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SUMMARY

In the foreseeable future, NASA space milestones include a permanent manned presence on the Moon and an expedition to the planet Mars. Such steps will require careful consideration of environmental interactions in the selection and design of required power systems. Several environmental constituents may be hazardous to performance integrity. Potential threats common to both the Moon and Mars are low ambient temperatures, wide daily temperature swings, solar flux, and large quantities of dust. The surface of Mars provides the additional challenges of dust storms, winds, and a carbon dioxide atmosphere. In this review, the anticipated environmental interactions with surface power system radiators are described, as well as the impacts of these interactions on radiator durability, which have been identified at NASA Lewis Research Center.

INTRODUCTION

The exploration of our solar system represents one of the major technological challenges facing the nation. Twenty years after Apollo 11 successfully placed the United States of America on the Moon, President George Bush challenged the country with " . . . back to the Moon, back to the future. And this time, back to stay. And . . . a journey into tomorrow . . . a manned mission to Mars." To accomplish these goals, NASA is developing the technology for the permanent presence of humans on the Moon, and a manned expedition to the surface of Mars. Lewis Research Center has been given the lead role in providing the technology for lunar and Martian surface power systems.

Careful consideration must be given to the environment in which these power systems must perform because several environmental constituents may be hazardous to performance integrity. Environmental factors which are a common threat to both the Moon and Mars, include low average temperatures, wide temperature swings, solar fluxes of electromagnetic and particle radiation, and large amounts of dust. In addition, the Martian environment has the winds, dust storms, and a carbon dioxide atmosphere. In this paper, the expected environmental interactions with surface power system radiators are reviewed, and the consequences to durability which have been studied at Lewis are described.

SURFACE POWER REQUIREMENTS

The development of the power systems needed for a permanent presence of humans on the Moon and a manned exploration of the Martian surface represents a significant challenge. Highly reliable, lowmaintenance power systems are required for space exploration. The anticipated electrical power and energy requirements for lunar or Martian surface activities range anywhere from 20 kW to 1 mW (ref. 1), and depending on the power needs, the recommended technologies are photovoltaic or nuclear power as shown in table I.

The report of the Synthesis Group on America's Space Exploration Initiative recommends the adoption of a nuclear power system to meet the power requirements for a lunar or Martian base. NASA's SP-100 Program is developing the technology to provide 10 to 100 kW using uranium nitride fuel in a liquid metal-cooled reactor, incorporating thermoelectric converters for the regime below 100 kW, or Rankine or Brayton dynamic cycles for higher power regimes (ref. 1). A necessary component for any nuclear power system is radiators to maintain the cold-end temperatures for the electrical power generator.

There are several candidate materials for power system radiators. The radiators must have high thermal conductivity so heat is distributed evenly throughout the radiator, and high emittance to enable heat to be radiated away efficiently. Another critical factor in radiator design is durability in harsh working environments.

EFFECTS OF LUNAR AND MARTIAN ENVIRONMENTAL FACTORS

Being completely unprotected by an atmosphere, the lunar surface receives an average solar irradiance of about 1370 ± 30 W/m^2. The equatorial surface temperature cycles from about 100 to 400 K with local variations due to shadowing of surface features.

The solar irradiance reaching Mars is 60 percent less than what reaches the Moon. The Martian surface receives only about 360 ± 50 W/m^2. Like Earth, Mars has a moderating atmosphere (about 1 percent the density of Earth's) and a relatively short day (24 hr 37 min). The Martian surface temperatures range from 300 K during the equatorial day to below 150 K during the polar night.

The large temperature excursions in the lunar and Martian environments may cause several problems for surface power systems. The coefficient of thermal expansion (CTE) mismatch between radiators and protective or thermal control coatings may cause cracking and spalling. Welds and joints throughout the spacecraft may also suffer from thermal stresses potentially leading to cracking or structural weakening.

Another factor to be considered in the design of radiators for the lunar and Martian surfaces is the effective sink temperature. On the Moon this value varies from 221 to 325 K, depending on orientation and properties of the surface radiators (ref. 2). A radiator in any orientation will have a view of the surrounding lunar surface. Because the soil is highly absorbing, daytime sink temperatures will be higher than at night. Radiator efficiency, and therefore power system performance, will vary throughout a day-night cycle. According to preliminary calculations for the effective sink temperatures at Mars, the values range from 175 to 250 K. The effect of these Martian sink temperatures on the efficiency of the radiators are not expected to be as critical as on the Moon.

