (larger dimension and gas pressure) than the ones we chose. However, the FWHM of the pulses increases with the gas pressure and dimensions. The chosen counters give a good compromise between the intrinsic sensitivity of the counter and the background (8). By adding electronically the pulses from three counters we obtained a FWHM of the set comparable to that of a single counter with a sensitivity about three times as large.

Each counter is connected to an HV filter and a preamplifier-amplifier studied and mounted in our laboratory to minimize the noise (7), (8).

The output of the amplifiers are connected to an analog mixer and sent to a gated MCA (8). The data acquisition is performed via a CANDI system (9).

Fig. 1 shows a typical spectrum of the pulses from the three ^{3}He detectors in parallel exposed to a AmB neutron source. The 0.765 MeV reaction product peak as well the wall effect continuum are well visible. The best FWHM we obtained was 7%.

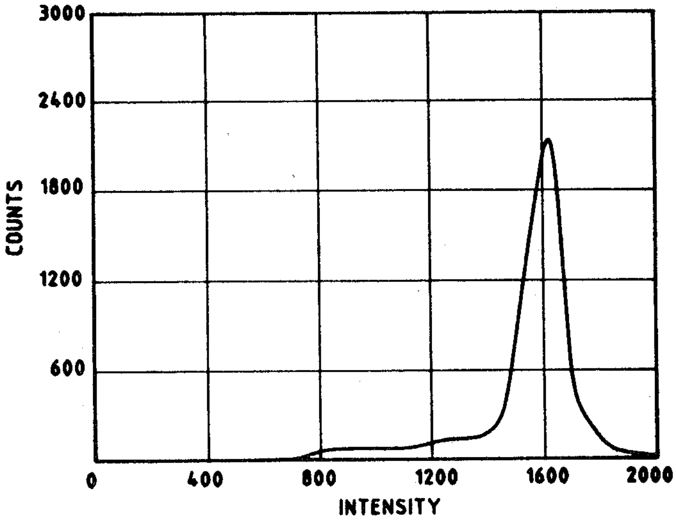

FIG. 1 = Pulse spectrum from the three counters in parallel exposed to AmB neutron source. FWHM ≈ 7%.

The climate conditions in the tunnel were rather rough (temperature 7 °C, humidity about 99%, possibility of noises in the supply line) such that much care was used in protecting the electronic components and the detectors.

For the measurement of fast neutrons each of the three counters was introduced in a cylindrical paraffin moderator of 30 cm diameter. The moderating thickness is then about 12 cm: this thickness was found to be a good compromise between the necessity of measuring with the maximum efficiency neutrons up to 10 MeV and the possibility of producing detectable unwanted neutrons by nuclear interaction of cascade products with the moderator itself (10). The three detectors were positioned at the 3 sides of a vertical square: Fig.2 shows a view of the apparatus.

A single cylindrical counter of such dimensions as well as our set of three counters form a very anisotropic detector. We expect the neutron field in the underground laboratory to be isotropic. The calibration of the apparatus is not straightforward: we describe in (11) the method we used. The anisotropy of the apparatus shall be used in next measurements to check the isotropy of the neutron field and to try to separate the cosmic from the rock component. The overall sensitivity of the whole apparatus in an isotropic AmBe fast neutron field is 106 c $n^{-1}cm^2$ (11).

