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THE CONCEPT VERIFICATION TESTING OF MATERIALS SCIENCE PAYLOADS

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16. ABSTRACT
The Concept Verification Testing project at the Marshall Space Flight Center, Alabama, is a developmental activity that supports Shuttle Payload Projects such as Spacelab. It provides an operational 1-g environment for testing NASA and other agency experiment and support systems concepts that may be used in Shuttle.

A dedicated Materials Science Payload was tested in th[illegible]al Purpose Laboratory in December 1974 to assess the requirements of a space processing payload on a Spacelab type facility. Physical and functional integration of the experiments into the facility was studied, and the impact of the experiments on the facility (and vice versa) was evaluated. Three Principal Investigators who had proposed experiments were on board, and one Principal Investigator was in a consulting status in the test control complex.

A follow-up test designated CVT Test IVA was held in November 1975. The purpose of this test was to repeat Test IV experiments with a crew composed of selected and trained scientists. These personnel were not required to have prior knowledge of the materials science disciplines, but were required to have a basic knowledge of science and the scientific method.

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THE CONCEPT VERIFICATION TESTING OF MATERIALS SCIENCE PAYLOADS

I. TEST IV

A. Introduction

The Concept Verification Testing (CVT) project at the Marshall Space Flight Center, Alabama, is a developmental activity that supports Shuttle Payload projects such as Spacelab. It provides an operational 1-g environment for testing National Aeronautics and Space Administration (NASA) and other agency experiment and support systems concepts that may be used in Shuttle.

Through testing in the General Purpose Laboratory (GPL) simulator, the program initiates data that either formulate or verify Spacelab-type payload requirements. It accomplished these objectives by concentrating on the interrelationship of areas basic to the Spacelab: experiment integration, subsystem integration, and man/system integration.

A dedicated materials science payload was tested in the GPL in December 1974 to assess the requirements of a space processing payload on a Spacelab type facility. Physical and functional integration of the experiments into the facility was studied, and the impact of the experiments on the facility (and vice versa) was evaluated. Off-the-shelf equipment was used together with flight type hardware for comparison. The Principal Investigators (PI) who had proposed experiments were onboard and in a consulting status on the ground. This provided a means for determining the extent of necessary scientist participation in flight experiments. A core of characterization equipment for onboard analysis was provided.

B. General Purpose Laboratory

The GPL (Fig. 1) has a 4.27 m (14 ft) external diameter, 4.11 m (13.5 ft) internal diameter, and a length of 7.32 m (24 ft). It is furnished with water,

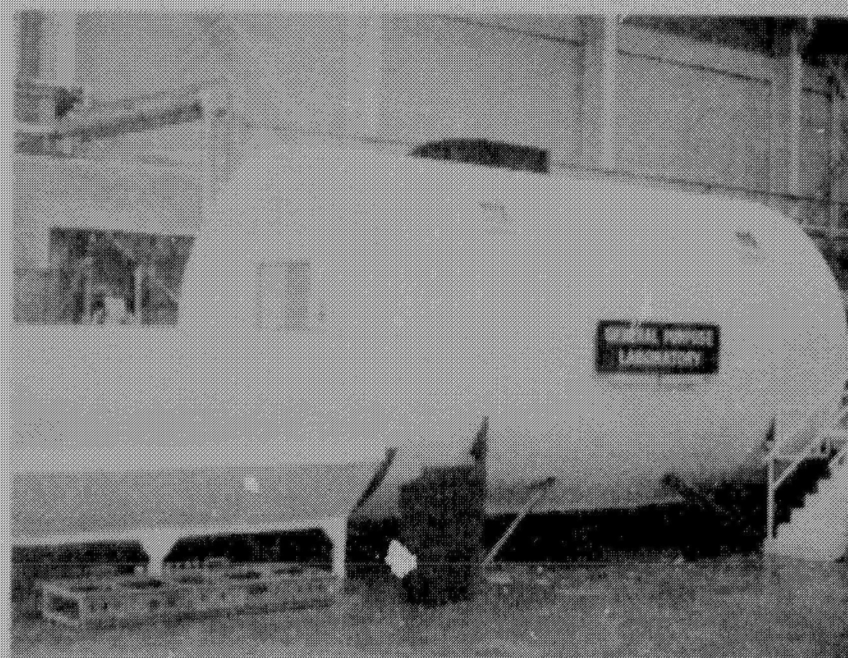

Figure 1. General purpose laboratory.

sewerage, vacuum, GN_2, missile grade pressurized air, lighting, and hot and cold potable water. Available power includes 29 Vdc, 100 Vac and 220 Vac (1 phase, 60 Hz). Humidity and temperature are controlled and are recorded together with specific experiment required data such as radiation levels and vibration. The supporting facilities for the GPL consist of a test control room, a data handling room, and a test support room.

C. Materials Science Payload

The purpose of the dedicated materials science payload was to conduct engineering and operational tests of materials processing facilities that embody the design concepts for space processing experiments. Data were obtained concerning experiment integration and operational techniques for installing and using equipment with high thermal requirements, critical atmosphere control, and constant thermal monitoring.

