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CONDENSATION ON SPACECRAFT SURFACES DOWNSTREAM OF A KAUFMAN THRUSTER

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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This report presents preliminary results of an experiment begun in October 1969 to evaluate the effects of thruster exhaust products on surfaces located downstream of a mercury electron-bombardment ion thruster (Kaufman thruster). Previous reports have treated the condensation problem analytically (refs. 1 and 2). At that time, neutral mercury flow resulting from thruster propellant inefficiency was felt to be the most probable contaminant material to be concerned with. Results of the present experiment show that more severe contamination problems may result from grid sputtering under certain conditions. Grid sputtered material, though it may be considerably smaller in magnitude than the neutral mercury flow, will readily adsorb and not re-evaporate at the normally expected spacecraft temperatures. The problem is of general interest to the electric propulsion spacecraft designer, and of particular interest in connection with a solar cell contamination experiment to be conducted on the SERT II flight test of a Kaufman thruster (ref. 3).

The experimental arrangement reported herein is shown in figure 1. The vacuum facility is 7.6 m in diameter. The thruster used in the tests is 1.5 m diameter and uses 10 oxide cathodes (ref. 4). The solar panels used are shown in figure 2 and are similar to those to be used on the SERT II flight spacecraft shown in figure 3.

A comparison of the SERT II and present experiment critical dimensions and thruster parameters is given below.

	Present experiment	SERT II
Thruster radius, R, m	0.75	0.075
Beam current density, A/m^2	5.7	14.1
Neutral mercury efflux rate, $atoms/cm^2$ sec	3.6×10^{15}	1.8×10^{15}
Distance from thruster exit to experimental solar cells, L, m	4.21	0.317
L/R ratio	5.63	4.23
Angle from thruster center-line to solar cell experiment, deg.	57	61
View factor; ratio of flux arriving at solar cell to flux leaving thruster exit, $\mu/\nu = F$	0.019	0.025

In the experiment, the flood lamp used to illuminate the solar cells was mounted so that the experimental cells and a calibration cell could be illuminated alternately. The calibration cell was mounted on a rotatable shield inside the tank. The calibration cell thus could be located in front of the experimental cells to set the lamp power, rotated out of the way to check the experimental cell output, then the shield retracted into the window well to protect both the quartz window and the calibration cell from contamination between readings.

The calibration cell accounted for any accumulation of sputtered coating on the quartz viewing port. Short circuit cell current, cell surface temperature and surface resistance were monitored throughout the experiment. Surface resistance was also measured after the runs, with the solar cells removed from the tank. Cumulative running times for the tests were 15 to 30 hours each.

Previous reports (refs. 1 and 2) indicate that at the location chosen for the cells, they should be well out of the way of the primary ion beam. However, they are subject to the arrival of stray primary ions, charge exchange ions, neutral mercury atoms (present due to thruster inefficiencies), and sputtered accelerator grid material that arises because of charge exchange ion erosion of the grid (ref. 5).

The calculated neutral mercury arrival rate at the cells is sufficiently low so that at the operating cell temperatures of from $0^{\circ}C$ to $25^{\circ}C$ during the experiments, no neutral mercury condensation was expected. In the experiments, however, cell output degraded by 50 percent in about 12 hours. Surface resistance measurements made during and after the tests also confirmed that some material was arriving at the cell surfaces and sticking. The coating was readily removed and the cells restored to their original output by simply wiping them with a cloth dipped in dilute nitric acid. Spectrographic analysis qualitatively identified the following metallic constituents in the coating: Fe, Cr, Ni, Si, Mo, Cu, Sn, Pb, and trace Ti, Zn. All these materials are identifiable with thruster components. In particular it is noted that the accelerator grid is made of stainless steel.

The cell coating thickness, as estimated from comparing with surface resistivity changes for particular elements (e.g., ref. 6) indicates a coating thickness of possibly 10 to 30 monolayers, corresponding to a deposition rate of about 1 to $2\frac{1}{2}$ monolayers per hour. Similarly, a comparison of the attenuation of light transmission through thin metallic films (ref. 7) with the results of these solar cell degradation rate measurements indicates a film deposition rate of about $1\frac{1}{2}$ monolayers per hour.