In addition to causing large temperature variations, the solar flux incident on the lunar and Martian surfaces is also a source of short wavelength or hard ultraviolet light (UV). As a result, some protective coatings will degrade, and perhaps darken, limiting their useful lifetime (ref. 3). The problem may well be compounded by simultaneous thermal cycling. The UV flux on the Martian surface is thought to be a factor in the formation of the chemically reactive species in the soil as detected by the

Viking I label release experiment. Because of their great reactivity, they are thought to be peroxides or superoxides, a potential threat to a variety of power system components. The high operating temperatures of radiators and buried reactor cores also may enhance reactions with the soil on Mars as well as the Moon.

Aside from possible chemical reaction, dust particles pose other serious implications for radiators. On the Moon, significant dust transport will occur as a result of human activity on a lunar base. Walking, roving vehicles, mining and construction, and most importantly, launch and landing events will disturb lunar dust particles. These particles can land great distances from the source, accumulating indiscriminantly and creating optical and thermal problems for base components. The retrieved components of the Surveyor III such as the television camera mirror, shown in figure 1, provided a unique opportunity to observe the accumulation of dust resulting from the landing of the Apollo 12 lunar module. Thus, aiding in the prediction of an accumulation profile with distance and number of landing/launch events for future lunar excursion vehicles (ref. 4).

The predicted levels of dust accumulation may have significant ramifications in the performance integrity of radiator surfaces, as indicated by preliminary heat transfer calculations. Even if, it is assumed that the radiator-dust interface provides no thermal resistance (best-case scenario) the heat rejection efficiency of the radiator degrades exponentially with increasing dust thickness (ref. 4) (fig. 2). This is attributed to the very low thermal conductivity of the lunar material, which causes substantial thermal resistance through an accumulated dust layer, despite the soil's high emittance.

Similar dust problems may also be encountered on the Martian surface. Changes in the distribution of dust have been observed in the Viking lander photographs. One of the most striking evidences of dust accumulation is the mantle of dust found on a large rock near the Viking Lander 2 named "Big Joe," shown in figure 3. Since dust is transported by the wind, even without human activity, radiators at Mars may suffer similar degradation to radiators on the Moon.

In order to test the effects of Martian dust transport on radiator surfaces, a series of simulations in the Martian Surface Wind Tunnel (MARSWIT) at NASA Ames Research Center have been carried out. The ability of dust to be removed from surfaces was found to be a strong function of angle, with the highest removal rate near 45°, and the lowest for a horizontal plate (ref. 5). These tests indicated that once dust settles on the radiators wind velocities greater than 30 m/s would be required to remove it even at the optimum 45° (ref. 6). Dust removal was found not to be strongly dependent upon dust composition (ref. 7), but was strongly dependent upon particle size (ref. 8).

Furthermore, when dust was carried in the simulated Martian wind, surfaces erosion was particularly significant when the velocity exceeded 90 m/s (ref. 9). Although the abrasion rate is highest with wind-blown dust, MARSWIT tests show that significant damage occurs even when clear air blows across the dust-covered surfaces (fig. 4). It has been shown experimentally that abrasion dramatically decreases radiator emittance, figure 5. Although Martian winds rarely reach 90 m/s, exhaust gases from launch and landing events on the Martian surface will undoubtedly entrain particles at much higher velocities. Such abrasion will also be a serious issue on a lunar base.

The Martian atmosphere is essentially carbon dioxide (95 percent), which will attack carbon at the elevated temperatures (ref. 10). This is potentially serious in light of the important role of carbon in the high emittance surfaces of both carbon-carbon composite and arc-textured radiators. Preliminary calculations, indicate that the rate of attack will be low, but this must be experimentally confirmed.

LUNAR AND MARTIAN ENVIRONMENTAL FACILITIES

In order to anticipate and solve potential problems for surface power systems, evaluation of the materials and components in simulated lunar and Martian environments is being undertaken.

A MARSWIT facility at NASA Ames Research Center has been a valuable resource in the evaluation of the effects of wind-blown dust under Martian conditions. Using these experiments as an underpinning, computer modeling is now underway to expand our knowledge of these aeolian effects.

The Martian Atmospheric Chemistry Simulator (MACS) at NASA Lewis Research Center simulates Martian atmospheric conditions and has the capability for testing power components up to temperatures of 800 °C, figure 6. In the next few years the facility will be modified for Martian temperatures, UV light exposure, thermal cycling capabilities, and accelerated testing of components.

The Lunar Environmental Simulator (LES) (fig. 7), also located at NASA Lewis, is being constructed to test the interactions of lunar dust with power system components in vacuum, including the effects of adhesion and electrostatics, in order to recommend dust abatement strategies.

Dust-covered radiator performance will be evaluated by low and high temperature calorimetric vacuum emissometry. These studies will help to elucidate the nature of heat transfer through the radiator-dust interface, and will determine the effective emittance of dust-covered radiators.

