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December 16, 1998

NRA-98-HEDS-05

RESEARCH ANNOUNCEMENT

Microgravity Materials Science: Research and Flight Experiment Opportunities

Letters of Intent Due: ..... January 26, 1999

Proposals Due: .... March 16, 1999

OMB Approval No. 2700-0042

MICROGRAVITY MATERIALS SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

NASA Research Announcement
Soliciting Research Proposals
for the Period Ending
March 16, 1999

NRA-98-HEDS-05
Issued: December 16, 1998

Office of Life and Microgravity Sciences and Applications
Human Exploration and Development of Space (HEDS) Enterprise
National Aeronautics and Space Administration
Washington, D.C. 20546-0001

NASA RESEARCH ANNOUNCEMENT
MICROGRAVITY MATERIALS SCIENCE:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

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NASA RESEARCH ANNOUNCEMENT

MICROGRAVITY MATERIALS SCIENCE:
RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

This NASA Research Announcement (NRA) solicits proposals for flight experiments and for ground-based experimental and theoretical microgravity research in materials science. The materials science discipline represents a broad range of research areas ranging from metals and alloys to radiation shielding materials. Descriptions of materials science research activities and interests are given in Appendix A.

Investigations selected for flight experiment definition must successfully complete a number of subsequent development steps, including NASA and external peer reviews of the proposed flight experiment, in order to be considered for a flight assignment. NASA does not guarantee that any investigation selected for definition will advance to flight experiment status. Proposals are sought for a number of upcoming flight opportunities. Investigations selected for support as ground-based research under the Microgravity Research Division (MRD) ground-based research program generally must propose again to a future solicitation in order to be selected for a flight opportunity.

Participation is open to U.S. and non-U.S. investigators and to all categories of organizations: industry, educational institutions, other nonprofit organizations, NASA centers, and other U.S. Government agencies. **Though NASA welcomes proposals from non-U.S. investigators, NASA does not fund Principal Investigators at non-U.S. institutions.** Proposals may be submitted at any time during the period ending March 16, 1999. Proposals will be evaluated by science peer reviews and engineering feasibility reviews. Late proposals will be considered if it is in the best interest of the Government.

Appendices A and B provide technical and program information applicable only to this NRA. Appendix C contains general guidelines for the preparation of proposals solicited by an NRA.

This announcement will not comprise the only invitation to submit a proposal to NASA for access to the reduced-gravity environment and is part of a planned sequence of solicitations inviting proposals in the disciplines of the microgravity program.

NASA Research Announcement Identifier:	**NRA-98-HEDS-05**
NRA Release Date:	**December 16, 1998**
Letters of Intent Due:	**January 26, 1999**
Proposals Due:	**March 16, 1999**
Selection Announcement:	**September 1999**

This NRA is available electronically and Letters of Intent should be submitted electronically via the Microgravity Research Division web page at:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address: loi@hq.nasa.gov
If electronic means are not available, you may mail Letters of Intent to the address given below.

Submit Proposals to the following address:

Dr. Michael J. Wargo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-05)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

NASA can not receive deliveries on Saturdays, Sundays or federal holidays.

Proposal Copies Required:.............15

Proposers will be notified by electronic mail confirming receipt of proposal approximately 10 working days after the proposal due date.

Obtain programmatic information about this NRA from:

Dr. Michael J. Wargo
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Selecting Official:

Director
Microgravity Research Division
Office of Life and Microgravity Sciences
  and Applications
NASA Headquarters

Your interest and cooperation in participating in this effort are appreciated.

Arnauld E. Nicogossian, M.D.
Associate Administrator for
  Life and Microgravity Sciences and Applications

APPENDIX A
NRA-98-HEDS-05

TECHNICAL DESCRIPTION

MICROGRAVITY MATERIALS SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

I. INTRODUCTION

A. BACKGROUND

The Human Exploration and Development of Space (HEDS) Enterprise, one of four National Aeronautics and Space Administration (NASA) strategic enterprises, conducts a program of basic and applied research using the reduced-gravity environment of space to improve the understanding of fundamental physical, chemical, and biological processes. The scope of the program, sponsored by the Microgravity Research Division (MRD), ranges from applied research into the effects of low gravity on the processing of various materials, to basic research that uses low gravity to create test conditions to probe the fundamental behavior of matter. This announcement is part of an ongoing effort to develop research in a specific scientific discipline, Microgravity Materials Science. The Division last released a NASA Research Announcement (NRA) for Microgravity Materials Science in 1996 and expects to continue to release NRAs in microgravity materials science every two years.

NASA has supported research in microgravity materials science for over three decades. An extensive research program supports theoretical and experimental investigations in ground-based laboratories. A number of investigations are conducted using materials science research apparatus built to take advantage of the limited low gravity test times available in ground-based facilities such as the drop tube at Marshall Space Flight Center, the drop-towers at the NASA Lewis Research Center, or NASA's parabolic low gravity flight research aircraft. These ground-based experiments, along with theoretical modeling, form the basis for most of our current understanding of the effects of gravity on materials processes and phenomena.

In the MRD program, ground-based research has been used to gain a preliminary understanding of phenomena, and to define experiments to be conducted in the extended low gravity test times available in spacecraft in low-Earth orbit. The MRD anticipates limited near-term flight opportunities for investigations capable of making use of existing hardware where no or minor modifications would be required.

The MRD is also preparing for flight opportunities using International Space Station research instruments. Several instruments are being developed to conduct materials science research that offer a wide range of experimental capabilities and diagnostics. The MRD is currently studying the development of modular research instruments that can be configured (or reconfigured) to accommodate multiple experiments and multiple users. This is envisioned as an evolutionary program with the objectives of providing experimental data in response to increasingly sophisticated science requirements and of permitting the evolution of experimental approaches and technologies as needed for scientific investigations throughout the era of the International Space Station.

This announcement is being released as part of a coordinated series of discipline-directed solicitations intended to span the range of the MRD program. Other MRD-supported solicitations planned, as is this one, for periodic release over the next several years include:

Biotechnology
Combustion Science
Fluid Physics
Fundamental Physics

B. RESEARCH ANNOUNCEMENT OBJECTIVES

This NRA has the objective of broadening and enhancing the MRD microgravity materials science program, the goals of which are described in Section II, through the solicitation of:

1. Experiment concepts which will define and utilize new instruments for space-based experiments in materials science with an emphasis on research concepts that can be accommodated by small, simple instruments;
2. Experimental studies that require the space environment to test clearly posed hypotheses, using existing or slightly modified instruments in space-based experiments to increase the understanding of materials science;
3. Ground-based theoretical and experimental studies which will lead to the definition or enhance the understanding of existing or potential flight experiments in materials science; and
4. Ground- or flight-based theoretical and experimental studies with an emphasis on research that will provide a scientific foundation for technologies required by future human space missions; specifically, to improve and experimentally test radiation transport codes needed to develop a cost-and mission-effective radiation shielding strategy, and to identify materials processing issues, and propose and test processing strategies to enable human operations on extraterrestrial surfaces such as those on the Moon or Mars using in situ resource utilization (ISRU) concepts.

Further programmatic objectives of this NRA include objectives broadly emphasized by the civil space program, including: the advancement of economically significant technologies; technology infusion into the private sector; enhancement of the diversity of participation in the space program, public education and outreach; and several objectives of specific importance to the microgravity research program. These latter objectives include the support of investigators in early stages of their careers, with the purpose of developing a community of established researchers for the International Space Station and other missions in the next 10-20 years, and the pursuit of microgravity research that shows promise of contributing to economically significant advances in technology.

In support of the HEDS Enterprise goal to "Enrich life on Earth through people living and working in space," individuals participating in the microgravity research program are encouraged to help foster the development of a scientifically informed and aware public. The microgravity research program represents an opportunity for NASA to enhance and broaden the public's understanding and appreciation of the value of research in the microgravity environment of space. Therefore, all participants in this NRA are strongly encouraged to promote general scientific literacy and public understanding of the microgravity environment and microgravity materials science through formal and/or informal education opportunities. Where appropriate, supported investigators will be required to produce, in collaboration with NASA, a plan for communicating to the public the value and importance of their work.

C. DESCRIPTION OF THE ANNOUNCEMENT

With this NRA, NASA is soliciting proposals to conduct research in microgravity materials science, with an emphasis on experimental efforts that are sufficiently mature to justify near-term flight development and are of a scale that provides sufficient flexibility to be accommodated on various research platforms. The goals of the discipline along with some identified research areas of interest are described in Section II.

Proposals describing innovative low gravity materials science research beyond that described herein are also sought.

NASA is currently developing several types of flight instruments for microgravity materials science research. Brief descriptions of the current and planned capabilities are given in Appendix B, Section I. NASA anticipates several near-term flight opportunities for investigations with requirements that can be met by existing apparatus with only minor modifications. Successful proposals for use of the existing apparatus will be funded for advanced definition studies that will produce a detailed Science Requirements Document (SRD). Authorization to proceed into flight development is contingent upon successful peer review of the experiment and SRD by both science and engineering panels. NASA does not guarantee that any experiment selected for definition that plans to use existing hardware will advance to flight experiment status.

NASA also encourages submission of experiment proposals for which none of the existing flight instruments is appropriate. NASA anticipates the development of new materials science research experiment apparatus for the International Space Station. The hardware descriptions included in Appendix B, Section I should be viewed as examples to allow researchers to consider capabilities that might meet their science requirements. However, researchers should not feel limited by these capabilities. Selected proposals requiring development of new capabilities will be funded for definition studies to determine flight experiment parameters and conditions and the appropriate flight hardware. The length of the definition phase will be based on the experiment requirements, but will normally range from 6 to 24 months and will culminate in the preparation of an SRD and and the conduct of a Science Concept Review (SCR).

Authorization to proceed into flight development is contingent upon successful peer review of the SRD by both science and engineering panels at a Requirements Definition Review (RDR). NASA does not guarantee that any experiment selected for definition which requires new instrument development will advance to flight experiment status. Investigations that do not proceed into flight development will normally be asked to submit a proposal for continuation of support at the conclusion of a typical four-year period of funding. Promising proposals which are not mature enough to allow development of a flight concept within two years of definition may be selected for support in ground-based research program. Investigations selected into the ground-based research program must generally propose again to a future announcement in order to be selected for a potential flight opportunity.

II. MICROGRAVITY MATERIALS SCIENCE RESEARCH

A. INTRODUCTION

Materials science plays a key role in virtually all aspects of the nation’s economy. While the ability to process materials to yield a given set of properties is clearly beneficial to humankind, the ability to produce a certain structure, and hence materials properties, is not yet at hand. Advances in materials science benefit a wide range of applications where materials are important as well as other areas of research which depend on advances in materials science as a basis for their continued progress. Long-duration microgravity is an important tool for establishing quantitative and predictive cause-and-effect relationships between the structure, processing, and properties of materials. Establishing, understanding and using these relationships are important elements in achieving increased international competitiveness.

The NASA microgravity materials science program currently supports research in a broad range of areas that can be categorized in two orthogonal ways. The program has previously been described in terms of the class-like behavior of materials. Using this approach, the materials systems being investigated included electronic and photonic materials, glasses and ceramics, metals and alloys, and polymers and nonlinear optical materials. Alternatively, the Materials Science Discipline Working Group (DWG), an advisory body to NASA's Microgravity Research Division (MRD), has identified research areas, classified in terms of fundamental physical and chemical phenomena, that it believes would benefit from access to long-duration, high-quality microgravity conditions. Also included in the recommended research areas are those activities that the DWG believes are required to fully realize the potential of microgravity research (e.g. process modeling, materials characterization, etc.). The recommended research areas are: (1) Thermodynamics and kinetics of phase transformation; (2) Theory, modeling and experimental control of microstructure and defect formation; (3) Interfacial phenomena; and (4) Measurement of relevant material properties. The MRD has endorsed these recommendations and each of these areas is discussed in detail in the sections which follow.