As a check, calculations of sputtered grid material arrival rate at the experimental locations were made, assuming a grid erosion rate of 1 atom per incident charge exchange ion. In reference 8, a charge exchange ion current of 0.00327 times the primary ion current was calculated for charge exchange ions which would be expected to reach the accelerator grid (called Group 3 ions in ref. 8). The arrival rate at the experimental cell of sputtered grid material was calculated herein from the relation,

$$\mu = F\,\nu = F\,\frac{I\ f\ (3600\ \text{sec/hr})}{q\ A_o\ \sigma}$$

where

μ	arrival rate, monolayers per hour
ν	emission rate, " " "
I	current, A
A_o	thruster cross-section area, cm^2
σ	monolayer concentration, (1 monolayer $\cong 1.6\text{x}10^{15}$ atoms/cm^2)
q	$1.6\text{x}10^{-19}$ coulombs per unit charge
F	view factor for cosine distribution from thruster exit to solar cell location, function of L/R (see table in text)
f	fraction of primary ion current converted to charge exchange current

For the SERT II design values of $A_o = 177\ cm^2$, $I = 0.25\ A$, $f = 0.00327$ and $F = 0.025$, the calculated arrival rate, μ, of sputtered grid material is about 1.5 monolayers per hour.

In an independent check, a calculation was made based on measured grid erosion from a 1000 hour test of a SERT II type thruster. The volume of material sputtered was about $8 \times 10^{-5}\ cm^3$ from a unit of area of about $0.0877\ cm^2$. These numbers yield an equivalent sputtering rate of about 36 monolayers per hour. Applying the view factor of 0.025 gives an expected arrival rate of sputtered grid material at the experimental solar panels of the SERT II contamination experiment of about 0.9 monolayers per hour.

The foregoing experimental results and calculations strongly indicate that sputtered material from the accelerator grid is arriving at and sticking on the cell coverplate.

As compared with the SERT II thruster, the 1.5 m thruster operated at lower propellant utilization efficiency and lower beam current density. These differences were compensating in terms of relations for charge exchange ion production rates as given in reference 8. The net effect of the different operating conditions was to yield an estimated arrival rate of sputtered grid material to the test cells in this experiment of about 1.0 monolayers per hour compared with the values of from 0.9 to 1.5 calculated for the SERT II experiment.

Thus, it is clear that sputtered grid material arriving at downstream surfaces may present a potential spacecraft design problem independent of the effects of mercury. In terms of the effect on solar cells, figure 4 shows the typical intensity variation and surface resistance variation with time found in the present experiment. Condensed mercury propellant is not anticipated to pose a problem in the forthcoming SERT II solar cell contamination experiment. It will be interesting though to compare the flight experiment results with the intensity variation curve of figure 4.

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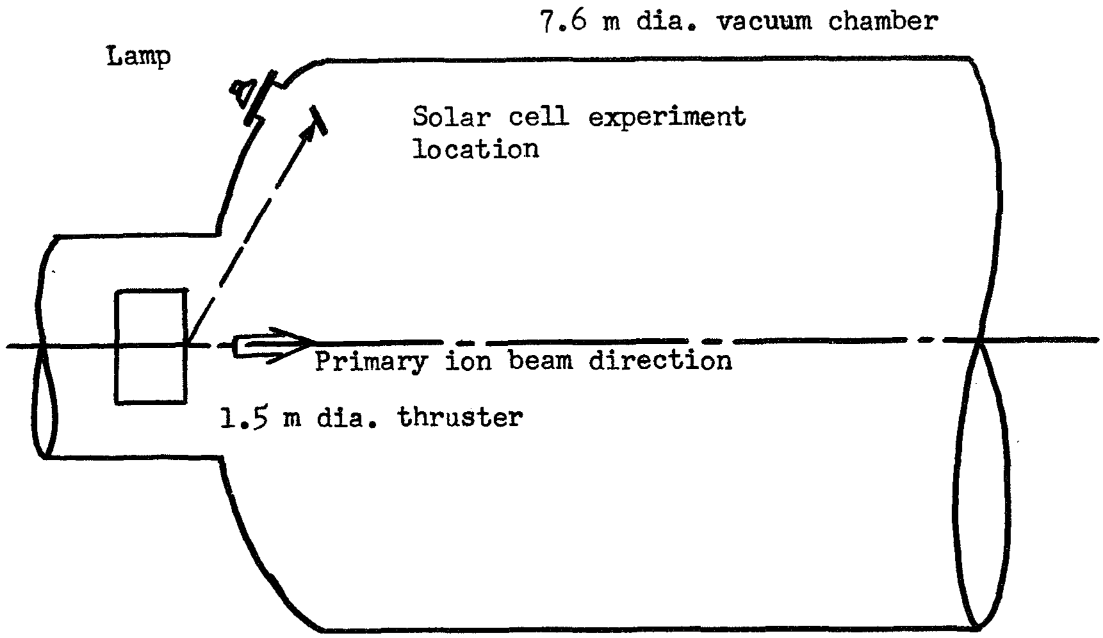