The study areas of materials science for this effort were (1) purification-separation, (2) solidification, (3) mixing, and (4) materials characterization and evaluation. The specific experiments in each area were chosen for their applicability to space processing and their probability for actual flight in the future. These are discussed in the following paragraphs.

1. MSP 100, Characterization — The core of characterization equipment consisted of polishing and mounting apparati, etching system, microscope, tensile and hardness testers, and an optical analysis system. These provided each PI with the necessary tools for evaluating the progress of her experiment.

2. MSP 101A, Infiltration Sintering — Infiltration sintering is accomplished by placing a compact, either in the green state or presintered, into contact with a molten lower melting point material. The molten material will be drawn up into the compact by a complex capillary action. A current limitation of this process in 1-g is its inability to flow uniformly into complex compacted shapes. This flow distribution is primarily an effect of the wetting of the materials, the preparation of the compact, and the gravitational field acting as a drag force on the infiltrant.

The principal objective of this experiment was to characterize the infiltration height and distribution of molten tin into various metallic powder compacts. The compact materials were chosen for their wetting and powder size characteristics.

3. MSP 101B, Liquid Phase Sintering – Liquid phase sintering is a process whereby two different powders are mixed, compacted and heated to the melting point of one of the constituents. The shape of the resultant ingot and the relative distribution of the two materials is a function of the gravitational environment.

Green (unsintered) compacts were sintered in the high temperature furnace. The parameters examined were compaction pressure, compact material, and sintering time.

4. MSP 102A, Eutectics-Magnetic Materials — The eutectic and off-eutectic compositions of bismuth-manganese were directionally solidified. The MnBi phase in this material is known to be ferromagnetic, but in its bulk form it is very susceptible to atmospheric corrosion. When "grown" as a phase in the Bi-MnBi eutectic, it is not subject to corrosion and yields an alloy of very high saturation magnetization.

It is the intent of this experiment to determine if lamellar off-eutectic compositions of Bi-Mn (which will contain greater amounts of MnBi) can be solidified under carefully controlled growth conditions. An inherent obstacle to achieving the required regular structure is the onset of convection during the solidification process. With carefully selected growth conditions, the amount of fluid flow can be controlled and its subsequent influence on the alloy substructure can be determined. This will indicate specifically if the processing of off-eutectic materials in the near zero-gravity environment of space, will yield materials with properties unattainable on Earth.

4. MSP 102B, Eutectics-Optical Materials. The eutectic and off-eutectic compositions of NaCl matrix is a desirable type of structure either for use as fiber optics or as a method of obtaining long fibers of an optically transmitting material.

The NaF-NaCl eutectic has excellent transmission properties in the infrared, but unfortunately the NaCl phase, which is the IR transmitter, is the matrix of the eutectic. To obtain a fiber optic type of material, NaF must be the matrix. To achieve this, an off-eutectic material must be solidified with a regular structure.

As in MSP 102A, convection is a major obstacle to achieving regular eutectic structure in an off-eutectic material. This experiment will study the influence of fluid flow on the growth structure to determine if processing halide off-eutectics in zero-gravity will yield useful materials.

5. MSP 103, Casting. A typical casting structure has three distinct zones: chill zone, columnar zone, and equiaxed zone. The proportion of these zones which comprise the ingot determine, to a large extent, the subsequent properties of the casting.

A greater understanding of casting solidification has been achieved through the study of metal-model materials (these are transparent organic materials with entropies of melting in the same range as metals). This experiment will visually observe and photograph the influence of gravity on casting solidification when the mold is cooled from the top and the sides and bottom.

6. MSP 104, Undercooling of Materials Prior to Solidification. Undercooling is the phenomenon by which a molten material cools below its solidification temperature before it freezes. The resultant material is generally very homogeneous with improved physical properties. To take advantage of this phenomenon, the factors which inhibit undercooling must be singled out. This experiment will provide a significant advance toward that goal.

Parameters which are thought to influence the degree to which a material undercools are (1) Cycling through the melting point, (2) hold time above the melting temperature, (3) holding temperature, (4) fluid perturbations, and (5) purity. This experiment will study the effect of these parameters on the undercooling of a Ag-5 wt% Cu alloy.

7. MSP 105, Diffusion Coefficient in Glasses. The objective of this experiment was to investigate the $GeO_2 \cdot Na_2O$ glass system in the 1-g environment. The diffusion coefficient of this glass system was studied for samples processed at 950°, 960°, and 970°C. The effect of the gravitational acceleration on the diffusion process was analyzed as a function of diffusion temperature for a specified length of time. This experiment is a predecessor of the zero-gravity processing of glasses.

8. MSP 106, Oxide Glasses. A polycrystalline oxide glass rod will be processed in the Artcore furnace, a furnace especially designed for efficient high temperature operation. The homogeneity and optical characteristics of the resultant boules are of primary interest. Glasses, like most other materials, are subject to the effect of gravity during processing. Glasses are extremely viscous in the molten state creating different fluid flow dynamics from that of molten metals. Again, the driving parameter is the presence of convection currents.

9. MSP 107, Study and Use of Ferrofluids. Ferrofluids are a relatively new invention, the most notable application of which has been in rotating seals where a magnetic fluid is held in a "liquid O-ring." This fluid bridges the gap between a rotary shaft and its housing and is held in place by the field from a permanent magnet. These fluids behave as true homogeneous fluids with the exception of being highly susceptible to magnetic fields. The potential applications of ferrofluids are numerous.