CONCLUSIONS

Numerous factors have been identified within the lunar and Martian environments which may pose serious threats to the performance of surface power system radiators. These include thermal cycling, solar radiation, pervasive surface dust, and reactive Martian atmosphere. The potentially serious impacts of such factors are critical considerations for successful radiator design. Continued efforts at NASA Lewis Research Center will incorporate lunar and Martian simulation facilities to further elucidate the nature and implications of these environmental interactions.

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TABLE I.-SURFACE POWER AND ENERGY REQUIREMENTS (REF. 1)

Surface activities	Mars power	Moon power	Suggested technology
Day only	20 kW		Photovoltaics
Habitat/lab			
Initial operational capability	to 30 kW	to 50 kW	Photovoltaics or nuclear
Next operational capability	50 kW	100 kW	Nuclear
Base power			
Initial operational capability	to 100 kW	to 100 kW	Nuclear
Next operational capability	to 800 kW	to 1 mW	Nuclear
Rovers			
Unloader/construction	240 kW-hr	240 kW-hr	Fuel cells

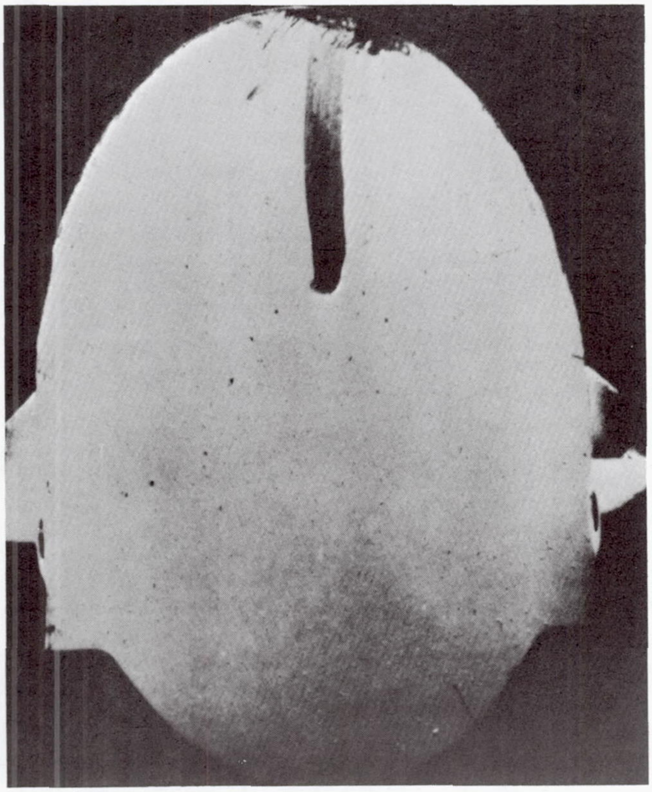

Figure 1.—This lunar dust coating on the Surveyor III's television camera mirror resulted from the landing of the Apollo 12 lunar module 155 m away.

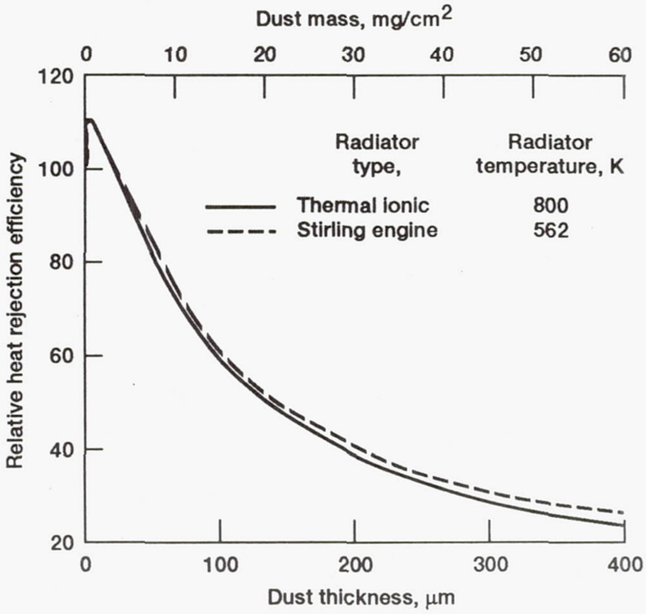

Figure 2.—Relative heat rejection efficiency of dust-covered radiators on the moon. For this model it has been assumed that the radiator and soil are in ideal thermal contact.

