THERMOLUMINESCENCE OF LUNA-24 CORE SAMPLES

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Three samples of Luna-24 core are studied. Natural as well as artificially induced thermoluminescence (TL) glow curves are recorded. Approximate calculations of dose rate from galactic cosmic rays and the radioactivity of the lunar soil are made. The utility of TL data for determining the age of deposition of the core samples is explored.

INTRODUCTION

A number of workers have carried out thermoluminescence (TL) studies on lunar soils (Durrani *et al.*, 1972, 1976 and references therein, Nambi *et al.*, 1974). Durrani *et al.* (1976) have inferred the temperature and duration of the shadow of a boulder on the lunar surface. In the present work, TL studies are carried out on three samples of Luna-24 core namely from 123, 163 and 190 cm layers.

EXPERIMENTAL

The glow curves are recorded from about 2 mg of the sample spread uniformly over a heater strip. The strip is heated at a linear rate of 300 °C/min by a temperature programmer (Samant *et al.*, 1974). The TL emission from sample is seen by an EMI 9514S photomultiplier through a hole in stainless steel diaphragm covered with HA_3 heat filter. The HA_3 filter helps to reduce the thermal noise to a great extent and makes it possible to record high temperature glow peaks upto 550 °C. Fig. 1 shows the natural TL(NTL) glow curves of three samples.

Fig. 2 shows glow curves due to irradiation in laboratory after removal of NTL by heating upto 550 °C during read out.

In order to eliminate the interference of spurious TL, all glow curves are recorded in oxygen-free nitrogen atmosphere. After mounting the sample on the heating strip, the heater-photomultiplier chamber is flushed with nitrogen gas before heating of the sample is started. An optimum flow rate of 750 ml/min is continuously maintained throughout the read out. No spurious is detectable with this procedure. Spurious TL is observed only if the TL is recorded in air atmosphere after disturbing the sample and allowing it to remain in air for one hour or more. However, there is no regular pattern in spurious TL signal growth with the time of storage in air. A typical spurious TL glow curve of lunar sample is shown in Fig. 3.

The lunar regolith samples received are just a few milligrams in total weight. In order to prevent any further loss and possible contamination of samples, the normal grinding and seiving operation of the samples is not carried out. Equal aliquots of virgin samples are made to read NTL and NTL plus different gamma-doses. Readings

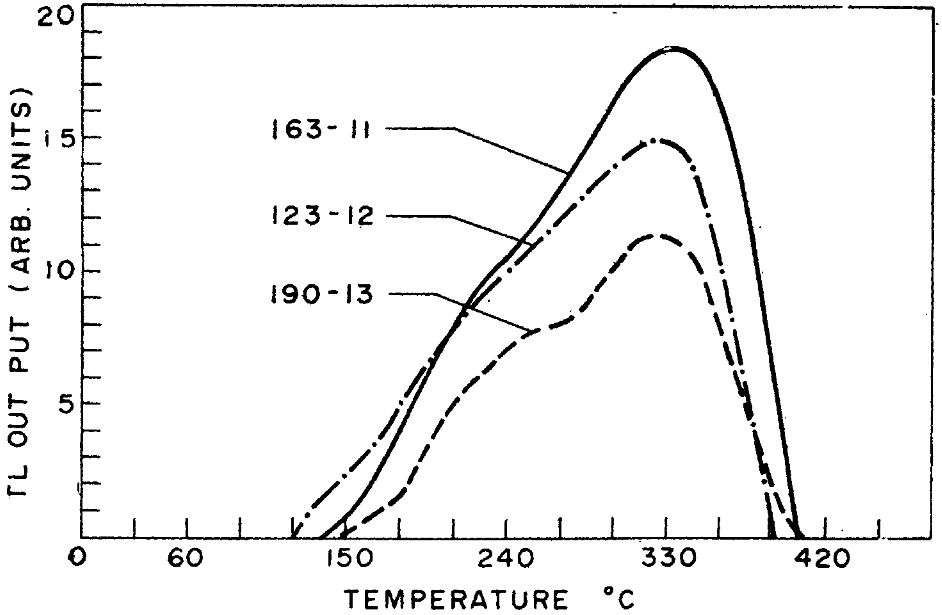

FIG. 1. NTL glow curves of the three Luna-24 samples. Sample Nos. are indicated.

