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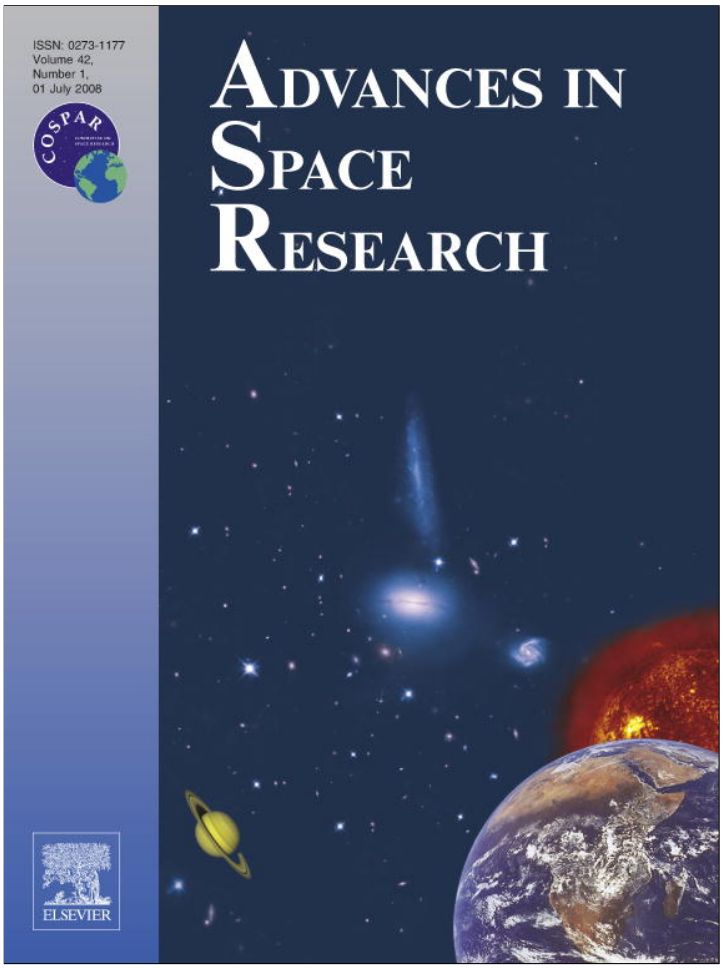

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A sample collector for robotic sample return missions II: Radiation tests

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Abstract

Sample return from small solar system objects is playing an increasingly important part in solar system exploration. Critical to such missions is a robust, simple, and economic sample collector. We have developed a collector such as this for near-Earth asteroid sample return missions that we have termed the Touch-and-Go Impregnable Pad (TGIP). The collector utilizes a silicone substrate that is pushed into the dust and gravel surface layer of the asteroid. As part of a systematic evaluation of the TGIP, we have investigated the resilience of this substrate to ionizing radiations. Several miniature versions of the collector, containing typically ~3 g of the collection substrate, were exposed to 0.564 MeV beta particles from a ^{90}Sr source and a 6 MeV electron beam in a linear accelerator to simulate the wide range of energies of solar and galactic ionizing radiation. Various radiation levels up to eight times greater than expected on a six-year asteroid mission (in the case of beta radiation) and 50 times greater than expected (in the case of the 6 MeV electron radiation) were administered to the substrate. After irradiation, the efficiency of the substrate in collecting samples of mock regolith was compared with that of collectors that had not been irradiated. No difference beyond experimental uncertainty was observed and we suggest that the operational TGIP will not be affected adversely by radiation doses expected during a typical six-year inner solar system mission.
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Keywords: Radiation; Sample collection; Hera near-Earth asteroid sample return mission; Near-Earth asteroids; TGIP; Polydimethylsiloxane

1. Introduction

The Hera mission was a Discovery class mission that aimed to collect regolith samples from a near-Earth asteroid (Sears et al., 2004a,b). It is one of many such missions likely to be proposed in the next few decades. After launch, the spacecraft would approach a pre-determined asteroid, map the surface, and select locations for the collection of samples. The spacecraft would then hover for closer observations, adjust its movements to match the rotation of the asteroid, gently descend to the surface, touch for a few seconds, and ascend. The collector we are developing, known as the touch-and-go impregnable pad (TGIP), is a passive device in which regolith material is embedded in silicone polymer substrate. After collection, the pad and its sample are returned to a canister in the spacecraft where they are secured for return to Earth.