In addition to these areas of Materials Science, research in areas that support the Human Exploration and Development of Space (HEDS) are a priority. Specifically, these are: Radiation shielding appropriate for long-duration lunar or Mars missions; and the effects of gravity on the materials processes necessary to convert resources found on other bodies of the solar system into usable commodities.

B. GOALS OF THE MICROGRAVITY MATERIALS SCIENCE PROGRAM

Materials science deals with the relationships between the processing, structure, and properties of materials. The importance of materials processing lies in the understanding that the properties of most materials are dictated by the microstructure of the material, i.e. the morphology, size, spatial distribution, and chemical composition of the material's constituent phases, as well as internal defects. Thus, if the relationship between processing and microstructural development is well understood, then first-principles design of a material with desired properties can indeed be realized. This design of materials is occurring today to a limited extent by applying a fundamental understanding of materials at the atomic, molecular, mesoscopic, and macroscopic levels. Nevertheless, a fully predictive model of the relationships between processing techniques and the microstructure of a material remains an elusive goal. Microgravity offers a unique environment that can be used to extend our present understanding of materials processing in ways which are not possible in terrestrial laboratories.

The Microgravity Materials Science Program is part of NASA's Human Exploration and Development of Space (HEDS) Enterprise. The primary goal of the Microgravity Materials Science Program supporting basic and applied research within HEDS is to:

- Use microgravity to establish and improve quantitative and predictive relationships between the processing, structure and properties of materials.

Two other Microgravity Materials Science Program goals relate to supporting the exploration aspects of NASA's HEDS Enterprise. They are:

- Improve and experimentally test radiation transport codes needed to develop a cost and mission effective radiation shielding material/concept to protect a crew for one year in transit to/from and on the surface of the Moon/Mars.
- Identify materials processing issues and propose/test processing strategies to enable human operations on the surface of the Moon/Mars using In Situ Resource Utilization concepts.

Many of the techniques used to process materials are strongly influenced by the presence of a gravitational field. For example, during the formation of a solid phase from a fluid, as is the case during crystal growth and solidification, gravitationally driven convection of the fluid is probable. This fluid flow can alter the spatial distribution of impurities in the liquid and resulting solid, induce structural defects in the crystal, and, due to the complexity of the flows which are possible, make the results of crystal growth and solidification experiments performed on earth difficult to interpret. The presence of a gravitational field also can lead to sedimentation when two phases have different densities and at least one phase is a fluid. This sedimentation can lead to unwanted coagulation of the minority phase, as is the case during phase separation in certain polymer blends and in the colloidal processing of ceramics.

A microgravity environment thus offers new opportunities to develop a deeper understanding of the relationships between many materials processing techniques and the resultant microstructures and materials properties. As the magnitude of the gravitationally induced body force is much lower, the convective flow of fluids can be greatly reduced, thus permitting a more precise control of the phase transformation. In addition, gravitationally induced sedimentation, hydrostatic pressure, and deformation can be greatly reduced. Non-contacting forces such as those developed by acoustic, electromagnetic, and electrostatic fields can be used to position unconfined specimens and thus reduce the contamination of reactive melts. Finally, experiments performed in a microgravity environment will allow phenomena that are usually masked by the presence of gravity to be studied rigorously.

The technological applications of importance to this discipline are quite broad. They range from directional solidification and crystal growth to the production of ceramic powders. The Materials Science DWG's recommendation for the key elements of the supporting scientific knowledge base underpinning these process technologies are (listed in descending priority):

1. Thermodynamics and kinetics of phase transformations (e.g., mechanisms of phase selection, oriented amorphous materials, and crystallization of amorphous materials)
2. Theory, modeling and control of microstructure and defect formation (e.g., studies of morphological evolution, growth-induced defect formation, aerogels and foams, colloidal and sol-gel processing)
3. Interfacial phenomena (e.g., wetting behavior, self-assembly mechanisms)

Along with the knowledge base, a database provided by the quantitative measurement of relevant thermophysical properties is of high priority. These data are of paramount importance for precise modeling and interpretation of experimental phenomena.

It should be noted that this list is not intended to be fully inclusive. Section C includes many more specific examples in each category. There are also topics sufficiently broad as to be included in all of the above categories. These include understanding the processes involved in producing novel materials and developing unique technologies supporting low-gravity experiments and practical aspects of materials processing. In addition, research in each of these broad categories is relevant to the program only insofar as microgravity is necessary for the successful completion of the research, or is in support of experiments performed in microgravity.

The objectives of the basic and applied research aspects of the microgravity materials science research program are:

2. to advance the scientific understanding of materials processes affected by gravity,
3. to use low-gravity experiments for insight into the basic mechanisms of materials processes,
4. to provide the scientific knowledge needed to improve these processes,
5. to contribute to the understanding and performance of Earth-based systems that depend on materials science, and
6. to develop unique technologies specifically supporting low-gravity experiments and materials science.

C. AREAS OF RESEARCH RECOMMENDED BY THE MATERIALS SCIENCE DISCIPLINE WORKING GROUP

1. Nucleation and Metastable States

In order for a material to transform to a more ordered phase (vapor to liquid or solid, and liquid to solid), it is necessary to first form an aggregate or cluster of molecules above a critical size to initiate the process. Such an aggregate may form on a foreign surface, such as a container wall or an inclusion (heterogeneous nucleation), or may form spontaneously from random internal fluctuations (homogeneous nucleation). Homogeneous nucleation can occur only if the melt or vapor is cooled well below its normal phase transformation temperature without solidifying. Heterogeneous nucleation will almost always occur first if there are any impurities that can act as nucleation sites. Understanding and being able to control nucleation is extremely important in materials processing.

For example, if it is desired to produce a fine grained casting, one would try to produce a very large number of nuclei and distribute them randomly throughout the melt. Gravity-driven convection plays an important role in this process as was demonstrated both on earth and in a series of experiments conducted under reduced gravity conditions using sounding rockets. This is an example of how microgravity experiments may be used to elucidate the essential features of a process and to suggest better control strategies for use on earth, in this case by enhancing convection or artificially stirring the melt.

On the other hand, it is often desirable to suppress nucleation in order to be able to cool a melt to a temperature well below its normal freezing point. Solidification of deeply undercooled melts is usually initiated by a single type of nucleation site, is very rapid and yields a crystal grain density that is related to the number of nucleation sites. Rapid solidification can produce an extremely fine microstructure with enhanced mechanical properties. If the solidification is rapid enough, the atoms simply do not have time to arrange themselves in their lower energy or equilibrium configuration and metastable crystalline or amorphous phases can be produced. Because metastable phases are less stable than equilibrium phases, they have a lower melting temperature, compared to the stable phase. Metastable phase formation therefore requires the undercooled liquid to exist below the reduced melting temperature. A metastable phase can have a different crystalline structure than the stable equilibrium phase, and this can greatly alter its physical properties. Alternatively, it can represent the stable phase structure, but have a high supersaturation of alloying solute elements. Perhaps the best known example of a metastable crystalline phase is diamond, which is the metastable phase of carbon. Graphite is the equilibrium phase.

Another example of a metastable state is an amorphous phase. It may be thought of as a liquid structure, which lacks long-range crystalline order, frozen in place. Glass is an example of an amorphous solid. Amorphous materials are highly resistant to chemical attack because there are no crystalline grain boundaries, sites which are particularly susceptible to chemical reactions. Similar amorphous structures can be achieved in some metallic alloys by rapid solidification. One example is ‘Metglas’ which consists mainly of iron and boron. The absence of grain structure makes it extremely easy to magnetize and demagnetize with very little hysteresis loss, thus making it very useful in transformer cores where it is three times more efficient than the conventional iron-silicon core material. Contrast this with the new iron-boron-neodymium magnet material which is an extremely good permanent magnet because its fine grain structure tends to pin the magnetic domains and prevent demagnetization. These examples demonstrate how crucially the physical properties of a material depend on its microstructure.

Moreover, the recent discovery of bulk glass forming alloys has led to a resurgence of interest in metallic glasses. The bulk glass forming systems are multicomponent alloys such as Zr-Al-Cu-Ni that form amorphous structures at low cooling rates (i.e. <100(C/s) in sizes of several cubic centimeters. The new bulk glasses have unique elastic properties, exceptionally low sliding friction coefficients, and offer the capability to form composites with certain crystalline reinforcements. Due to the large separation between the glass transition and the crystallization onset these materials may be readily formed into net shapes by molding processes. They have also been shown to act as excellent precursors for the development of microstructures with a high density of nanocrystals, which can provide extraordinarily high strength in Al-base systems, and both soft and hard magnetic properties in Fe-base systems. This is a good example of how a continued study of undercooling behavior has resulted in a new perspective. In effect, the discovery of bulk glass forming alloy systems has changed the rules of glass formation and has lead to rapid commercialization of this discovery.

The recent work on bulk metallic glass formation has also opened up new issues concerning liquid structure in highly undercooled systems. For example, in multicomponent systems there is evidence for liquid phase separation reactions in the undercooled state and an indication that the phase separation influences the development of crystallization. The new perspectives on glass formation also challenge the fundamental understanding of viscous behavior (e.g., strong vs. fragile characteristics) and the atomic level interpretation of transport in liquids. Similarly, other work on the containerless processing of undercooled melts in systems forming quasicrystals has pointed to the importance of polytetrahedral-short range order in understanding liquid structure. Recent reports of magnetic behavior in Co-Pd melts at extremely large undercooling (i.e., hypercooling) are also intriguing.

The ability to melt and solidify specimens without a container removes a major source of impurities and heterogeneous nucleation sites, thus permitting very large undercooling to be achieved. On Earth, this can be accomplished for small samples by levitating and melting them electromagnetically, electrostatically or by dropping small molten droplets through a long evacuated tube and allowing them to solidify during free-fall.

These techniques have been used extensively but have limitations. It is not possible to control the heating and levitating force independently in an electromagnetic levitator because of simultaneous electromagnetic heating. Use of a quench gas to cool the sample seems to introduce surface nucleation in some cases. There is also some evidence that flows in the melt driven by the induced currents may induce nucleation and limit the amount of undercooling. These difficulties can be overcome in a drop tube, but it is difficult to observe the droplet continuously as it cools in order to make accurate temperature measurements. Also, the sample size and the amount of undercooling are limited by the time available for the fall. However, within these conditions there have been a number of recent advances in undercooled melt solidification from ground-based drop tube studies. These include a comprehensive analysis of phase selection in undercooled Fe-Ni alloys, the identification of a metastable ferromagnetic phase in Mn-Al alloys, and the development of a statistical analysis for nucleation kinetics behavior.

In reduced gravity, the sample may be electromagnetically positioned by a much lower induced current or may even be allowed to float freely. This decouples the heating from the levitation and reduces the amount of stirring in the melt. The temperature may be measured optically during the cooling and solidification process and thermophysical properties such as specific heat, heat of fusion, viscosity, surface energy and thermal diffusivity can be inferred. The recent availability of several flight opportunities as well as new experimental and measurement capability afforded by the TEMPUS (electromagnetic levitation furnace and diagnostics) facility has confirmed the advantages of microgravity operation and has allowed for new measurements of growth kinetics, statistical analysis of nucleation kinetics and measurements of thermophysical properties over a wide undercooling range. The results of this work have yielded an impressive knowledge database.