for ATL (artificially induced TL i.e., TL induced due to irradiation in laboratory after removal of NTL by heating upto 550 °C during read out) calibration and for TL spectra are taken on NTL read samples. Each TL output is then normalised to 1 mg sample weight on the heater pan. Because of acute inadequacy of the sample material for repeat readings, statistical error on TL readings of the sample cannot be given. However, the complete set up is fully checked in all respects by forerunning all these planned set of readings on USGS Standard Basaltic rock (BCR-1) (Nambi *et al.*, 1978). The system reproducibility is better than ± 5 per cent throughout the range of our interest. The TL response of lunar samples with changing dose is shown in Figs. 4 and 5.

The optical spectra of TL emission are synthesised from the glow curves taken with different interference band pass filters interposed between photomultiplier and the sample. The characteristics of various filters used are given in Table I. The signal output is corrected for total system response. The synthesised spectra are shown in Fig. 6.

The experimental data obtained on Luna-24 samples is summarised in Table II.

NATURAL DOSE

TL studies are basically capable of determining the irradiation and thermal history of the samples. The irradiation of the lunar material can take place from two sources, (1) cosmic rays and (2) radioactivity of the lunar soil. Gross cosmic ray levels on lunar surface are shown in Table III (Taylor, 1975). It can be seen from the table that the solar flare and solar wind do not have enough penetration to cause irradiation