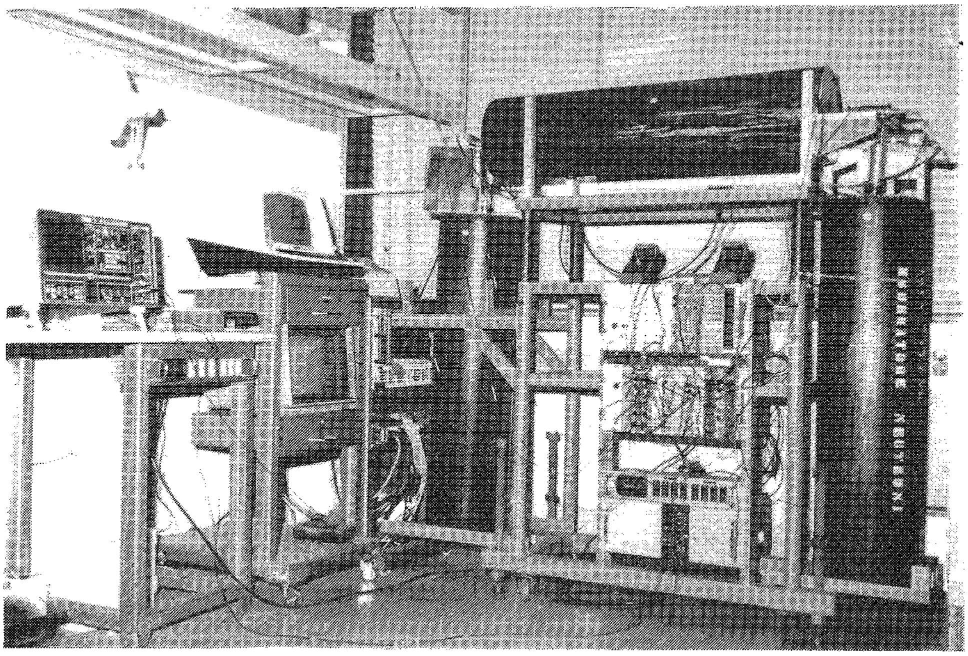

FIG. 2 - View of the apparatus with the three counters inside the moderators and part of the electronics for data acquisition.

3. - THE MEASUREMENT

We will call thermal neutron flux the difference between the measurement made with the counters bare and that with the counters introduced inside a cylinder of Cd 1.5 mm thick: by superimposing the absorption cross section of Cd and the (n,p) cross section of ^{3}He one can see that this region includes neutron of energy between about 0.025 and 0.3 eV. For evaluating the flux in this region we used the sensitivity provided by the manufacturer of the counters.

We call epithermal flux that measured with the counters surrounded by Cd, which includes neutron between about 0.3 eV and 500 eV. For the sensitivity in this region we scaled the thermal sensitivity according to the neutron cross section of ^{3}He.

The fast neutron flux is measured with the counters in paraffin, using the calibration factor we experimentally found with the AmBe source (11); it includes neutrons between about 0.5 and 10 MeV.

From the 2nd and 3rd measurement we subtracted what we call the "total background" which is a measurement made with the counters surrounded by Cd introduced into the paraffin moderator. We first performed measurements in the open air, outside the tunnel. They gave the following fluxes

Thermal neutrons: 1.4×10^{-3} n cm^{-2} s^{-1}
Epithermal neutrons: 6.9×10^{-3} n cm^{-2} s^{-1}
Fast neutrons: 5.7×10^{-3} n cm^{-2} s^{-1}

The statistical error is negligible.

This measurement matches rather well the expected neutron flux at an altitude of about 1000 m.

Fig. 3 shows a spectrum of the pulses registered during the measurement in open air outside the tunnel with the counters inside the moderators.

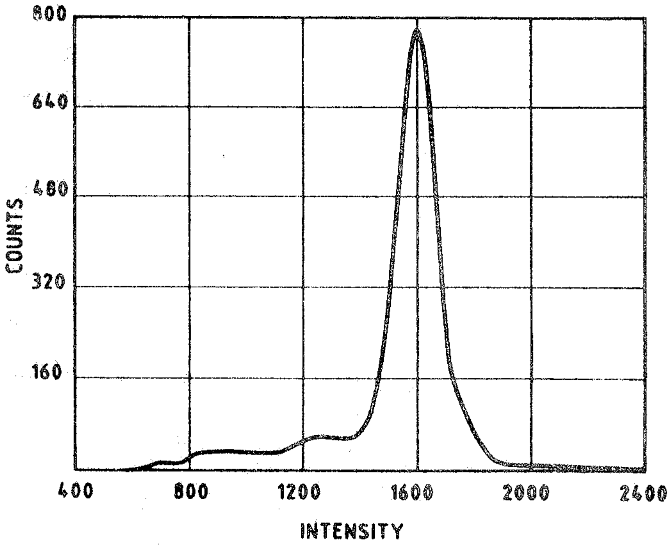

FIG. 3 - Pulse spectrum from a measurement in open air with the counters inside the moderator.

The measurements inside the underground laboratory gave the following results:

Thermal neutrons: $2.05\ (\pm\ 0.06) \times 10^{-6}$ n cm^{-2} s^{-1}
Epithermal neutrons: $1.28\ (\pm\ 0.31) \times 10^{-6}$ n cm^{-2} s^{-1}
Fast neutrons: $2.56\ (\pm\ 0.27) \times 10^{-6}$ n cm^{-2} s^{-1}

Only the statistical error is indicated.

The number of pulses counted were recorded every four hours. We then plotted the number of counts versus the progressive time for checking that nothing wrong had happened during the measurement. Fig. 4 shows one of these plots taken during the measurement with the counters bare. Fig. 5 shows the final spectrum of the pulses from that measurement.