The collector will have to survive the space environment for the duration of the mission, which might be as long as six or more years, and one of the factors to be considered is radiation from galactic and solar sources. Elsewhere, we consider temperature (Franzen et al., 2007), vacuum, mechanical stress (Azouggagh-McBride et al., 2007), and other environmental factors.

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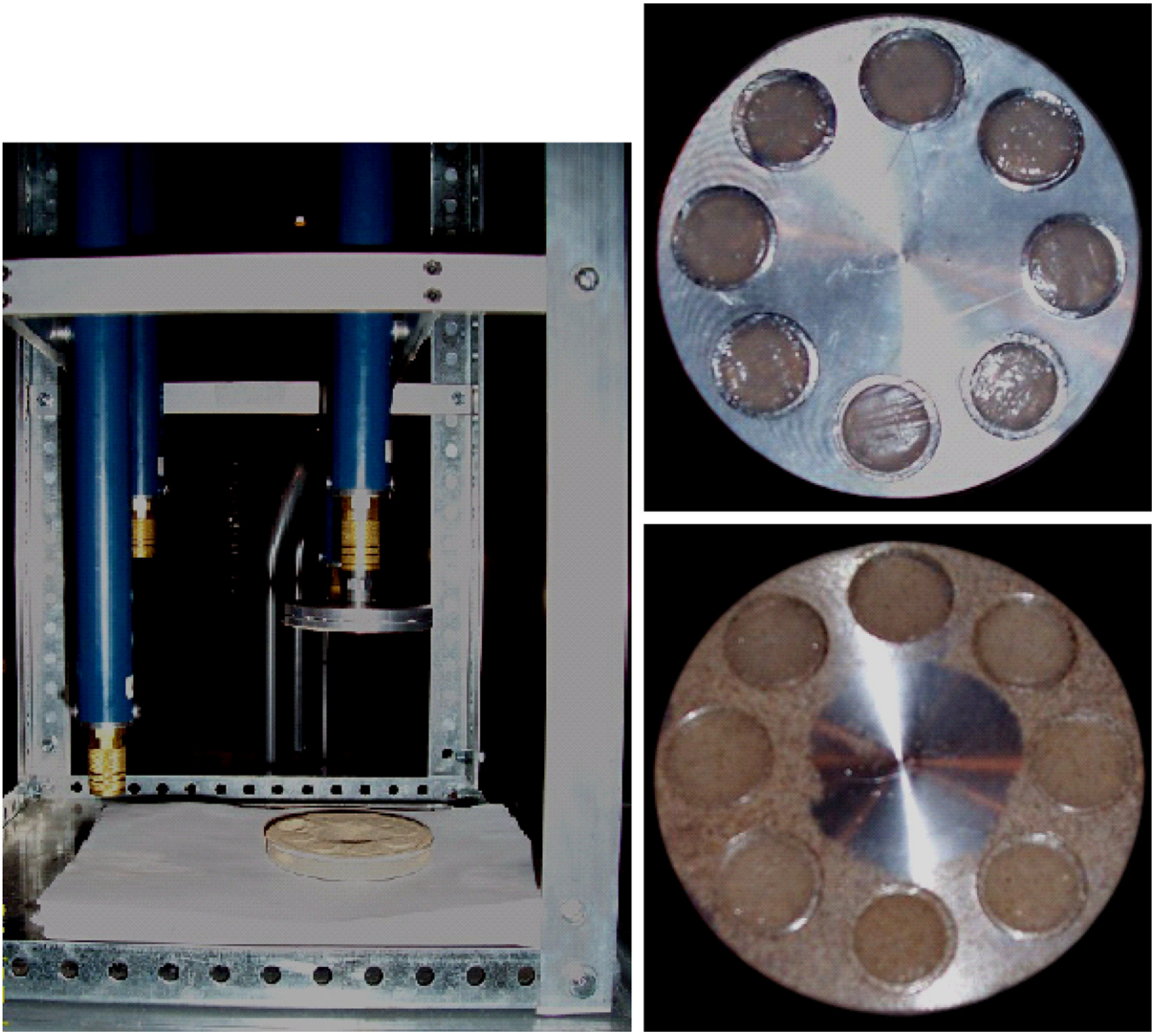

