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THE MEDITERRANEAN SEA**

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ABSTRACT

The flux of environmental neutrons have been measured at various depths in the mediterranean sea, near a Roman Ship wreck from which various lead ingots were extracted to be used in experiments on rare events. A rapid decrease with depth was found and no count was recorded in the position of the ship. Relevant cosmogenic activities due to this source can therefore be excluded.

This search has been stimulated by the recent discovery of a Roman ship (*navis oneraria magna*), carrying an exceptional load of lead and sunk in the period between 50 and 70 years B.C. near the South-West coast of Sardinia. The wreck, laying at a depth of 28 meters, contains about 1500 ingots of lead, each weighting 33 kilograms. Measurements were carried out¹ on one of these ingots with X-ray fluorescence and diffraction and with gamma and alpha ray spectroscopy. While the surface of the ingot shows an activity of about 40 Bq cm⁻², due to the ²²⁶Ra content of the sea water, the bulk is remarkably free from any contamination. This is mainly due to the absence of ²¹⁰Pb, typical of old lead, but other different reasons could be invoked for the extraordinary purity of the metal. Our measurements have shown in fact that the lead had been previously desilvered, a procedure (coppellation) which could be very beneficial since it could have greatly reduced the content of heavy radioactive contaminants.

Another advantage could have been the natural shield against neutrons provided over such a long time by the overburden of water, with the consequent reduction of the activation of the metal. Environmental neutrons are mainly produced by cosmic rays and by spontaneous fissions of the surrounding materials. This is proved by the fact that the neutron flux deep underground is suppressed much less than the flux of charged particles (mainly muons), and depends on the nature of the rock. Measurements carried out in the Mont Blanc Laboratory⁽²⁾ at a depth of about 5000 meters of water equivalent yield fast and thermal neutron fluxes which are roughly equivalent between themselves and lower by about two orders of magnitude than on surface. The charged particle flux is on the contrary reduced by about seven orders of magnitude. On the other side measurements carried out in the Gran Sasso Laboratory at the lower depth of ~3500 m.w.e. yield a reduction of more than three orders of magnitude⁽²⁻⁴⁾ both of the thermal and of the fast neutron flux, versus a reduction of about six orders of magnitude of the charged cosmic ray component. The modest suppression of neutrons in the Mont Blanc Tunnel is clearly due to radioactivity of the rock

(granite) which is much larger⁽²⁾ than for the rock of Gran Sasso Tunnel (dolomite).

We are not aware of recent measurements of neutron flux underwater. An experiment carried out in 1950 at various depths in the Cayuga Lake (Ithaca, New York) shows the expected strong decrease with depth⁽⁵⁾. Even if the same behaviour has to be expected also in our case, we decided to perform neutron measurements near the wreck of the roman ship to ensure against a substantial contribution of the neutron flux from spontaneous fissions. These measurements are by no means easy due to the expected low flux of neutrons and to the very poor weather conditions of the sea near the Mal di Ventre island where the ship not surprisingly sank. As it is well known vibrations of gas neutron counters can prevent or at least spoil measurements of weak neutron fluxes.

The rugged detector specially constructed for these measurements is shown in Fig. 1. It consist of a steel cylinder containing four ^3He neutron counters of 25 cm length and 5 cm diameter with a gas pressure of 4 atmospheres. The detector has to be operated at a considerable distance from the recording system with is placed on the support boat. The electronic scheme is shown in Fig. 2. Each counter pre-amplifier is followed by a buffer to drive the 50 m long twisted cable. Each cable is separately shielded in order to avoid cross talk among the channels, and connected to the differential amplifier operating on the ship. Pulses from these amplifiers are send to a single analysing chain via a multiplexer. Due to the low rate of the signals, multiplexing was implemented simply by comparing the pulses from all channels and gating only those above a fixed threshold. The high voltage power supply was located near the counters for noise and safety reasons and was remotely controlled.

After calibrating the detector with a weak ^{252}Cf source (10^3 neutrons sec⁻¹), measurements were carried out on surface (3 hours), at a depth of 10 meters (11 hours) and near the wreck of the ship (2 hours). The times of measurement had to be limited due to the poor weather conditions of the sea. The spectrum of the four channels obtained on surface is shown in Fig. 3. The counting rates in the 100 keV region around the

763.8 keV peak are reported in Table I. The corresponding thermal neutron fluxes have been evaluated by calibrating the detector, surrounded by different layers of paraffin and cadmium⁽²⁾, with the above mentioned neutron source. The thermal neutron flux measured on the surface is similar to the one previously recorded in Milano⁽²⁾. It can be seen for Table I that the 10 m of water already reduces this flux by two orders of magnitude. No count was recorded in any of the four channels in the two hours of measurement carried out near the ship wreck. We can therefore exclude at the 90% confidence level a flux larger than $5 \times 10^{-6} \text{ n cm}^{-2} \text{ sec}^{-2}$, more than two orders of magnitude lower than on the surface. This limit applies only to thermal neutrons, which represent however the only relevant component of these particles deep underwater.

