place primarily in the iron-containing pyroxenes, which are quite sensitive to radiation and temperature (in air) and should be a dynamic system when subjected to the direct solar wind even in vacuum.

Ever since the successful landing of Surveyor 1 it has been observed that gentle disturbance of the lunar soil, except by compression, results in a material which is as much as 30 percent darker than the undisturbed surface (*4*). We attempted to test several of the proposed explanations for this effect.

1) *Ultraviolet bleaching* (*10*). Ultraviolet irradiation of the soil caused albedo increases of approximately 6 percent; this value is of the same order as the disturbance effect observed by Surveyor 5.

2) *Packing.* The albedo of the soil is affected by the micromorphology of the surface in the sense that the looser the packing, the lower the albedo. The following albedos were obtained, depending on surface preparation: (i) sifted, 0.085; raked with a needle, 0.087; spooned onto a plate, 0.090; jarred by dropping the container from a height of about 5 cm, 0.094; tamped by pressing gently with the flat side of a spatula, 0.10. Since the lunar soil is continually stirred by micrometeorites it is doubtful that the natural condition of the surface is similar to that produced by tamping. Thus packing effects apparently are capable of altering the albedo by up to 10 percent.

3) *Particle size* (*11*). The albedos of fractions of fines separated as to particle size by dry sieving were measured with the following results: >149 μm, 0.089; 74 to 149 μm, 0.081; 37 to 74 μm, 0.080; <37 μm, 0.079; unseparated, 0.090. Hence albedo differences of about 10 percent might be possible if the upper layer of particles are larger on the average than those below the surface.

4) *Lunar varnish* (*12*). Samples of the fines were examined with an optical microscope, a scanning-electron microscope, and an electron microprobe for coatings of dark material which might be scrubbed off by solar wind sputtering, but no definite evidence for such coatings was found. However, under high magnification the surfaces of many grains exhibited peculiar textures, which we were unable to interpret. These may indicate the presence of an amorphous coating on parts of some grains. In order to test the possibility that coatings of carbonaceous material might be present, a thermogravimetric analysis was carried out by heating a soil sample to 1200°C in air and measuring the change in weight (*13*). The weight of the sample increased continuously and monotonically with temperature because of oxidation, and no decrease, such as might be caused by ignition of a carbonaceous coating, was observed at any temperature.

5) *Conclusion.* Although several effects can alter the albedo of the lunar soil by up to 10 percent, none of the hypotheses yet advanced to explain the disturbance effect seem capable of completely accounting for all observations, but any or all of the hypotheses discussed here may contribute.

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Determination of Manganese-53 by Neutron Activation and Other Miscellaneous Studies on Lunar Dust

Abstract. *A highly sensitive determination of spallogenic* ^{53}*Mn* (T = 2 × 10^{6} *yr*) *was accomplished in 0.99 g of lunar soil. The chemical yield of Mn is determined with "carrier-free"* ^{52}*Mn tracer. During a 23-day reactor irradiation the* ^{53}*Mn is transformed into* ^{54}*Mn* (T = 300 *days*)*. Appropriate chemical recycling was done by ion exchange and distillation. Interferences of the (n,p) and the (n,2n) nuclear reactions were carefully studied. A* ^{53}*Mn disintegration rate of 30.3 ± 5.5 dpm/kg results. This extremely economic method is proposed for further detailed lunar profile measurements. The Re content, which is of possible cosmochemical interest, was determined to be 11 ppb. Appropriate separation techniques were used. The rather weak and complex thermoluminescence properties made a more basic study advisable. Thermogravimetric analysis, mass spectroscopy, and Moessbauer spectroscopy were applied. The presence of ilmenite, metallic Fe etc., and of an unidentified* Fe^{2+}*-containing compound was deduced. Natural thermoluminescence could not be proved with certainty in our surface sample. However, the complexity of the artificial thermoluminescence demands better defined mineral fractions. The fission track method was used to measure U distribution in glass spherules etc.*

Manganese-53, favored by its high production cross section and long half-life of about 2 × 10^{6} years, is one of the most interesting nuclides in space research. However, detection of the ^{53}Mn nuclide is rather difficult because of its soft x-rays, and only sophisticated "low-level" techniques succeed. This contrasts with ^{26}Al, which can be detected nondestructively by its characteristic γ-cascade with fairly high sensitivity. (Even with our 5-g sample of lunar dust, we were able to detect the stronger γ-emitters.)