Fig. 1.- Schematic of solar cell experiment arrangement in large vacuum chamber.

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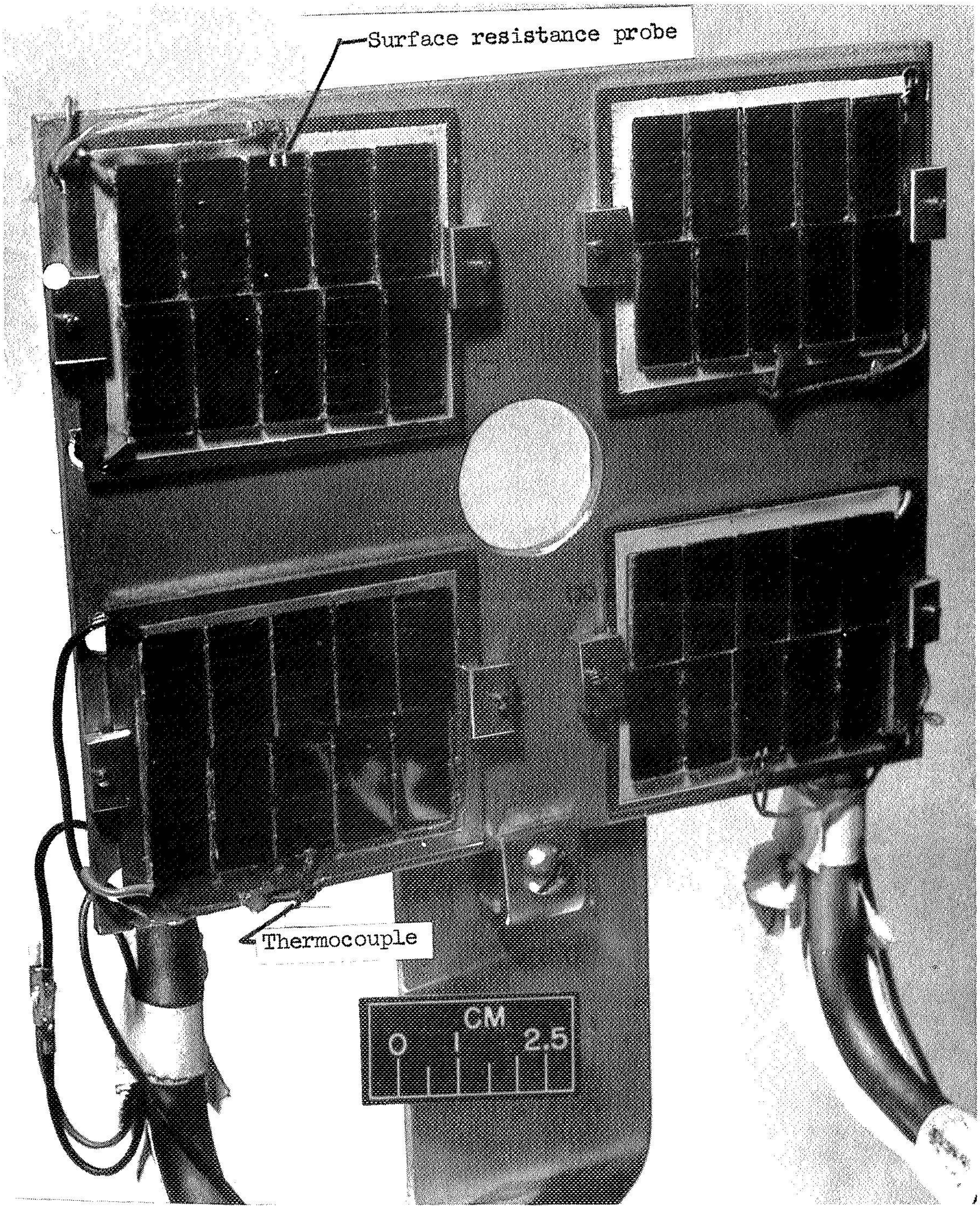

Fig. 2.- Experimental solar panels.

