

# Engineering Notes

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## Space Shuttle Externally Induced Environment Compared with Skylab's Natural Environment

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### Introduction

THE primary objective of this Note is to report recent electret measurements of the particulate contamination environment inside the Shuttle bay. These results will be compared with ground measurements of the particulates emitted by the Shuttle solid rocket boosters (SRBs) and, for completeness, with the expected natural particulate environment as measured by Skylab. It will be demonstrated that chemical analysis reveals the difference between natural and man-made space debris. It will be shown that, based on the concentrations of aluminum and chlorine in the electret observations and in the SRB tests, the primary source of the Shuttle particulate environment is most likely the SRB exhaust. An attempt will also be made to define the size of these particulates. As such, this particulate environment may pose a potential threat to the space station and deserves careful consideration in the future.

### Rocket Exhaust Measurements

First consider a major potential source of particulates—the SRBs. The solid rocket motor (SRM) contaminants have been studied at length by Mueller and Kessler.<sup>1</sup> To date, little detailed analysis has been performed on the effects of these rocket contaminants on the near-Earth orbital space. It is, known, for example, that 34% of the rocket's exhaust products are  $\text{Al}_2\text{O}_3$  particulates and that most of these particulates are between 0.1 and 10  $\mu\text{m}$  in diameter.<sup>2</sup> Ground-based measurements of the exhaust materials from STS-1-4 during launch from Kennedy Space Center do give some idea, however, of the composition of these particulates.<sup>3</sup> In addition, SRB firings in the Utah desert by Morton Thiokol have been presented by Susko<sup>4,5</sup> for the demonstration motor models DM2 and DM3 tests. Aluminum and chlorine were identified in the exhaust products analyzed in these studies. As will be

discussed, high concentrations of aluminum and chlorine are not common constituents of natural meteoroids.

The most widely used propellant in SRBs is ammonium perchlorate as the oxidizer with powdered aluminum filler that acts, in part, as a fuel and partially as a stabilizer to control the burning rate. The exhaust products from this type of fuel composition for normal burn (percent by weight of nozzle exit plane flow) contain hydrogen chloride (21.2), chlorine (0.3), carbon monoxide (24.1), carbon dioxide (3.4), hydrogen (2.1), hydroxyl and atomic hydrogen (0.02), nitrogen (8.49), water (9.3), aluminum oxide (30.1), aluminum chloride (0.02), and iron chloride (0.97), for a total of 100%.<sup>6,7</sup>

### Micrometeoroids

Micrometeoroids in the near-Earth vicinity were expected to strike Skylab, America's first space station. To take advantage of this fact, Hemenway,<sup>8</sup> director of the Dudley Observatory in Albany, New York, devised an experiment in which thin foils and polished metal plates were exposed in space to record penetration by such particles. The exposed materials were returned to Earth and studied with optical microscopes and scanning electron microscopes.<sup>9</sup>

Brownlee et al.<sup>10</sup> and Lundquist<sup>9</sup> both presented measurements of the elemental abundances in typical high velocity impact craters from these micrometeoroid impacts. Considerable amounts of micrometeoroid residue were found in the bottom of rough-textured craters. The results of two electron-probe analyses of the residues are shown in Fig. 1.<sup>9</sup> The relative abundance is normalized to the amount of silicon found. Elements identified were iron, silicon, magnesium, calcium, nickel, chromium, and manganese. Upper limits were also obtained for titanium and cobalt. For comparison, the relative elemental abundances for two types of carbonaceous chondrite meteorites (C1 and C3) are also given in Fig. 1. There is a marked similarity, but this should not be construed as evidence that both objects have a common source. The similarities are possibly only a consequence of their both being primitive, well-preserved samples of early solar system materials. A sulfur analysis at a later date indicated that sulfur is also present in the crater with an abundance similar to the abundances of iron, magnesium, and silicon and also comparable to the abundances for carbonaceous chondrites. No aluminum or chlorine was observed.

As described by Clanton et al.,<sup>11</sup> the Apollo windows from Skylab 4 were removed and examined for meteoroid impacts. Impact data were also available from a meteoroid impact experiment on the telescope mount on Skylab.<sup>12</sup> The hypervelocity impacts were examined by a scanning electron microscope and discovered in both cases to contain a large amount of aluminum.