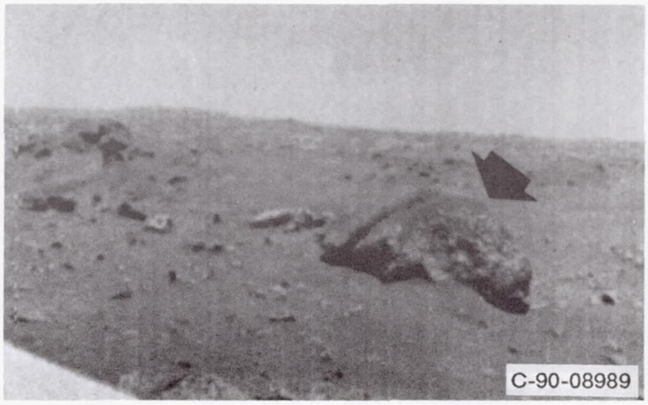

Figure 3.—Dust accumulated on a large rock "Big Joe" near Viking Lander 2.

Figure 4.—The carbon layer has been abraded off of the upper left part of this arc-textured Nb-1%Zr radiator surface on exposure to 97 m/s dust-laden wind.

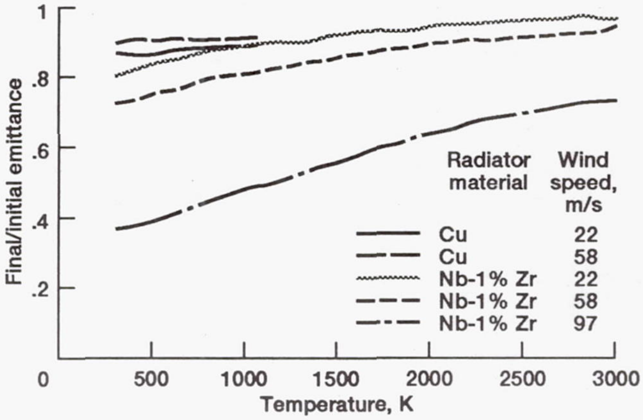

Figure 5.—Degradation of initially clear radiator samples subjected to dust laden wind.

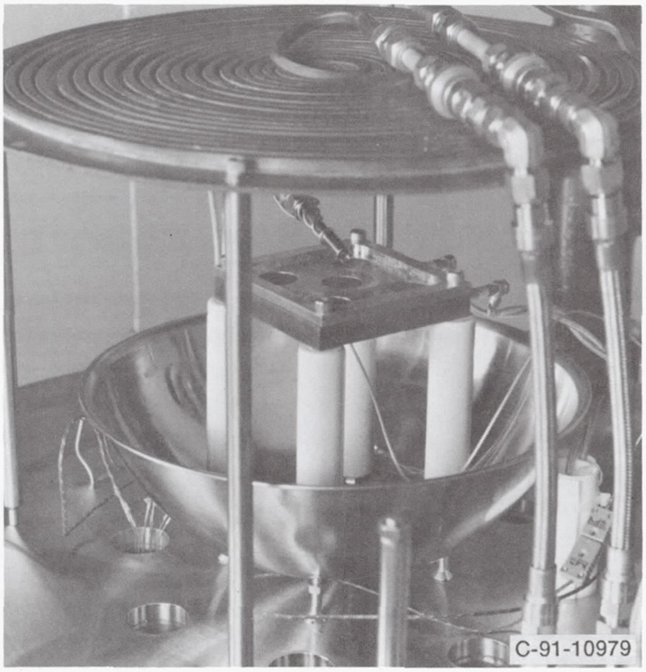

Figure 6.—Martian Atmospheric Chemistry Simulation (MACS) facility.

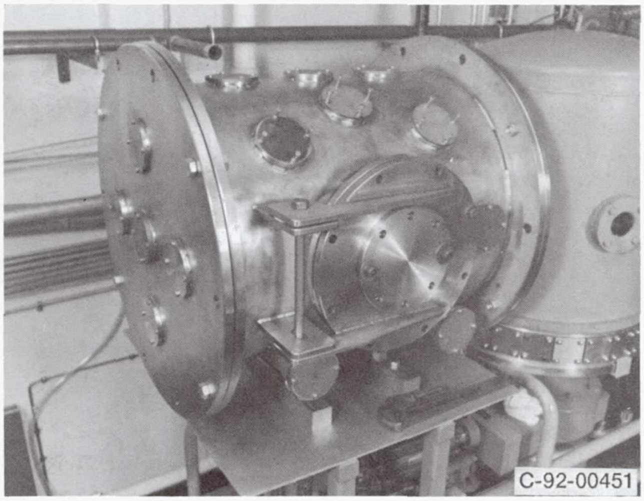

Figure 7.—Lunar Environmental Simulation (LES) facility.

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