The magnetic susceptibility of these fluids facilitates their control and, thus, makes them especially attractive for use in bearing systems in zero-gravity. The magnetic bearing proposed for use in CVT is one of several designs to be used with magnetic fields. It consists of a glass sleeve with a permanently magnetized journal. Features of the bearing system to be investigated include lubricant positioning, transfer and distribution, field strength effects, bearing load carrying capacity, and overall feasibility and factors leading to improved design.

The second phase of the experiment deals with characterization of ferrofluid properties pertinent to lubrication and includes the determination of flocculation tendencies, viscosity as a function of magnetic field direction, and wetting ability.

10. MSP 108, Zone Purification. The purpose of this experiment was to purify three aromatic hydrocarbon organic semiconductors (anthracene, perylene, and napthalene) using a zone purification technique. In this process a zone of molten material is passed through unpurified material. In general, the impurities that lower the melting point of the material move with the zone and those that raise the melting point of the material move against the zone. After a specified number of passes determined by the ratio of zone length to the total material length, major type of impurities, and the desired purification level, the ultrapure material is selected for characterization from an area between the first two zone lengths and the (m-1)/2 zone where m is the number of zone points.

Zone purification in zero-gravity appears to be particularly suited to organic semiconductors. Well defined temperature profiles in the absence of convection currents should yield ultrapure materials which to date are unattainable under 1-g conditions.

D. Integration of Equipment

In previous materials science experiments in the GPL, the equipment was moved individually into the facility. Water, power, etc. connections were then "plumbed" into the available outlets. The dedicated materials science payload utilized a new concept for Spacelab designs, that of "modules" of skids. A typical skid is shown in Figure 2. It is 2.74 m (9 ft) long and provides the following connections: cold water (1), hot water (1), gaseous nitrogen (1), missile grade air at 200 psia (1), 10^{-3} torr vacuum (1), 0.1 torr vacuum (1), 29 Vdc, 100 Vac, 220 Vac (1 phase 60 Hz), 120/208 (3 phase, 400 Hz). The skid is shipped to the experimenters laboratory. The PI mounts the experiment hardware to the unistrut on the skid and makes the necessary connections to the facilities. The experiment hardware is then completely checked out in the laboratory. Once a satisfactory laboratory checkout is completed, the skid and hardware are shipped "in toto" to the GPL and are rolled into the facility. Connections are made between the skid and the facility and a pretest hardware checkout follows. If this checkout is satisfactory, the payload is ready for operation.

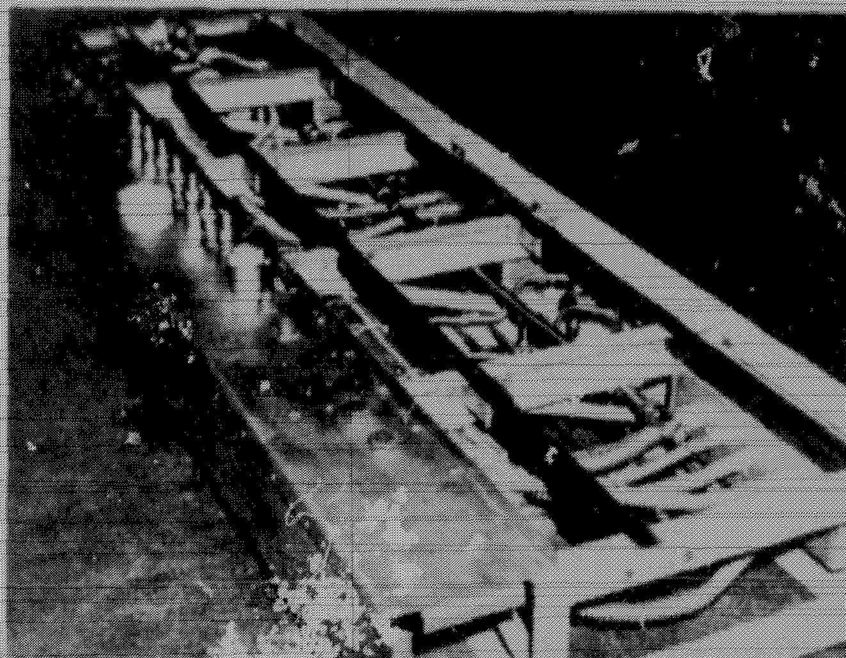

Figure 2. Basic skid.

The GPL facility accommodates four skids. These can be converted into "bench tops" as shown in Figures 3 and 4, or simply provide hard mounting platforms for relay racks and furnaces as shown in Figures 5 and 6. For CVT Test IV, the experiment hardware shown in Figures 3 through 6 were mounted on the skids, installed in the GPL, and completely operational in 3 weeks (Fig. 7). Since the tests were run entirely at MSFC with the entire payload originating there, no significant amount of time was needed for shipment of the skids to the test facility.

