UNDERWATER MEASUREMENTS OF MUON INTENSITY

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ABSTRACT

Previous results of the experiment on underwater measuremens of muon intensity at depths down to 5 km are reported.

1. Introduction. Experimental measurements of cosmic ray muon intensity deep underwater aimed at determining a muon absorption curve are of considerable interest, as they allow to reproduce independently the muon energy spectrum at sea level. The comparison of the muon absorption curve in sea water with that in rock makes it possible to determine muon energy losses caused by nuclear interactions. The data available on muon absorption in water and that in rock are not equivalent. Underground measurements are numerous and have been carried out down to the depth of $\sim$15km w.e., whereas underwater muon intensity have been measured twice /1,2/ and only down to $\sim$ 3km deep.

2. Apparatus and Operation. To carry out muon intensity measurements in sea water at depths of 2 to 7km, a three-unit Cerenkov detector was developed to register Cerenkov light flashes of muons in the surrounding sea water. A detailed description of the Cerenkov unit and the results of its operation test have been given elsewhere /3/. In our case all the unit photomultipliers were connected into one electrical group, pulses inside the group being summarized. Unit signals were put to the three-fold coincidence scheme with a resolving time of 50nsec. The coincidence signals were recorded within 15 minute time intervals. The general design of the detector made it possible to change relative position of the units which could be arranged either abreast on a horizontal plane or in an upright chain("string"). The detector was fully autonomous, electric power being fed from an accumulater. The device was exposed at chosen depths on a cable from the board of a drifting research vessel. The depth of the device exposition was maintained constant with an accuracy of $\simeq$ 1-3%.

In 1983 during the 37-th voyage of the Soviet r/v "Akademik Kurchatov" measurements were taken of global intensity. Three detector units were arranged abreast horizontally, with photocathodes directed upwards. The measurements were carried out in the Caribbean sea (19°N; 76°W) and in the Atlantic Ocean within the DUMAND zone (22°N; 37°W). The results of the measurements are given in Table 1.

Underwater measurements of muon intensity were also carried out during the 40-th voyage in 1984, the detector units being arranged in an upright chain("string") with spacing of 3 m. When all the units photocathodes were directed upwards, mostly vertical muon fluxes were registered. The other way, when the photocathdes of the upper unit ewre directed downwards, a lateral flux was registered, i.e. particles move at the angle of more than $\gtrsim 60^{\circ}$ to the zenith. The studies were carried out within "DUMAND" zone in Canary Hollow. The results of the measurements are given in Table 1.

Table 1

Flux measured	Depth, km	Exposition time, min	Registration threshold	Number of events
Global	2.0	150	≃ 1e	709*
	3.0	585		622
	2.0	150		744*
	2.0	135	≃ 1.5e	441*
	4.0	1200		288
	2.0	135		470*
	3.0	180	≃ 2e	75*
	5.0	1305		86
Vertical	2.0	330	≃ 1e	1304
	3.0	480		417
	5.0	1920		168
Lateral	1.5	345	≃ 1e	291
	2.0	765		177
	2.5	960		69
	3.0	540		16
	3.5	300		5

* - Normalization measurements

3. Results and Discussion. To obtain correct quantative results with the given detector, it necessary to consider background events which imitate muon registration. Since a three-fold coinsidence scheme is used to separate useful events, there may be events caused by appropriate combination of various background components. The Cerenkov light caused by sea water radioactiviyt is mainly due to the decay of K^{40}. The activity of K^{40} in sea water was determined from potassium salinity relation and was equal to $\sim 1.14.10^4 m^{-3}s^{-1}$ (ß-decay) and $\sim 1.34.10^3 m^{-3}s^{-1}$ (e-capture). The calculation of an average number of photons generated in one act of K^{40} decay is performed in /4/. The average photon numbers as fractions of the number of photons generated by a muon per 1cm path in water are equal to $9.7.10^{-2}$ at ß-decay, and to 0.141 at e-capture (in the first Compton scattering), and to 0.034 (in the second Compton scattering). Bioluminescence in deep sea water is a less studied background source. The latter depends strongly on various factors, such as exposition place, depth, excitation nature, etc. For a series of the measurements taken, the estimation of the background value can be obtained from the data registered at the depth of 3.5km by the detector, with the upper unit being directed downwards. In this case the expected muon number is much less then the detected number of events which can be taken for an averall background for the particular deepwater muon detector at the place where the measurements are carried out. The value of such a background is of the order of one event per an hour of the device operation.