Another alternate method for the containerless processing of undercooled melts and supersaturated solutions is based upon the use of electrostatic fields much like in the classical Millikan oil-drop experiment. This technique offers the potential advantage of achieving a quiescent metastable liquid as well as inducing controlled perturbations, which have been demonstrated to be useful for the measurement of thermophysical properties such as viscosity and surface energy. In low temperature systems, the capability to process fine droplets without a container can be used to advantage in nucleation studies for both aqueous and polymeric solutions. In multicomponent systems, nucleation sequences can be examined where an initial heterogeneous primary nucleation may catalyze or inhibit the nucleation of a secondary phase. For polymeric systems the geometric confinement imposed by the limited droplet size limits on earth can be removed in microgravity, so that the development of large polymer chains in aerosols can be examined without interference. The experience base on electrostatic containerless processing is growing, and further uses to study basic materials behavior may be expected.

Containerless processing techniques including drop tube and levitation methods have been demonstrated to be most effective in providing melts with a very large undercooling potential, which are essential for the examination of nucleation and metastable phases. These methods have also provided critical conditions for related areas. For example, for some time, the common observation of an abrupt decrease in equiaxed grain size at a critical undercooling was an intriguing, but not understood behavior. A number of possible mechanisms for the behavior were proposed involving special nucleation processes, but these were not experimentally confirmed. However, an elegant model based upon a dendrite instability was recently developed and supported by experimental studies of dendrite growth behavior. Similarly, nucleation kinetics studies on levitated Zr and bulk glass forming alloys under carefully controlled environments have shown the undercooling potential and glass formation in these systems is very sensitive to oxygen content. This is a good example of how the study of undercooled melt solidification over a wide range of undercooling enhances the understanding and predictive capability for microstructure development.

It is apparent that continued experiments on the factors that limit the degree of undercooling, such as the degree of superheat required to dissolve or evaporate potential nucleation sites, the use of fluxing agents to remove impurities and prevent oxidation, and the effects of stirring and other process variables on nucleation are valuable. A further emphasis of research should be on how phase selection controls metastable and amorphous phase formation including the determination of the metastable and amorphous phase properties. It should also be possible to perform critical tests to evaluate various nucleation models and develop improved analysis of nucleation behavior.

Nearly all commercial glass products are formed from high temperature melts (liquids), so it is important to possess both good scientific knowledge for such melts in much the same way as similar knowledge is valuable for metallic melts. Most importantly, the ability to form a glass from a high melting point liquid is controlled by the ability to prevent or control crystal nucleation and growth during cooling. Microgravity offers unique opportunities to investigate the properties and processing of high temperature glass forming melts and their crystallization behavior, for which there is only limited knowledge at this time because of problems directly dependent on gravity. Better understanding of fundamental scientific phenomena such as nucleation/crystallization, mass transport (diffusion), separation of immiscible liquids, and surface tension/segregation forces is possible in microgravity. Microgravity eliminates problems caused by thermally driven convection occurring in fluid (viscosity < 1 Pa.s) melts in one-g that limit our ability to acquire precise and accurate data.

Polymeric materials are unique in the sense that they form two distinct architectural classes: those that can crystallize (semicrystalline) and those that cannot (amorphous) due to the lack of stereoregularity in their backbone. Solidification of a polymer melt leads to a nonequilibrium state due to freezing in of strained polymer chain conformations. This traps "free-volume". As the temperature approaches the glass transition temperature, T_g, rotation about bonds begins and diffusion and aggregation of free-volume occurs leading to "physical aging". As polymers age their mechanical and electrical properties may change substantially. A more detailed understanding of the effects of microgravity on the nucleation of free volume and, on the aging process in general would be beneficial in predicting the long term macroscopic properties of these polymeric materials. Molecular modeling of microstructural changes which occur near T_g in a microgravity environment would provide an additional dimension from which to understand and perhaps predict the change in macroscopic properties with aging.

In the case of a stereoregular polymer melt the onset of nucleation and crystal growth will depend on the molecular weight of the polymer chains, their diffusion coefficient and the extent of undercooling which occurs. Convection currents which lead to density fluctuations within the melt perturbs the distribution of nuclei.

2. Prediction and Control of Microstructure (including pattern formation and morphological stability)

The microstructure developed during the solidification process plays a crucial role in determining the properties of a material. Since different microstructures can be developed in a given material by changing processing conditions, it is important to understand how the changes in processing conditions influence the fundamental physics of microstructure formation. This knowledge is required for the design of processing conditions to develop a specific microstructure that gives optimal properties to the material. A proper design of microstructure involves the selection of stable or metastable phases and the appropriate morphology of the selected phase. Thus, understanding of the fundamental physics and chemistry that control the selection of phases as well as microstructures is critical to improving our ability to tailor microstructures to obtain optimal properties in a given material.

The primary solidification processing variables are the growth rate at which the freezing takes place and the temperature profile in the region near the solid/melt interface. The best control of these variables is achieved by the process of directional solidification in which the material is solidified in one direction under known conditions of growth rate and temperature gradient. Such a directional solidification process is present in many industrial processes such as directional freezing of cast turbine blades, welding of alloys and Bridgman growth of electronic materials. By changing growth conditions, it is possible to solidify a given alloy with a planar, cellular or dendritic interface of a single phase, or a eutectic or layered structure of a two-phases. The microstructure selection is controlled by the relative partitioning of the available driving force into thermal/mass transport effects and interface energy effects as the growth conditions change. Quantitative understanding of this partitioning effect is difficult to evaluate terrestrially since the thermal and mass transport in the liquid occurs by both the diffusive and convective modes of transport. Although there has been significant recent progress in modeling the development of microstructures during solidification, the role of convection is still poorly understood. To a large extent, this is due to the inability of theoretical models to quantitatively account for convective effects whereas earth-based experiments cannot avoid them. Microgravity experiments provide a unique opportunity to quantitatively understand the fundamental interaction between diffusive transport phenomena and interface energy effects, and thus allow the precise correlation of these interactions with the development of different phases and microstructures.

Some critical, unresolved theoretical problems in microstructure selection are to understand the role of processing conditions in: (1) selection of stable or metastable phases, in which both the nucleation and the growth play important roles, (2) interface pattern evolution producing planar, cellular, dendritic, eutectic or layered microstructures in a given alloy, and (3) development of scaling laws which quantitatively relate the microstructural length scales with processing conditions. These characteristic scales, for a given phase and given microstructure, are related to the mechanical properties of the material.

Theoretical models have predicted that the anisotropy of the crystal-melt interface energy, as well as the value itself, plays a crucial role in the selection of microstructures. Experimental studies carried out terrestrially have not been able to quantitatively establish the role of anisotropy because of the presence of convection effects. Convective flows are unavoidable in Earth's gravity since density gradients due to lateral thermal and solute gradients cause convective motion of the fluid, making it impossible to test and refine the existing theoretical models and to quantify the importance of convective effects in ground-based solidification processing.

The solidification conditions in most welding and casting processes give rise to a cellular or dendritic interface which is characterized by a significant segregation of solute in the solidified material. This is due to the solute content in the cell or dendrite being much lower than the mean solute composition causing the intercellular or interdendritic region to become richer in solute. The region in which solid cells and dendrites coexist with the surrounding liquid is called “the mushy zone.” When the last liquid finally solidifies, a complex pattern of solute remains which controls the properties of the material. In addition, the solute concentration in the mushy zone can become large enough to form a nonequilibrium phase (for a given alloy composition) which is often an intermetallic compound that can significantly alter the mechanical properties of the material. Through proper understanding of the correlation between microstructure formation and processing conditions, it would be possible to avoid undesirable phases and obtain an optimum microstructure for a given processing technique.

Through the control of processing conditions, two-phase coupled growth of eutectic can be obtained with a structure consisting of regularly spaced rods of one phase embedded in the other, or alternating lamellae of the two phases. Eutectic structures show superior mechanical properties because of their finer microstructural scale. In addition, the zero freezing range of eutectic alloys gives them excellent fluidity so that eutectic alloys are used as casting, soldering and brazing materials. Another important example of two-phase growth occurs in peritectic systems in which a variety of two phase microstructures can be developed. These include the formation of (a) a banded structure in which alternating layers of the phases form perpendicular to the growth direction, (b) two-phase cooperative growth, and (c) nucleation of the peritectic phase ahead of the primary solid phase- liquid interface. These microstructures in peritectic systems form under complex growth conditions in which both the dynamics of nucleation at or ahead of the moving boundary and the growth competition between the two phases need to be considered simultaneously to predict non-steady-state microstructural evolution. In addition, convection effects have been found to give rise to a new class of microstructures in peritectic systems so that microgravity experiments provide an opportunity to establish the critical roles of dynamic nucleation at a moving boundary and the competitive growth of the two phases in the microstructure selection process.

One of the crucial aspects of microstructure evolution is the selection of specific microstructure as well as the selection of specific periodicity of that microstructure. The selection process generally occurs dynamically during the growth process. Theoretical models of dynamical microstructure evolution are thus crucial to our understanding of the physics of the selection process. Mathematical techniques, such as the phase-field technique, need to be developed and applied to the complex time-dependent pattern formation process.

When solid and liquid or gaseous phases coexist for some time, microstructure changes can occur such that larger particles will grow at the expense of smaller ones so as to lower the free energy of a system by reducing the total surface energy. This effect, known as Ostwald ripening or microstructural coarsening, is important in the time evolution of microstructures under operating conditions, and in the sintering of fine particles. There is also a large class of industrially important dispersion-hardened alloys in which extremely small particles are either added to or caused to precipitate from the melt during solidification. Since the strengthening effect of the dispersed particles diminishes as their size increases, the coarsening process must be understood and controlled. The process of coarsening requires mass transport which can be influenced by gravitationally induced flow of liquid between particles, or settling of particles in the solid plus liquid or vapor phase. In extreme cases, liquid flow in the two-phase zone can lead to transport of solid fragments over large distances. Microgravity experiments provide a unique opportunity to understand the coarsening phenomenon through the suppression of convective and sedimentation effects.

Many industrial processes in polymer production rely on processing polymer particles or aggregates dispersed in a solvent matrix. Layering or stratification of polymer and solvent occurs on the ground because of gravitational effects. This leads to anisotropic properties in the final product. Conducting experiments in a microgravity environment would eliminate stratification and lead to a better understanding of fundamental processes involved. The comparison between the properties of material processed in 1-g and in low-gravity will help to establish quantitative relationships between stratification effects and anisotropy.

Most high technology polycrystalline ceramics are sintered or densified assemblages of small single crystal particles. The densification occurs to minimize the high surface energy associated with the small particles. Both isolated particles and systems of particles tend to adopt configurations that minimize surface energy, e.g., coarse particle size and, in anisotropic systems, faceted particle shape. Both the nature of the minimum energy state and the pathway by which it is achieved are important topics for study. From a technology standpoint, both faceting and coarsening can be viewed as undesirable processes during sintering, because both can reduce the amount of energy stored in a powder without causing densification. Monitoring the evolution of particle size and shape offers the opportunity to gain direct information regarding the mechanism(s) responsible for their change and the relative importance of the different mass transport paths: vapor phase, grain boundary, and volume diffusion.

The study of coarsening and faceting of dispersed or loosely agglomerated particles in microgravity offers the opportunity of obtaining a much better understanding of these two processes that are so essential to the technological production of crystalline ceramics. While neither the transport mechanisms nor the driving force involve gravity directly, working in a one-g field can complicate the experimental investigation of such phenomena. Single particles will always be in contact with a substrate. This leads to additional technical issues including chemical reactivity, frictional drag, and morphology of the contact point. In one-g, studying systems of particles effectively requires working with powder compacts due to the need for mechanical stability. This restricts the range of variables that are accessible. For example, it may be desirable to work with low number densities of particles that are not fully connected in order to test deviations from mean field models. In addition, the contiguity and connectedness of the particles may strongly influence growth and faceting processes. Furthermore, morphologies produced at particle contacts by a balance of surface energy can obscure that which would otherwise be dominated by surface energy.

