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Analysis of the composition and sources of deposition on the ISS surface

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The fine deposition delivered from the surface of the International Space Station (ISS), particles of cosmic dust, particles of meteoroid, volcanic and marine origin, enriched with organic matter. These particles are present in the Earth's exosphere and, under conditions of corpuscular, X-ray and ultraviolet irradiation, are an aggressive agent for the surface materials of orbital stations. An analysis of the elemental composition of deposition on the ISS surface made it possible to assess the effect of the detected elements on the stability of the structural materials of the orbiting objects, as well as to identify the sources of their entry onto the ISS surface.

Keywords: international space station, fine deposition, exosphere.

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Introduction

Possible sources of regular deposition of fine particulate matter on the surface of an orbital station may be particles of meteoroids and comet tails, delivering molecules of the interstellar medium adsorbed by them, and cosmic dust particles from outer space [1–7]. Data on 36 regular streams of comet tails crossing near-Earth space are well known; particle velocities are in the range from 18 to 70 km/s. The "UV Atmosphere" telescope on the ISS registers micrometeorites entering the nadir zone. At this time, the ISS is located in the zone of a comet tail particle stream, and the registration of meteoroid glow by the "UV Atmosphere" telescope is a sign of possible contact of particles with the ISS surface. This proves that the Earth's exosphere includes minute particles of cosmic origin continuously moving toward the Earth [3], which fall onto the surface of an orbital object. In addition, particles from the Earth resulting from volcanic activity and the uplift of

microparticles in the electric fields of the global electric circuit of the Earth may also be present in the exosphere [1, 7]. All these particles may be present in the sediment on the ISS surface, along with products of station material degradation. From 2010 to 2024, under the "Test" program, sampling of fine particulate matter from the external surface of the pressure hull of the Russian segment of the ISS was carried out, and disperse, chemical, and geological-mineralogical analyses of the samples delivered to Earth were performed. Based on the analysis of the sediment from different elements of the ISS, conclusions can be drawn about the composition of the sediment, as well as about its sources. In addition, conclusions can be drawn about the possible danger of the sediment to station materials or to cosmonauts.

Analysis of sediment composition

The following methods are used to obtain the results of post-flight physicochemical analysis

of fine particulate matter on the surfaces of elements of the "Test-Exponat" device after a long period in open space: mass spectrometry, inductively coupled plasma atomic emission spectrometry, electron paramagnetic resonance spectrometry, and scanning electron microscopy. In the experiment completed in 2024, during the research carried out under the "Test" program, the elemental composition of the contaminant on the fluoroplastic body of the "Test-Exponat" device, which had been located on the external surface of the "Poisk" module for 3.5 years, was studied. The quantitative and elemental composition was determined by inductively coupled plasma optical emission spectrometry (the ICP-OES method) as the most reproducible and metrologically supported. The microwave sample digestion system allows all elements contained on various carriers to be transferred into solution.

In micrographs of the body surface, the pattern of sediment deposition can be observed (Fig. 1). The contamination is contained on any irregularities and roughnesses left by the milling cutter during fluoroplastic processing. At the same time, no particles were detected on the surface of the material. For investigation using a scanning electron microscope, a section (Fig. 1) of the contaminated surface layer of fluoroplastic from the body of sampler No. 17A was made. It should be noted that the contrast of the scanning electron image is due to the difference in electrical conductivity of the material. The cracks were formed as a result of section deformation (Fig. 1) and do not contain contamination. The rest of the material surface, and especially the pores in it, are contaminated with sediment, as a result of which they have some electrical conductivity, and consequently, appeared dark in color.

Studies of the elemental composition of the contaminant on the fluoroplastic body of the "Test-Exponat" device (Fig. 2) have a number of advantages, since fluoroplastic does not change during subsequent sample preparation and contains a minimal amount of mineral impurities. A control sample of the fluoroplastic scraping was obtained from the same body. The original fluoroplastic contains extremely few foreign

inclusions, and the method error can be assessed by the only factor that is difficult to account for in this experiment – the degree of contamination by hands and dust contamination of the sample with ordinary dust. These contaminants, as a rule, introduce calcium into the sample, and to a lesser extent magnesium and silicon, which is observed in the analysis results.