Fig. 1. Left, the collector and the collector heads for the present experiments. The collector head is attached to the linear actuator and is pressed into the simulated regolith sample in the dish below. Right, the sampling head assembly before (top) and after (bottom) sample collection. Half of the locations contain a pad that has been irradiated, and half of the locations contain control samples.

Spacecraft experience radiation from the Sun, which tends to be in the 100 s keV range, and from the galactic medium, which tends to be in the GeV range. Solar radiation is easily shielded but produces secondary radiation while galactic radiation is difficult to shield. The primary radiation is essentially protons and alpha particles, but the secondary radiation takes a wide range of forms including ions and electromagnetic radiation. It is thus very difficult to simulate space irradiation in the laboratory, but since a typical bond energy is only 0.25 eV, a reasonable model can be provided by any radiation capable of ionizing and breaking bonds. In terms of the absorbed dose rate, experiments in connection with the human space program suggest that galactic dose rates in the Earth–Mars vicinity of the solar system are ~14 cGy/year (Morgenthaler et al., 1998). The suggested solar dose can be up to 2 Gy/day on the outside of a spacecraft (Petrov, 1994). Knowing the dose rates of our sources, we can express the administered dose in our experiments in terms of dose expected on a typical six year near-Earth asteroid mission.

2. Experimental details

The first of our radiation sources were two ^{90}Sr sealed sources that produced beta particles with a maximum energy of 564 keV. In order to obtain higher energies for

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comparison, we used a linear accelerator located at the Northwest Arkansas Radiation Therapy Institute that could produce a focused beam of 6 MeV electrons. Small, cylindrical, lipped aluminum pans, 2.2 cm in diameter and 0.51 cm in height, held the collection substrate during exposure and the times were selected to obtain the desired total absorbed dose. The pans contained ~3 g of substrate with an area 0.63 cm^2. An approximately equal number of control samples were also prepared. Triplicate samples were run at each dose in the case of the beta cell irradiations, but single samples were run in the accelerator. This is reflected in the uncertainties reported for the experiments.

Table 1
Radiation sources, doses, and average mass collected for the present experiments

Sample set	Radiation source	Dose[a]	Mass (mg)
1	^{90}Sr-β	0.1	44.3
2	^{90}Sr-β	0.2	44.3
3	^{90}Sr-β	0.5	40.0
4	^{90}Sr-β	1.0	40.0
5	^{90}Sr-β	2.0	50.0
6	^{90}Sr-β	4.0	46.7
7	^{90}Sr-β	8.0	45.0
9	Control	None	44.6
10	6 MeV e^-	0.25	30.0
11	6 MeV e^-	0.5	40.0
12	6 MeV e^-	1.0	50.0
13	6 MeV e^-	2.5	30.0
14	6 MeV e^-	5.0	40.0
15	6 MeV e^-	10	50.0
16	6 MeV e^-	50	40.0
17	Control	None	46.3

[a] Dose is expressed in terms of multiples of the dose expected for a typical six-year mission to a near-Earth asteroid.

After irradiation, samples were weighed, placed in a holder that would take eight at a time, and then pressed into a simulated regolith (Fig. 1). The simulated regolith consisted of 210–300 μm sand particles in a dish atop a scale. The force applied, as determined by the scale, varied between 44 and 78 N, depending on the thickness of the sand. After collection, the samples were reweighed and the mass of sand collected was determined.

3. Results

Our results are shown in Table 1 and Fig. 2. The control samples and the triplicates, where available, have been averaged. The error bars represent one standard deviation on the mean.