Ceramic processing science has progressed little beyond the needs of traditional ceramics. Yet the emergence of new and improved technologies hinge critically on rational improvements in wet (or suspension) processing of ceramic powders. Previous research in ceramics has focused on model systems consisting of single phase, monosized ceramic particles. However, real systems are complex in which multiphase particles with engineered size distribution (bimodal or trimodal) may be present. The microgravity environment provides an opportunity to study these complex systems, since density-driven phase separation and/or particle size-induced segregation effects can be minimized.

Microgravity conditions also offer the possibility for producing composite structures which are not possible or easily obtainable on earth. Of particular interest are ceramic-metal or other composites consisting of phases of widely differing density, and composites which consist of discrete areas of a second phase contained within a major phase. In the first case, approaches to fabricating metal-ceramic composites on earth are restricted by density differences and thus segregation of phases during fabrication. For example, efforts to impregnate ceramic preforms or to mix ceramic and metal powders or other precursors are impeded by problems associated with ceramic preforms floating to the surface and metal phases being non-uniformly distributed. Processing approaches which allow uniform mixtures to be prepared on Earth and heat-treated under microgravity conditions should allow the formation of layered ceramic-metal mixtures, uniform interconnecting two-phase structures, or homogeneous particulate-reinforced structure. The removal of gravity effect on phase segregation will allow wetting interactions between the two or more phases to be more clearly understood.

In addition, a uniform mixing of whiskers or other second phase particles with ceramic powders to produce composites can be achieved under microgravity conditions. Although aggregation of particles can occur under microgravity conditions, the clusters will not settle. Thus, it is possible to grow clusters of certain sizes and make layered structures under microgravity conditions.

Combustion synthesis of ceramics generates high temperatures at and ahead of the reaction front. These high temperatures generate liquids and possibly gases which are subject to gravity-driven flow. The removal of such gravitational effects is likely to provide increased control of the microstructure of the synthesized ceramic products. Experiments need to be developed to determine the role that gravity (and lack of gravitational forces) plays in the synthesis process.

Polymeric materials form unique microstructures such as foams when they are prepared from volatile solvents. Polymer foams have good mechanical and thermal properties (e.g., expanded polystyrene) and have a very low dielectric constant. Hence they have attracted much interest recently in the microelectronics industry. Issues of sedimentation, bubble uniformity and distribution are critical to the performance of these materials and space experiments could provide strategies for optimization of properties. Recent reports of processing of homopolymers from supercritical fluids (carbon dioxide) have been encouraging and represent an environmentally safe process where microgravity could also have an effect.

3. Phase Separation and Interfacial Phenomena

Another class of polyphase materials of interest to microgravity materials science research is the monotectic systems, characterized by a region of liquid phase immiscibility. For a range of compositions, the melt of such systems will separate into two immiscible liquids as the temperature is lowered. The two liquids may form initially as a fine dispersion of one phase in the other, a potentially good starting point for a useful microstructure. However, when these materials are solidified, it is normally found that the liquids have formed much less desirable large agglomerates. If this agglomeration process could be understood and controlled, a range of useful materials might result.

Sedimentation is the most obvious effect causing agglomeration of dispersed liquids. Since the two liquids of a monotectic system are always of different composition, they will invariably have different densities. In Earth's gravity, the two liquid phases will stratify before they can be frozen, resulting in a highly segregated solid. It was once believed that if this buoyancy-driven sedimentation could be avoided by solidifying such systems in microgravity, a fine dispersion of one phase in the other would be produced. However, attempts to accomplish this have been only partially successful, indicating that effects other than gravity also lead to separation of the two liquid phases. An extensive series of ground and space experiments, using transparent organic systems having similar monotectic phase diagrams, and which can also be made neutral buoyant, has revealed phenomena which occur when gravitationally-induced segregation is relatively unimportant. These experiments uncovered a rich variety of phenomena driven by interfacial energy.

A clear example of the dominating influence of interfacial energy effects occurs in monotectic alloy systems as the temperature falls below the critical temperature at which liquid phase separation first occurs. Over a limited range of temperature below the critical value, one of the liquids exhibits "perfect wetting" behavior, encapsulating the other liquid and coating any container. If final freezing occurs within this temperature range, massive segregation is produced. Alternatively, if final solidification occurs via the monotectic reaction, below the perfect wetting temperature range, a well aligned two-phase structure with a uniform spacing between phases may be achieved in a directional growth process. Regularity of the structure requires that flows driven by the temperature and composition dependence of surface energy be suppressed. The minority liquid phase may form droplets which migrate in a gradient of temperature or composition. Because larger droplets move faster than smaller ones, the latter will be overtaken and engulfed. Eventually, all of the minority phase is therefore segregated into a few large droplets. In fact, depending on the alloy system, thermal gradients as small as one (1) Kelvin per centimeter in low gravity can have the same effect as Earth gravity in causing massive segregation.

The temperature and composition dependence of surface energy may also cause mixing in single-phase liquids. Convective flows driven by surface energy forces can be similar in magnitude or even greater than those induced by gravity. When temperature gradients are large, such as in welding, these flows can be very rapid, and their quantitative understanding is critical for modeling the shape of weld pools. Surface tension is a function of both temperature and composition, so that a gradient in either will drive flows. Fluid flow driven by variations in the surface tension along a free surface is called Marangoni convection. Usually, Marangoni convection is obscured by density-driven convective flows. Limited experience during space experiments indicates that above a critical Marangoni number (ratio of surface tension force to viscous force), the flow becomes unsteady and temperature fluctuations in the melt are observed. In addition, a detailed series of ground and low-gravity experiments have demonstrated that striations due to Marangoni convection are produced in float-zone grown silicon. Magnetic fields are used in crystal growth to reduce bulk fluid motion, but these fields cannot completely compensate for surface tension driven flow, which is confined to a thin boundary layer near the surface of the growing crystal. A microgravity environment is very effective for studying these surface tension driven flows because other, buoyancy driven, phenomena are suppressed.

Additional interfacial energy effects are the determining factors in other forms of microgravity materials processing. One example is the formation of potentially unique composite materials by the directional solidification of an alloy melt that initially contains a uniform dispersion of fine solid particles. In this case, the interplay between solidification velocity and particle/liquid interfacial energy is crucial in determining the distribution of the strengthening particles. Some combinations of these processing variables result in the particles being entrapped at the solidification front to give a uniform microstructure, while others result in particles being repelled from the solidification front, producing segregation of the particles and poor properties.

Many of the phase separation and interfacial issues important in the processing of metals also play a role in the processing of ceramic materials. These issues are becoming increasingly important as processing methods are developed to enhance the properties of new ceramic compositions and materials for advanced technological applications.

Interfacial energy effects are also critical in containerless processing, where the extent of wetting between the solid(s) forming from the liquid controls the degree of undercooling and thus, the resulting microstructure. Brazing, soldering, and welding operations are additional processes which are influenced by interfacial phenomena. Here, understanding of both wetting and surface energy driven flows can be primary factors in successfully joining materials. Joining processes in low gravity may play an important role in the assembly of space-based structures.

In addition to the phenomena which occur at interfaces between two fluids, processes occurring at solid-vapor interfaces can be influenced by gravitationally-induced convective flows. Compound semiconductors are materials whose unique properties can be optimized when they are formed as single crystals by a process called physical vapor transport (PVT). Mercurous chloride, an acousto-optic material, mercuric iodide, a gamma ray detector, and silicon carbide, a wide band gap semiconductor, represent several examples. In PVT, the material to be crystallized is evaporated from a heated source, transported as vapor, and finally deposited on a seed crystal held at a lower temperature. Crystal properties are influenced by atomic attachment kinetics at the crystal vapor interface, by the rate of arrival of species from the vapor (and hence influenced by convection phenomena), and by the formation of compositionally variant or impurity enriched boundary layers in the vapor near the crystal surface. Sharp, well defined facets are a characteristic feature of high quality PVT crystals grown under reduced gravity which minimizes convective flow in the vapor. These crystals exhibit greater crystallographic homogeneity than their Earth-grown counterparts. A quantitative explanation for these improvements is still lacking. However, this homogeneity results in significantly improved resolution for radiation detectors fabricated from these crystals, and an understanding of this effect would therefore be of potential benefit for terrestrial processing.

Thermodynamic immiscibility in diblock (and triblock) copolymers leads to microphase separation and results in the formation of a range of unique morphologies extending from spherical domains in a host matrix to stacks of alternating lamellae. Since the components, A and B chains in diblock copolymers, are covalently bonded to one another the length scale of phase separation is on the order of 100-1000 angstroms. The shape (rods, spheres, slabs) and perfection of the domains formed are a critical function of the relative molecular weights of A and B, their interaction parameter, and the chain's molecular architecture. In both the rod and lamellar morphologies, anisotropic orientation of these microstructures can be induced through the application of shear, indicating that interfacial interactions at the substrate could be weak. It is possible that the development of these domains (rods, lamella, etc.) and their orientation could be substantially affected by a microgravity environment. Recent earth-based experiments have shown that if one of the components (e.g., B) of the diblock copolymer is liquid crystalline, microphase separation produces a high degree of ordering parallel to the substrate resulting in a stratified lamellar morphology. Small angle x-ray reflection studies indicate a high perfection of the layers which gives rise to many higher order reflections. Exploring the ordering of the layers and their directional orientation as a function of gravitational forces would provide a fundamental understanding of thermodynamic phase separation in coil-rod diblock copolymer systems. This understanding could lead to the development of anti-reflective coatings, omnidirectional reflectors and optical diffraction gratings.

Another area of significant interest is the adsorption of polymers from solution onto substrates. Polymer self-assembly onto metallic substrates from dilute solutions is one example of a process that is diffusion limited at early times due to the small amount of polymer in solution. The kinetics have been well studied under 1-g conditions but may change substantially in microgravity. The configuration of the polymer backbone on the substrate is another factor which may be substantially affected by sedimentation but definitive experiments in this area have not yet been carried out.

It is clear that a consideration of interfacial phenomena is common to numerous materials processing technologies. While limited studies of these interfacial effects are possible on Earth using density-matched immiscible systems, even in these systems, perfect density matching is possible only at a single temperature. Therefore, a microgravity environment provides a unique opportunity to study and quantify surface energy phenomena in order to promote more effective materials processing both on Earth and under microgravity conditions. A microgravity environment also provides a unique opportunity to measure the interfacial properties required to predict and control the phenomena discussed in this section.

4. Transport Phenomena (including process modeling and thermophysical properties measurement)

All of the important phenomena that determine materials structure and properties during processing are controlled by heat, mass, and momentum transport. For each of these effects, the nature of the transport is determined by the relative importance of convective and diffusive transport. Whereas the system response is controlled by materials properties when diffusive effects are dominant, the system response is controlled by processing conditions when convective effects dominate. Microgravity provides a unique environment in which the relative importance of convective and diffusive transport can be controlled by the experimenter.

Convective flows originate in solidifying systems because the many thermophysical properties vary with both composition and temperature. For example, density differences interact with gravity to produce buoyancy forces that drive convection. Even if gravitational effects are suppressed, as in microgravity, convection may still occur, driven by surface tension gradients caused by the variation of surface tension with temperature and/or composition with an imposed temperature gradient.

It is often desirable to suppress this convection, producing materials under purely diffusive conditions. Examples range from the control of segregation in crystal growth to influencing polymer orientation during casting. The control of convection is also critical to the testing of theories of microstructure development. To accomplish this requires a comprehensive understanding of transport processes.

This understanding can be significantly improved through process modeling. The goal of a process model is to represent the experimental system as a set of mathematical equations, whose solution describes the system behavior. Varying system parameters in the model allows exploration of the system, enabling the design and interpretation of experiments, and comparison of theoretical predictions with experimental results. Realistic process models are therefore an invaluable adjunct to experimental investigations.

