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RESULTS OF UNDERGROUND DOSE RATES USING TL DETECTORS AND PRELIMINARY TL CHARACTERISTICS OF IRRADIATED SALT ROCK*

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Abstract. This paper presents the first deep profile of the integrated dose of the salt mine "Unirea" from Slănic-Romania, obtained with commercially TL detectors. The TL characteristics of natural salt rock of this mine are also put in evidence. These results contain useful physical information for a characterization of the radioactivity of the mine galleries for their use as underground laboratory.

Key words: thermoluminescence, detector, NaCl.

1. INTRODUCTION

Thermoluminescence (TL) is the thermally stimulated emission of light from an insulator or a semiconductor following the absorption of energy in different processes, usually from ionizing radiation. A large number of TLD systems, namely LiF-TLD 100, CaF_2, CaF_2:*Dy*, LiF:Mg, Tm, Al_2O_3, $Li_2B_4O_7$, NaCl:Ca, NaCl:Tl, NaCl:Ba, KCl:Ba etc. have been developed for all types of radiations and are used in dosimetry.

The thermoluminescence of pure and impurity activated natural and synthetic salts (NaCl and KCl in pure as well as doped form) has been the subject of research for many decades.

Nowadays, astroparticle physics is a rapidly growing field of research at the intersection of astrophysics, particle and nuclear physics and cosmology, and the study of extremely rare phenomena is an important thematic. These researches are

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usually realized in deep underground laboratories, especially in salt mines, that must be free of noise events and well shielded from cosmic rays.

The paper presents the first deep profile of the integrated dose of the salt mine "Unirea" from Slănic-Romania, obtained with commercially TL detectors for environment measurements. These results contain useful physical information for future underground astroparticle experiments as well as for complete characterization of the low radioactivity underground laboratory existent in the mine.

Another problem is related to the possibility of cosmic ray shower to penetrate into deep salt rocks and to induce excitation, in particular TL, and if the effects are measurable. Recently, Murthy and co-workers [1] suggested that the salt rocks could be used as "natural dosimeters", and thus a natural question is if they could be used as a "natural calorimetric detector" for hadronic and electromagnetic showers developed in the underground caverns. This paper reports the preliminary results obtained in the field of the TL characteristics with natural NaCl rock, with samples extracted from Slănic mine. Some essential characteristics required to a TL powder material to be a shower detector are also discussed.

2. EXPERIMENTAL STUDIES

2.1. Dose rate versus depth in the Slănic salt mine

Slănic is situated at 400 meters of altitude. The level difference between the surface and the mine hearth is of 208 m. 2.6 million cubic meters of rock salt were excavated during the working time of the mine. The ventilation is naturally made, and the temperature of 12 degree Celsius is constant throughout the whole year. The humidity levels in the underground are of the order of 50–60% with about 10% below the current values of the region.

The major sources of the recorded radioactive background are: cosmic rays, environmental radioactivity, radioactive impurities from detectors and shielding material. The gamma dose in this mine and trace elements were investigated [2], [3], [4]. In this mine, an exceptional low radioactive background has been showed to exist in the previously cited papers.

The most important components of the background are muons, gammas and neutrons. The muons from primary cosmic rays lose energy in matter and their intensity decreases. In this case, the decrease of energy and intensity of the muon spectra manifest simultaneously.

High energy muons passing through matter lose energy due to electromagnetic processes: ionization (order α^2), bremsstrahlung (order α^3), direct pair production (order α^4) and higher corrections to these processes, or nuclear interactions. The energy transferred to the nucleus in the processes is between 15 and 20 MeV and therefore above the neutron emission threshold. In the conditions of this mine, neutrons are dominantly produced in interactions of muons and not from natural radioactivity.

In the composition of NaCl salt, Na enters with the ^{23}Na stable isotope with about 100% abundance and Cl with the stable isotopes: ^{35}Cl (75.77%), and ^{37}Cl (24.23%) respectively. The neutron production by muon underground is mostly obtained by the following processes: a) the muon capture by nucleus followed by neutron emission; it is important from tens up to hundreds m.w.e depths; b) neutron generation in muon inelastic scattering on nuclei; c) neutron production by hadrons in the muon generated nuclear showers; d) neutron production by gammas in the muon induced electromagnetic showers. Together with the electromagnetic de-excitation mode, muon captures account for more than 95% of the total reaction probability [5], [6], [7].

2.2. Investigation of TL properties of natural salt rock

The Harshaw 4 500 TLD installation [8] was used in the studies. Natural NaCl samples extracted from Slănic's mine were used. All samples were collected from a depth of 208 m. To put in evidence the response of samples to radiation doses powder samples were irradiated with gamma rays from a calibrated Co-60 source, with doses: 5, 5, 7.5 and 26 kGy. The TL glow curve after 26 kGy was recorded 1 hour after irradiation and also after 2, 18, 20, 22, 70, and 72 h permitting to obtain the fading behaviour.

The salt has been stored at room temperature. The humidity level in the laboratory has not been controlled, but the estimated values are 50–60% during the measurements.

3. RESULTS AND DISCUSSION

In Fig. 1, the depth dependence of integral dose rate, obtained with environmental TL detectors, is represented. A power decrease in the dose rate is obtained ($\cong -0.72$), with a chi square of 0.98.

The preliminary studies of the TL response of powder natural NaCl to high doses of gamma radiation are presented. In agreement with the standard theory, in alkali halides, TL is thought to be due to the recombination of trapped electrons (F and F aggregate colour centres) and interstitial halogen atoms (H centres) produced during irradiation.