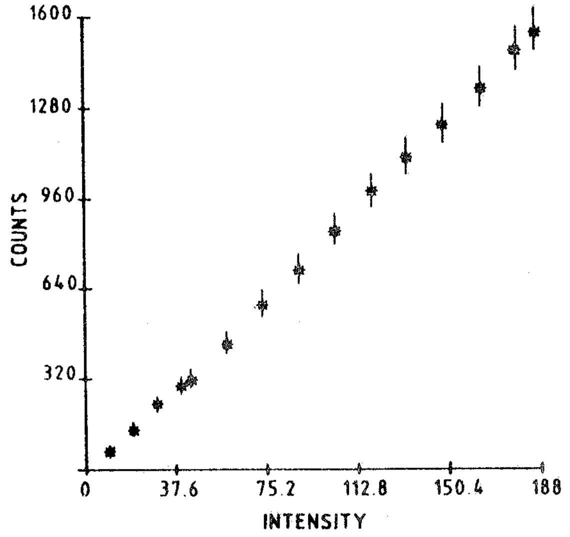

FIG. 4 - Number of recorded pulse versus elapsed time from a measurement inside the tunnel with bare counters.

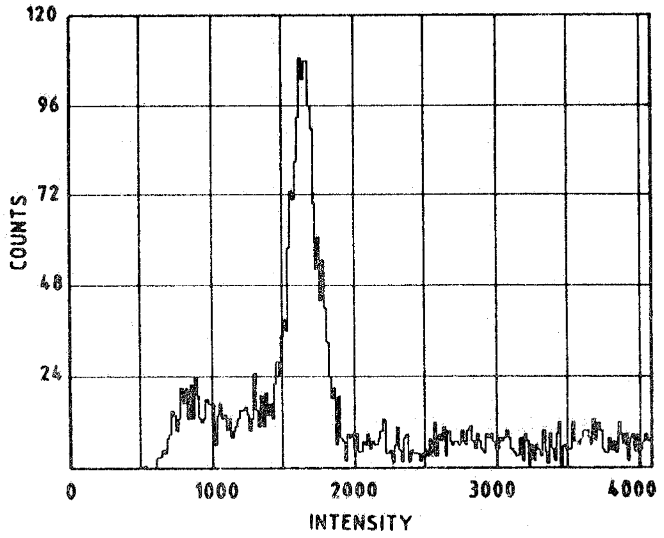

FIG. 5 - Pulse spectrum from a measurement inside the tunnel with bare counters. In ordinate the sum of 16 channels.

In Table I we show the ratios of the fluxes in the three region.

TABLE I - Ratios of neutron flux

	Thermal	Epithermal	Fast
Inside the tunnel	1	0.62	1.25
Outside the tunnel	1	5	4.1

By comparing these ratios with those calculated for a $1/E^n$ spectrum for various values of n, one can deduce that while the spectrum in open air follows rather well, as expected, an 1/E shape, the one inside fits better a $1/E^{1.3}$ shape with, as expected, a large excess of fast neutrons coming from the surrounding rock.

Fig. 6 show the result of a channel by channel subtraction of the "background" spectrum obtained with the counters surrounded by Cd inside the paraffin moderator from a spectrum of counters bare both taken inside the tunnel.

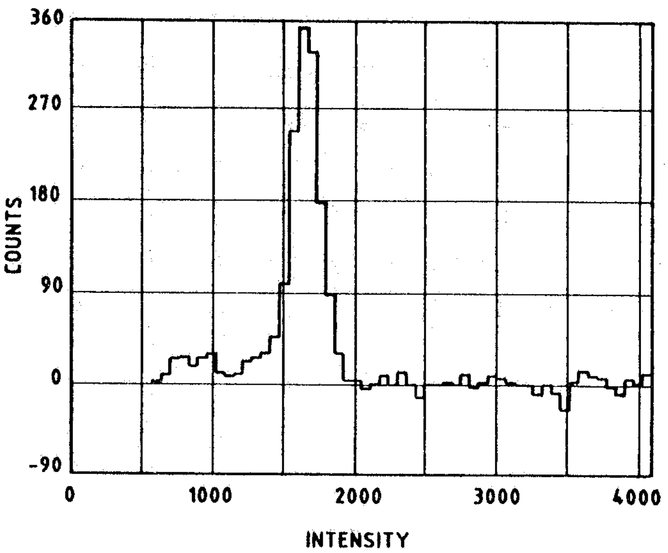

FIG. 6 - Subtraction of the "background" spectrum (measured with the counters surrounded by Cd inside the paraffin moderators) from a spectrum of bare counters inside the tunnel. In ordinate the sum of 64 channels.

It shows that the location of the remaining noise lies mainly outside the neutron peak region where the sensitivity is derived.

Further measurements are foreseen for interpreting the counter noise and for trying to separate the neutrons of cosmic origin from those coming from the rock.

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