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5.0 EXPERIMENTAL COSMOCHEMISTRY IN THE SPACE STATION

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5.1 Executive Summary and Recommendations

This report summarizes the proceedings of two workshops devoted specifically to Experimental Cosmochemistry, which were held at the Lunar and Planetary Institute, Houston, Texas, on September 12-13, 1985, and February 24-25, 1986 as part of the overall Space Station Planetary Experiments Activities (NCC 9-14 to Arizona State University and NAS-17023 to the Lunar and Planetary Institute). The purpose of these workshops was to identify and discuss experiments in cosmochemistry that cannot be conducted under the conditions available in terrestrial laboratories, but may be carried out successfully in the proposed Space Station. The scientific discussions focused on two general areas of research: 1) chemical and physical processes in the earliest history of the Solar System, and 2) general principles of magmatic processes applicable both to planetary formation and evolution, as well as present-day magmatic activity in and on terrestrial planets.

From these discussions, it was clear that the environment within the Space Station uniquely lends itself to a very broad range of experimentation that can logically follow the evolution of the Solar System from condensation-sublimation in a solar nebula, through equilibrium-evaporation and condensation in silicate, oxide, metal and sulfide systems, to magmatic processes in larger planetary bodies. The information provided in the individual summaries below shows that, whereas we cannot hope to quantify fundamentally important aspects of such processes with the experimental data-base attainable in terrestrial laboratories, a program of experimental cosmochemistry based on investigations conducted within the Space Station environment could provide these data.

Discussions also focused on possible additional projects that are not covered in this report. These might, for example, include thermochemical measurements of silicate minerals and melts with calorimetric techniques. In addition, utilization of microgravity to produce crystallographically perfect crystals for subsequent terrestrial experiments in mineral physics and experiments on trace and minor elements between minerals and melts were discussed. There are certainly additional relevant cosmochemical experiments which could be performed in the unique environment of the Space Station. Although this report does not claim to be exhaustive in terms of possible experiments that can be performed on the Space Station, it does represent a reasonable summary of the types of experiments of current interest.

The Space Station will provide a unique environment, wherein a wide range of geochemical experiments may be conducted under conditions of microgravity and high vacuum. These conditions, which cannot be duplicated in terrestrial laboratories, provide an opportunity to investigate a variety of experimental problems, ranging from vaporization-condensation of silicate, oxide, metal and sulfide systems to magmatic processes on and within small planetesimals. These experiments will lead to a better understanding of the processes that controlled the formation and chemical fractionation of the Solar System and the magmatic differentiation of planetary bodies. There is a significant overlap of interest with Microgravity Sciences which is most evident in some equipment needs. For example, acoustic levitators have the potential for measurement of physical parameters such as surface tension, viscosity, and density, as well as for containerless studies of melting, crystallization, growth, phase separation, and mixing. The molecular shields promise a stable vacuum of $\sim 10^{-12}$ Pa (10^{-17} atmospheres) with an oxygen partial pressure of $\sim 10^{-19}$ Pa in which experiments can be performed with vanishingly small chance of oxygen contamination. Participants recognized the many areas of technical overlap between experimental cosmochemistry and adjoining disciplines such as materials science, for which the theoretical and analytical basis, as well as the synthesis facilities are often identical. In line with this, the planetary program has developed instruments capable of sample characterization such as mass spectrometers and scanning electron microscopes which could be mutually beneficial to both planetary and material science principal investigators if they were part of a facility on the Space Station.

Because of the potential value of such automated analytical devices in the limited human-time environment of the Station, and because of the relatively simple nature of many of the proposed experiments, *the Workshop participants recommend that a Robot Experimental Cosmochemistry Facility be designed for the Space Station.* Such a facility might include furnaces, controllers, and temperature-recording equipment, as well as modifications of the analytical and observational equipment which is the heritage of the Solar System Exploration Division of NASA. If such a facility were automated sufficiently that a series of experiments could be conducted remotely from the ground, then it would qualify for early installation on the Space Station when crew time is likely to be at a premium. *A continuing committee composed of researchers active in the program should review the designs and studies for the facility periodically.*

We further recommend that our colleagues in the international scientific community be encouraged to participate in the Space Station. In particular, the workshop participants would welcome collaboration with either U.S. or foreign investigators in taking full advantage of the unique environmental aspects afforded by the Space Station. Such international participation was particularly beneficial to the scientific results obtained from the Apollo program. We anticipate that international scientific cooperation in the Space Station programs will be similarly beneficial.