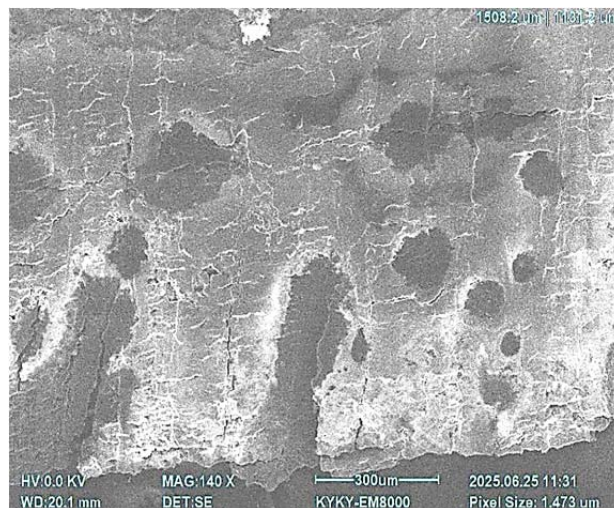


Fig. 1. Micrograph of the fluoroplastic fragment obtained by scanning electron microscopy (SEM) after conducting the ICP-OES.

Among the 65 chemical elements identified in the composition of fine particulate matter on the ISS surfaces in the period from 2010 to 2024, the most common element was iron, which is practically not used in the structural elements of the station. Moreover, iron was not detected in only 5 out of 46 samples studied under the "Test" program. Analysis of the relative content of iron and nickel in the samples allows clarification of the origin of iron in the sediment. According to the obtained results of the study of exposed bodies of the "Test-Exponat" device [2], iron was detected in significant quantities: 536 µg/mL. A peak of nickel content was also detected in the OES spectrum, but its content is lower: 1.6 µg/mL. Thus, the iron/nickel ratio in the studied sample is 335, whereas in samples of meteoritic origin, as is well known, the iron/nickel ratio is practically constant and ranges from 11.5 to 14, averaging 12. This allows the conclusion that the iron particles are not only of meteoritic origin.

