Lunar Based Particle and Radiation Detectors

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Introduction

- NASA
  - Apollo 11, July 1969
  - Apollo 12, Nov 1969
  - Apollo 13, Apr 1970
  - Apollo 14, Feb 1971
  - Apollo 15, July 1971
  - Apollo 16, Apr 1972
  - Apollo 17, Dec 1972
  - Lunar Reconnaissance Orbiter, 2008
- Chang’e
  - 一号 2007
  - 二号 2010
  - 三号 2013
  - 四号 2018
  - 五号 2020

Apollo 14

- Charged-Particle Lunar Environment Experiment
  - to measure the fluxes of charged particles (electrons and ions) with energies ranging from 50 to 50 000 eV

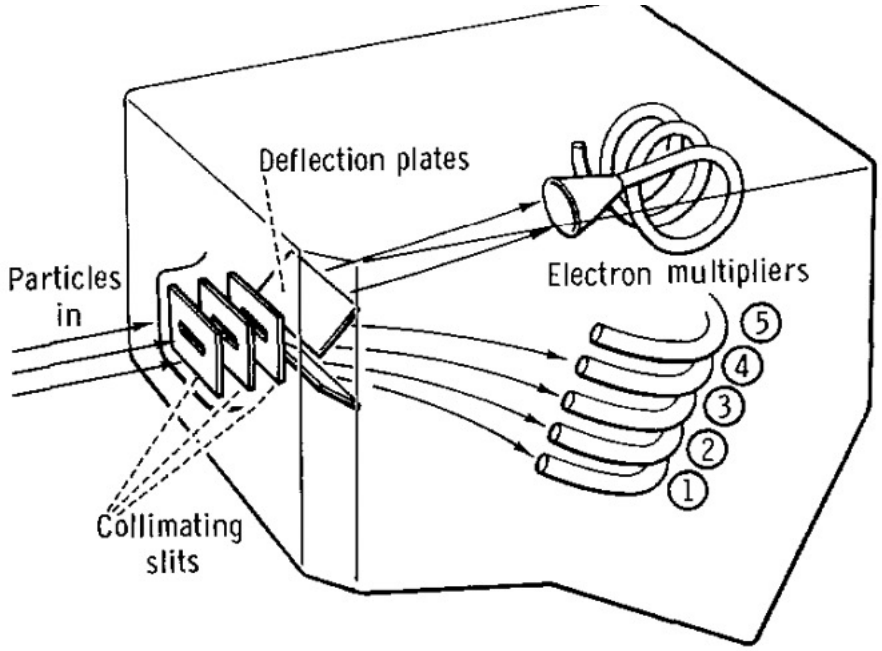

FIGURE 10–2.—Schematic sketch of the CPLEE physical particle analyzer, showing the deflection plates and channel electron-multiplier stack.

Apollo 15

- Suprathermal Ion Detector Experiment
  - designed to provide information on the energy and mass spectra of the positive ions close to the lunar surface (the lunar exosphere)
- Gamma-Ray Spectrometer Experiment
  - geochemical mapping of the lunar surface
- X-Ray Fluorescence Experiment
  - orbital mapping of the lunar surface composition
  - for X-ray astronomical observations during transearth coast
- Alpha-Particle Spectrometer Experiment
  - radon map of the Moon
- Lunar Orbital Mass Spectrometer Experiment
  - to measure the composition and distribution of the ambient lunar atmosphere

Apollo 16

- Orbital Science (selected)
  - The **X-ray Fluorescence Spectrometer Experiment** measured the composition of the lunar surface.
  - The **Gamma-ray Spectrometer Experiment** measured the composition of the lunar surface.
  - The **Alpha Particle Spectrometer Experiment** measured radon emission from the lunar surface.
  - The **Orbital Mass Spectrometer Experiment** measured the composition of the lunar atmosphere.
- Surface Science (selected)
  - The **Cosmic Ray Detector** measured very high energy cosmic rays from the Sun and other parts of our galaxy.
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Apollo 17

- Orbital Science (selected)
  - The **Ultraviolet Spectrometer Experiment** studied the composition of the lunar atmosphere.
- Surface Science (selected)
  - The **Lunar Neutron Probe** measured the penetration of neutrons into the lunar regolith, which helped to measure the overturn rate of the regolith.
  - The **Cosmic Ray Detector** measured very high energy cosmic rays from the Sun and other parts of our galaxy.
  - The **Lunar Surface Gravimeter** attempted to detect gravity waves.

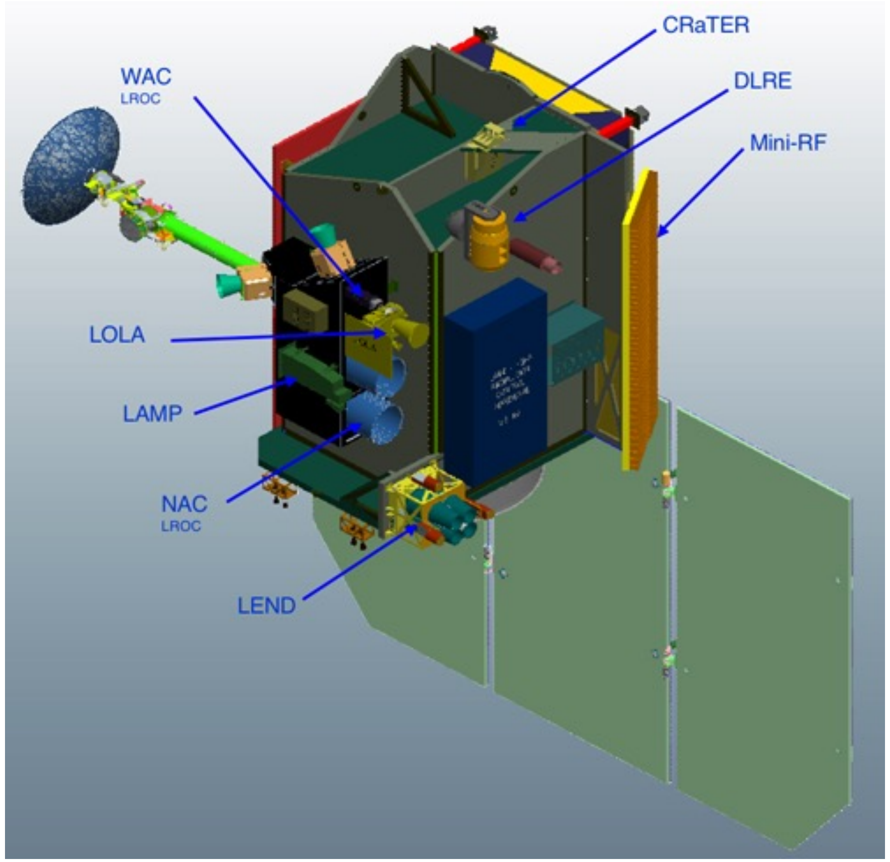
Lunar Reconnaissance Orbiter

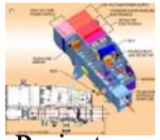
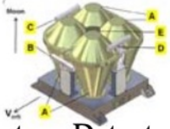
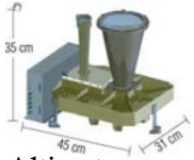
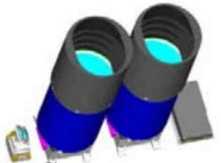
- Launched in 2009 by NASA, still in operation
- Orbiting the Moon at about 50km