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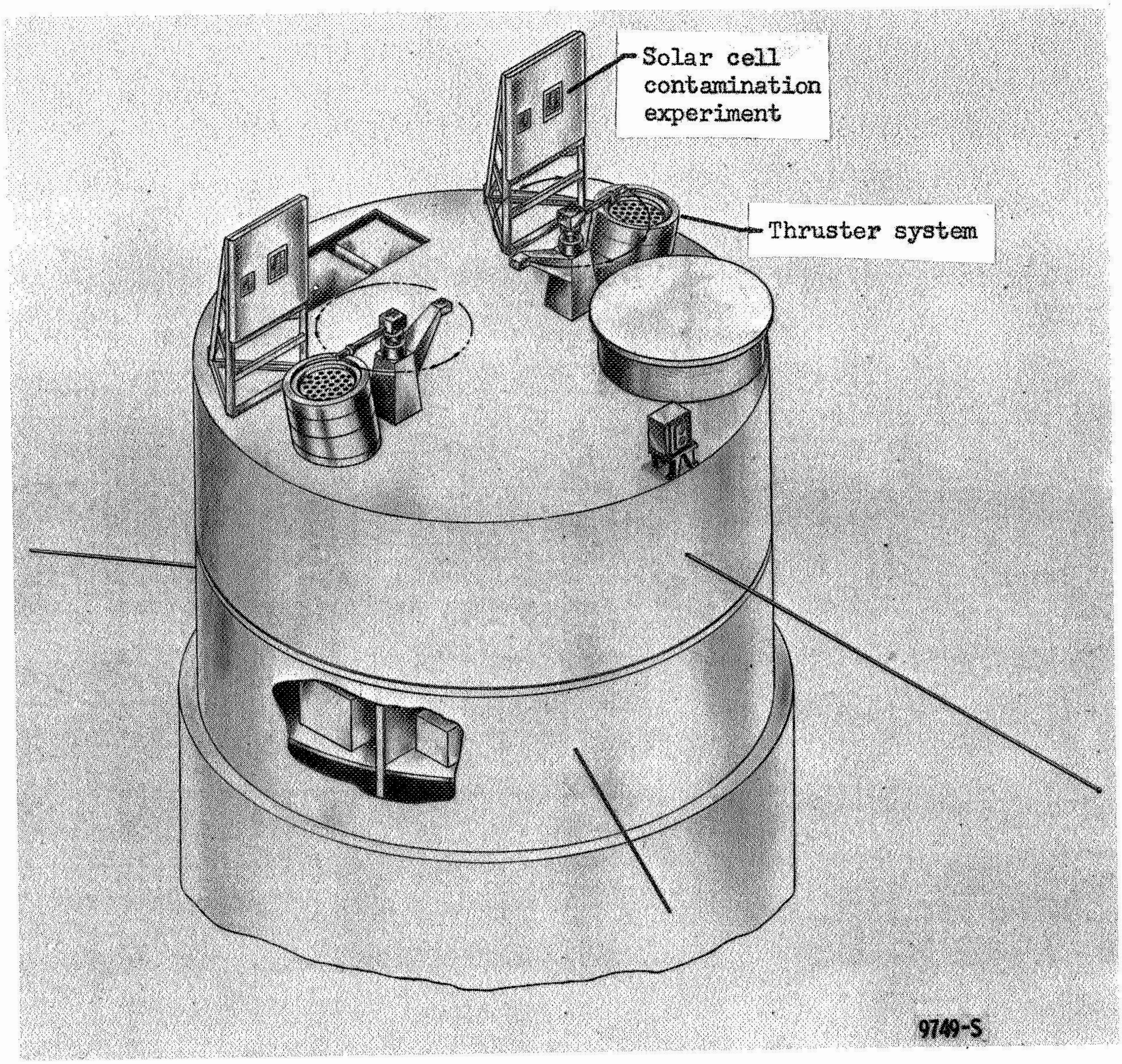

Fig. 3.- SERT II spacecraft and support unit.