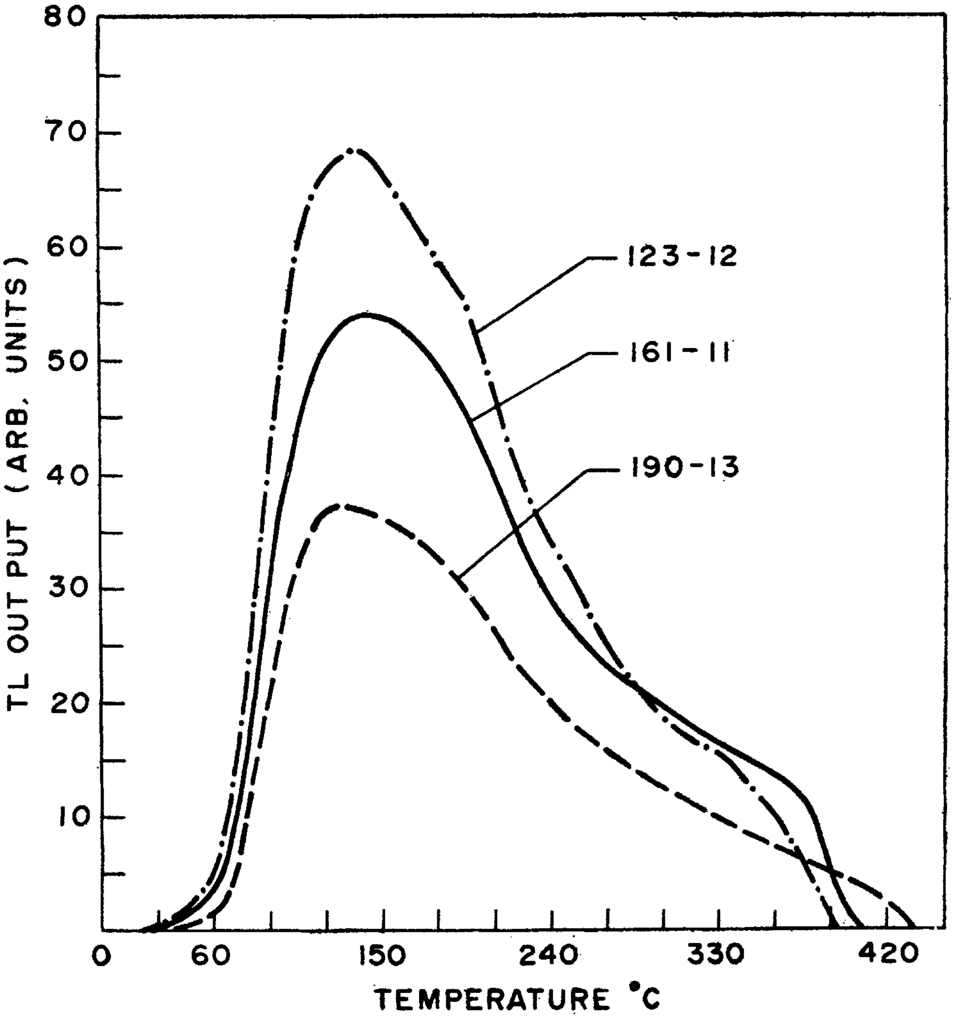

FIG. 2. TL glow curves after artificial irradiation subsequent to annealing at 550 °C. Dose = 40,000 Rads. Sample Nos. are indicated.

below the surface. The major component of the penetrating cosmic rays namely the galactic cosmic rays (GCR) consists of protons which constitute 86 per cent of total GCR flux. The alpha particles and other nuclei which may account for as much as two thirds of the surface GCR dose will not contribute in the deeper layers. An estimate of GCR proton dose was, therefore, made at various depths from lunar surface. The GCR proton intensities were taken from Gloekler (1974) and proton ranges and stopping powers from Barkars and Berger (1964). Lunar soil density is assumed as 1.9 g/cm^3 (Taylor, 1975). The proton energy groups with respective average intensities used for approximate calculations are shown in Fig. 7. Fig. 8 curve '*a*' shows the calculated dose rate at different depths.

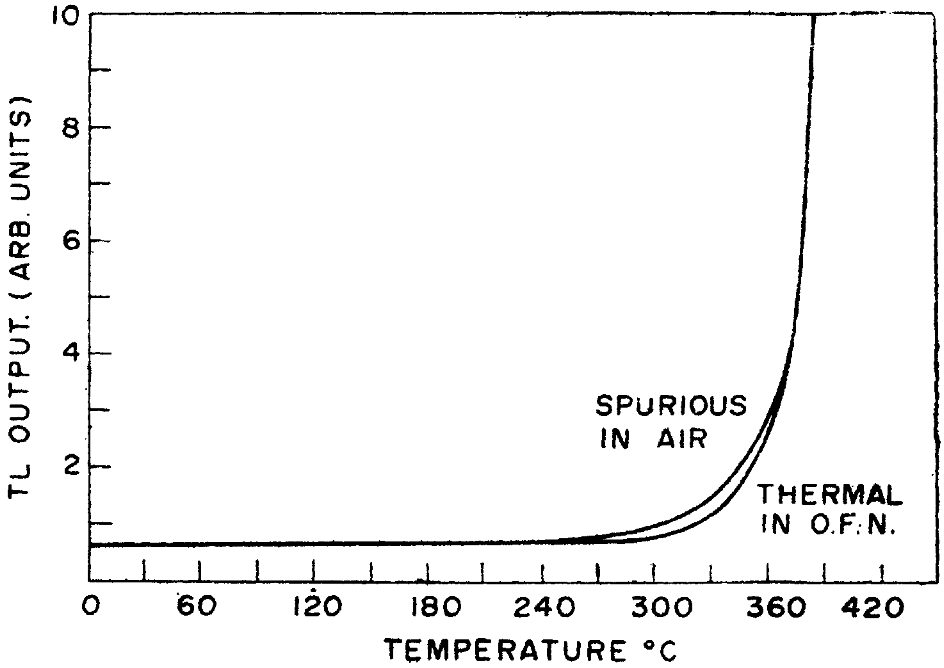

FIG. 3. A typical spurious TL glow curve of Luna-24 sample.