The values of vertical cosmic muon intensity at large depth underwater were obtained on the basis of global muon flux data treatment and by taking traditional cosmic muon angular distribution into consideration. These are:

$$I_o(H=2925^{+45}_{-65}\ m) = (3.1\pm0.5).10^{-8}\ cm^{-2}s^{-1}sr^{-1}\ ;$$

$$I_o(H=4025^{+22}_{-26}\ m) = (5.9^{+2.0}_{-2.5}).10^{-9}\ cm^{-2}s^{-1}sr^{-1}\ ;$$

$$I_o(H=5020^{+140}_{-200}\ m) = (4.1^{+1.6}_{-2.0}).10^{-9}\ cm^{-2}s^{-1}sr^{-1}\ .$$

The total of experimental data on muon absorption in sea water /1,2,5/ was treated with the help of the least square method and fitted by empirical expression:

$$I_o(H) = A\, H^{-\alpha}(H + H_o)^{-1}\ (1 - \exp(-\gamma H))\ \exp(-\beta H)$$

where: H - depth, $hg.cm^{-2}$, $I_o(H)$ - vertical intensity, $cm^{-2}s^{-1}sr^{-1}$, values of free parameters are equal

$$A = 3.73 \pm 0.06$$

$$\alpha = 1.130 \pm 0.004$$

$$\beta = (5.42 \pm 0.23).10^{-4}$$

$$H_o = 11.4 \pm 1.3$$

$$\gamma = (3.7 \pm 0.2).10^{-2}.$$

The data on cosmic muon intensity obtained at different depths in sea water and those obtained previously are presented in Fig.1. Here are also given estimated curves of muon absorption in water which were calculated on the basis of modern conception of muon generation/6/ and muon absorption/7/.

4. Conclusion. The experimental data are in a satisfactory agrrement with the estimated ones within the limits of measurement errors. Hence the integral muon energy spectrum at sea level within the energy range $2-3.10^3$ GeV is described by the mean value of index $\gamma_{\pi,K} = 1.65$ for particles - parents of muons.

References

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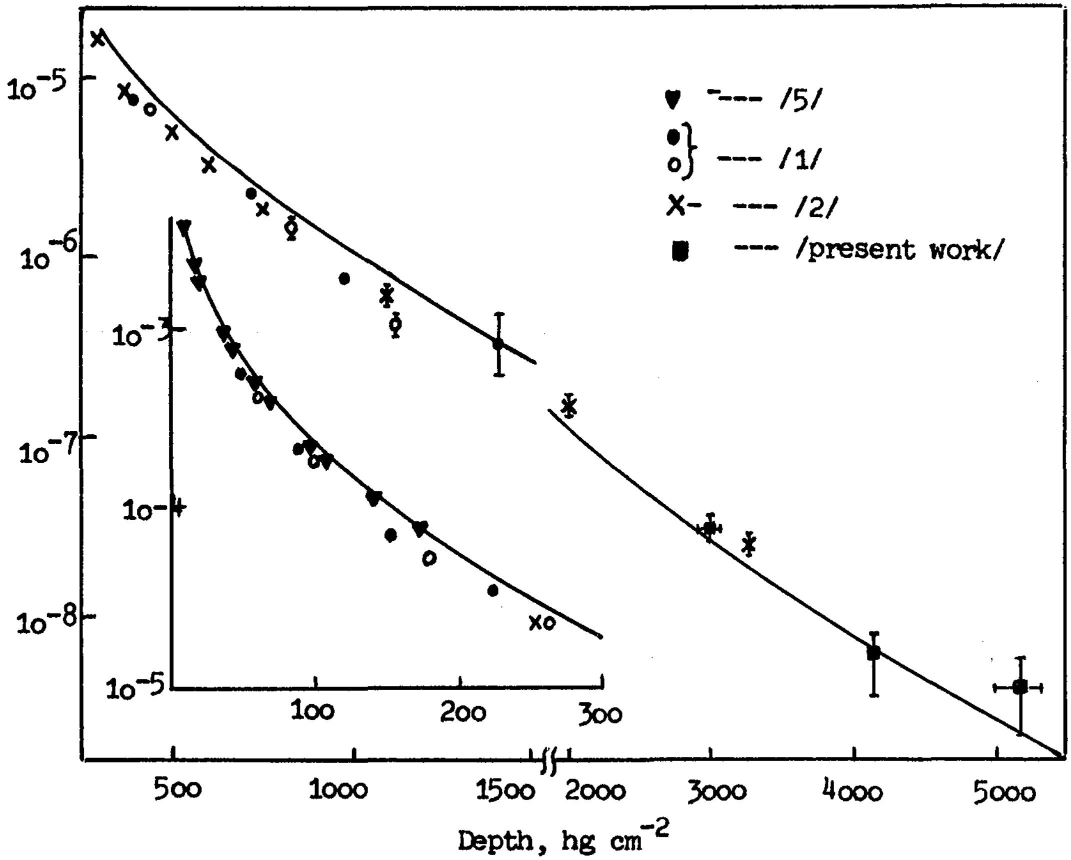

Fig.1. The total of experimental data on muon absorption in water as a function o fdepth.