Science mission:

- Environmental characterization for safe access
- Global topography and targeted mapping for site selection and safety
- Resource prospecting and assessment of In-Situ Resource Utilization (ISRU) possibilities
- Technology “proving ground” to enable human exploration

LRO payloads



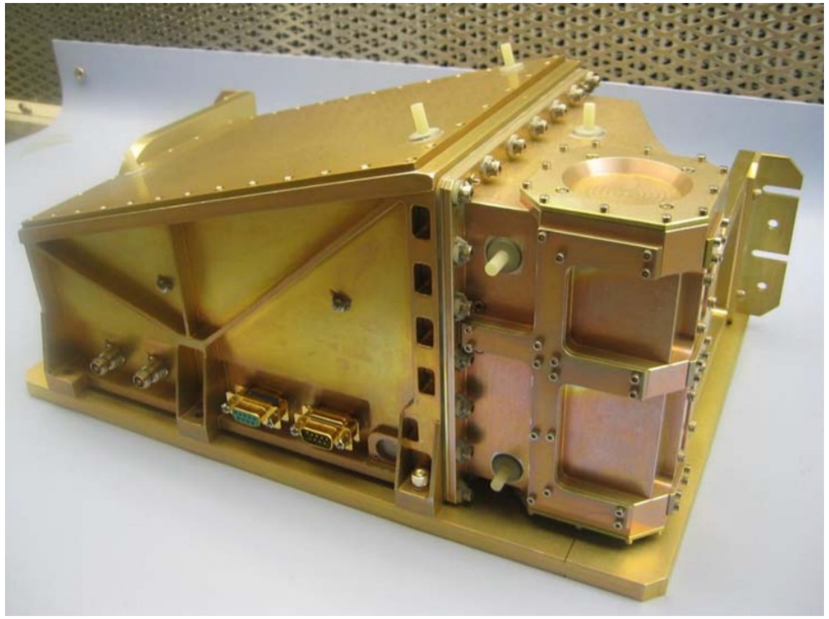
INSTRUMENT	Measurement
CRaTER (BU+MIT) Cosmic Ray Telescope for the Effects of Radiation 	***Tissue equivalent response to radiation***
Diviner (UCLA) 	***300m scale maps of Temperature, surface ice, rocks***
LAMP (SWRI) Lyman-Alpha Mapping Project 	***Maps of frosts in permanently shadowed areas, etc.***
LEND (Russia) Lunar Exploration Neutron Detector 	***Hydrogen content in and neutron radiation maps from upper 1m of Moon at 5km scales, Rad > 10 MeV***
LOLA (GSFC) Lunar Orbiter Laser Altimeter 	***~50m scale polar topography at < 1m vertical, roughness***
LROC (NWU+MSSS) Lunar Recon Orbiter Camera 	***1000's of 50cm/pixel images (125km²), and entire Moon at 100m in UV, Visible***

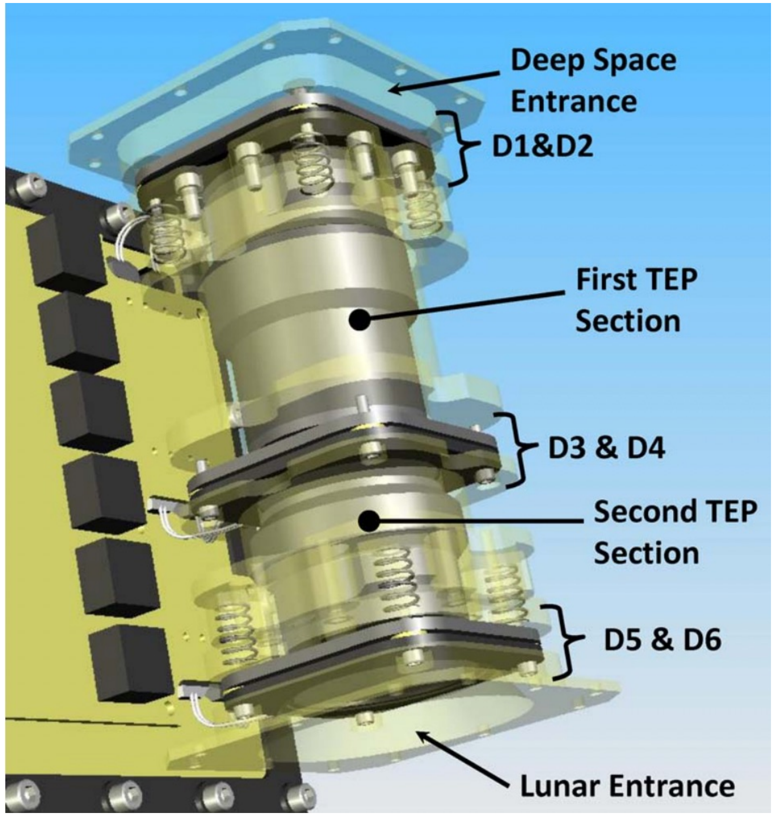
CRaTER

Space Sci Rev (2010) 150: 243–284

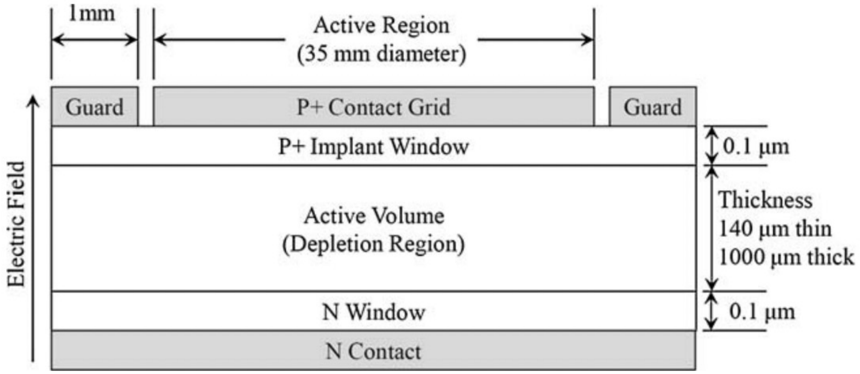
- Designed to characterize the global lunar radiation environment and its biological impacts
  - galactic cosmic rays (GCR), solar energetic protons (SEP), secondary radiation
  - with energies above 10 MeV