Working with meteorites, a very sensitive and therefore economic method was found in which we convert ^{53}Mn by neutron capture into γ-emitting ^{54}Mn (*1–3*), as Millard (*4*) had proposed some years ago.

In 1957 Sheline and Hooper (*5*) predicted that, in meteorites, the long-lived ^{53}Mn isotope should be produced in relatively high yield. Honda *et al.* (*6*) thereafter confirmed this experimentally. Although the half-life of ^{53}Mn is not yet fully established, a half value of (1.9 ± 0.5) × 10^{6} years was suggested by Kaye and Cressy (*7*). They compared the ^{53}Mn activity of an iron meteorite of high terrestrial age with the ^{53}Mn activity of a chondrite with short radiation age. However, the method involves a number of uncertainties, which must be allowed for. Millard showed that the product of the

^{53}Mn (n,γ) activation cross section, σ, and the ^{53}Mn half-life, T, is (350 ± 100) × 10^{6} barns × years.

From this follows an activation cross section $\sigma = 170$ barns, on the basis of an estimated ^{53}Mn half-life of $T = 2 \times 10^{6}$ years. The latter value is accepted as the first approximation and has been used in the present study.

The spallation product ^{53}Mn is converted by an (n,γ)-reaction into the ^{54}Mn nuclide, and it has been proved that the latter can be identified conveniently by its characteristic 0.84 MeV γ-line. Because stable ^{55}Mn is present in the "lunar fines" with an abundance of about 0.2 percent, we preferred to work without any Mn carrier.

"Lunar fines" (0.990 g) were fused with NaOH in a Ni crucible. In order to establish the chemical yield of Mn a practically "carrier-free" ^{52}Mn ($T \simeq 5$ days) tracer was used. Dowex 1 × 8 ion-exchange resin served for purification. For better handling 50 mg of MgO and 5 mg of ZnO (the latter used as internal standard) were added. The chemical yield was 96.0 percent, as determined by means of a short reactor irradiation and nondestructive γ,γ-coincidence spectroscopy. Our dust sample (grain size ≤ 100 μ) was found to contain 1690 ± 80 ppm normal ^{55}Mn. The sample was then reactor irradiated for 23 days, together with 10 mg of MnO$_2$, 5 mg of ZnO, and 2 Fe-standards in a thermal flux of 8.10^{12} n cm^{-2} sec^{-1} in the FRJ-2 reactor (Dido type) at Juelich. It is important to note that, in the appropriate position, the flux ratio ϕ(fast)/ϕ(therm) ≤ 0.001. Hence, neutron activation results in an activity ratio of

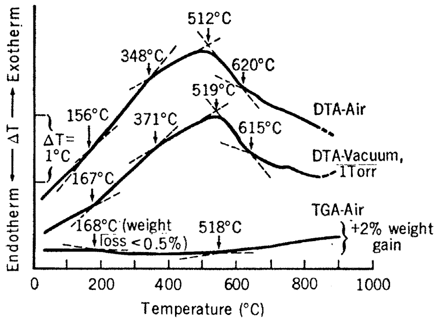

Fig. 1. Differential thermal and thermogravimetric analysis of lunar dust (sample 10084). Heating rate, 20°C/min; reference, Al$_2$O$_3$; sample weight, 5 to 7 mg.

$$\frac{^{53}\text{Mn [dpm]}}{^{54}\text{Mn [dpm]}} = \frac{1}{6000}$$

At the end of the irradiation the relative flux deviations were controlled by counting the ^{65}Zn annihilation radiation in a coincidence circuit. Absolute flux calibrations were done with a standardized ^{22}Na sample.

The recycling of probe and standards consisted in taking up in 12N HCl, oxidizing with H$_2$O$_2$, adding 47.5 mg Fe (inactive carrier) and treating with a Dowex 1 × 8 ion exchanger. The eluate was brought to dryness, taken up in 2N HCl and loaded on a cation exchanger (Dowex 50). The eluate was digested with strong H$_2$SO$_4$, 1 g of NaIO$_4$ was added, and finally the manganese distilled at 40° to 50°C under reduced pressure. The distillation was repeated.

Influence of the (n,p) and the (n,2n) interfering reactions is best demonstrated in the Table 1. While the interference of the ^{54}Fe (n,p) ^{54}Mn process can be suppressed largely by radiochemistry and is only in the range of 2 percent, the other nuclear reaction ^{55}Mn (n,2n) is more serious, contributing up to about 40 percent. Clearly the latter interference is dependent mainly on the reactor irradiation conditions, and may be reduced by choosing the highest available ratio of ϕ(therm)/ϕ(fast).