E. Experiment Hardware

This series of experiments encompassed a broad range of material science investigations and, consequently, employed a variety of experimental apparati. Some major experiment hardware together with characterization equipment was purchased as commercial items with no special modifications. These were complemented by specially designed and built equipment for comparison. All of this equipment was evaluated as to (1) its adequacy in meeting experiment objectives, (2) complexity of integration into the GPL and with other experiment hardware, (3) environmental impact on the GPL, and (4) feasibility of usage and maintenance. Principal experiment hardware and the associated experiment title are shown in Table 1.

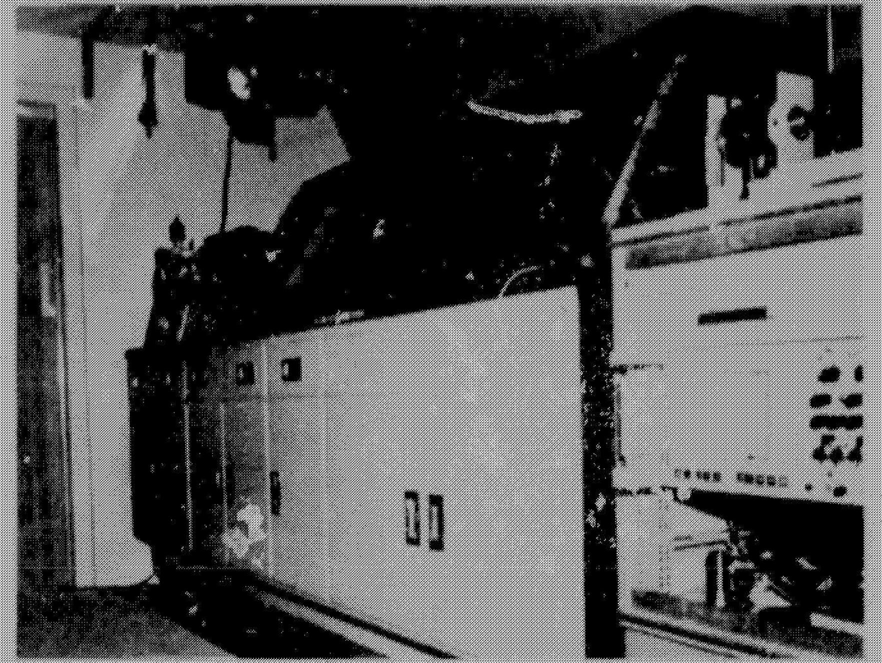

Figure 3. Bench top skid configuration with fume hood, sink, saw, and polisher.

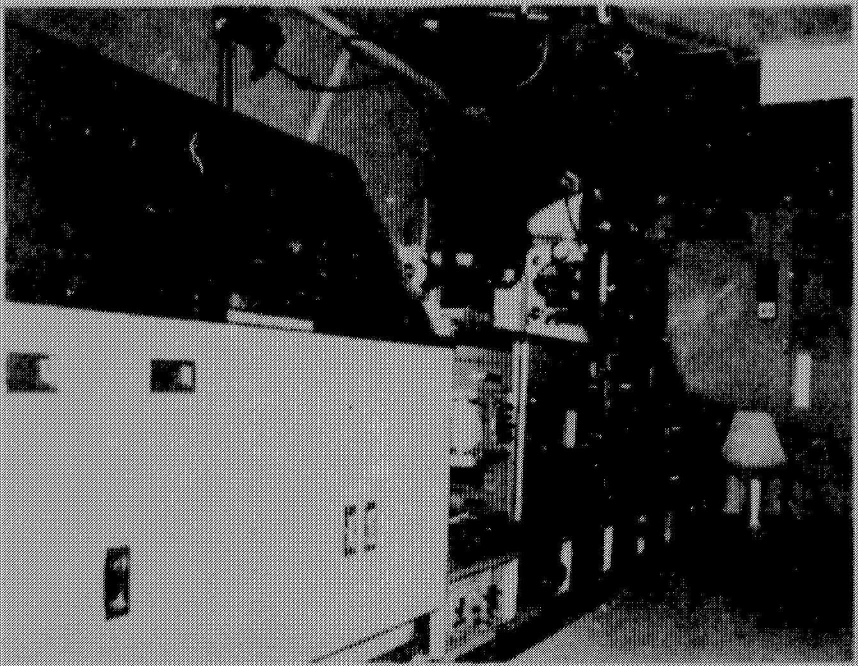

Figure 4. Bench top skid configuration with fume hood, bearing test fixture, and microscope.