Tissue equivalent plastic (TEP)





Pairs of thin & thick silicon detectors

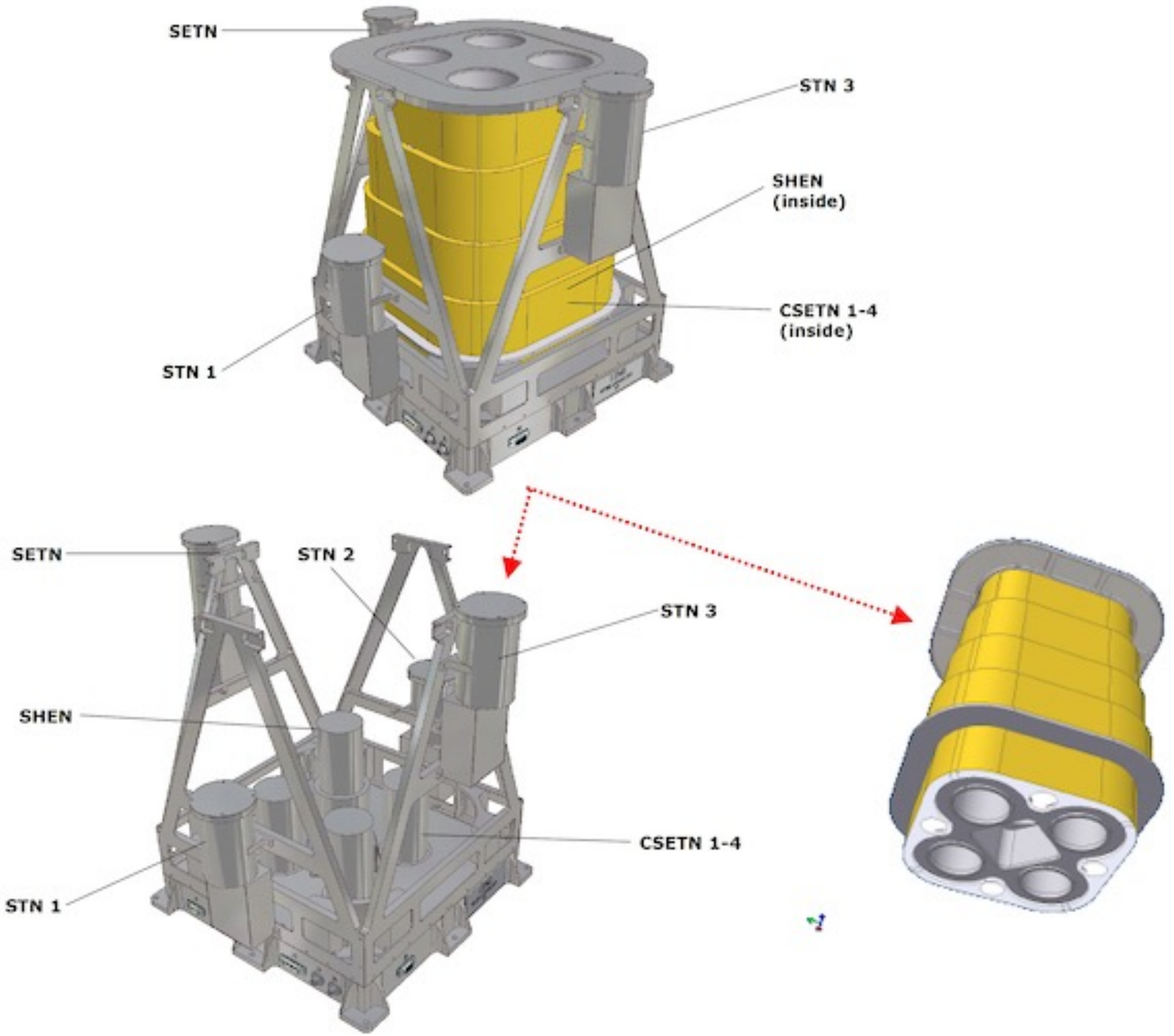


LEND

[Space Sci Rev (2010) 150: 183–207](#)

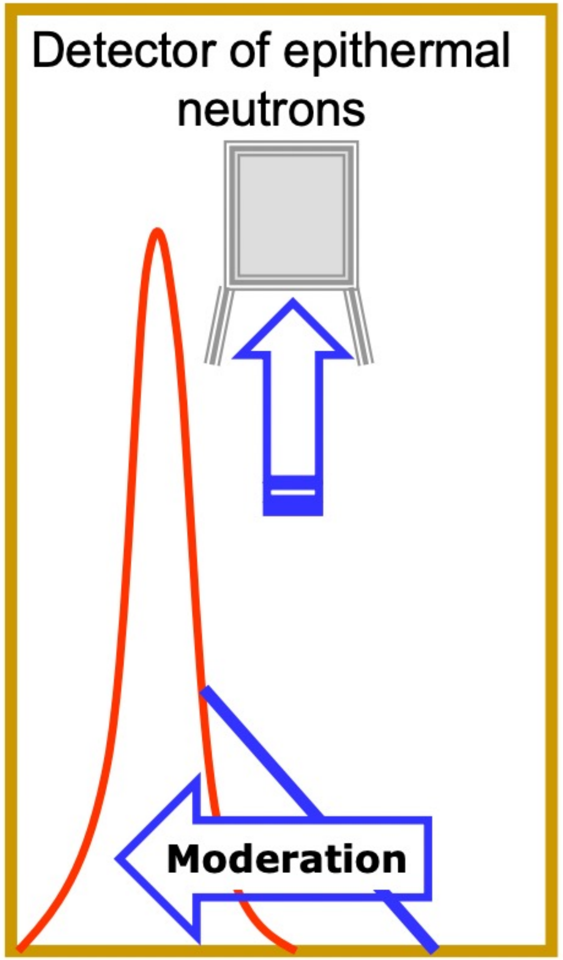
- To measure the neutron emission from the lunar surface and the local neutron background in orbit
  - To map the spatial distribution of hydrogen over the entire surface of the Moon
  - To determine the possible presence and abundance of water (ice) at the Moon's poles
  - To measure the lunar neutron flux (energies up to 15 MeV)

9 neutron sensors:
Sensor of thermal neutrons (STN, 3)
Sensor of epithermal neutrons (SETN)
Collimated sensor of epithermal neutrons (CSETN, 4)
Sensor of high energy neutrons (SHEN)