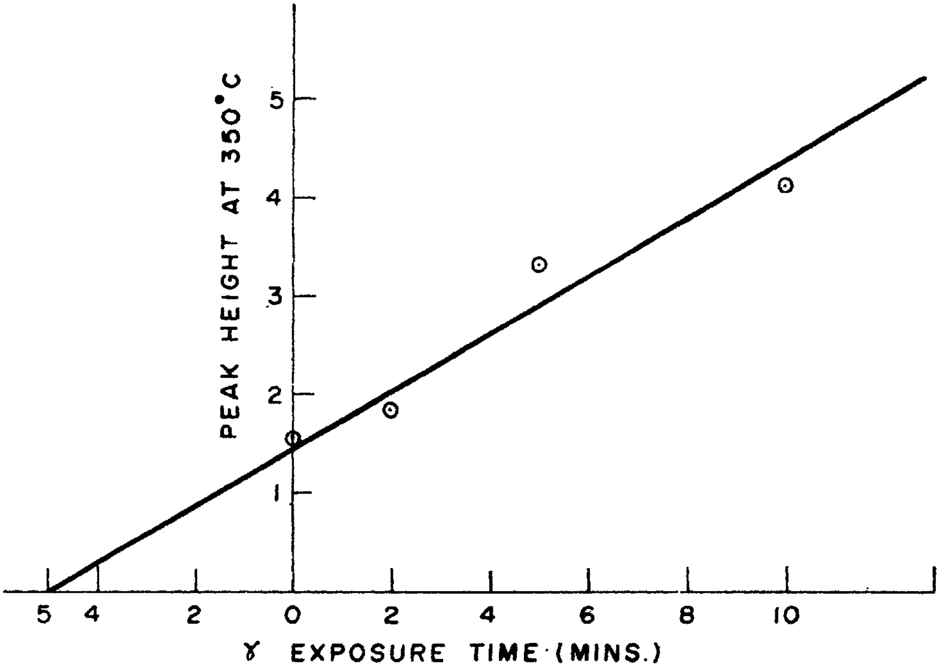

FIG. 4. Growth of TL with additional γ-dose. Sample No. 190–13. Dose rate = 4480 Rads/min, Equivalent γ-dose from NTL = 5 × 4480 = 2.24×10^4 Rads.

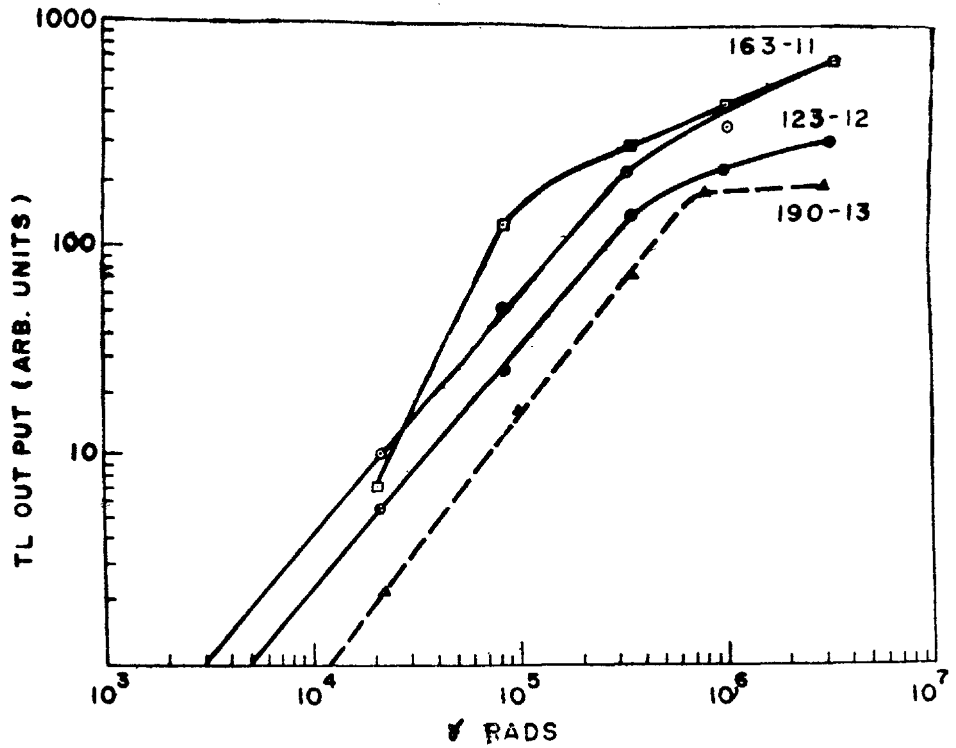

FIG. 5. Growth of TL with γ-dose after annealing of NTL. Sample Nos. are indicated. Two graphs are shown from sample 163-11, indicating erratic nature.

