

matters arising

Viking Mars labelled release results

THE labelled release (LR) Mars experiment^{1,2} yielded a positive response from Mars soil when a radioactive organic solution was added and a negative response when the soil was heated to sterilisation temperature. After storage of the soil at 10 °C for two to three months in the spacecraft, there was almost no response on addition of radioactive nutrient³.

Nussinov *et al.*⁴ proposed that LR Mars life-detection response arose from water-induced outgassing of CO₂ from Mars surface fines. They state that the kinetics of outgassing in LR and GEX are similar and that the characteristic time of the yield of O₂ in GEX and CO₂ in LR are also similar.

We are surprised that they ignored the fact that the CO₂ released by the LR is radioactive and, therefore, must have arisen from the radioactive nutrient added to the soil sample. Further, we do not agree that the reaction kinetics in GEX and LR are similar. GEX outgassed all of the measured O₂ in ~2 h whereas the half-time for the LR production of radioactive CO₂ was ~8 h, after which production tapered off, but continued slowly, for the duration of the particular experiment (up to 90 Sol).

Although we are not yet certain whether the LR response was biological or chemical, we are sure that it cannot be explained by the outgassing of CO₂ trapped in Mars surface fines.

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3. Levin, G. V. & Straat, P. A. *20th COSPAR Meet.*, Tel Aviv (1977), *21st COSPAR Meet.*, Innsbruck (1978).
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NUSSINOV *ET AL.* REPLY—We should like to correct here a false impression that our paper¹ contained a conclusion about registration in the LR experiment of 'CO₂ trapped in Mars surface fines'. We assumed that due to the radioactivity of the ¹⁴CO₂, such a conclusion could never be drawn either by us or by readers. No conclusion as such can be made about the origination mechanism of the registered gases on the basis of the GEX and LR kinetics. It is only natural to think that

¹⁴CO₂ resulted from interaction between nutrient and O₂, the latter developing from the soil's reaction with water. The time trend of the count curve is typically filtrational which means that the formation of O₂ was rapid as compared with its transport. From a classical physical viewpoint, their kinetics implies quantitative similarity only of GEX and LR curve shapes, itself implying identity of the power dependence ($\sim t^{1/4}$ at small t) and exponential saturation ($t \rightarrow \infty$). Qualitative differences are easily explained by the fact that the very designs of GEX and LR were incorrect from the physical standpoint, namely: (1) shapes (and masses) of the GEX and LR samples were not identical; (2) specific quantity of nutrient differed in the experiments; (3) the most informative initial segments of the kinetic curves were not registered. These are the reasons that it was impossible to expect a better than order of magnitude agreement. Therefore the similarity of the GEX and LR kinetics should undoubtedly be considered as fact.

Note that the data by Levin and Straat on 'almost no response upon addition of radioactive nutrient' after storage of the soil at 10 °C for two to three months, are readily explained by our model. Indeed, O₂ physically adsorbed within the micropores at elevated temperatures can be converted to a chemisorbed state, thereby losing its reactivity. At low Martian temperatures the chemisorption of O₂ is inhibited¹.

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Mechanisms of sputtering

THE letter by Pollitt *et al.*¹ on sputtering makes an interesting suggestion but also several incorrect assertions about the adequacy of existing theories and ignores other publications.

In currently accepted theories of the sputtering of metals the incident ion generates collision cascades amongst the target atoms^{2,3}. If these intersect the surface, atoms receiving more than a binding energy E_b , related to the heat of sublimation, may be ejected and appear with a

characteristic energy distribution having a peak at $E_b/2$ and falling off as E^{-2} at high energies of ejection E . Integration of the distribution leads to the total sputtering yield which is inversely proportional to E_b and directly proportional to the energy deposited by the incident ion in generating atomic recoils near the surface. In a crystal the lattice imposes a structure on the spread of momentum in the cascade, focuses momentum into close packed directions and leads to anisotropic emission.

The cascade lasts for a very short time, of the order 10^{-13} s. Afterwards it leaves a local heating effect in a region known as the thermal spike which may persist for up to 10^{-11} s. In cases where the density of energy is high enough and the binding energy is low enough one expects sputtering by evaporation into a characteristic energy distribution, something like a maxwellian with a peak at a few tenths of an eV^{4,5}. The spike temperature and hence the sputtering yield depends on the ambient temperature of the solid⁶.

These two basic mechanisms are complementary to one another, not alternatives as Pollitt *et al.* seem to suggest. The cascade component usually dominates unless the solid is at a temperature approaching its melting point, the heat of sublimation is low or the bombarding ion is of such a mass and energy as to produce cascades of high energy density. The main observations are in accord with these predictions contrary to the assertions of Pollitt *et al.*¹. The energy spectrum of sputtered atoms closely follows E^{-2} at high energies over many decades, generally has a peak at half the sublimation energy^{2,7-11} and develops a low-energy peak near 0.1 eV when thermal spike conditions are fulfilled^{2,12,13}. The total yield for various elemental targets with a fixed ion and energy is inversely proportional to sublimation energy. (The dependence on ion species for fixed target is a much more complex problem involving ion implantation phenomena)¹⁴. From single crystal targets anisotropic emission is observed¹⁵⁻¹⁷ with angular widths¹⁸⁻²⁰ and energy distributions^{2,21} consistent with momentum focusing effects. The measurements of yield over several decades of ion energy, when thermal spike conditions are not fulfilled, accurately follow cascade theory³. They definitely do not correlate with the energy deposited in electron excitation, which they should if the model proposed by Pollitt *et al.*¹ were operating.

In insulators, and particularly alkali