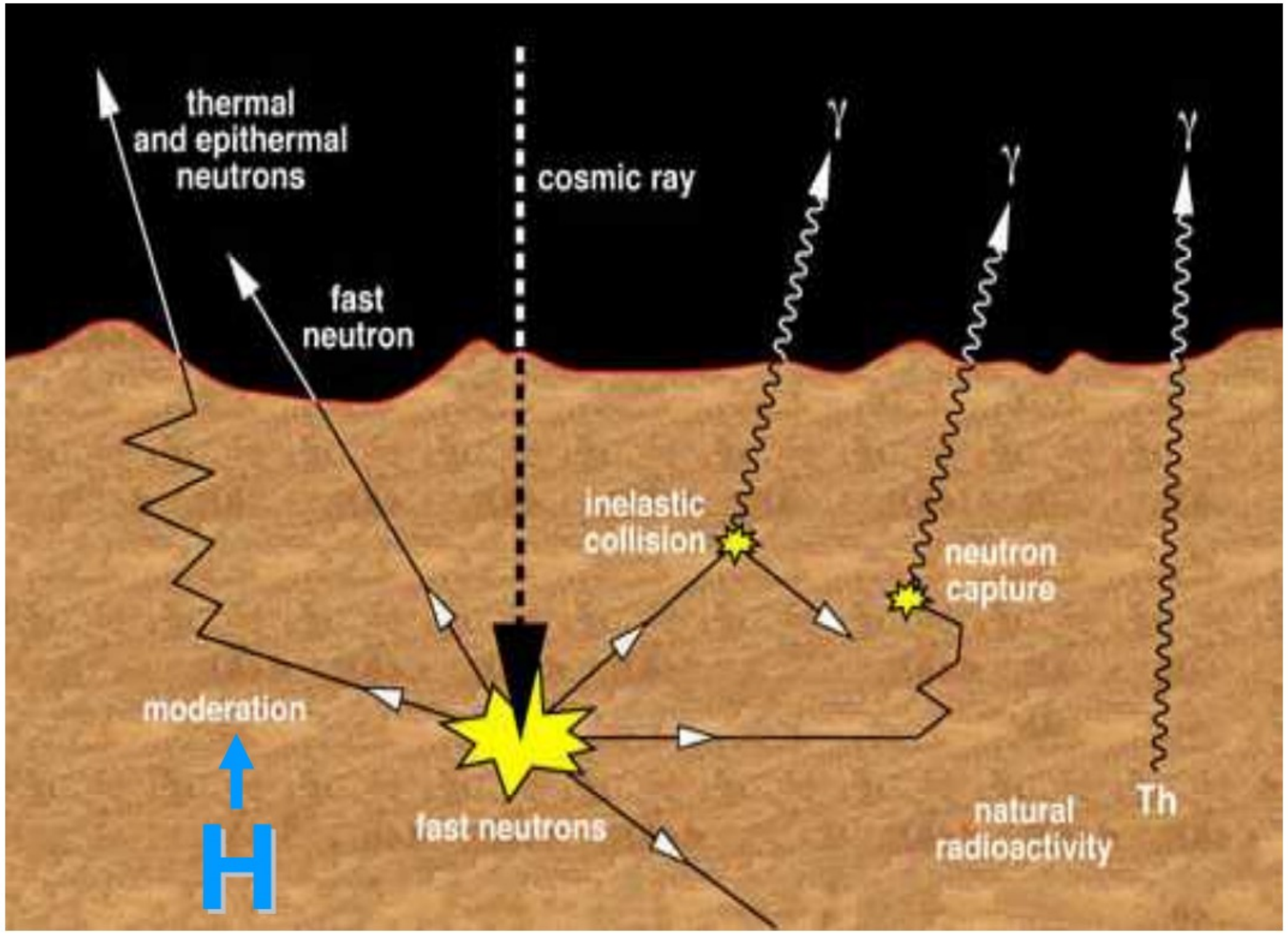


LEND

Physics of neutron method of measurement of hydrogen (water) in Lunar regolith



Energy spectrum of neutrons



Chang’e 1

- 有效载荷(探月卫星)
  - γ射线谱仪 Gamma-ray spectrometer (GRS)
    - 测量月表物质的γ射线谱(300keV~9MeV)，探测月表元素的含量和分布
  - X射线谱仪 X-ray spectrometer (XRS)
    - 测量月表物质的X射线谱(1~10, 25~60 keV)，探测月表元素的含量和分布
  - 高能粒子探测器 High Energy Particle Detector (HPD)
    - 探测高能带电粒子成分、能谱、通量和分布特性
  - 太阳风离子探测器 Solar Wind Ion Detector (SWID)
    - 探测太阳风离子能谱

由 3 片半导体 硅探测器组成

图 1　CE-1 太阳高能粒子探测器

探测器类型	高能粒子探测器
时间分辨率（s）	1
电子2个能道	E1：≥100keV
	E2：≥2.0MeV
质子6个能道	P1：4MeV~8MeV
	P2：8MeV~14MeV
	P3：14MeV~26MeV
	P4：26MeV~60MeV
	P5：60MeV~150MeV
	P6：150MeV~400MeV
重离子3个通道	He：13MeV~105MeV
	Li，Be，B：34MeV~210MeV
	＞C：117MeV~590MeV

Chang’e 3

- 有效载荷（着陆器）
  - 粒子激发X射线谱仪 Active Particle induced X-ray Spectrometer (APXS)
    - 探测月壤元素种类及含量

Chang'e-4

- 有效载荷（着陆器）
  - 低频射电谱仪 Low-Frequency Radio Spectrometer (LFRS)
    - 太阳低频射电特征和月表射电环境的观测
  - 月表中子与辐射剂量探测仪Lunar Lander Neutrons & Dosimetry (LND)
    - 测量月表综合粒子辐射剂量
  - 中性原子探测仪Advanced Small Analyzer for Neutrals (ASAN)
    - 测量月表的能量中性原子，正离子
  - 低频射电探测仪Netherlands China Long Wavelength Explorer (NCLE)
    - 进行低频无线电试验，开展天体物理学研究

探测器类型	月表中子与辐射剂量探测仪
快中子能谱（MeV）	2~20，32个能道
热中子能谱（/min）	10~104
质子能谱（MeV）	7~30，32个能道
电子能谱（keV）	60~500，32个能道
α粒子能谱（MeV/n）	10~20
重离子能谱（MeV/n）	10~100
LET谱范围（keV/μm）	0.1~430
数据率（bps）	平均200（约2MB/天）