TABLE I

Details of band pass filters used in the study of TL spectra from lunar samples

Wavelength peak max. nm	Transmission max %	Half width nm
343.5	27	9.5
363.0	39	10.5
405.0	30	11.0
456.0	32	11.0
504.0	39	13.0
555.0	41	10.0
607.0	31	12.0

The annual dose rate due to radioactivity was calculated assuming following concentration of radioactive elements : Th 1.5 ppm (Bhandari *et al.*, 1978), U 0.4 ppm (assumed arbitrarily as 25 per cent of Th concentration) in equilibrium with daughters and K 0.035 per cent (Murali *et al.*, 1978). These concentrations provide an annual alpha dose of 222 mRads and annual β + γ dose rate of 34.4 mRads (Bell, 1976).

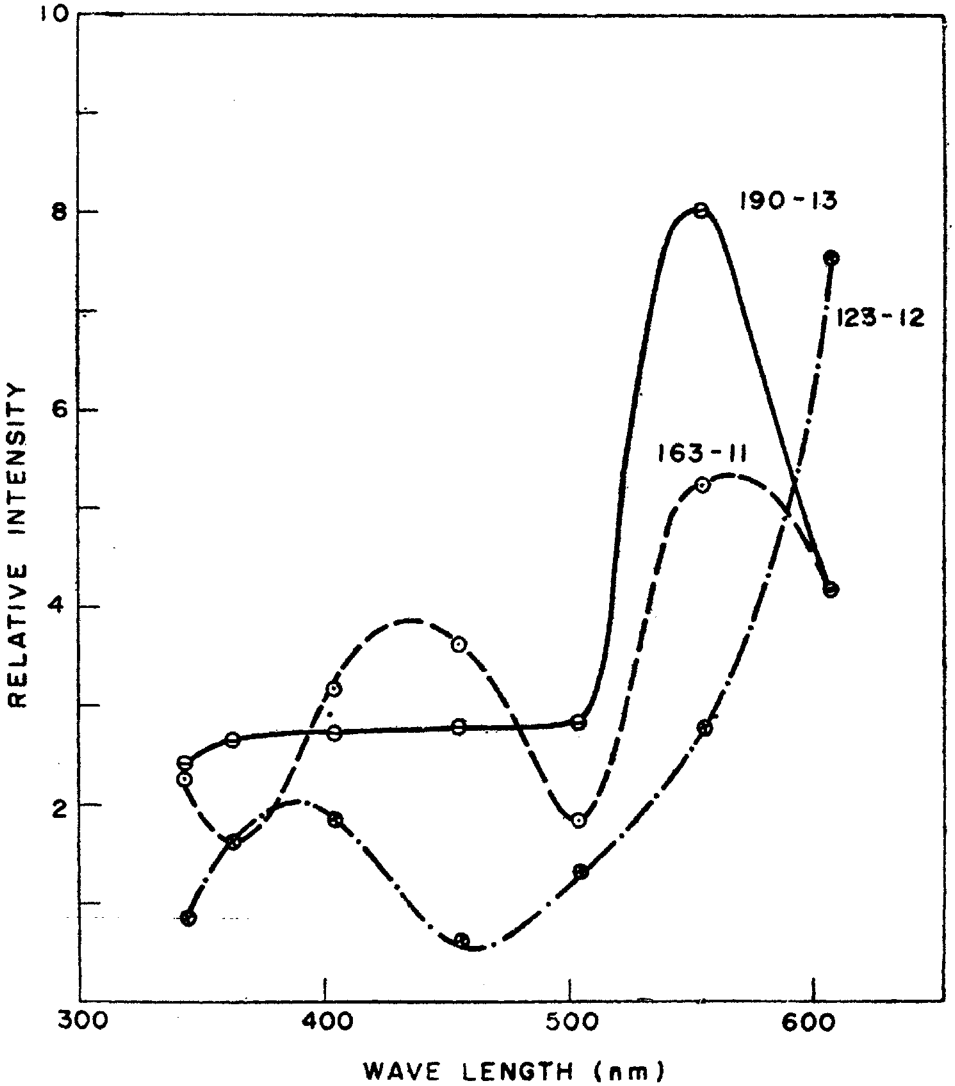

Fig. 6. TL spectra of the three samples.