As an example of this interplay, one may consider the recent Microgravity Isothermal Dendritic Growth Experiment. By conducting experiments at reduced gravity, experiments could be performed at very low undercooling under purely diffusive conditions. Comparison of the observed dendrite morphology and growth characteristics against prevailing theoretical models indicates that dendritic growth velocity and tip radius are much more strongly influenced by the growth of secondary and tertiary dendrite branches than previously believed. Recent theoretical models using advanced phase-field techniques discovered the same phenomenon. Because the model permits variation of parameters over a larger range than is possible in experiments, the theoretical calculations were able to demonstrate that this phenomenon occurs only at low undercooling.

Most of the process models developed to date focus on either macroscopic phenomena such as fluid flow, or microscopic behavior, such as atomic attachment kinetics. Additional model development is needed to couple transport phenomena with microstructure formation models that are truly multiscale in dimension and time. In addition, it is now recognized that transient and oscillating acceleration in an orbiting spacecraft, so-called g-jitter, can strongly impact experimental conditions. Such phenomena can only be examined by comprehensive modeling in conjunction with experiments. Extension of these models to evaluate, in detail, the sensitivity of proposed microgravity experiments to g-jitter will continue to be a significant benefit in design of equipment for space experiments.

Existing codes are capable, in principle, of modeling these phenomena. However, current computer hardware are still insufficient to perform routine fully three-dimensional analyses including the disparate length and time scales important to processing. New algorithms and models of materials behavior continue to be necessary in order to represent accurately the essential physics.

Another serious deficiency in the ability to model materials processing is the lack of accurate thermophysical property data for most materials in the molten state. This is a problem not only for scientists modeling microgravity experiments, but for many industrial researchers who are using process modeling for terrestrial processes. The lack of high temperature thermophysical data is partially due to the extreme difficulty of making accurate measurements on melts in terrestrial laboratories. Recent studies conducted in microgravity using the TEMPUS electromagnetic positioning and heating facility have enabled, for the first time, precise measurements of the specific heat, viscosity, surface tension, spectral emissivity, and thermal conductivity of refractory and transition metal alloy liquids. In the past, contamination of the melt by containers and strong convective flows have caused large measurement errors in such studies. Similarly, the effect of thermo-diffusion (Soret effect) was found in space experiments to be nearly an order of magnitude larger than previously expected. No accurate measurements had been made of this effect on earth, although it now appears to play a more important role in mass transport in many terrestrial processes than had been realized previously.

The relevant thermophysical properties needed for reliable materials processing models include:

- Electro-optical properties
  - Emissivity
  - Electrical conductivity
  - Optical properties

- Mechanical properties
  - Elastic moduli
  - Plastic moduli
  - Yield stress

- Physical and Calorimetric properties
  - Specific heat
  - Heats of mixing, formation, transformations, etc.
  - Density
  - Vapor pressures and activity coefficients
  - Surface tension / interfacial energies

- Transport coefficients
    - Thermal conductivity
    - Viscosity
    - Diffusion coefficients

- Thermodynamic properties
    - Thermal expansion coefficients
    - Compressibility, etc.

- Equations of state
- Defect generation models

There are numerous examples of the impact of transport phenomena on dendritic alloy solidification, nucleation from the melts, and crystal growth defect control. These phenomena are equally important in ceramic and polymer processing. For example, the most time-consuming step in manufacturing common glasses on Earth is bubble removal, or "fining." Information that leads to faster fining on earth would have enormous economic value. Thermal convection on earth is a major complication in studying bubble motion and the diffusion of gases from bubbles; convection destroys simple diffusion profiles. An improved understanding of fining of glass would be much more easily obtained without the effects of gravity.

A fundamental issue of ceramic-metal joining and the fabrication of interpenetrating three-dimensional ceramic-metal and ceramic-ceramic composites is the wetting of the solid ceramic phase by the molten metal or molten ceramic. Most wetting experiments are carried out under terrestrial conditions, where gravity can influence the spreading and contact of the molten phase with the solid substrate. This gravity-induced contact can lead to increased reaction and spreading of the molten phase and misrepresentation of the real degree of wetting. This effect can be suppressed by conducting infiltration experiments, where the pressure forces can be made subordinate to surface tension forces. However, observations of infiltration behavior of molten metals and ceramics into porous ceramics to produce composites is inconsistent with wetting experiments made at unit gravity.

Orientation in polymers is primarily controlled by the application of external stresses during processing. This stress may arise from interfacial stress at the common boundary with a substrate, tension applied at the end of a polymer fiber, or shear fields experienced by a polymer film as it is extruded through a die. The net result is the introduction of localized orientation which extends to the macroscopic domain. Mass and heat transport are critically important in many polymer processes from film casting to fiber spinning. In polymer casting processes, a concentrated solution of polymer, often at elevated temperature, is deposited on a substrate which may be heated. The rate of drying and the extent of preferred orientation depends strongly on the transport of solvent molecules away from the polymer as they diffuse to the surface and this, in turn, may be quite dependent upon gravity. Likewise the spinning of a fiber from a hot melt is done vertically so that gravity can aid in the drawing process. The process also orients polymer chains and crystalline regions preferentially along the fiber axis. Microgravity experiments could potentially distinguish the degree to which the development of orientation, the extent of crystallization and the size and perfection of crystallites found in terrestrial spinning line are influenced by body forces. This information would lead to a better understanding of the relationship between molecular level effects and polymer macroscopic properties.

<u>5. Crystal Growth, and Defect Generation and Control</u>

Temperature gradients in the melt are unavoidable during directional solidification of materials such as semiconductors. Furthermore, in growth from solutions, segregation of primary contituents, and to a lesser extent impurities, produce compositional variations in the melt. Under most processing conditions on Earth, the resulting density gradients yield significant buoyancy-induced convection that gives rise to property variations on both macroscopic (e.g., axial and radial segregation) and microscopic scales (e.g., point defect density fluctuations). These gravity-induced flows can produce local thermal and compositional variations at the growth surface, which in turn introduce defects into the solid with variable pattern, type, and number density. Another source of defects is the container wall, which can introduce strain and impurities into the crystal. The number and distribution of these defects, superimposed on macroscopic variations, then influence, often strongly, the performance of devices manufactured on or in these crystals. Indeed, the inability to control the defect structure of bulk crystals has led, for example, to the need for epitaxial thin films to improve the quality of semiconductor devices. It is clear that a better understanding of the mechanisms of defect generation would help in devising processes to control them. The space laboratory with variable acceleration vector has proven useful to improving our understanding of the crystal growth process.

As an example, nearly all Earth-grown crystals exhibit radial and axial compositional non-uniformities characteristic of growth from well-mixed or nearly well-mixed melts. Diffusion controlled segregation can sometimes be achieved on the ground, for example by applying periodic magnetic fields, centrifugation under certain conditions, or rotation of a vertical ampoule about its own axis, all combined with a solidification rate significantly faster than the convective velocity. These approaches, however, can introduce other complicating effects. Growing crystals in space provides the opportunity to reduce the convective flow velocity and, for some classes of systems and charge sizes, achieve diffusion-controlled mass transfer growth. The early crystal growth experiments of the Apollo-Soyuz Test Project (ASTP) and Skylab established the potential of microgravity processing to achieve diffusion-controlled growth in small diameter charges. This would be useful, for example, in the growth of bulk solid solutions with constant properties (e.g., lattice constant, bandgap energy) over large segments of the boule.

There is broad interest in the growth of crystals by methods other than melt growth, as for example solution growth and vapor phase growth. In solution growth the reduced convection possible in a microgravity environment reduces the sensitivity to variations in temperature at the growth surface, dramatically slows the transition from dissolution to growth, and reduces instabilities in trains of growth steps that can lead to trapping of solution as inclusions. It has been possible to grow crystals from seeds without the solvent inclusions that mark the seed/crystal boundary and give rise to dislocations on earth. The improvement is quite dramatic and could help in understanding the origins of defects on earth (e.g., why is temperature control so critical in solution growth (often 0.001˚C)?). In vapor growth the densities are very much less, but fluid-phase transport is important to the process. There has been some excellent agreement between flight results and numerical predictions.

Experimentation in a reduced gravity environment has allowed second order phenomena such as acceleration vector direction variation (g-jitter), Marangoni and advective flows, mechanical vibrations, and detached growth to be studied. In some materials systems, for example, when the normally occurring density variation in the melt is aligned with the gravity vector the system is nominally stable. Transients in the direction and magnitude of the acceleration vector (g-jitter) encountered in a reduced gravity environment results in a nominally unstable situation. The influence of g-jitter on the growth process is only beginning to be addressed, primarily through numerical simulations. As another example, space experiments have shown that during growth the melt may separate from a non-wetting crucible to give crystals with lower defect densities. The conditions under which detachment occurs are not well understood and only rarely observed on Earth. As a final example, there is evidence that mechanical vibrations can influence the growth process in a microgravity environment, but the influence is not well defined from both experimental and modeling perspectives, particularly at high frequencies. These examples point to the use of a reduced gravity laboratory to study phenomena normally masked during ground based processing. Although secondary, these phenomena can influence defect generation and a better understanding holds the promise of improved Earth grown crystals.

The complexity of interpreting experimental observations has demanded the development of realistic models to describe the growth process. Advances in computational methodology and capacity have permitted the generation of meaningful numerical results that have led to more sensible design of experiments and equipment, and to understanding the impact of secondary phenomena on the growth process. Capturing the reduced and dynamic acceleration vector found in space experiments, however, requires robust models that address fully coupled, time dependent, 3-dimensional flow with multiple driving forces. For some systems the models need to incorporate more accurate boundary conditions (e.g., radiation view factors) and constitutive relations (e.g., temperature and solute dependency of the density and surface tension, emissivity, and absorption coefficient within partially transparent media). Comparison of the characteristics (e.g., composition profiles) of crystals grown in space with those predicted by advanced models suggests boundary condition descriptions need improvement and, for many systems, more accurate thermophysical properties need to be measured. Further understanding of defect formation mechanisms is needed if they are to be incorporated in advanced simulations. Previous studies have shown that meaningful conclusions cannot be developed by simple reduction of the gravity level in the simulations, and that more comprehensive models are needed. Although considerable advances have occurred in modeling crystal growth, most previous flight experiments have examined complex crystal growth materials, designs, and practice. Thus the validation of numerical simulation results has not been obvious. It is clear that sound experimental-based research progresses more rapidly when coupled to a meaningful modeling effort. It is further believed that molecular simulations can be helpful in understanding the relations between interfacial flows and molecular attachment mechanisms, including those that generate lattice defects.

Simulations of crystal growth under microgravity conditions that produce axisymmetric flow configurations, for example, have shown that the alignment of the gravity vector is important. If the vector is aligned parallel to the growth surface, as opposed to perpendicular to the growth surface, a 100-fold increase in the convective velocity can result. This phenomenon has been observed experimentally in growth experiments on the first United States Microgravity Laboratory (USML-1) and the second United States Microgravity Payload (USMP-2) missions in HgZnTe and HgCdTe, respectively. In a detailed analysis of g-jitter effects, the compositional variations in the melt associated with the transients in residual acceleration have been shown to persist over time periods much longer than those characterizing g-jitter. This example illustrates that diffusion-controlled growth may be only marginally achievable in space and that comprehensive models are required for full interpretation.

Although many examples exist of flight growth studies, along with supporting numerical modeling efforts, it is noted that our ability is limited to visualize flow and detect defects generation in-situ. A variety of techniques have been used to study the fluid dynamics of high temperature, opaque liquid metal systems, but many of these methods are of low sensitivity, intrusive, or not easily adaptable to flight based experimentation. A need exists to develop appropriate sensors and diagnostice techniques for detecting flows, interfacial processes, and defect formation.