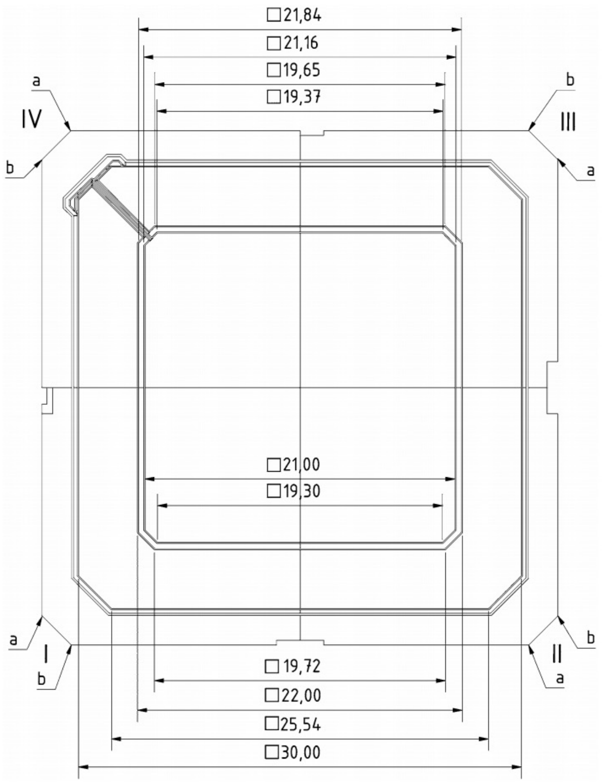
The Lunar Lander Neutron & Dosimetry (LND)

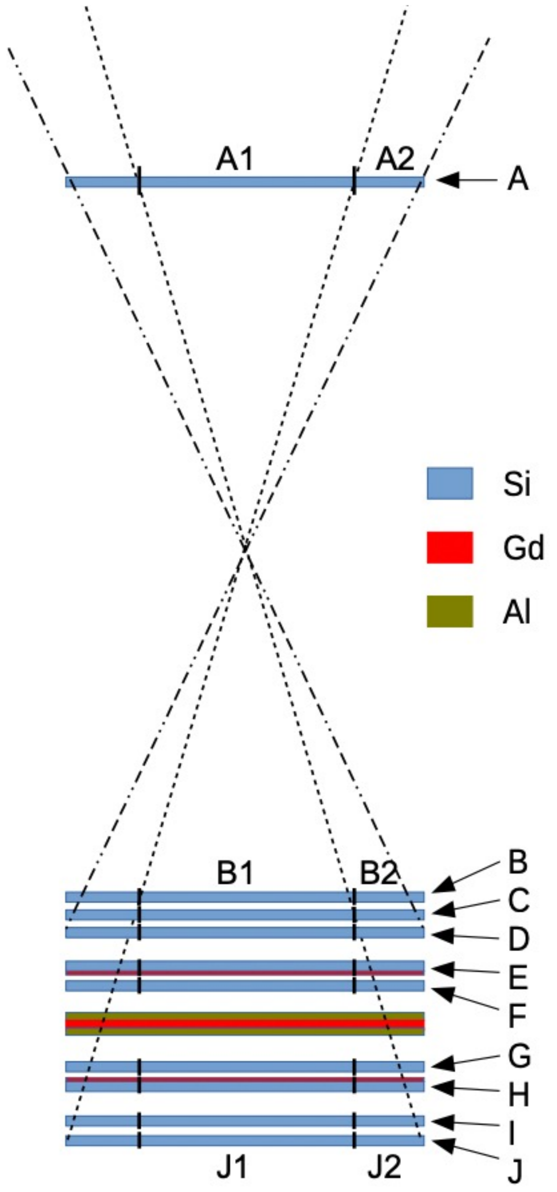
[*Space Sci Rev* **216,** 104 (2020)]

- provides time-resolved measurements of the radiation exposure

10 segmented 500 μm-thick Si solid-state detectors (SSDs), A–J.

Detectors B/C, E/F, G/H, and I/J are mounted in a sandwich configuration, the inner segments of the A and B detectors, A1 & B1, span the telescope opening





First results of LND

[Science Advances eaaz1334 (2020)](#)

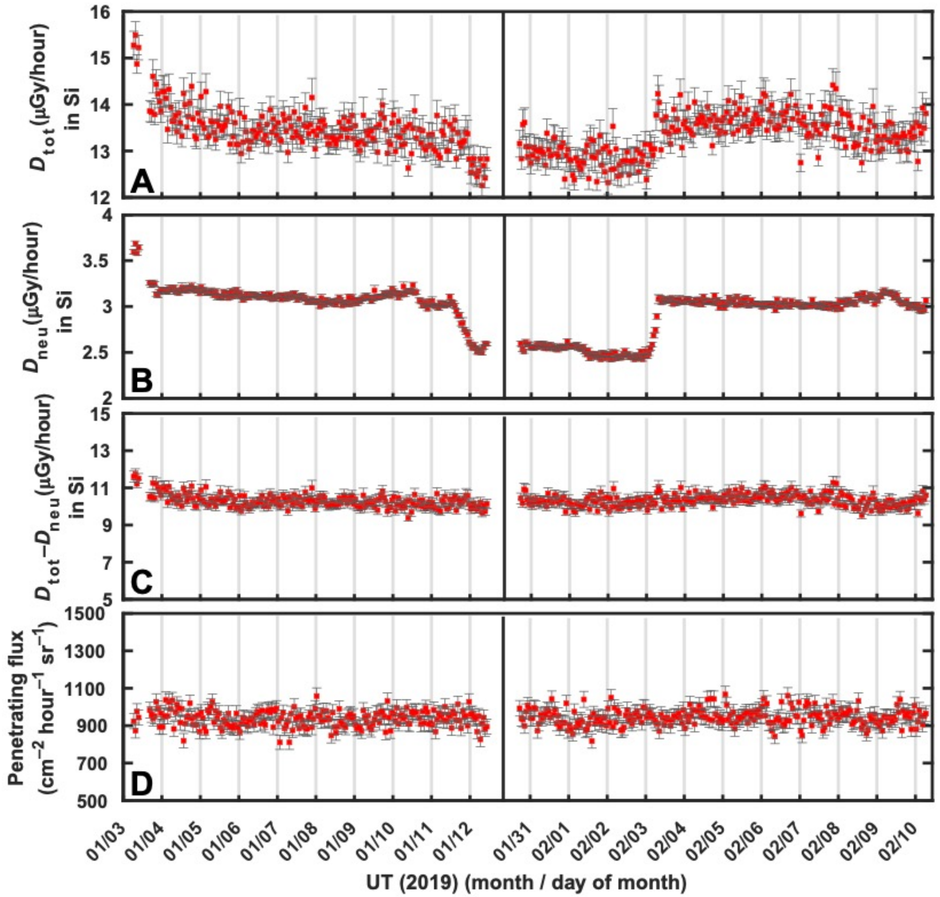


Fig. 3. Temporal evolution of the radiation environment on the Moon as measured by LND on Chang'E 4 during the first and second lunar day after Chang'E4 landed. The left-hand panels show data for the first lunar day, and the right-hand panels show data for the second lunar day. (**A**) Total absorbed dose rate measured with the LND B detector. (**B**) Neutral particle dose rate recorded in the LND C1 silicon detector. (**C**) Total absorbed dose rate from charged particles only [i.e., (A and B)]. The known background from the RTG and RHUs (*20*) has been subtracted from the values reported in (A) and (B). (**D**) Temporal evolution of the flux of penetrating particles. UT, universal time.