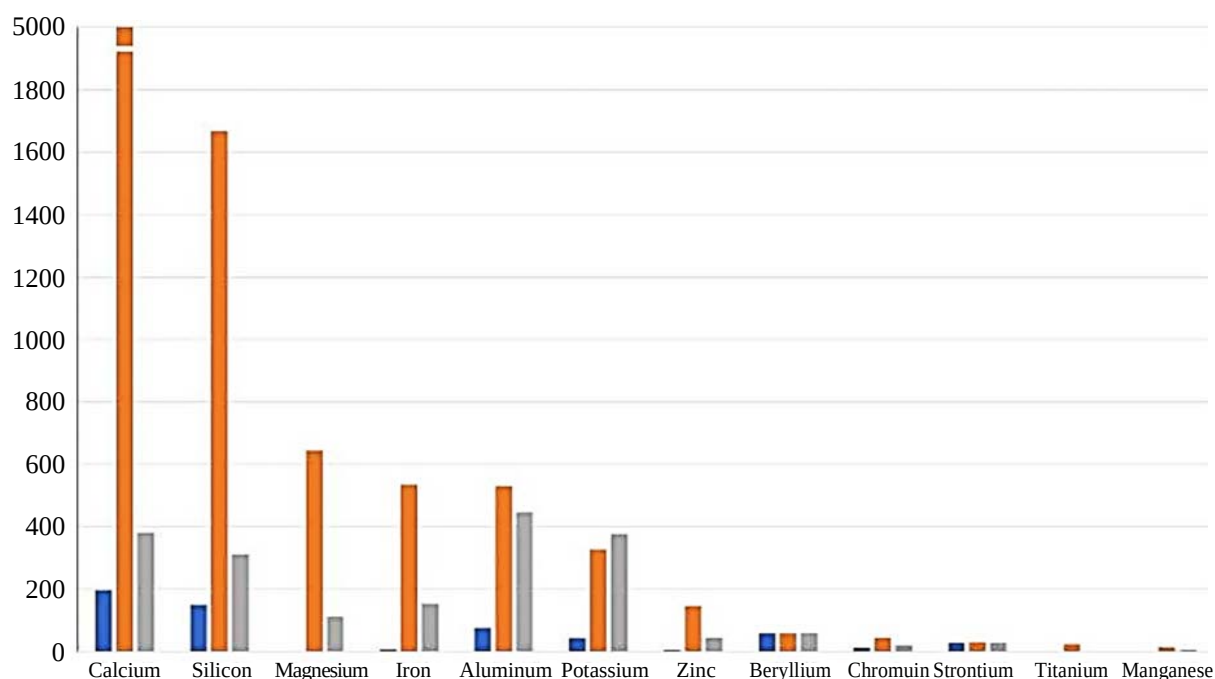


Fig. 2. Elemental composition of the scraping from fluoroplastic bodies. Left blue column – pure fluoroplastic, middle orange column – sampler 17A, right gray column – sampler 18A

The elemental composition of cosmic dust collected from the ISS surface earlier suggests a significant contribution of mixed tropospheric aerosol of terrigenous and marine origin [6, 7]. Volcanic gases rising beyond the atmosphere may contain iron chloride, released at high temperatures from magmatic melt. The presence of iron chlorides in volcanic gases is associated with the reaction of magma with chlorine-containing compounds, which can also be released during an eruption. Anhydrous iron (III) chloride (FeCl_3) becomes volatile, which upon strong heating transitions to a gaseous state, forming monomers (FeCl_3) and dimers (Fe_2Cl_6).

Studies of the physicochemical properties of fine particulate matter on the ISS surface have confirmed the possibility of its active participation in the development of microdestruction of ISS structural elements. Upon interaction of iron chloride with compact aluminum of the ISS body, accumulation of iron ions occurs, culminating in the release of iron in a free state and the appearance of ferrimagnetic particles, which was detected on the fluoroplastic surface. Chloride ions migrate through the oxide film to the metal, primarily at defect sites, increasing the corrosion rate and microdestruction of ISS elements.

In 27 out of 46 samples of fine particulate matter, elements of high electron affinity were

identified, including Cl, F, and S. These elements are not permanent elements of cosmic dust, but they are always present in volcanic gas emissions, constituting up to 5 % of their total volume. It has been established that chemical processes involving elements of high electron affinity negatively affect the tightness of paronite seals in window structures.

The amount of detected magnesium exceeds the content of iron and aluminum not only in the samples of the fluoroplastic device that was exposed for 3.5 years, but also in other samples from the ISS surface. As a result of sampling on the ISS pressure hull in 2012 under the screen-vacuum thermal insulation, the following result of element content levels ($\mu\text{g/mL}$) was obtained: Mg – 181.55; Al – 39.85; Mn – 2.18. These data indicate a significant (4.5-fold) excess of magnesium content in the sample compared to aluminum, for example, in the composition of the AMg6 alloy: Mg – 6.8 %; Al – 93.68 %; Mn – 0.8 % [7].

It is known that the concentration of magnesium in marine and oceanic aerosols can vary from a few units to several tens or even hundreds of micrograms per cubic meter of air, and magnesium is one of the main components of aerosols of marine origin reaching orbital altitude via the global electric circuit [1]. The dynamic equilibrium of the Earth's exosphere is achieved

by a continuous flow of aerosols via the global electric circuit from the Earth and continuously moving streams of comet tail particles and cosmic dust in near-Earth space, arising from collisions of comets, asteroids, and other bodies in the Solar System.

Cosmic dust consists of small particles of solid matter composed of diatomic oxides MgO, SiO, CaO, FeO. Magnesium is almost entirely in the solid phase (as part of dust particles), rather than in the gas phase. The ratio of the magnesium-26 (Mg) and ordinary magnesium-24 (Mg) isotopes in meteorites allows dating of their formation [4, 5, 6]. The isotope 26(Mg) is a decay product of radioactive aluminum-26 (Al), which was present in the early Solar System. Its half-life is 717,000 years. In iron meteorites, this isotope is abundant compared to ordinary magnesium, while in chondrites it is practically absent. This indicates that chondrites arose somewhat later, when aluminum-26 in the rocks was already very scarce. It is estimated that this occurred approximately two to three million years after the formation of the Solar System. Thus, chondrites are meteorites of the second generation. The content of elements in particles of meteoric origin of the chondrite type averages: O (33.24 %), Fe (27.24 %), Si (17.19 %), Mg (14.29 %), S (1.93 %), Ni (1.64 %), Ca (1.27 %), Al (1.22 %), Na (0.64 %), Cr (0.29 %), Mn (0.25 %), P (0.11 %), and K (0.08 %).