While aluminum is a common element, it has never been found to be the only detectable element in meteoroids, as was observed in these pits. In addition, the pits on the windows showed the unusual character of containing an "aluminum liner." Such a liner has not been observed in meteoroid pits found on returned lunar rocks. There is evidence to suggest that the preceding experiments to detect meteoroids also sampled particulates from SRMs. Kessler<sup>2</sup> concluded that

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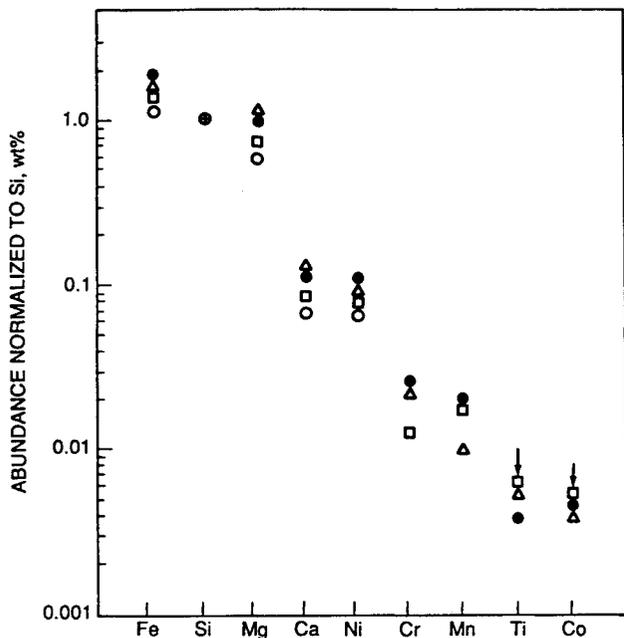


Fig. 1 Elemental composition (normalized to silicon) of micrometeoroid residue found in the crater. Open squares and circles represent different electron-beam probe runs; • = C1 and + = C3.

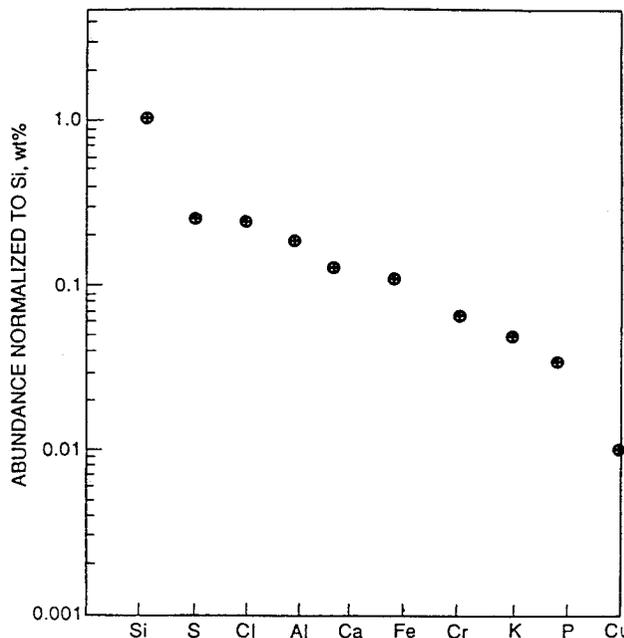


Fig. 2 Elemental composition (normalized to silicon) of rocket exhaust from average of four orbital flight tests of the first four Space Shuttle flights.

most of the impacts originated from an Earth-orbiting population. The possible source of this orbiting population is SRMs fired in Earth orbit.

Studies by Mueller and Kessler<sup>1</sup> show that the STS uses SRMs to boost communication and weather satellites into geosynchronous Earth orbit (GEO). The aluminum oxide Al<sub>2</sub>O<sub>3</sub> particles are discharged from the nozzle at speeds of 1-4 km/s and the range of particulates is 0.1-10 μm. In the second burn of the GEO transfer, most of the particles that are inserted into orbit do not re-enter. These studies reveal that the flux (number of impacts/m<sup>2</sup>/yr) resulting from one burn can exceed the natural meteoroid flux from particles of like size (1-10 μm).

**Elements Obtained from Four Orbital Flight Tests and SRB Firings**

Next consider the data from measurements in the Shuttle bay. The results from four orbital flight tests (OFTs) (STS-1-4) are documented by Linton et al.,<sup>13</sup> in which electrets, a contamination detection device developed by the NASA Marshall Space Flight Center (MSFC)<sup>14</sup> measured the residue of the pollutants in the cargo bay. The word electret was derived by Heaveside<sup>15</sup> to describe a permanently polarized dielectric. A Japanese physicist, Eguchi,<sup>16</sup> prepared the first electret in 1919 from carnauba wax. The MSFC electret, by comparison, is a small (quarter size) disk of Teflon-polytetrafluorethylene, (C<sub>2</sub>F<sub>4</sub>)<sub>n</sub>. These electrets are dielectrics with a permanent surface charge (approximately 10<sup>-8</sup> C/cm<sup>2</sup> density) that gives them properties analogous to magnets by retaining electrically active particles and ions on their surface. Measurements are made in the energy range from 0.707 to 30 keV ± 0.170 keV (i.e., fluorine to silver) using an x-ray microprobe to analyze the effluents collected on the Teflon electrets. Thus, an elemental analysis and an estimate of the abundance of the elements are obtained. The area scanned, selected arbitrarily by the microprobe operator for a representative area of particle density, measured approximately 0.1 cm<sup>2</sup>. As shown in Fig. 2, the relative abundance of each species is normalized to the amount of silicon found. Elements identified during the four OFT flights as residue and contamination were silicon, sulfur,