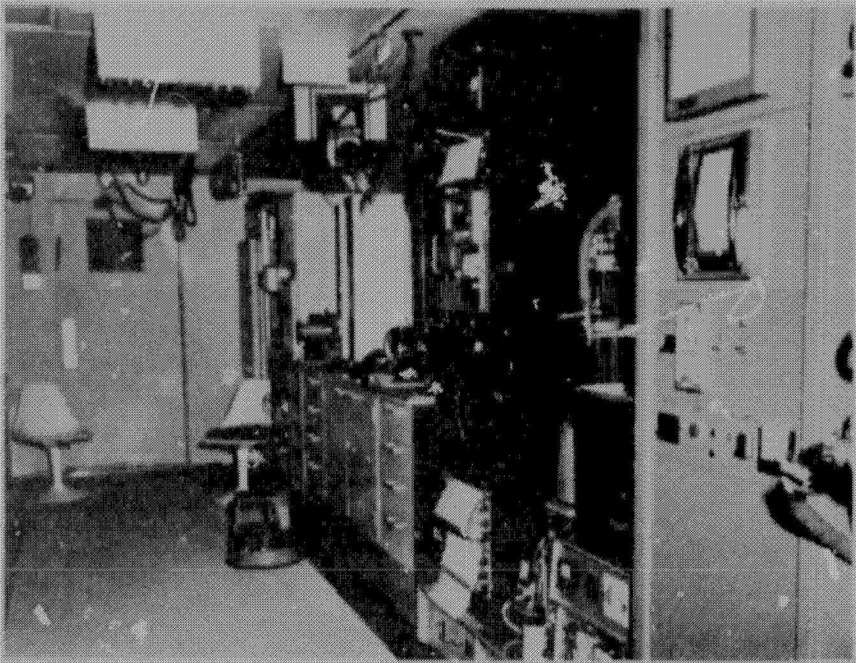

Figure 5. Skid in both bench top and direct equipment mounting configurations.

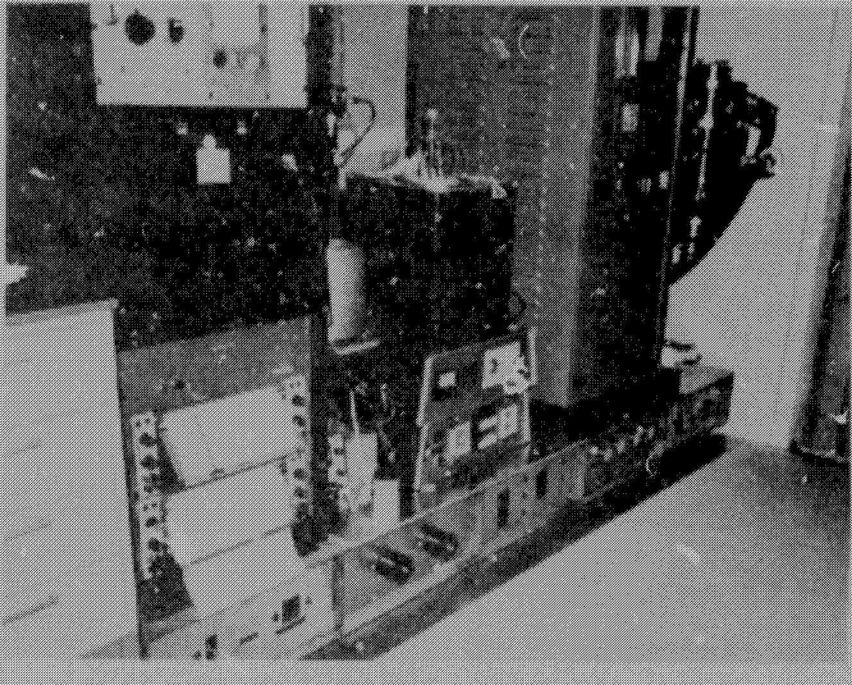

Figure 6. Basic skid mounted with relay rack, crucible, eutectic, and high temperature furnaces.

Figure 7. CVT Test IV crew (left to right) Carolyn Griner, Doris Chandler, Ann Whitaker, and Mary Helen Johnston.

Figure 8 shows the GPL equipment layout. This arrangement utilizes the aisle concept with the characterization equipment placed at optimum locations for all experimenters. During the test all experiment hardware performed well, although some repair of peripheral equipment by the crew was required.

F. Experiment-Facility Interaction

Previous multidiscipline tests in the GPL facility had reflected the mechanical and electrical interaction between the experiment hardware and the facility itself. Specifically in the materials science experiments, the amount of vibration through the facility structure was evident in the molten materials. Various causes of vibratory excitation were crew movement, opening and closing of storage areas, and motion of the PI in the immediate area around her experiment. The furnaces used in the materials science experiment did, in fact, thermally load the facility. The internal temperature of the GPL increased to the top end of the comfort level.

TABLE 1. MATERIAL SCIENCE PAYLOAD MAJOR EQUIPMENT HARDWARE

Experiment	Principal Equipment Hardware
Infiltration Sintering, 101A	Infiltration furnace, microhardness tester, Zeiss microscope, macrotome saw, Buehler microetcher
Liquid Phase Sintering, 102A	Astro high temperature graphite furnace, other equipment same as in 101A
Eutectics-Magnetic Materials, 102A	Eutectic furnace, other equipment same as in 101A
Eutectics-Optical Materials, 102B	McPherson optical system, other equipment same as in 102A
Casting, 103	Molds, cyclohexanol, camera
Undercooling of Materials, 104	Lindbergh crucible furnace, Universal testing machine, other equipment same as in 101A
Diffusion Coefficient in Glasses, 105	Astro high temperature graphite furnace and control system
Oxide Glasses, 106	Artcore furnace with controller
Study and Use of Ferrofluids, 107	Journal bearing, Brookfield viscometer
Zone Purification, 108	Fisher zone purifier for organics, McPherson optical system