Magnetic damping of convection in electrically conductive melts is an alternative approach to reducing the magnitude of flow velocities. In this approach, the motion of an electrically conductive melt in a magnetic field produces an opposing Lorentz force that effectively increases the melt viscosity. Modeling results indicate that the superimposed effect of a moderate magnetic field and the microgravity environment of low earth orbit can reduce convective flow intensities to an extent unreachable either by using magnets on Earth, or by microgravity processing alone. Although not fully understood, applied magnetic field effects have been observed in poor conducting solution systems such as that used for protein crystallization. Magnetic damping also can potentially reduce the influence of Marangoni convection and high-frequency transients in the melt flow velocities associated with g-jitter. Magnetically stabilized Czochralski crystal growth experiments indicate that intensive turbulent flow perturbations can be suppressed at relatively low magnetic field strengths (of the order of 0.1-0.2 Tesla). This suggests that magnetic fields may significantly reduce the deleterious effects of convective perturbations associated with g-jitter.

The generation and propagation of defects during the fluid to solid phase change is not fully understood for many types of defects (e.g., twins, grain boundaries). For example, it is known that defects are often generated (or nucleated) at the tri-junction between the container wall, the solid, and the melt during directional solidification, and that these defects tend to propagate along a direction approximately perpendicular to the melt-solid interface. The degree of fluid motion is also known to have an influence on defect concentration and distribution as demonstrated by the striations observed in Czochralski-grown materials. The deconvolution of growth rate and fluid flow contributions to defect generation is an active and important area of research. Defects, whether they are impurity atoms or lattice defects, have a major impact on electronic and optical properties.

New characterization techniques, such as atomic force microscopy and synchrotron x-ray topography, are providing new insights to the study of defects in crystals. Atomic force microscopy shows that the established technique of etch pit density determination, even when done accurately, does not provide a complete representation of the defect structure at the semiconductor surface. Synchrotron x-ray topographs reveal not only twins but also a cellular structure of low angle grain boundaries, lines indicating slip planes initiating at the twin boundaries, and dislocations within the subgrains. The addition of advanced characterization tools coupled with samples grown under different and highly controlled conditions should contribute to increased understanding of defect generation mechanisms.

There is mounting evidence from flight experiments that fluid flow influences defect generation and propagation, and microgravity experiments should provide an excellent method for learning more about this important topic. For example, results from a TEXUS (sounding) rocket flight experiment show many growth-induced striations in InSb in the Earth-grown portion, and no striations in the space-grown portion except for those induced for interface demarcation by electric current pulses. One important experiment that does show promise of providing useful information in this area is the Bridgman growth of $Cd_{0.96}Zn_{0.04}Te$. The defect generation observed in this material was markedly reduced in two ingots grown aboard the Shuttle during the USML-1 mission, compared to ingots grown under otherwise identical conditions on Earth. A quantitative explanation for these results is still being sought.

Polymer crystal growth is more complex than the growth of inorganic crystals because of the large molecular weights of the individual polymer molecules and their structural complexity that makes molecular attachment to a growing crystal stereochemically complicated. Equally important is that, in microgravity, it is possible to study the fundamentals of polymer crystal growth. Not only can the effects of temperature and compositional gradients on growth kinetics in the absence of gravity-induced convective effects be studied, but also the effect of the size of the individual polymer units and their interaction with the solvent molecules on the crystal growth be studied.

Many polymeric materials have potential as unique nonlinear optical materials. Thin films of polymers produced by vapor deposition contain high defect concentrations that limit their utility as nonlinear optical materials. Microgravity experiments on inorganic crystal growth by vapor deposition clearly show that materials with lower defect concentrations can be produced. A quantitative explanation for these results is still lacking.

It has been demonstrated that much larger, and defect-free protein crystals can be grown in microgravity compared to those grown on Earth. These results suggest that gravity can play a role on the kinetics of rearrangement of large molecules during crystal growth from solution. There are many other polymers, such as nonlinear optical materials, for which the availability of single crystals would be extremely useful for property studies and to determine the effects of crystal defects on properties. Microgravity provides the opportunity to investigate the growth of such crystals.

The development of unique polymer morphologies (dendrites, spherulites, single crystals) from solutions and melts at elevated temperatures as they are cooled depends on the diffusion of polymer chains to the developing growth face of a crystal. Thus the polymer diffusion constant will affect the crystallite size, its perfection and the resulting molecular organization of the morphological feature. Little is known about the effect of destabilizing temperature gradients on the crystallization process in either concentrated polymer solutions or in melts. A series of carefully planned experiments designed to evaluate the effect of uniform temperature on the growth of polymer crystalline habits in space would provide fundamental information which could be used to optimize polymer macroscopic properties.

6. Radiation Shielding, and Extraterrestrial Processes and Technology Development

As one of NASA's four core Strategic Enterprises, the Human Exploration and Development of Space (HEDS) Enterprise is a catalyst to open the space frontier by exploring, using and enabling the development of space and expansion of the human experience into the far reaches of space. Understanding of the fundamental role of gravity in the space environment in chemical and physical systems, however, is needed to achieve breakthroughs in science and enabling technology, and will be required should a national mandate for human exploration exist. The need for improved understanding of fluid phenomena to enable future space technologies and operations should be recognized as one of the primary opportunities of the discipline. The focus of the MRD program in the HEDS strategic Enterprise is to foster fundamental understanding, building a foundation of knowledge that can be applied to both Earth- and space-based technologies.

Gravity plays a dominant role in many of the systems, processes and technologies that are needed to achieve the exploration goals of the HEDS Enterprise. There are many specific scientific problems and issues that must be addressed prior to optimizing designs or developing more efficient systems for extraterrestrial exploration. These include physical and chemical processes in the areas of spacecraft systems, life support systems, use of in-situ resources and power generation in extraterrestrial environments and bio-fluids. Fundamental research is required to develop scaling laws for ranges of gravity levels between the microgravity environment of interplanetary travel to the partial gravity on Mars (3/8g) or the Moon (1/6g). Many areas of materials science research directly impact systems required for extraterrestrial exploration. As a result research in the following areas is sought to help answer fundamental questions underpinning the relevant technologies.

Radiation Shielding

The goal of this part of the microgravity materials science program is to improve and experimentally test radiation transport codes needed to develop a cost and mission effective radiation shielding material/concept to protect a crew for one year in transit to/from and on the surface of the Moon/Mars.

The provision of shielding for a Mars mission or a Lunar base from the hazards of space radiation (solar flares, galactic cosmic radiation) is a critical technology since astronaut radiation safety depends on it and shielding safety factors to control risk uncertainty appear large. Thus, the development of radiation transport code and the evaluation of high performance radiation shield materials is a research area where materials science can play a pivotal role. Understanding the basic physics of the radiation shielding process is necessary in order to tailor shielding performance through materials selection and processing. Radiation transport codes (computer models) play a critical role in the timely solution of the radiation shielding problem. They need to incorporate all of the relevant physics that describes the interaction of space radiations with materials. Experimental testing of the transport codes is necessary to reduce uncertainties that lead to increased mass in proposed shielding concepts.

Understanding the basics physics of the shielding process should then allow the tailoring of materials performance through control of structure. High performance shielding materials are essential to protect crews during a protracted journey to, from and on the surface of Mars.

In Situ Resource Utilization (ISRU)

The goal of this segment of the microgravity materials science program is to identify materials processing issues and propose/test processing strategies to enable human operations on the surface of the Moon/Mars using ISRU concepts. Robust and energy efficient processes using local materials and resources are necessary to enable safe, productive, and cost effective human exploration of the inner solar system. Fundamental studies would yield a non-empirical approach to process development and design, thus generating support technologies independent of the process chosen for actual manufacturing to imbue flexibility and efficiency in the designs.

ISRU is a rapidly developing area relevant to exploration of other bodies in the solar system. Due to the cost constraints associated with transporting all of the necessary resources for a sustained visit and return trip from either the Moon or Mars, utilization of natural resources at the landing site is receiving strong consideration. Basic physical and chemical methods will be applied to process local resources into usable commodities. The focus of activities of the materials research community must be to develop an understanding of these processes in non-Earth environments. Examples of local resource utilization related physical and chemical processes include lunar derived oxygen and metals production from regolith (soil), creation of bricks from regolith for radiation protection and structures fabrication, and energy conversion and storage.

Lunar regolith contains significant amounts of oxygen, chemically bound in various minerals, which would require processing to manufacture oxygen for use in propulsion and for life support systems. A major challenge is to combine the processing of regolith to produce oxygen as well as metals present in the same minerals. Similarly, it is believed that Martian soil contains significant amounts of water that can be electrolyzed into oxygen and hydrogen again for propellants and life support. In all of these scenarios, a fundamental understanding of the dynamics of solid/gas and liquid/solid phase transformations, and the performance of electrochemical systems are required for representative techniques expected to be used for regolith processing. Energy conversion and storage is considered a basic aspect of “living off the land” in both Lunar and Martian environments. Examples can be as simple as the transformation of solar energy into thermal energy and stored in lunar regolith bricks for subsequent release during night time periods. More complex approaches include fabrication of solar cells from regolith derived materials and storing the resulting energy in advanced batteries, compounds (e.g. hydrogen and oxygen), high performance flywheels, etc.

III. EXPERIMENT APPARATUS AND FLIGHT OPPORTUNITIES

A. EXPERIMENTAL APPARATUS

In order to accommodate aspects of the research described in Section II, a number of pieces of flight hardware are being developed by NASA and its international partners. These are described in Appendix B, Section I. Section II of Appendix B lists the ground-based facilities that are available to support definition studies.

Flight opportunities under this NRA will be on sounding rockets, the Space Shuttle or the International Space Station (ISS). During sounding rocket flights five to ten minutes of microgravity (10^{-4} g) experimentation time is available. For the Shuttle opportunities, the experimental apparatus are located in the middeck or Spacehab, allowing direct human interaction, or in the cargo bay which does not permit such interaction. Residual acceleration levels on the order of 10^{-4} g are available in the Shuttle for limited periods of time. Flights range from 7 to 16 days in duration. The Space Acceleration Measurement System (SAMS) is expected to be available to measure and record actual accelerations at or near the apparatus for both Shuttle and ISS experiments. Considerable additional information on the Shuttle accommodations and capabilities can be found in the STS Investigators' Guide (see Bibliography). Experimental apparatus for the early utilization of the International Space Station will primarily be in facilities such as the Microgravity Science Glovebox (MSG) and Express rack (ISS versions of Shuttle middeck class experiments) followed by the Materials Science Research Facility during the late stages of assembly of the ISS. A high-capacity communications network supports Shuttle and ISS payload operations. Downlink channels enable users to monitor their instrument status and science data streams in real time.

An uplink channel enables them to act on that information. The effective use of these downlink and uplink capabilities enables telescience on a near realtime basis.

B. DIAGNOSTIC MEASUREMENTS

The capability to characterize science experiments in reduced-gravity is essential to scientific progress in this program. NASA, in ground-based normal and reduced-gravity studies, is developing techniques for enhancing imaging and visualization, and improving in situ measurement of temperature, solidification interface location and velocity. As these techniques mature, those most required by investigators will be reviewed for space flight development as part of the future flight equipment capability.

C. FLIGHT OPPORTUNITIES

Missions available for this program may include several Shuttle flights, sounding rocket flights and missions on the International Space Station. These flight opportunities are dependent on the progress of the construction of the International Space Station. The complexity of the hardware required to complete the investigation may have a significant impact on the flight definition selection.

D. EXPERIMENT DEFINITION AND FLIGHT ASSIGNMENT PROCESS

Ground-based research is usually necessary to clearly define flight experiment objectives. This research may involve experimentation in NASA-provided ground-based facilities, including those which can provide a limited duration low gravity environment. (These facilities are described in Appendix B, Section II.) Successful proposals for flight opportunities will be supported for a ground-based definition phase before review for flight assignment. The amount of support (technical, scientific, and budgetary) and the length of the definition period (usually from 6 months to 2 years) will depend on the specific investigator needs and the availability of resources from NASA. However, in preparing their budget plan for this research announcement, all respondents should estimate their annual costs for four years.