4. Discussion

The TGIP collector depends critically on the physical properties of the collection substrate, and any change in these properties while in space could jeopardize the mission. Of concern, is that radiation would cause a hardening and increase in viscosity (or a decrease in penetrability) by increasing the cross-linking of the polymer. In the present case, we found that the properties of the collector substrate were unchanged, suggesting that this process did not occur during our experiments.

In that silicone compounds of various sorts have often flown on spacecraft, perhaps this conclusion is not surprising. Similarly, silicone greases are often used in the laboratory in high radiation environments, such as electron beam or other charged-particle instruments, without any long-term deterioration in its properties. The reason for such stability is of interest and presumably relates to the extraordinary strength of the Si–Si bond (453 kJ/mol), although

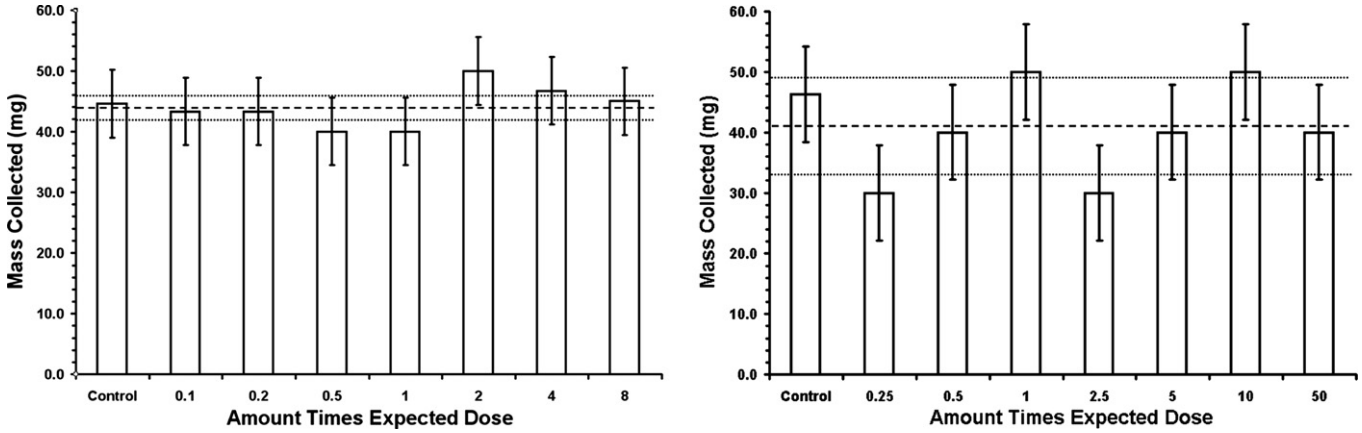

Fig. 2. Amounts of sand collected by each pad after irradiation by ^{90}Sr β particles (left) and 6 MeV electrons (right) compared with control samples. Data for the control samples and triplicate samples have been averaged. The dashed line is the average of all samples and the dotted line represents $\pm 1\sigma$ from the average. Within the experimental uncertainties, neither irradiation by 564 keV β particles or irradiation by 6 MeV electrons cause a change in the ability of the collector substrate to collect samples of the simulated regolith, even though the dose of β particles was up to eight times that expected for a near-Earth asteroid sample return mission and the dose of 6 MeV electrons was up to 50 times that expected for such a mission. The experimental uncertainties in our experiments reflect variations in the force applied to the pad that, in turn, reflect regolith thickness, and packing.

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other factors may be involved such as the material's ability to repair broken bonds and the ability to dissipate energy by other means.

The extent to which our irradiations simulate irradiation in space is obviously of concern. Above we argued that since the energy of the radiations we used was orders of magnitude greater than typical bond energies this was a reasonable test. Further tests could be performed using larger accelerators and proton and ^{4}He projectiles, but given the present results and the numbers of instances in which similar materials have flown on previous missions we doubt it is necessary. Further tests should perhaps be performed combining the effects of radiation with temperature and low pressures.

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