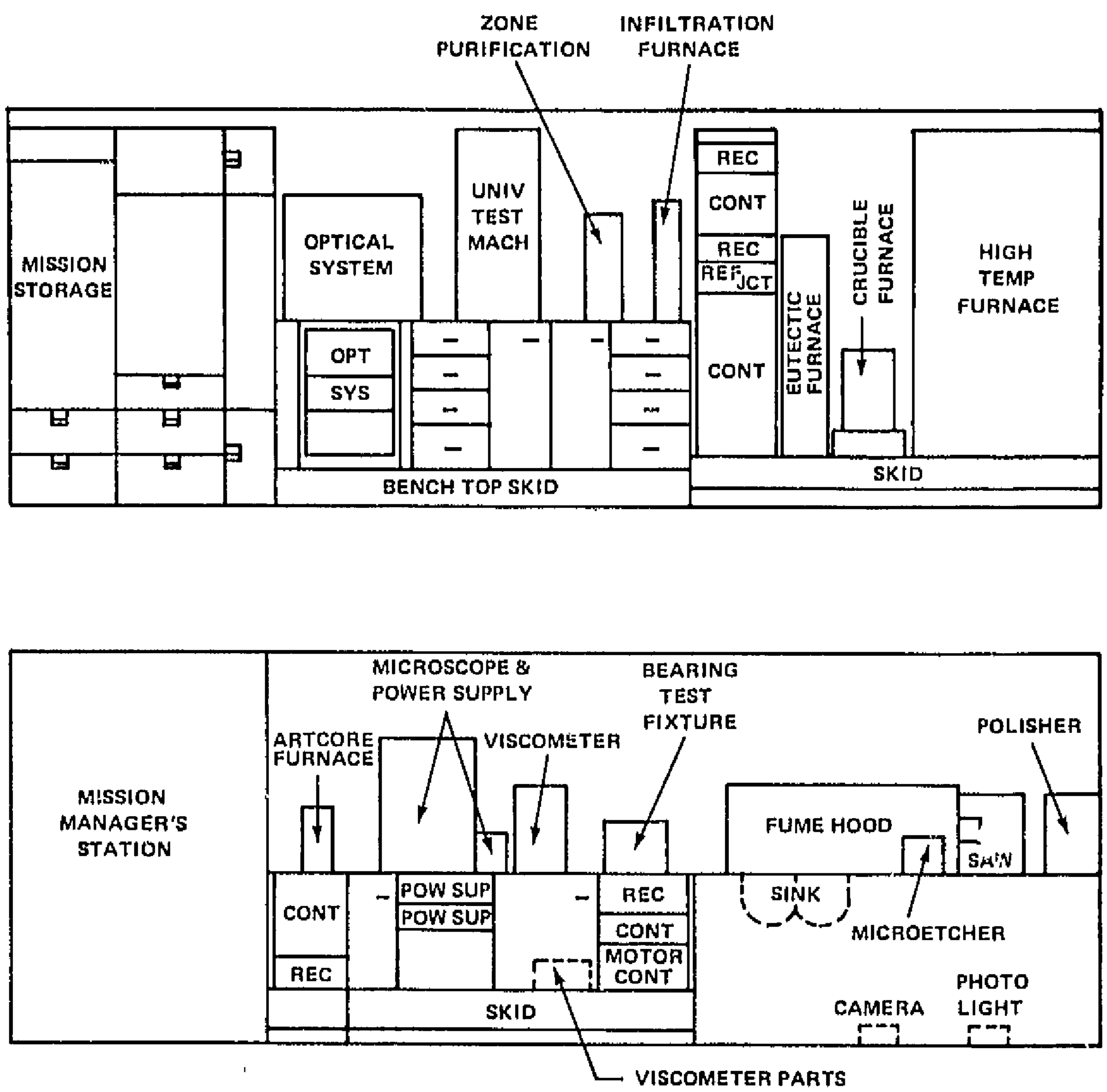

Figure 8. GPL equipment layout.

Test IV, the dedicated materials science payload, was again plagued by the vibration problem. An isolation pad had been placed in the crew walkway, but vibrations still travelled through the structure, skids, and experiment hardware. Levels up to 0.5 g were measured at the experiment interfaces. A redesign of the support structure may be necessary.

The high temperature furnaces did not significantly affect the environment of the GPL. Temperatures of 20° to 24°C (68° to 75°F) were maintained. It should be noted that this GPL II had a higher capacity environmental control system than the GPL I used in the previous tests.

The single most important integration factor for any scientific payload is the data acquisition, storage and retrieval system. Earlier CVT tests had not used a common data system for the materials science experiments. Interface information to evaluate Spacelab payload requirements was needed for space processing payloads and to this end the data system available was tied into the experiment hardware. During the pretest integration phase, it became apparent that the needs of this type payload differed considerably from that of astronomy or biological payloads. Materials processing requires lower data rates and higher accuracy than was available. Discrete temperature measurements in nonzeroed ranges were required and proved to be almost unattainable. The data system was disconnected from the experiment systems during the second day of test. Electrical grounding problems were adversely affecting experiment data. Strip chart recorders already onboard as part of the experiment hardware were then used exclusively for data acquisition. The data loss was not extensive enough to obviate the mission experiment objectives.