Shortly after selection of projects for flight definition, NASA will initiate a process to identify fundamental technical feasibility issues. A small team of engineers and scientists at the NASA field centers will work with the Principal Investigator to translate requirements into the appropriate experiment technical requirements. The result is a systems engineering approach which prioritizes and links the facets of the experiment development process assuring that the objectives of the experiment can be met. The process will help determine whether there are any outstanding issues that would inhibit the success of the flight project, considering both technical challenges and required resources. At that point NASA may make a judgment as to whether a project will continue the flight definition process or revert to the ground-based program (see below).

1. Near-Term Flight Opportunities. Successful proposals for use of the existing instruments will be funded for a period of advanced definition work, after which time the investigator will generate a detailed SRD. The SRD, a detailed experiment description outlining the specific experiment parameters and conditions, as well as the background and justification for flight, must be prepared jointly by a NASA-appointed project scientist and the Principal Investigator and submitted for peer review. This formal review by both science and engineering panels will determine if space flight is required to meet the science objectives and if instrument capabilities can be provided to meet the science requirements. Following approval by the panels, subject to program resources, continuation support will be awarded and the hardware will be modified to meet the science requirements. NASA does not guarantee that any experiment selected for definition will advance to flight experiment status. Investigations with unresolved science or engineering issues at the review of the SRD may be placed in ground-based status with support of limited duration (normally from one to three years), and asked to submit a proposal to a subsequent solicitation for further support.

2. Future Flight Opportunities. Successful proposals for the development of new apparatus will be funded for a period of experiment definition. The length of the definition period will be based on the experiment requirements, but will generally be from 6 to 24 months. At the end of the experiment definition phase, the investigator will generate a detailed SRD. Following successful peer review of the SRD by science and engineering panels, the experiment will proceed into flight development and be considered for flight. As with opportunities for existing instruments, NASA does not guarantee that any experiment selected for definition will advance to flight development status, and the possibility exists that investigations may be placed in ground-based status, with continuing support from NASA for a limited period.

3. Ground-Based Definition Opportunities. Promising proposals for experimental research which are not mature enough to allow development of an SRD after two years of definition, and proposals for development of theory in areas of current or potential microgravity experiments, may be selected for support in the MRD ground-based research program. Ground-based studies are funded for periods of up to four years. A new proposal to a future announcement is currently required in order to be selected for a flight opportunity or to continue ground-based studies if appropriate. Proposals for development of new technologies for flight experiments that will provide new capabilities for materials science research are encouraged.

IV. PROPOSAL SUBMISSION INFORMATION

This section gives the requirements for submission of proposals in response to this announcement. The research project described in the typical proposal submitted under this announcement must be directed by a Principal Investigator who is responsible for all research activities and may include one or more Co-Investigators. Proposers must address all the relevant selection criteria in their proposal as described in Section VI and must format their proposal as described in this section. Additional general information for submission of proposals in response to NASA Research Announcements may be found in Appendix C.

A. LETTER OF INTENT

Organizations planning to submit a proposal in response to this NRA should notify NASA of their intent to propose by electronically sending a Letter of Intent (LOI) via the MRD Web Page:

http://microgravity.hq.nasa.gov/

Alternatively, Letters of Intent may be submitted via e-mail to the following address: loi@hq.nasa.gov

If electronic means are not available, you may mail Letters of Intent to the address given for proposal submission in the following section or Facsimile transmission is acceptable; the MRD fax number is (202) 358-3091.

The Letter of Intent, which should not exceed two pages in length, must be typewritten in English and must include the following information:

- The potential Principal Investigator (PI), position, organization, address, telephone, fax, and e-mail address.
- A list of potential Co-Investigators (Co-I's), positions, and organizations.
- General scientific/technical objectives of the research.
- The equipment of interest listed in this NRA, if appropriate.

The Letter of Intent should be received at NASA Headquarters not later than 4:30 pm EST, January 26,

1999. The Letter of Intent is being requested for informational and planning purposes only, and is not binding on the signatories. Institutional authorizations are not required. The Letter of Intent allows NASA to better match expertise in the composition of peer review panels with the response from this solicitation. In the Letter of Intent, investigators may request more detail on the capabilities of the specific equipment (Appendix B) that might be used to accomplish their scientific objectives and/or items listed in the Bibliography (Appendix A, Section IX).

B. PROPOSAL

The proposal should not exceed 20 pages in length, exclusive of appendices and supplementary material, and should be typed on 8-1/2 x 11 inch paper with a 10- or 12-point font. Extensive appendices and ring-bound proposals are discouraged. Reprints and preprints of relevant work will be forwarded to the reviewers if submitted as attachments to the proposal.

The guidance in Appendix C, Section D regarding the content of renewal proposals is not applicable to this NRA. Proposals should not rely on references to previous proposals for any information required for a complete proposal.

What's different about the proposal preparation procedures for this NRA?

It is particularly important that proposers who seek to extend an existing NASA research activity that is relevant to this NRA must submit proposals that clearly identify and document achievements on their current effort and how it supports their request for additional sponsorship. Such follow-on proposals will be reviewed on an equal basis with all other submitted proposals.

To ensure consistent assessment of bugets, proposers must use the budget forms provided for each requested year of support and a separate summary budget form (also provided) totalling all requested years of support.

The same budgetary detail must be provided for all subawards as that provided for the Principal Investigator and home institution.

Proposers should include in the budget a request for travel funds to support attendance at each Microgravity Materials Science Conference that will be held during the grant period of performance. For planning purposes, Microgravity Materials Science Conferences are scheduled for the Summers of 2000, 2002, and 2004

Fifteen copies of the proposal must be received at NASA Headquarters by March 16, 1999, not later than 4:30 PM EST. Treatment of late proposals is described in Appendix C. Send proposals to the following address:

Dr. Michael J. Wargo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-05)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

NASA can not receive deliveries on Saturdays, Sundays or federal holidays.

Proposals submitted in response to this Announcement must be typewritten in English and contain at least the following elements (in addition to the required information given in Appendix C) in the format shown below. Electronic versions of the forms are available via the internet (see p. iii) and are configured to allow data entry and printing. The proposal should be assembled in the following order:

1. Form A (Solicited Proposal Application with budget summary information)
2. Form B (Proposal Executive Summary - replaces Abstract). The executive summary should succinctly convey, in broad terms, what it is the proposer wants to do, how the proposer plans to do it, why it is important, and how it meets the requirements for microgravity relevance
3. Form C (Budget For Entire Project Period)
4 Form D (Summary Proposal Budget - 1 copy for each year)
5. Table of Contents
6. Research Project Description containing the following elements:
   - Statement of the hypothesis, objective, and value of this research.
   - Review of relevant research.
   - Justification of the need for low gravity to meet the objectives of the experiment.
   - Description of the diagnostic measurements that would be required to satisfy the scientific objectives of any proposed low gravity experiments.
   - Estimation of time profile of reduced-gravity levels needed for the experiment or series of experiments.
   - A clear and unambiguous justification of the need to perform the experiment in space as opposed to ground-based reduced-gravity facilities.
   - A description of a ground-based testing program that might be needed to complete the definition of the space flight experiment requirements in terms of experiment conditions, acceleration levels and durations, control and diagnostic measurement requirements, etc.
   - Management plan appropriate for the scope and size of the proposed project, describing the roles and responsibilities of the participants
7. Prior Period of Support

   For follow-on proposals of ongoing MRD sponsored projects, a summary of the objective and accomplishments of the prior period of support, including citations to published papers derived from the existing tasks, must be included as part of the proposers justification for continued support.
8. Appendices:
   - Budget Justification Page: supplementary budget information and budget explanations. The information desired is explained below.
   - Summary of current and pending support for the Principal Investigator and Co-Investigators.
   - Complete current curriculum vita for the principal and Co-Investigators, listing education, publications, and other relevant information necessary to assess the experience and capabilities of the senior participants.
9. **3.5 inch computer diskette containing electronic copy of Principal Investigator's name, address, complete project title, and executive summary**

Proposal Cost Detail Desired. Sufficient proposal cost detail and supporting information will facilitate a speedy evaluation and award. Dollar amounts proposed with no explanation (e.g., Equipment: $58,000, or Labor: $10,000) may cause delays in evaluation or award. The proposed costing information should be sufficiently detailed to allow the Government to identify cost elements for evaluation purposes. Generally, the Government will evaluate cost as to reasonableness, allowability, and allocability. Enclose explanatory information, as needed. Each category should be explained. Offerers should exercise prudent judgment as the amount of detail necessary varies with the complexity of the proposal.

V. NRA FUNDING

The total amount of funding for this program is subject to the annual NASA budget cycle. The Government's obligation to make awards is contingent upon the availability of appropriated funds from which payment for award purposes can be made and the receipt of proposals which the Government determines are acceptable for an award under this NRA.

For the purposes of budget planning, we have assumed that the Microgravity Research Division will fund up to 8 flight experiment definition proposals. These definition-phase proposals will be funded on an average of $175,000 per year. Approximately 70 ground-based study proposals will be funded, at an average of $100,000 per year, for up to 4 years. The initial fiscal year (FY) 2000 funding for all proposals will be adjusted, if required, to reflect partial fiscal year efforts. **It is particularly important that the proposer realistically forecast the projected spending timeline rather than merely assuming an equal amount (adjusted for inflation) of requirements for each year. Specifically, the resources required for the first year should not be overestimated.** The proposed budget for ground-based studies should include researcher's salary, travel to science and NASA meetings (for a flight investigation, roughly eight meetings per year with NASA should be anticipated, though travel activity will vary over the development of the experiment), other expenses (publication costs, computing or workstation costs), burdens, and overhead. During subsequent years, NRAs similar to this NRA will be issued, and funds are planned to be available for additional investigations.

VI. GUIDELINES FOR INTERNATIONAL PARTICIPATION

NASA accepts proposals from all countries, although this program does not financially support Principal Investigators in countries other than the U.S. Accordingly, proposals from non-U.S. entities should not include a cost plan. Non-U.S. proposals and U.S. proposals which include non-U.S. participation, must be endorsed by the appropriate government agency in the country from which the non-U.S. participant is proposing. Such endorsement should indicate that:

1. The proposal merits careful consideration by NASA
2. If the proposal is selected, sufficient funds will be made available from the country from which the non-U.S. participant is proposing, to undertake the activity as proposed.

Proposals, along with the requested number of copies and Letter of Endorsement, must be forwarded to NASA in time to arrive before the deadline established for this NRA. All proposals must be typewritten in English. All non-U.S. proposals will undergo the same evaluation and selection process as those originating in the U.S.

Sponsoring non-U.S. agencies may, in exceptional situations, forward a proposal directly to the address given on Page iv of the first section of this announcement if review and endorsement is not possible before the announced closing date. In such cases, an accompanying letter should indicate when a decision on endorsement can be expected.

Successful and unsuccessful proposers will be notified by mail directly by the NASA program office coordinating the NRA. Copies of these letters will be sent to the sponsoring government agency. Should a non-U.S. proposal or U.S. proposal with non-U.S. participation be selected, NASA's Office of External Relations will arrange with the non-U.S. sponsoring agency for the proposed participation on a no-exchange-of-funds basis, in which NASA and the appropriate government agency will each bear the cost of discharging its respective responsibilities. Depending on the nature and extent of the proposed cooperation, these arrangements may entail:

1. A letter of notification by NASA
2. An exchange of letters between NASA and the sponsoring government agency
3. An agreement or memorandum of understanding between NASA and the sponsoring government agency.