Whereas the ^{53}Mn content of most of the investigated smaller meteorite is in the range of 300 to 600 dpm/kg, the ^{53}Mn content in lunar dust is found to be only 30.3 ± 5.5 dpm/kg. However, we have to relate this figure to the amount of 13 percent iron present, the main source of spallation nuclides. So, we get a value of ^{53}Mn = 230 dpm/kg Fe of lunar surface material. This still is only about 50 percent of what is found and expected in smaller iron meteorites.

On the other hand, from studies of production rates, one knows that ^{53}Mn is mainly formed by secondary reactions and lower energy primaries and that it shows a pronounced depth effect. An increase of ^{53}Mn up to a 25 cm distance beneath the surface of a spherical iron target is known. Evidently we shall have to account for growth of ^{53}Mn activity if we take samples beneath the moon's surface. Moreover, differing from meteorites, we have to consider a 2π instead of 4π "falling in" of cosmic rays.

Still another point of interest is the relatively long half-life of ^{53}Mn, compared to ^{36}Cl and ^{26}Al. From the high ^{26}Al values (up to 100 dpm/kg) one is inclined to assume that this nuclide is in radioactive equilibrium. If the accretion and mixing rate of lunar dust is found to be high, we should have some doubt that radioactive equilibrium is fully established in the same way for the longer lived ^{53}Mn. Further studies on selected mineral probes—for example, samples of bore-holes, should bring the necessary information about spallation profiles. Since the activation method described is so sensitive, manganese-53 at even greater depths (up

Table 1. Determination of spallogenic ^{53}Mn in lunar dust.

		Lunar dust fr. V (0.9901 g)	Mn standard	Fe standard
	Weight	1.62 mg Mn	8.03 mg Mn	8.25 mg Fe
Chem. yield	Pre-irrad.	95.9%	—	—
	Recycl.	89.3%	69.0%	65.2%
Carrier after irrad.		47.5 mg Fe	—	10 mg Mn
^{I}spez$_{54}$ [cpm/mg Mn]	(n, γ)	7.64	—	—
	(n, 2n)	3.14	3.14*	0
	(n, p)	0.16†	0	(8.92* per mg Fe)
A$_0$spez$_{54}$ [dpm/mg Mn] at end of irrad.	(n, γ)	110.87	—	—
A$_{53}$	[dpm/kg]	30.3 ± 5.5	—	—

* Neutron flux normalized. † Originating from Fe-traces in isolated lunar Mn.

Table 2. Iron-containing compounds of lunar dust.

Source	Fraction of total iron (%)		
	Normal	Magnetic fraction	Nonmagnetic fraction
Olivinic Fe	19.3	18.8	20.1
Pyroxenic Fe	34.0	31.7	43.2
Fe^{2+} in ilmenite	26.0	18.6	24.9
Fe^{3+} in ilmenite	<3.5	<4.6	<3.0
Unknown compound	10.2	16.8	8.9
Metallic Fe	>7.0	>9.3	—

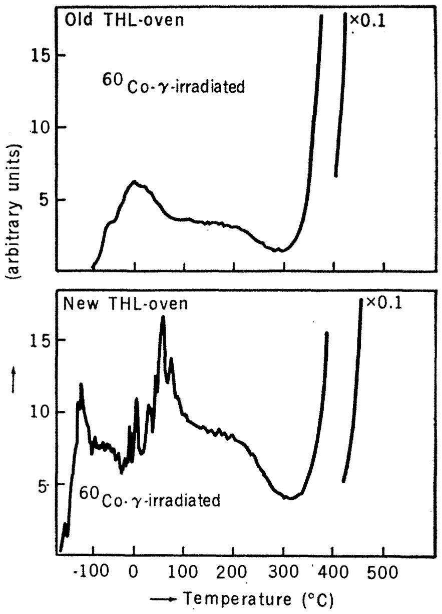

Fig. 2. Thermoluminescence glow curves of lunar dust (sample 10084); (upper curve) 40-mg sample; irradiated for 15 minutes; heating rate, 100°C/min; (lower curve) 47-mg sample; irradiated for 15 minutes; heating rate, 100°C/min.

several meters) should be measurable.

During the last decade the natural β^- activity of ^{187}Re was used by us successfully for geological age determinations (*8*). We showed that the ^{187}Os abundance varies considerably in the Re-containing minerals and in iron meteorites. It was pointed out, and D.D. Clayton showed this later in a detailed study, that the larger part of the terrestrial (stable) ^{187}Os should be regarded as having resulted from ^{187}Re decay and that most of that decay occurred before the formation of the solar system. These ideas are based on the now accepted s-process theory.