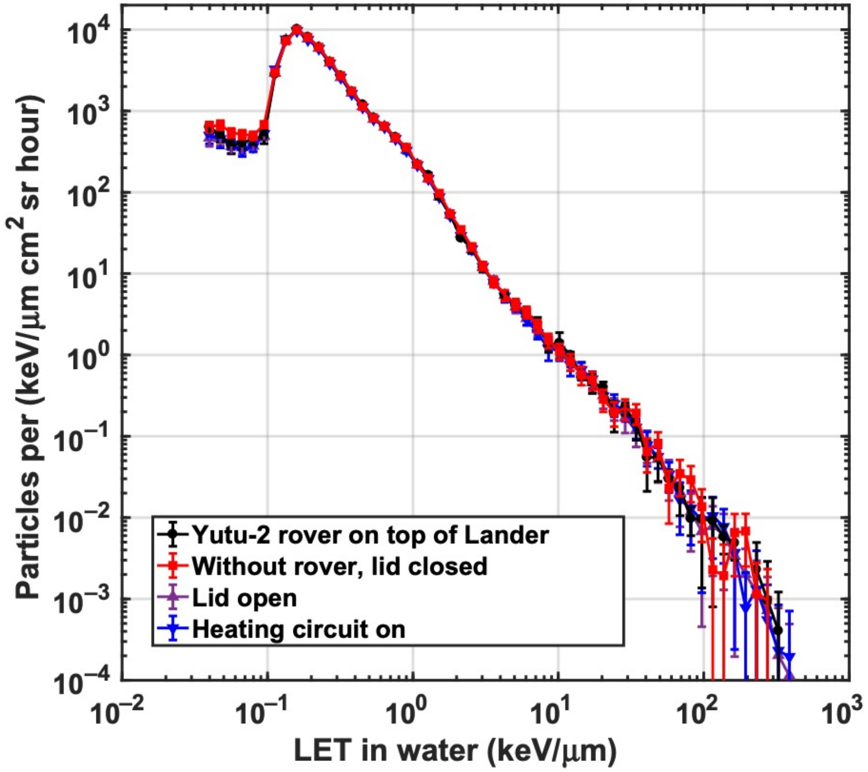


Fig. 4. Linear Energy Transfer (LET) spectra (converted to LET in water) measured during four different time periods show only small variations. The data shown as black circles were acquired before lander and rover separation; data shown in red after the rover left the lander but with the lid still closed; data in purple: normal operation of LND with the lid open; data in blue: with the Chang'E 4 heater circuit activated toward the end of the lunar day.

LND measured an average dose equivalent of 1369 μSv/day on the surface of the Moon

Chang’e-5

- 中国首次月球无人采样返回
  - 携带1731克月球样品 （Apollo 17: 110.52 kg）
- **有效载荷（着陆器）**
  - **月球矿物光谱分析仪**（Lunar Mineralogical Spectrometer, **LMS**）
    - 实现着陆表取采样区月表目标的光谱探测和分析任务，完成采样区月表矿物组成和分布分析
  - **月壤结构探测仪**（Lunar Regolith Penetrating Radar, **LRPR**）
    - 用于月壤厚度和结构探测，为钻取采样过程提供信息支持

Summary

Backup

Neutron energy distribution ranges

Neutron energy range names[2][3]

Neutron energy	Energy range
0.0–0.025 eV	Cold neutrons
0.025 eV	Thermal neutrons
0.025–0.4 eV	Epithermal neutrons
0.4–0.5 eV	Cadmium neutrons
0.5–1 eV	EpiCadmium neutrons
1–10 eV	Slow neutrons
10–300 eV	Resonance neutrons
300 eV–1 MeV	Intermediate neutrons
1–20 MeV	Fast neutrons
> 20 MeV	Ultrafast neutrons

Apollo 15: gamma-ray spectrometer

- construct a radon map of the Moon
- 10 totally depleted silicon surface-barrier detectors, each approximately 100 μm thick, having 3 cm^2 of active area and a 90° field of view, and operating at a -50-V bias
  - alpha energies from 5.3 to 8 .8 MeV

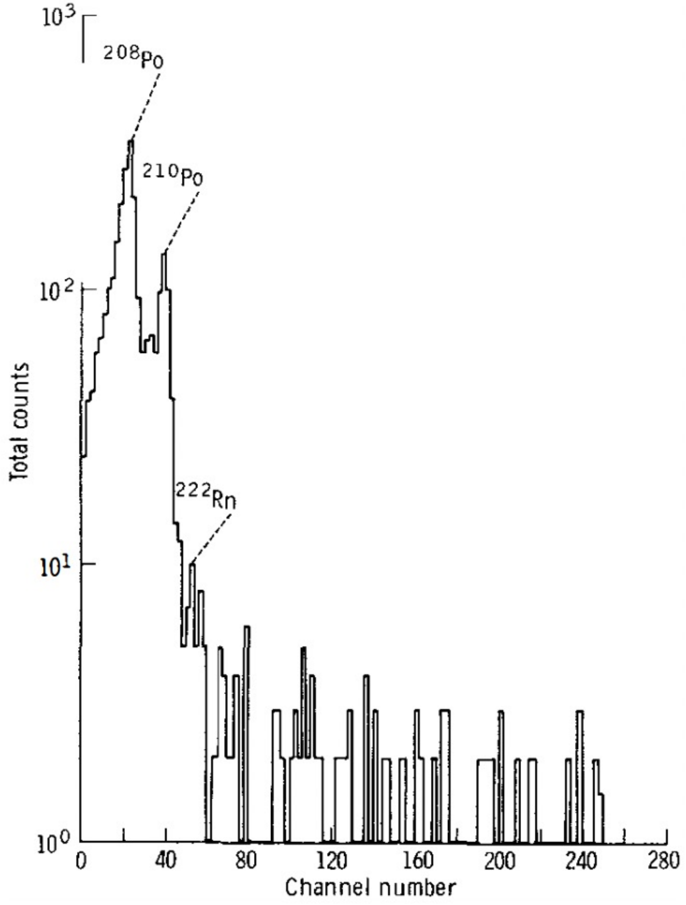


FIGURE 18-3.–An energy spectrum as displayed by the quick-look data system. This spectrum includes 47 min 23 sec of data beginning at 04:40 G.m.t. on July 30. The expected position of alpha particles from ^{222}Rn is indicated. This position has been determined by extrapolation from the ^{208}Po and ^{210}Po peaks.