Although the data system was not used to its fullest extent, the possible implication of data loss to Spacelab missions was a significant result of CVT Test IV.

G. PI-Mission Interaction

Previous singular experiments in materials science in the GPL were run with and without the PI being present. During the test period, the experiment emphasis was changed based on concurrent characterization of the processed samples. The mission timeline for these experiments changed to reflect experiment-PI interaction. This did not impact the mission and, in fact, it afforded an opportunity for the PI to obtain more data within the mission schedule.

The concept of onboard PI-mission interaction and onboard characterization was utilized in Test IV. A core of laboratory characterization equipment was assembled by the PI's for use by the entire scientific crew. The PI onboard was able to react dynamically to an experiment to refine and more fully explore results during the test week.

Some changes in the mission timeline were made real-time by the PI without impacting the attainment of scientific objectives. Using this approach, the maximum amount of scientific information was gleaned from the experiments.

The value of the well trained scientist crew was emphasized during Test IV. Several minor equipment malfunctions occurred during test week that were repaired onboard by the respective PI. At least two experiments would have been lost by Day 2 of the mission if it had not been for the fact that the crew was extremely knowledgeable concerning their experiment hardware as well as the science to be obtained from them.

II. TEST IVA

A. Introduction

A follow-up test designated CVT Test IVA was conducted in November 1975. The purpose of this test was to repeat Test IV experiments with a crew composed of selected and trained scientists. These personnel were not required to have prior knowledge of the materials science disciplines but were required to have basic knowledge of science and the scientific method.

B. Crew Selection and Training

Eight potential crewpersons were selected from a volunteer complement employed by NASA/MSFC. The initial screening was completed on a computer, matching requirements established by the PI to the qualifications of the applicants. The PI selected six people for interviews and final selection. The remaining two candidates were allotted for the mission specialist position.

All six personnel were concurrently trained in multiple sessions by the PI. The basic scientific background and experiment specifics were given in approximately three to six sessions. "Hands-on" training with the experiment hardware in the laboratory was emphasized. At the end of the basic training period, a 1-day simulation run of a mission timeline was made. The six trainees were assigned to one of two "crews" for the simulation run. The crews were observed by the PI in the Experiment Operations Center (EOC). On the basis of their performance, the flight and back-up crews were selected (Table 2).

TABLE 2. TEST IVA CREWS

FLIGHT CREW	
Mission Specialist:	John R. Levinson, EL03
Payload Specialist:	Donald B. Griner, EC32 Newton G. Tiller, EH14 James C. Bush, NA51
BACK-UP CREW	
Mission Specialist:	George H. McKay, EL32
Payload Specialist:	William L. Dowell, CP10 Catherine L. Hellmann, EL04 Norman Levine, PD34

C. Mission Performance

The crew performed satisfactorily during Test IVA. Basic experiment objectives were met within the mission timeline. It was apparent during the test that training time had been insufficient for the in-depth knowledge required of a crew member. Extensive communications with the PI in EOC were required by the Payload Specialists to evaluate experiment results. This support was almost continuously available. In a Spacelab mission, loss-of-signal time during an orbit would have seriously decreased the quantity and quality of data obtained.

Some equipment malfunctions occurred during Test IVA just as they had in Mission IV. Again, communications with the PI on the ground remedied most of these difficulties. In one instance the PI had to go onboard to clarify an equipment problem. Figures 9 and 10 show the crew of Test IVA inside the GPL during the test.

The test was considered a success by the PI's. Most experiments were completed satisfactorily. It is the opinion of the PI that more data would be obtained on an orbital mission if the PI's were the Payload Specialists. Experiment observation and real-time data evaluation by the PI could make the difference between a nominally successful experiment and a scientific discovery.

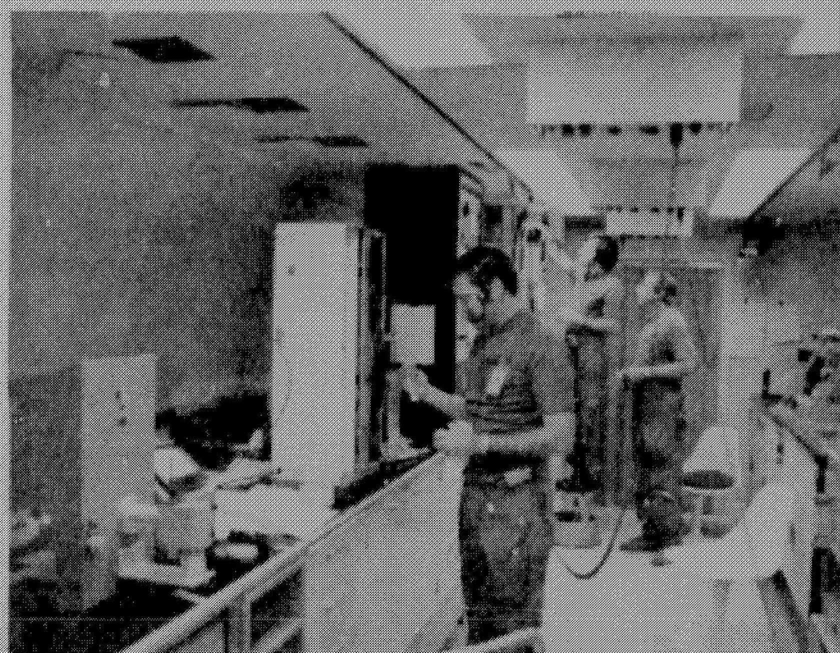

Figure 9. Test IVA payload specialists (left to right) Don Griner and Jim Bush with mission specialist George McKay.