The above estimates of natural dose rates show that the GCR protons by far predominate even in the deep layers.

The estimates of the γ-equivalent doses from the NTL of the different core samples are given in Table II. These equivalent doses were estimated by calibrating the samples with ^{60}Co γ-exposures in the laboratory. Assuming that the TL started building up only after the soil was deposited under the surface, the estimated equivalent doses represent the accumulated effect of irradiation since the time of subsurface deposition. It is presumed that the accumulation of TL while a soil is on the surface would be negligible due to intense UV exposures and high temperatures during the lunar day.

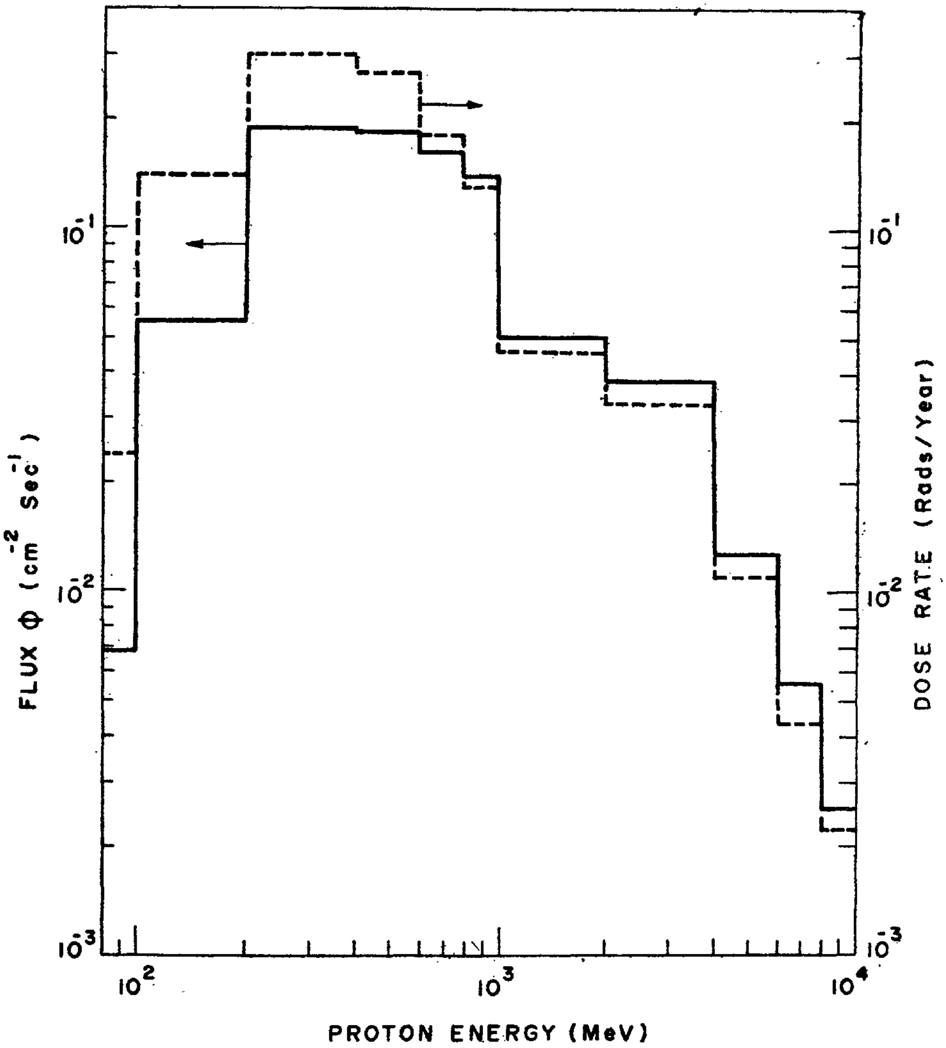

FIG. 7. Energy grouping of GCR protons used in estimating the GCR proton dose rate.