The suprathermal ion detector experiment (SIDE)

- Apollo 15 SIDE instrument is basically identical to those flown on the Apollo 12 and 14 missions
  - only major difference is in the mass ranges covered by the three instruments
  - approximately 50 eV down to near-thermal energies
- Because the Moon does not have a strong magnetic field, the solar wind can impinge directly on the lunar surface

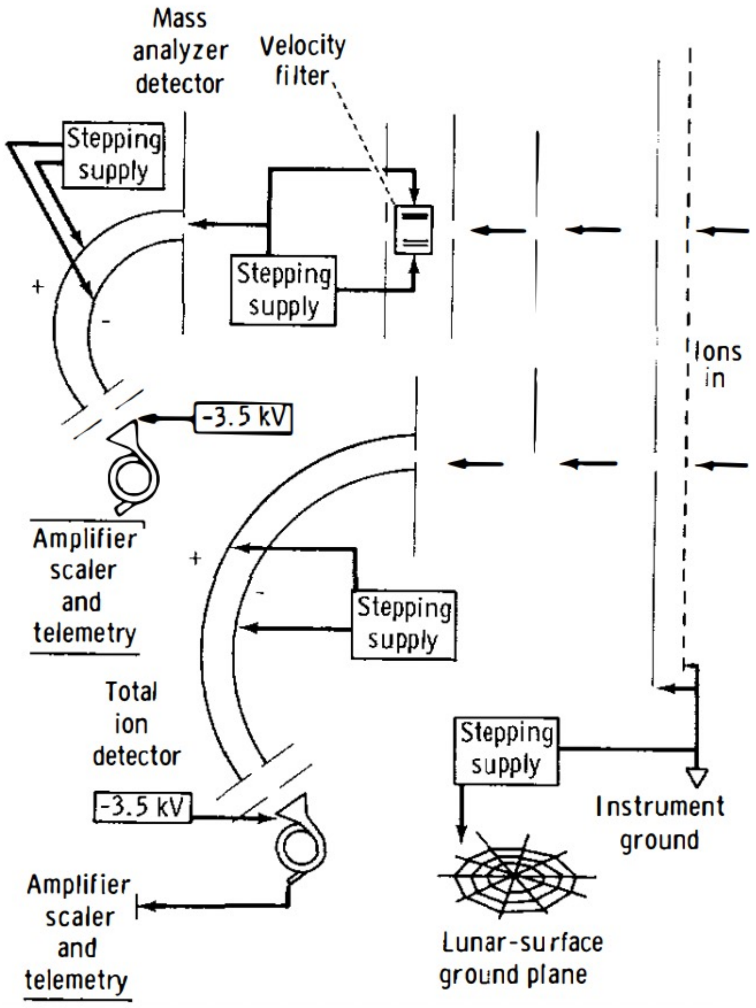


FIGURE 12-1.–Schematic diagram of the SIDE.

Apollo 17: Lunar Neutron Probe Experiment

- in situ experimental measurement of neutron capture rates as a function of depth in the regolith
- to retrieve information about the energy distribution of the equilibrium neutron flux
- The LNPE is in the form of a rod that is inserted into the lunar regolith to permit the measurement of neutron capture rates to a depth of 2 m

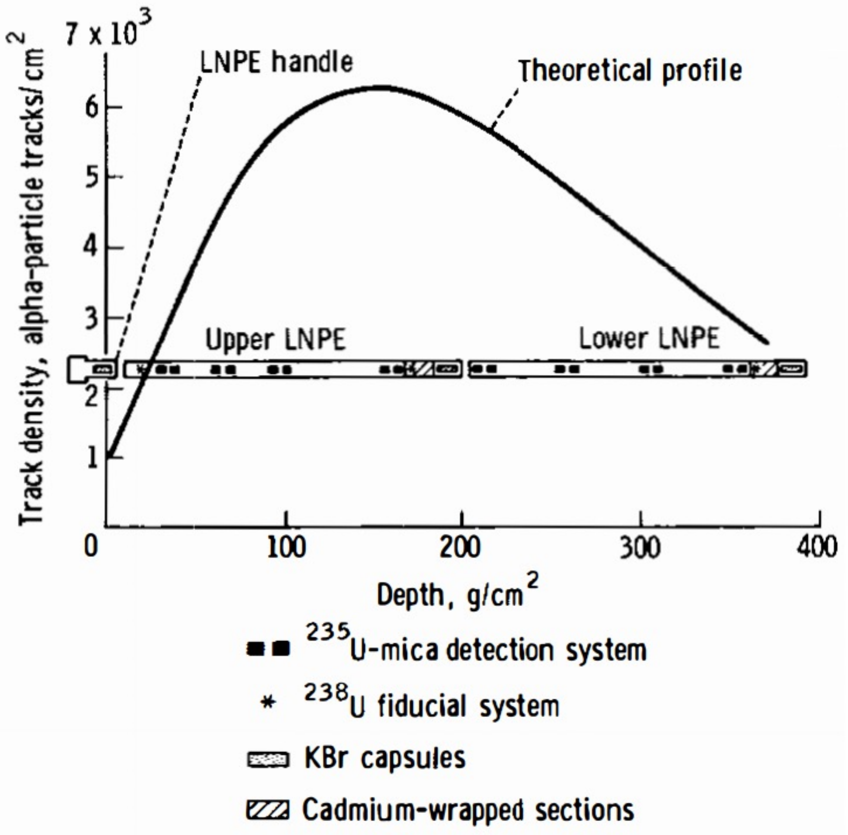
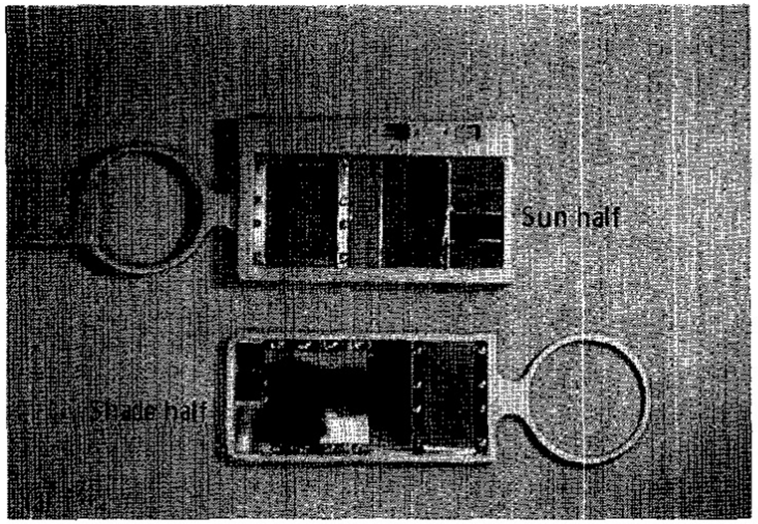


FIGURE 18-5.—A schematic view of the lunar neutron probe showing how the various targets and detectors are distributed with depth and including the theoretically predicted track density versus depth curve. The ^{10}B targets and plastic detectors (not shown) are essentially continuous along the entire length of the probe.