D. Observations and Recommendations; Test IVA

One of the primary purposes of Test IVA was to evaluate the training of scientific personnel in a minimal time. It is the consensus of the PI's that the time allotted for IVA training was indeed insufficient since both PI's and the training crews had many other responsibilities independent of the CVT test. The lack of in-depth training manifested itself in such things as misuse of consumable supplies and lack of intimate knowledge of experiment hardware to facilitate repair procedures.

To improve training procedures and crew performance, the following recommendations are made:

1. Training for a mission should be a full-time assignment with the individuals relieved of all other responsibilities.

2. After initial science training with the Principal Investigator, hardware training should be given by other personnel with feedback to the PI when necessary.

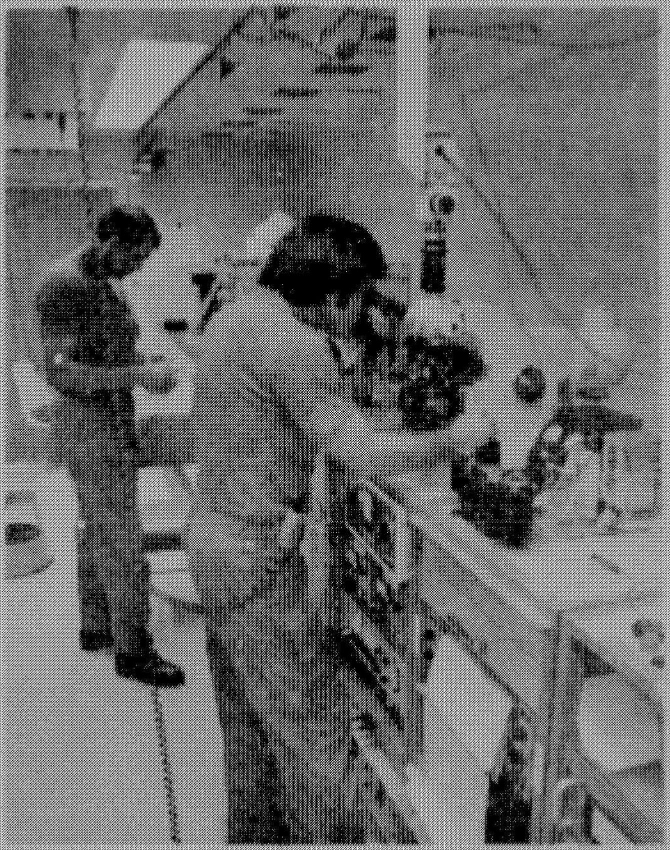

Figure 10. Test IVA payload specialists Bo Tiller and Jim Bush characterizing experiment samples.

3. A minimum 3-day simulation is necessary before a Spacelab mission to allow the crew to become comfortable in the working environment. The simulation also serves the purpose of debugging experiment hardware and operation.

4. Mission Specialist should have intimate knowledge of all experiment hardware to assist the Payload Specialist after an equipment failure.

E. Summary and Conclusions

Most of the test and experiment objectives of CVT Test IV were achieved. All scientific experiments on board were considered successful by the respective PI. Electrical interference caused by ground loops between the experiment hardware and the GPL/data system was eliminated by disconnecting the data system. The capability for multiple data recording onboard allowed successful completion of several critical experiments.

The experimenter-furnished off-the-shelf equipment performed reliably during the mission. PI familiarity with this equipment enhanced troubleshooting and repair during the mission with no impact to either mission timelines or objectives.

The mission timeline and flight plan were a useful marker for the PI for sequencing of experiments and real-time evaluation of the mission status. Timeline changes made by the PI during the mission did not adversely affect the mission in any way.

The experiment-facility integration was accomplished in minimum time, reflecting a useful concept for rapid turn around of space processing and other discipline payloads. With the exception of the data system, all interfaces functioned normally during the test sequence. Crew comments made during the mission debriefing will be used to modify and refine facility hardware.

CVT test IVA was nominally successful; however, training for Spacelab missions will have to be intensified beyond the level maintained for this test. Simulations with the experiment hardware were found to be the most beneficial training aids in preparation for the flight.

The CVT program at MSFC is an invaluable step toward cost-effective analysis of proposed spacelab payloads. Facility/experiment and person/systems integration can be accomplished with a moderate fidelity simulator. Success of future missions can be enhanced with direct interaction of the PI and Mission Specialists. The decade of the 1980's may provide through the Spacelab program the technological advances necessary to improve the Spaceship Earth.

APPROVAL

THE CONCEPT VERIFICATION TESTING OF MATERIALS SCIENCE PAYLOADS

By C. S. Griner, M. H. Johnston, and A. Whitaker

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

R. J. SCHWINGHAMER
Director, Materials and Processes Laboratory

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