5.2 Summary of Technical Requirements

Although the various proposed activities in this report are at stages ranging from the abstract format to projects that have already been tested in the participants' individual laboratories, it is clear each have numerous technical features in common. In most experimental plans, microgravity is the important parameter. The remaining experiments require access to high vacuums for their successful completion. For example, nearly all experimental durations range between several hours and several weeks. All experiments require temperature control. In specific instances, a furnace or the sample may require rotation in order to counteract small residual gravitational accelerations. In fact, a common denominator of nearly all of the proposed cosmochemical experiments is the very long duration during which the on-going experiment requires little or no crew interaction, but does require continuous control (through automated techniques) of the experimental parameters. The objectives of the two basic types of experiments discussed during the workshop sessions could be met using two experiment systems; additionally, these two types of experiments would benefit from an automated analytical facility. The general characteristics of these systems and facilities are:

Reduced-gravity experimental cosmochemistry

The objective is to study the processes of crystallization, melting, element distribution, and phase stability in natural materials under conditions relevant to small planetary bodies, free space, or planetary interiors. Samples are heated, at times with controlled heating rates, to temperatures as high as 1800°C under controlled atmospheres and either maintained at temperature for 10's to 100's of hours or slowly cooled at controlled rates as slow as 0.1°C/hr over several hundred degrees and then quenched. The data set for an experiment includes history of the intensive variables as a function of time, and the samples which are recovered for petrographic and chemical analysis. Terrestrial laboratory and flight design experience suggest that a typical furnace system including control electronics occupies less than 1 m^3 and requires less than 500 watts for heating and control. Although automated sample change-out would increase efficiency, several systems may be needed. Stable, low-g ($\leq 10^{-5}$) conditions are needed to minimize settling and convection during these very long experiments.

High-vacuum experimental cosmochemistry

The objective is to study the physical and chemical properties and phase stability of materials when exposed to the extreme vacuum ($< 10^{-11}$ Pa) and temperatures (300 to 2000

K) inferred for the primitive solar system. The experiment uses a wake (or molecular) shield to create very high vacuums and large pumping capacities; samples, furnaces, and monitoring equipment are contained within the cavity of the shield. Materials are heated at controlled rates (< 100°C/hr) or held at constant temperature for 10's to 100's of hours. In addition to a record of conditions as a function of time, the data set for an experiment would include in situ property measurements (such as conductivity or evolved volatiles) and recovered samples which are analyzed petrologically or chemically. A shield, 1 or 2 meters in diameter, is envisioned; experiment packages are < 0.5 m^3 and require no more than 500 watts.

Space Station automated analytical facility

There was agreement that certain standard analytical facilities should be available on the Space Station. These facilities can be shared with other groups of experiments (particularly in materials science). These include thin-sectioning, polishing facilities and ultra-microtomy to prepare experimental charges for microscopic examination, optical microscopes and scanning electron microscopy with energy dispersive spectrometry attachments, and capabilities for accurate weighing of samples (at least to 0.01 gram accuracy). For some applications, transmission electron microscopy with analytical capability as well as spectroscopic tools for surface analysis would be highly desirable. In certain important cases (volatilization experiments) a mass-spectrometric capability will add immeasurably to the attainable data base. All proposed experiments require real-time video and data communication between mission specialists and ground-based scientists during sample examination and possibly during preparation of samples for new experiments. This might take the form of a video conference which could average one or two hours per week. We note that several flight-quality analytical instruments that could be adopted for Space Station use have already been developed by the NASA Solar System Exploration Division.