The estimated γ-equivalent doses show a sharp fall with depth (Table II). Qualitatively, this tallies with the falling GCR dose rate with increasing depth from the lunar surface.

AGE OF DEPOSITION OF CORE SAMPLES

The TL results coupled with dose rate estimates can be used for age determination. The age of deposition can in principle be obtained by dividing the accumulated dose value (estimated from NTL) by the annual dose rate. The estimates of accumulated γ-equivalent doses and the γ-equivalent dose rates are summarised in Table IV. The age estimates from these data turn out to be in the range of 10^5 years, which is

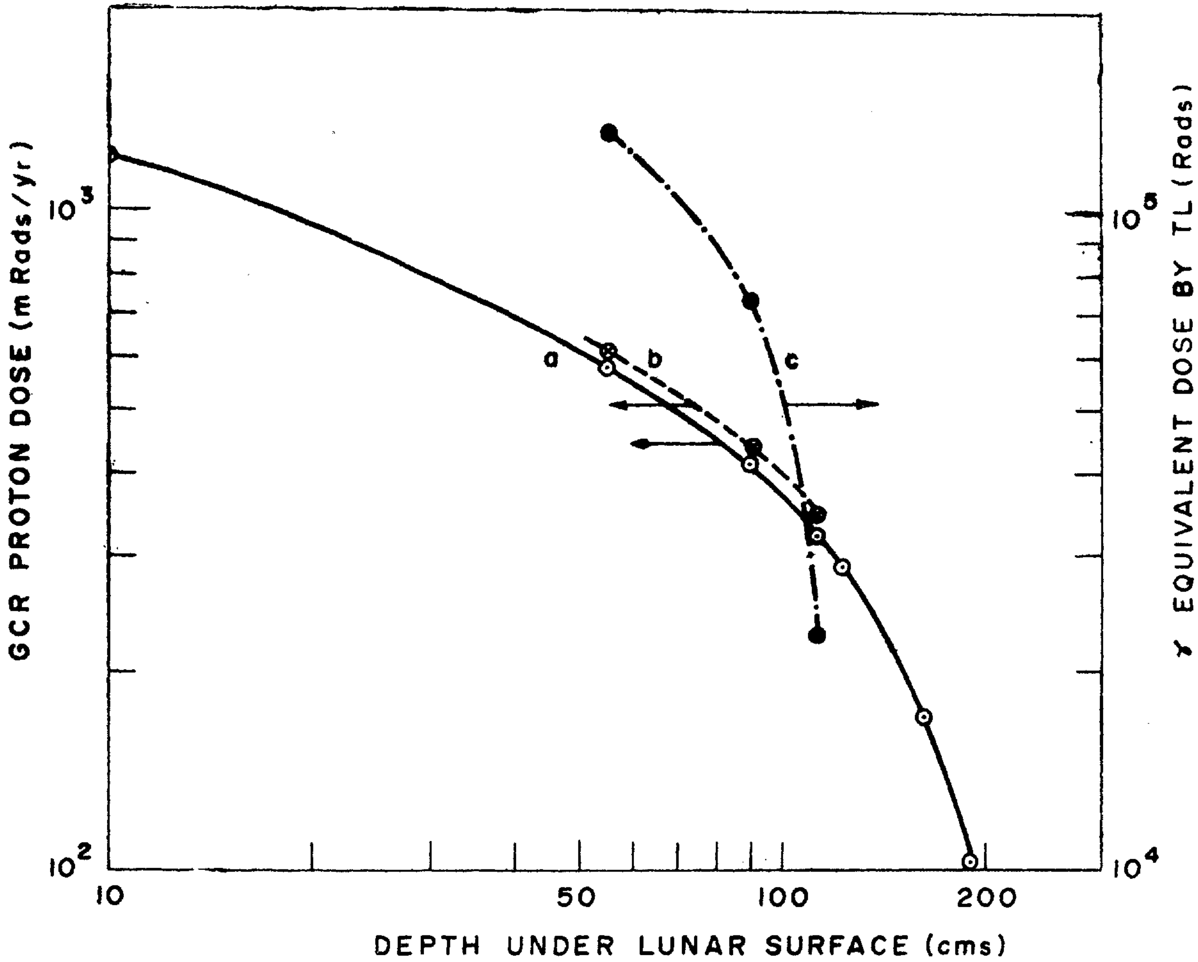

FIG. 8. (*a*) Calculated dose rates from GCR protons at different depths from lunar surface, (*b*) Dose rates from GCR protons plus radioactivity, (*c*) Equivalent -doses of samples based on NTL.