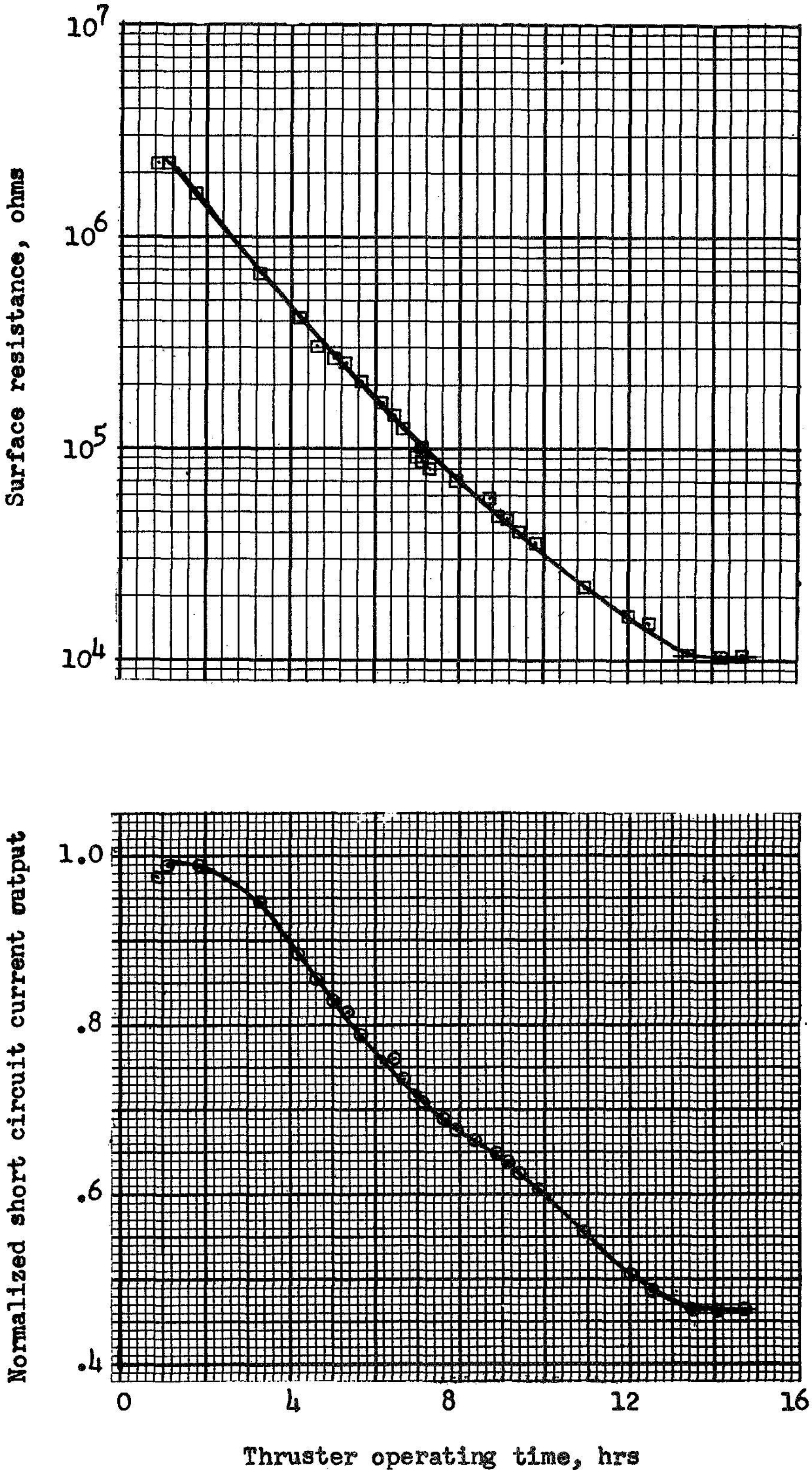

Fig. 4.- Variation in solar cell output and surface resistance with thruster operating time.