The β^- energy of ^{187}Re is extremely weak (~2 keV) and a problem arises about the mode of this decay. Quite recently Clayton (*9*) outlined the possibility that the radioactivity of ^{187}Re could be dependent on temperature and isotopic measurements of Re from lunar dust ("solar wind") could clarify the interesting problem of ^{187}Re cosmochronology. In view of these cosmological questions, we found it necessary to establish the presence of Re in lunar dust. As the abundance in Fe-meteorites is normally below 1 ppm, only neutron activation with chemistry could succeed. "Fines" (176 mg) were irradiated together with Re standards for 3 days, $\phi = 7 \times 10^{13}$ in the FRJ-2 reactor. Thereafter the mineral was fused by melting with NaOH + Na_2O_2 in the presence of 30 mg of Re-carrier. Several $Fe(OH)_3$ precipitations were followed by repeated dry distillation of Re_2O_7. The decay of ^{186}Re is observed. The Re content of soil (sample 10084, grains <100 μ) is calculated to be 11.2 ± 0.4 ppb if one assumes a normal terrestrial isotope abundance.

In the next step it is important to check the isotope ratio $^{187}Re/^{185}Re$.

The thermodifferential analysis (TDA) and thermogravimetric analysis (TGA) curves (Fig. 1) show distinct temperature regions where gas-loss and recrystallization or annealing occurs. A critical temperature is seen at about 510°C. Oxidation at 800°C leads to a gain in weight of about 2 percent (see the lower TGA curve).

By mass spectroscopy, ratios of $^{3}He/^{4}He = 724 \pm 118$, $^{20}Ne/^{22}Ne = 2.34 \pm 0.04$, and $^{22}Ne/^{21}Ne = 22.6 \pm 6$ were measured in dust. Only the $^{20}Ne/^{22}Ne$ ratio is found to be very constant.

Nuclear γ-resonance spectroscopy (with ^{57}Fe) was done on magnetic and nonmagnetic fractions of lunar fines. No trace of Fe^{3+} was detected. Troilite was practically not observed in the soil but metallic Fe, ilmenite, pyroxene, and olivine were present. The spectra were compared with those of tektites and the existence of an unknown Fe^{2+}-containing compound in the lunar soil is proposed (see Table 2).

For the thermoluminescence study different soil fractions were used. However, after 8 weeks of "storing" time we did not detect any natural THL with certainty. Probably the skin layer of dust is already strongly annealed on the moon. Highest glow intensities occur in the temperature range of 100° to 150°C, if irradiated at 30°C. At −196°C γ-irradiation the intensity is considerably greater. A ^{60}Co-γ-saturation experiment shows that saturation for the soil is reached at a dose of about 10^6 rads (see Fig. 2).

These preliminary results demand better defined and selected material probes.

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Specific Heats of Lunar Surface Materials from 90 to 350 Degrees Kelvin

Abstract. *The specific heats of lunar samples 10057 and 10084 returned by the Apollo 11 mission have been measured between 90 and 350 degrees Kelvin by use of an adiabatic calorimeter. The samples are representative of type A vesicular basalt-like rocks and of finely divided lunar soil. The specific heat of these materials changes smoothly from about 0.06 calorie per gram per degree at 90 degrees Kelvin to about 0.2 calorie per gram per degree at 350 degrees Kelvin. The thermal parameter* $\gamma = (k\rho C)^{-1/2}$ *for the lunar surface will accordingly vary by a factor of about 2 between lunar noon and midnight.*

The surface temperature of the moon varies from approximately 90° to 385°K between lunar noon and midnight (*1, 2*).

Cooling of the lunar surface depends on the so-called thermal parameter, $\gamma = (k\rho C)^{-1/2}$, where k is the thermal conductivity, ρ is the density, and *C* is the specific heat. Most calculations of lunar surface temperature that use earth-based eclipse data (*1, 3*) have assumed a constant value of γ. However, specific heats of silicates vary by a factor of 3 or 4 in the temperature range 100° to 400°K. Accordingly, γ should show a nearly twofold variation over the range of lunar surface temperatures.

In order to verify the temperature dependence of γ, we have determined the specific heats at approximately 8°K intervals between 90° and 350°K for the samples 10057 and 10084 from Apollo 11.

The low-temperature adiabatic cal-