TABLE II

Characteristics of Luna-24 samples

Sample No.	123-12	163-11	190-13
Core depth (cm)	123	163	190
NTL glow (Temp. range °C)	120–400	135–400	150–400
Peak temps. of NTL °C	215, 330	225, 335	240, 320
Peak temp (°C) after Co-60 irradiation in the lab.	136	130	130
Spectral quality (emission band nm)	390, 607	343, 435, 470	360–500, 555
Area of NTL glow peak (relative)	5.42	6.1	2.15
Equivalent gamma dose for NTL (R)	1.3×10^5	erratic (7.3×10^4)	2.25×10^4
Saturation dose (Rads)	$\sim 3 \times 10^6$	$> 3 \times 10^6$	7×10^5
NTL Dose as % of saturation	~ 4.3	< 2.4	2.8

TABLE III

*Lunar surface radiation environment**

Radiation type	MeV/nucleon	Proton flux cm^{-2} sec^{-1}	Proton penetration depth (cm)	Apox. Proton Dose rate Rads/year^{+}
Galactic cosmic rays (GCR)	10^2–10^4	1	1–10^3	1.2
Solar flare	1–100	10^2	1–10^{-3}	3.8×10^3
Solar wind	10^{-3}	10^8	10^{-6}	—

*after Taylor (1975)

$^{+}$Total GCR dose rate estimate comes to about 4 rads per year when alpha and other nuclides are also considered.

too low to appear reasonable. The relative age should increase with depth but the computation shows reverse of it. Such a situation is impossible unless the layers got overturned by recent cratering or the result should be in error due to inaccuracy in dose rate estimates. Fading of TL over the geological times could also be responsible for low estimate of age. Looking at the saturation behaviour of the samples (Fig. 5) and the dose rates at their respective locations, the NTL may saturate in about 10^6 years of stay in a subsurface layer. The estimated γ-equivalent doses from NTL are in an order of magnitude lower than saturation dose (Table II) indicating that either the age of burial of these soils is actually low ($\sim 10^5$ years) or there is strong fading of TL. The NTL may be reflecting the state of dynamic equilibrium between the TL accumulation and the fading. Durrani *et al.* (1976) have estimated that in the case of Apollo-17 lunar samples the mean life of TL appearing between 306 and 378 °C is 3.5×10^6 years at a storage temperature of 256 °K (shaded from direct sunlight). An

TABLE IV

Dose and dose rate estimates of Luna–24 core samples

Sample No.	Depth from surface *d* cm[*]	Proton energies which penetrate the depth MeV.	GCR proton dose rate Rads/year[+]	γ-equivalent dose, calculated from NTL Rads
123.12	55.0	> 450	0.573	1.3×10^5
163.11	89.0	> 600	0.410	7.3×10^4
193.12	112.5	> 700	0.318	2.25×10^4

[*] The sample depth is based on the lunar surface being at 60 cm level of the core tube and the core tube being inclined 30 °C off normal; $d = (x-60)$ Cos 30.

[+] To these dose rates should be added the contribution due to radioactivity to find the total effective annual dose rate. The contribution due to radioactivity consists of 34.4 m Rads/year of $\beta + \gamma$ and 222 m Rads/year of α. The TL induction efficiency of α–rays in comparison to $\beta + \gamma$ is assumed as 5%. Hence the effective dose rate from radioactivity = 45.5 m Rads/year (γ-equivalent). The TL induction efficiency of GCR protons can be assumed to be same as that of β because of similarity in stopping power.

anomalous fading (Wintle, 1975) common in feldspars and volcanic rocks may however, produce a much faster decay of TL than that estimated from its kinetic parameters. It is not possible to account for such fading of TL intensity at this stage.

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