Iron is one of the most abundant elements in the Universe after light elements such as hydrogen, carbon, and oxygen. Iron is most often found in gaseous form in stars, such as the Sun, and in condensed form on planets, in the composition of micrometeorites. Astrophysicists detect only low levels of gaseous-type iron [4, 5, 6]. This implies that it also exists in solid form or a molecular state; however, its identification remains an unresolved task that has been studied for decades. A working hypothesis suggests that interstellar iron combined with carbon molecules and formed molecular chains called iron pseudocarbynes. The spectra of these chains are identical to those of the much more common chains of carbon molecules, whose presence in interstellar space has long been known [6].

In the "Test" experiment, iron particles were identified on the ISS surface as part of fine particulate matter from outer space, which

presumably reached the surface as a result of interaction with the electric fields of the station:

1. Electric fields on spacecraft surfaces are formed due to the accumulation of charged particles, such as electrons and ions from the surrounding plasma, on them. If spacecraft surfaces are covered with dielectric materials (e.g., thermal control paints, fluoroplastic), they can accumulate charge, forming an electrical capacitance with the metal body of the spacecraft. Electrons and ions from near-Earth plasma can reach the spacecraft surface and accumulate on it, especially on non-conductive materials (Fig. 3).



Fig. 3. A cotton fabric bundle secured on the painted external surface of the Service Module of the ISS RS

2. Power sources, solar panels, instruments, and thrusters create electric fields.

3. Changes in the near-Earth plasma, for example, when passing through regions with different particle densities, can cause noticeable fluctuations in the surface electric potential and, as a consequence, changes in electric fields [4].

4. Mechanisms of the generation of electric fields and currents on the spacecraft surface upon collision with microparticles:

- 4.1 A microparticle under the influence of solar UV radiation charges positively due to the photoelectric effect, i.e., electron emission as a result of absorption of UV quanta. The particle charge can reach an order of a thousand electron charges. Currents induced by the negative electric charge flow over the metal surface. Upon contact of the particle with the surface, the particle charge transfers to the metal, and then this space charge dissipates.

- 4.2. When a microparticle collides with the spacecraft surface, compression of the medium occurs, which causes the appearance of an electric current and an accompanying EMF. The density of the resulting current can reach 10–1000 mA/cm². These currents arise in the volume

of the metal and dielectric and can also flow along the opposite side of the metal. Thus, particle impacts on the spacecraft surface lead to the creation of surface currents and electric fields.

As a result of the experiments conducted on the ISS under the "Test" program and the analysis of the sediment, an understanding of the operating environment of orbital objects has been formed, including the presence in the near-space environment of aggressive elements: atomic oxygen, elements of high electron affinity (sulfur, fluorine, chlorine), and other elements of volcanic gases reaching orbit, as well as cosmic sources of influx. Data on the composition of the continuously arriving fine particulate matter on the surface of orbital objects will allow the refinement of the requirements for the quality of spacecraft surfaces in terms of materials, coatings, and protective elements.

Conclusion

The results of the study of the composition of fine particulate matter on the ISS surface demonstrate viable ways of obtaining new data on the Earth's exosphere and outer space. The ISS

surface is a unique accumulator of cometary matter in its natural form and the only easily accessible platform for its regular collection. Particles of cometary matter ejected into interplanetary space from the comet nucleus (comet tail) burn up at an altitude of 80–100 km above the Earth. Using the ISS, scientists can regularly obtain factual material for studying cometary matter adsorbed on the ISS surface and, as shown in the "Test" space experiment, delivered to Earth in its natural state. Analysis of fine particulate matter from the surface of orbital stations is a source of information on the state of iron particles and compounds in outer space, as well as magnesium in the Earth's exosphere; furthermore, and based on the results of isotope analysis, it is possible to establish the sources of sediment on the surface of an orbital object. Space debris and massive orbital constellations are collectors and carriers on their surfaces of biological objects, aggressive chemical elements, and radioactive particles that can cause the degradation of station materials, which may also present new potentially hazardous factors accompanying the return of orbital objects to Earth.

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