Apollo 17: Cosmic Ray Experiment

The total weight of the assembled package was 163 g, and the overall dimensions were 22.5 by 6.3 by 1.1 cm



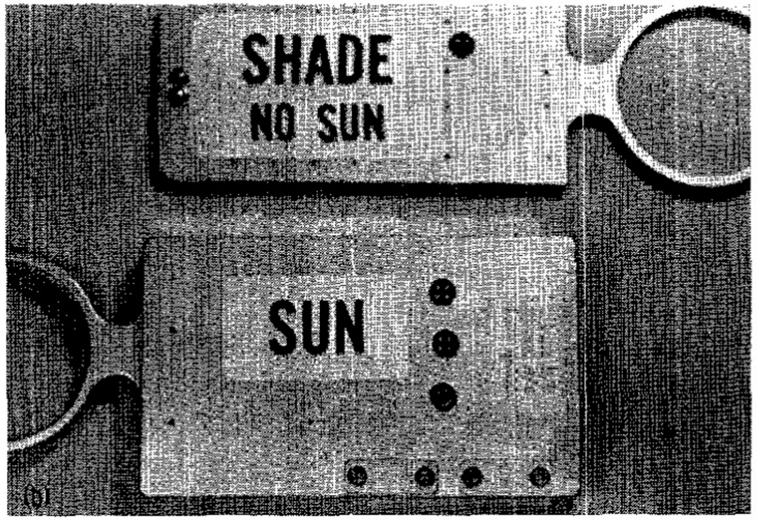


TABLE 19-I.—*Detectors in the LSCRE*

Number	*Detector*	*Component measured*	*Exposed area, cm^2*
		Sun-half detectors	
1	Mica	Heavy solar wind and low-energy cosmic rays	12.2
2	Aluminum foil	Light solar wind	5.1
3	Platinum foil	Light solar wind	11.2
4	Fused quartz (Suprasil 2)	Low-energy cosmic rays	5.4
5	Lead phosphate glass (Lal)	Low-energy cosmic rays	1.85
6	Mica	Heavy solar wind (Sun direction)	1.2
7	Platinum foil	Light solar wind	3.8
8	Platinum foil	Light solar wind	8.0
		Shade-half detectors	
9	Lead phosphate glass (Lal)	Low-energy cosmic rays	1.76
10	Phosphate glass (GE-1457)	Low-energy cosmic rays	1.62
11	Lexan	Low-energy cosmic rays	14.0
12	Platinum foil	Control piece for foils in Sun	6.8
13	Mica	Low-energy cosmic rays and radon atmosphere	9.1

Apollo 17: Cosmic Ray Experiment

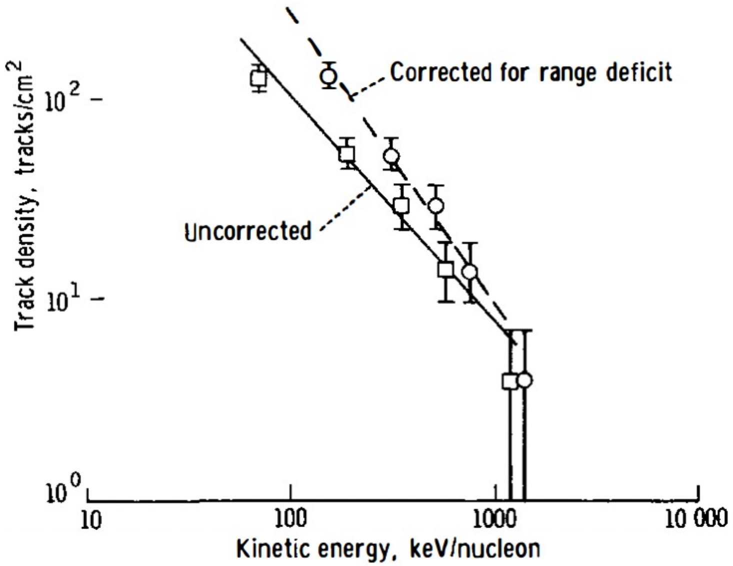


FIGURE 19-11.–Integral energy spectrum of the energetic iron particles observed in the sunlit and shaded micas. One set of points (squares) is obtained by assuming the tracks are etched for their total range. The circled points are plotted assuming a range deficit of 1.7 μm as given by Blok et al. (ref. 19-7).

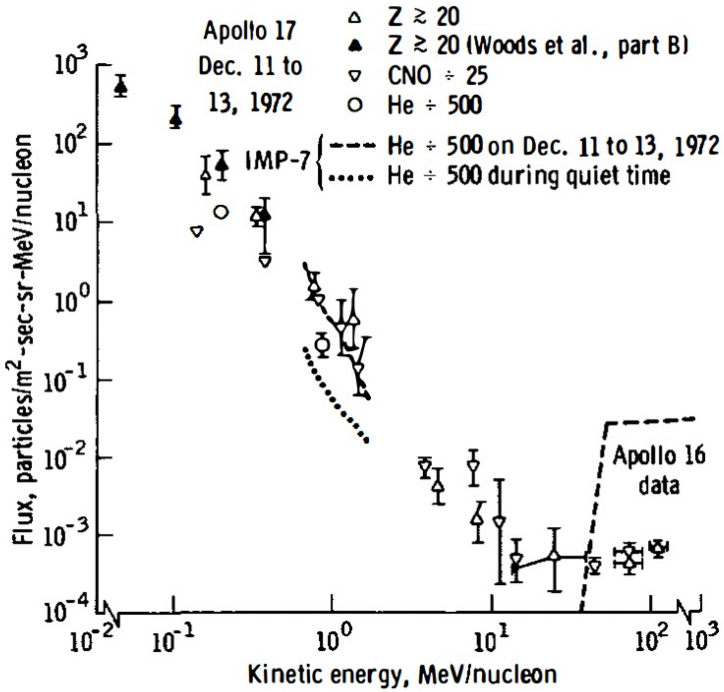


FIGURE 19-14.–Energy-dependent composition of low-energy interplanetary ions during solar quiet time. To display the enhancement of heavy elements at low energies, the fluxes of CNO and He have been scaled down by their abundances relative to Fe in the Sun. The enhancement appears to disappear at energies greater than ≈ 1 MeV/nucleon.