We conclude that the neutron component of the cosmic ray in correspondence of the ship wreck is indeed negligible, and that the roman lead was very efficiently shielded against neutron activation over more than two thousand years by the overburden of water. As a consequence of the present measurements 120 lead ingots from the ship have been transported to the Gran Sasso Laboratory immediately after their extraction and stored underground to preserve this property.

It is a pleasure to thank Mauro Arba and Sergio Serci for their help in the construction of the neutron detector and to acknowledge the support of Raul Benedet and Giorgio Sala and the kind hospitality of Antonio and Giulio Garau and of the crew of AmeliaI.

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TABLE I

Counting rates (counts h^{-1}) and neutrons fluxes (neutrons $cm^{-2} sec^{-1}$) at various depths

	Count.1	Count.2	Count.3	Count.4	Total	FLUX
Surface	112 + 8	122 + 8	102 + 7	113 + 7	446 + 15	$(1.8+.2) \times 10^{-3}$
10 metres	2.0 +.5	1.0 +.3	1.4 +.5	.9 +.4	5.3 +.8	$(2+.5) \times 10^{-5}$
28 metres	0	0	0	0	0	$<5 \times 10^{-6}$

FIGURE CAPTIONS

Fig. 1: The neutron detector

Fig. 2: Scheme of the electronic read-out

Fig. 3: The spectra of the four counters recorded on surface

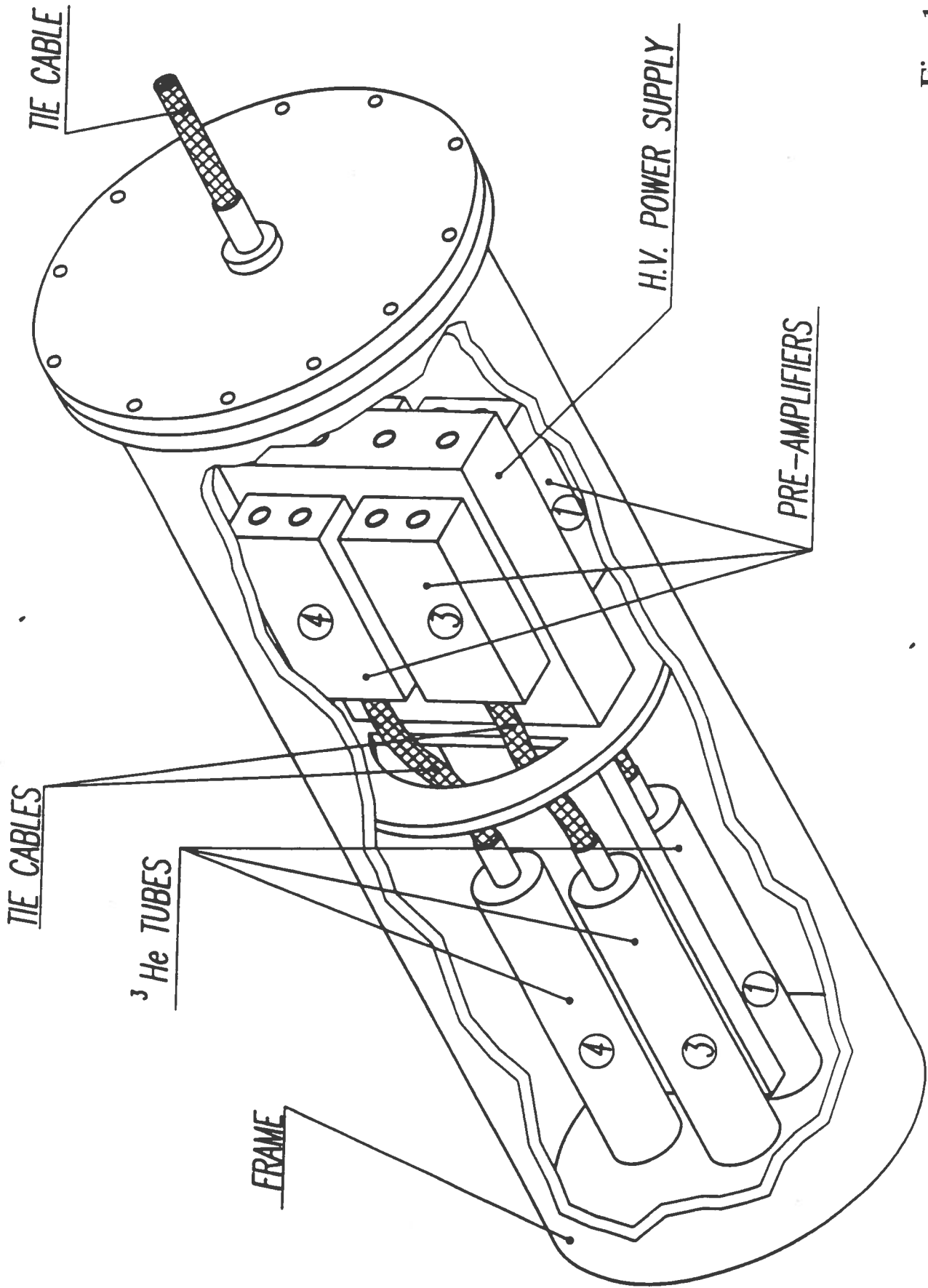


Fig. 1

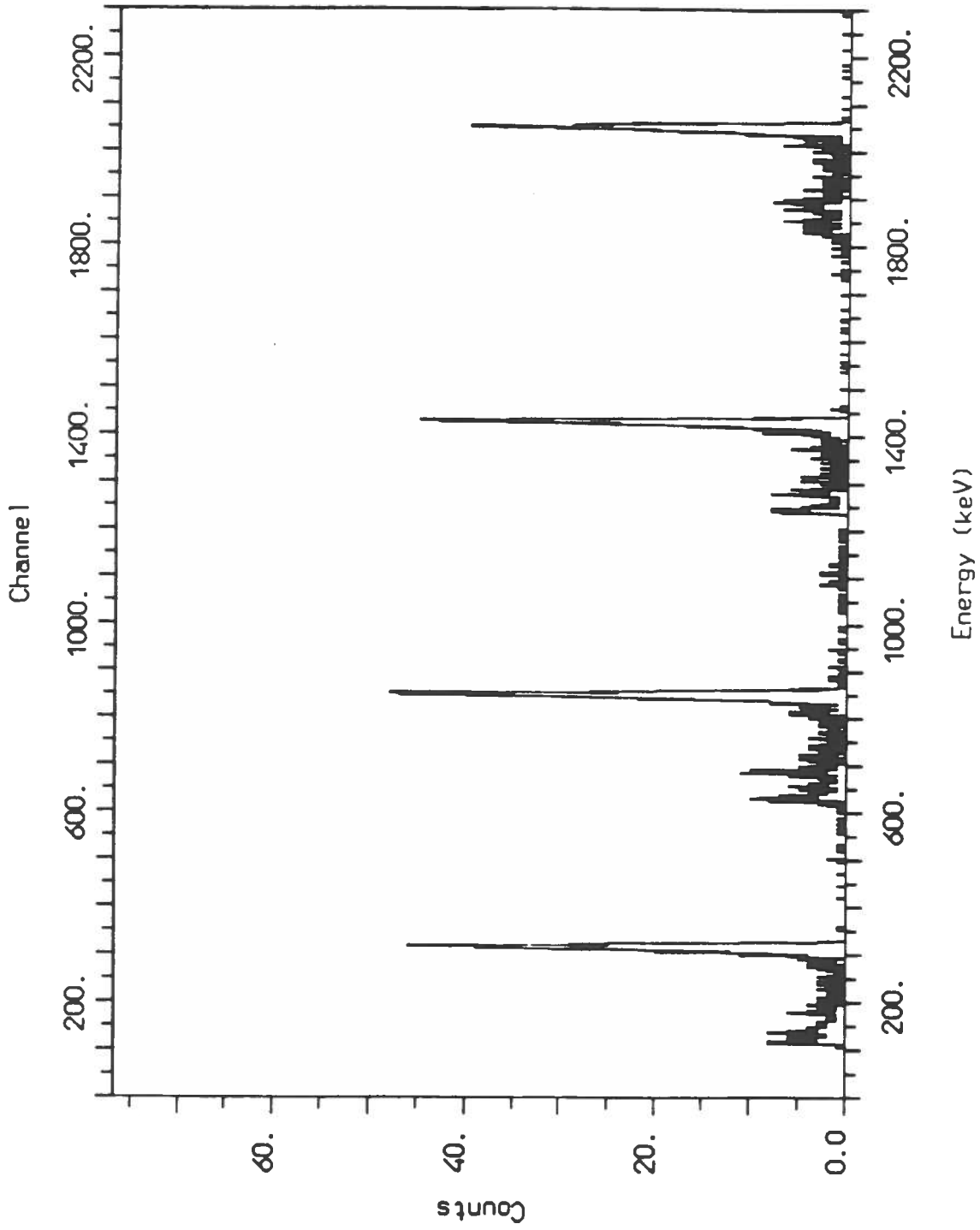


Fig. 3