ELEMENT	Counts	
	(-Z)	(+Z)
Si	135	160
Cl	125	100
K	25	0
Ca	75	25
Al	0	0
Cu	0	0
P	0	0
S	50	60
Cr	0	0
Fe	0	0

0 - Indicates no difference between sample and background

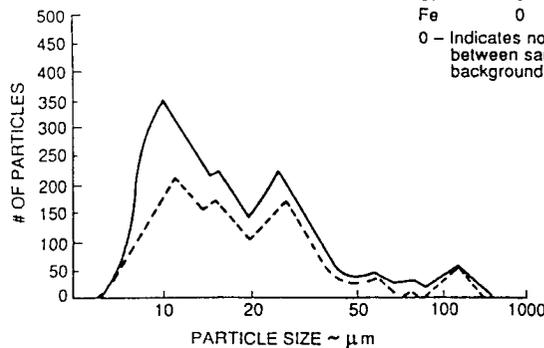


Fig. 3 Average particle size distributions on electrets in cargo bay, STS-3.

chlorine, aluminum, calcium, iron, chromium, potassium, phosphorous, and copper.

As indicated in Fig. 2, Cl and Al represent a significant amount (28 and 21%) of the elemental composition measurement in the cargo bay of the Space Shuttle. This compares reasonably with the exhaust products of HCl (21%) and Al oxide (30%) from the fuel composition of the SRBs. These two species are the main elements that identify the contamination signature of the SRB.

Now, consider the SRBs particulate airborne measurements during penetration into flights under the Space Shuttle's exhaust clouds during STS-1, -2, and -5. The behavior of HCl and Al<sub>2</sub>O<sub>3</sub> was the focus of the study by Coffey et al.<sup>17</sup> Further information on the behavior of HCl and Al<sub>2</sub>O<sub>3</sub> in the exhaust clouds was obtained by Strand et al.<sup>18</sup> X-ray fluores-

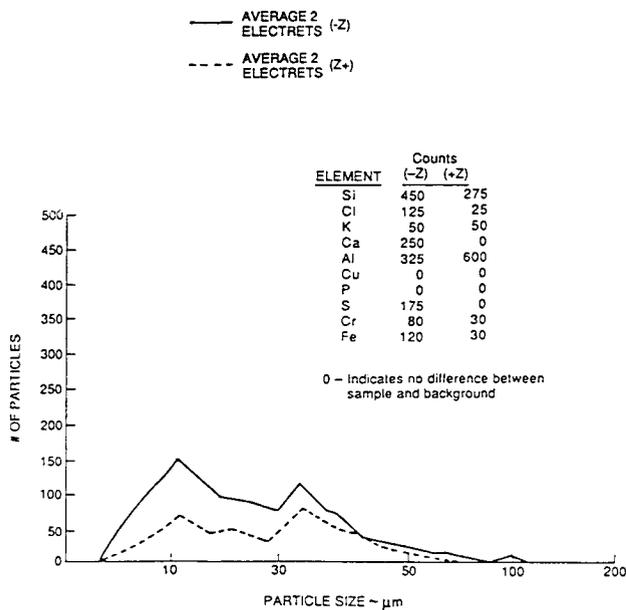


Fig. 4 Average particle size distributions on electrets in cargo bay, STS-4.

cence revealed aluminum, potassium, sodium, titanium, and significant quantities of iron and silicon. Samples collected by nuclepore filters and analyzed by electron spectroscopy revealed a significant amount of chlorine.

### Particle Size Distribution in Cargo Bay of Space Shuttle

Based on our research on the elemental analysis by an X-ray energy spectroscopy (XES), Al and Cl were found to be present during the four OFT flight electret experiments in the cargo bay of Columbia. For reference, the electrets were placed in the  $(-z_0)$  and  $(+z_0)$  orientation of Columbia's cargo bay. The particle size distributions and identification of elements for STS-3 and STS-4 for these two orientations are shown in Figs. 3 and 4.

The electrets in the  $(-z_0)$  orientation had the greater amount of particles when compared to the  $(+z_0)$  orientation. In the STS missions 1-4, the particle size distribution in the  $(-z_0)$  position for particles  $<10 \mu\text{m}$  decreased from 1900, 500, and 350 to 170 for the number of particles during the four missions.<sup>13,19,20,21</sup>

### Summary Remarks

This study has demonstrated the strong connection between the solid rocket booster exhaust and particulates in the Shuttle bay. It has further demonstrated the power of a chemical analysis in differentiating between the natural and man-made sources of particulates. Finally, it has derived an estimate of the likely size and composition distributions of the potential SRB-induced debris environment—a very real potential threat for the space station.

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