The role of impurities is important in TL phenomena. In natural samples, the concentration and the structural bounds of defects represent important factors of variability in the results.

The present results in natural NaCl samples reproduce the previous results obtained by Davidson and co-workers [9] in the same range of doses. The average temperature of the peak of (112 ± 14.7) ºC, is supported by the results of Davidson [9] and Murthy [1] in the experimental errors interval. In the paper of Murthy, the TL spectrum is obtained after beta irradiation, for which three well-defined peaks at 133, 205 and 238 ºC are obtained.

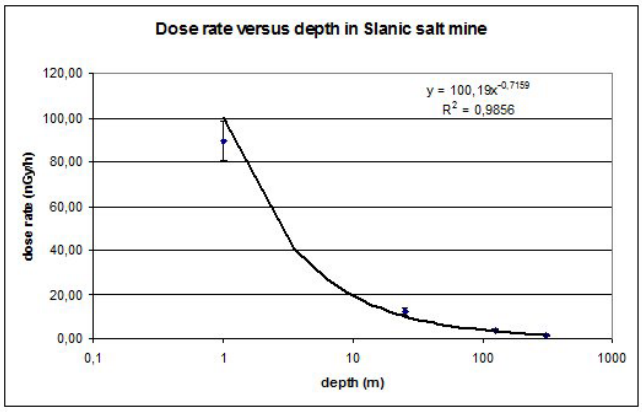

Fig. 1 – Integral dose versus depth in Slănic mine obtained with TLD.

To put in evidence the fading the TL, signals of irradiated salt samples were measured at different intervals of time: 1, 2, 18, 20, 22, 70 and 72 h. The modifications of the TL spectra were then recorded and are presented in Fig. 2.

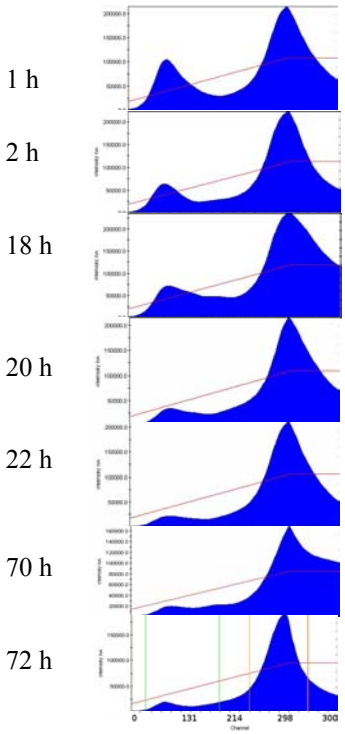

Fig. 2 – The fading the TL signals of irradiated salt samples.

A linear behaviour was obtained studying the fading. Fading calculations were made with an initial irradiation of 26 kGy. The parameters of the fit curve are: (1191.4 ± 64.2) and (–0.11 ± 0.02) for intercept and slope respectively, with a Chi square of 0.90. Figure 3 presents these results.

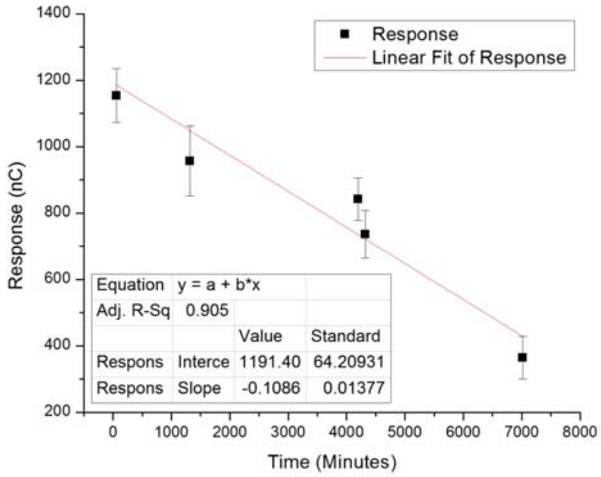

Fig. 3 – Time dependence of the TL response signal in salt samples.

The linearity of the response to dose is only suggested, because of the errors in measured TL signal responses. The intercept value of (122.8 ± 98.1) nC in the response signal (the slope is 35.0 ± 5.7 nC/kGy) is interpreted as effect of natural dose during the life cycle of rocks in conditions of continuous exposure to nuclear radiation from cosmic rays and to the local radioactivity background.

The conditions that are necessary to natural NaCl crystals to be a possible TL detectors are discussed by Okamoto and co-workers [10]. The essential TL characteristics required to a material for a shower detector are: a) the sensitivity of the powder must be sufficient to detect cascade showers of energies around 1 TeV; b) ideally no fading effects exist. In fact there must be slow time and temperature dependence. The thermal fading effects on the latent TL signal are expected to be small at temperatures lower than 30°C if the peak temperature of the powder is higher than 200°C in the glow curve; c) a low sensitivity to light and to granularity. In these preliminary studies we did not investigate all requirements.

4. PRELIMINARY CONCLUSIONS

The profile of the integrated dose of the salt mine Unirea from Slănic, at a depth of 208 m, was obtained with commercial TL detectors, putting in evidence a power decrease in rate of dose with a value of ≅ –0.72.

The preliminary studies of the TL response of powder natural NaCl to high doses of gamma radiation are presented. The fading effects are studied and put in evidence. More detailed studies are necessary to clarify the role of different factors as presence of impurities in the rock, humidity, granularity of the powder in the samples, environmental temperature.

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