VII. EVALUATION AND SELECTION

A. EVALUATION PROCESS

The evaluation process for this NRA will be based on a peer review of the proposal's intrinsic scientific and technical merit, articulated relevance to the microgravity program, and cost of the research plan. The reviewers will be scientific and technical experts from government, academia, and industry. Each proposal will be reviewed independently by members of the review panel and discussed at a review panel meeting to determine a consensus evaluation for the proposal. All proposals will be evaluated on a merit scale of 1 (worst rating) to 9 (best rating). A rating below 5 is not generally considered for funding. NASA will also conduct an internal engineering review of the potential hardware requirements for proposals that include flight experiments. The external peer review and internal engineering review panels will be coordinated by the NASA Enterprise Scientist for Materials Science. Consideration of the programmatic objectives of this NRA, as discussed in the introduction to this Appendix, will be applied by NASA to ensure enhancement of program breadth, balance, and diversity; NASA will also consider the cost of the proposal. The MRD Director will make the final selection based on science panel and programmatic recommendations. Upon completion of all deliberations, a selection statement will be released notifying each proposer of proposal selection or rejection. Offerers whose proposals are declined will have the opportunity of a verbal debriefing with a NASA representative regarding the reasons for this decision. Additional information on the evaluation and selection process is given in Appendix C.

B. EVALUATION FACTORS

The following section replaces Section J of Appendix C. The principal elements considered in the evaluation of proposals solicited by this NRA are: relevance to NASA's objectives, intrinsic merit, and cost. Of these, intrinsic merit has the greatest weight, followed by relevance to NASA's objectives, which has slightly lesser weight. Both of these elements have greater weight than cost. Evaluation of the intrinsic merit of the proposal includes consideration of the following factors, in descending order of importance:

1. Overall scientific or technical merit, including evidence of unique or innovative methods, approaches, or concepts, the potential for new discoveries or understanding, or delivery of new technologies/products and associated schedules;
2. Qualifications, capabilities, and experience of the proposed Principal Investigator, team leader, or key personnel who are critical in achieving the proposal objectives;
3. Institutional resources and experience that are critical in achieving the proposal objectives;
4. Overall standing among similar proposals available for evaluation and/or evaluation against the known state-of-the-art.

The following questions should be kept in mind by proposers when addressing the relevance to NASA's scientific and programmatic objectives:

1. Is microgravity of fundamental importance to the proposed study, either in terms of unmasking effects hidden under normal gravity conditions or in terms of using gravity level as an added independent parameter?
2. Do the issues addressed by the research have the potential to close major gaps in the understanding of fundamentals of materials science processes?
3. Is there potential for elucidation of previously unknown phenomena?
4. Is the project likely to have significant benefits/applications to ground-based as well as space-based operations involving materials processes?
5. Are the results likely to be broadly useful, leading to further theoretical or experimental studies?
6. Can another project in the specific sub-area be justified in terms of limited resource allocation?
7. Is the project technologically feasible, without requirements for substantial new technological advances?
8. How will this project stimulate research and education in the materials science area?
9. How does the projected cost/benefit ratio compare with other projects competing for the same resources?
10. What is the potential of this project in terms of stimulating future technological “spin-offs”.
11. Are there strong, well-defined linkages between the research and HEDS goals? (See Section II,B of this Appendix).

C. SELECTION CATEGORIES, PERIOD OF SUPPORT, AND FLIGHT PROGRAM PROCESS

Proposals selected for support through this NRA will be selected as either ground-based- or flight-definition investigations. Investigators offered support in the ground-based program normally will be required to submit a new proposal for competitive renewal after at most four years of support. Investigators offered flight definition status are expected, in addition to their research work, to begin preparing detailed flight experiment requirements and concepts for flight development shortly after selection in cooperation with the assigned Project Scientist from a NASA Center.

A flight experiment represents a considerable investment of resources, both human and financial. The Principal Investigator for a flight investigation in definition phase has the responsibility to continue the pursuit of basic knowledge that will make a flight experiment fully meaningful, and, in addition, will be responsible for major contributions to the large effort needed to define and build the flight experiment. In the first six months following selection, the Principal Investigator will meet with NASA representatives to discuss any technical feasibility issues related to the proposed flight experiment. These discussions will also include identification of resources needed to establish feasibility, produce a draft Science Requirements Document (SRD), conduct a Science Concept Review (SCR) of the flight experiment, and conduct the Requirements Definition Review (RDR) roughly one year after the SCR. Successful completion of these reviews will be required before the investigation will be approved for flight. It may be decided as a result of these discussions that the project should revert to ground-based status. This will not in any way preclude the PIs opportunities to propose for renewal of the research effort as a ground-based investigation, or to propose a flight experiment at a later date. The period of performance will be unchanged; the duration of support for the project will be as indicated at selection.

NASA may not have a specific opportunity to conduct a given flight experiment in it’s planning manifest at the time of selection from this NRA. However, if during the period of support, an opportunity arises to take this research to flight, this type of project would be directed to prepare a Science Requirements Document. This will place the project on the path of flight experiment development, entailing further peer review as well as project reviews. Should such an opportunity not arise within the first three years after selection, continued support for the project would be contingent upon submittal of a new proposal to the Microgravity Materials Science NASA Research Announcement to be released in the Fall of 2002.

The primary purpose of the SRD is to define a flight experiment to a level of specificity adequate to guide the development of a fully satisfactory experimental apparatus, as well as to justify the requirement for flight (as opposed to other low gravity platforms) in reference to specific individual experiments. The requirement for flight of specific experiments is a key determination of the SCR and RDR. Through the course progress to flight, the SRD will be a point of reference for decisions involving the scope of the flight experiment and allocation of resources. The SRD should clearly state and effectively justify a focused program of flight research, identifying what is considered to be minimal and optimal experiment outlines. Some limited evolution of the experiment definition over the following several years is expected, as continuing ground-based research refines objectives, but the document should be in final form by the time of the RDR. The SRD is used to guide the design, engineering, and integration effort for the instrument. The SRD describes specific experiment parameters, conditions, background, and justification for flight. Ground-based, normal, and reduced-gravity experimentation, as well as any necessary modeling efforts, may also be required to prepare an adequate Science Requirements Document. The amount of support (technical, scientific, and budgetary) provided to investigators by NASA will be determined by the Enterprise Discipline Scientist for Materials Science in collaboration with the Discipline Manager for Materials Science (at Marshall Space Flight Center) based upon specific investigator needs and the availability of resources to NASA and MRD.

These activities are in preparation for a Science Concept Review (SCR) to be held within approximately two years of the beginning of Investigator funding. Investigations not selected for flight because of scientific, technological, or programmatic considerations at the SCR will be placed in the ground-based program and funding will continue until the end of the original four-year period. This Review will be conducted before a scientific peer panel that will be asked to assess:

- The significance of the problem being investigated including the benefits that the experimental and theoretical results would provide to the materials science research community and industry.
- The maturity of the overall scientific investigation.
- The rigor with which the proposed flight experiment has been conducted terrestrially. (e.g. influence of gravity, reproducibility and quantification of experimental conditions and results, materials characterization, modeling, application/verification of current and/or developing theoretical framework etc.)
- The scientific objectives of the proposed flight experiments.
- The priorities of these scientific objectives.
- The need for a microgravity environment to achieve the proposed scientific objectives.
- The scientific specifications for the proposed flight experiments as expressed in the preliminary draft of the Science Requirements Document.
- The conceptual design for the apparatus and whether this design could be expected to deliver a level of performance that allows the scientific objectives to be achieved.
- Technology issues that would prevent a timely, successful achievement of the scientific objectives.

The selected investigations will be required to comply with MRD policies, including the return of all appropriate information for inclusion in the MRD archives during the performance of and at the completion of the contract or grant.

Commitment by NASA to proceed from flight definition to the execution of a flight experiment will be made only after several additional engineering and scientific reviews and project milestones have established the feasibility and merit of the proposed experiment. Investigations not selected for flight at these reviews will be funded for a limited period (approximately one year) to allow an orderly termination of the project.

VIII. **BIBLIOGRAPHY**

Background materials are available to NRA proposers upon written request to:

Dr. Donald C. Gillies
ES-75
Space Sciences Laboratory
Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812-0001
(256) 544-9302

Documents and Web Sites that may provide useful information to proposers are listed below:

1. Office of Life and Microgravity Sciences and Applications (OLMSA) Homepage at NASA Headquarters, http://www.hq.nasa.gov/office/olmsa/
2. Microgravity Research Division Homepage at NASA Headquarters, http://microgravity.hq.nasa.gov
3. Microgravity Research Program Office Homepage at NASA Marshall Space Flight Center, http://microgravity.msfc.nasa.gov.
4. STS Investigators' Guide, NASA Marshall Space Flight Center.
5. NASA Microgravity Materials Science Conference Proceedings, NASA Conference Proceedings 3342, October 1996.
6. Third Microgravity Material s Science Conference Extended Abstracts, http://www.ssl.msfc.nasa.gov/colloquia/mmsm/oralpresentations.html
7. Microgravity Science and Applications Program Tasks and Bibliography, 1997, http://peer1.idi.usra.edu/peer_review/taskbook/micro/mg97/mtb.html
8. Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA Conference Publication CP-1998-207431, http://LeTRS.lerc.nasa.gov/cgi-bin/LeTRS/browse.pl?1998/CP-1998-207431.html
9. NASA Reduced-Gravity Carrier Options for Microgravity Experiment Operations, http://peer1.idi.usra.edu/peer_review/prog/CarrierOptions.pdf

APPENDIX B
NRA-98-HEDS-05

HARDWARE AND FACILITY DESCRIPTIONS

The Microgravity Research Division (MRD) is conducting a program to acquire and fly scientific instrumentation flight hardware to successfully complete investigations selected through this and associated NRAs. After successful completion of the Science Concept Review (SCR), the Principal Investigator (PI) will work with Microgravity Research Program Office (MRPO) personnel at NASA's Marshall Space Flight Center (MSFC) to determine which existing scientific instrument can be used to conduct the flight experiments, or what type of new apparatus must be developed. The discipline of microgravity materials science has an advantage compared to other microgravity research areas in that a large number of high temperature apparatus of various capabilities have been developed by NASA and its international partners, and are available for use by U.S. investigators. MSFC, as the lead center for microgravity materials science research, maintains the management and engineering expertise to acquire/develop new flight hardware to meet an investigation's specific performance requirements, or can provide guidance/assistance to a PI who proposes to develop flight hardware as part of the investigation. In addition, NASA is currently planning the transition of most research flight operations from the Space Shuttle to the International Space Station (ISS) at the end of this decade. MRD has initiated development of the Materials Science Research Facility (MSRF) to meet the near term and long range goals of the Materials Science Program. This broad, evolutionary program is expected to meet the science requirements of increasingly sophisticated microgravity investigations and to permit the development of experiment equipment for research throughout the life of the ISS.

I. CURRENT FLIGHT HARDWARE

The experiment apparatus described in this section are existing or under development for flight on a Space Shuttle mission or the ISS (as noted). NASA anticipates flight opportunities for investigations capable of using Shuttle hardware through 2001 and ISS hardware beginning as early as 2002. Minor modifications of the current hardware may be possible to make it more versatile and able to accommodate users and experiments other than those for which it was originally designed. Several potential enhancements are highlighted in the descriptions for the current hardware. This listing is not fully inclusive of all available flight apparatus, and investigators are free to identify or propose against alternate existing apparatus to that mentioned in this section. Availability of the instruments described here, with or without modification, is contingent upon the availability and allocation of resources, and cannot be guaranteed at this time.

More detailed descriptions of the current flight hardware may be requested in the Letter of Intent described in Appendix A, Section V.

A. MATERIALS SCIENCE RESEARCH FACILITY (MSRF)

The Materials Science Research Facility (MSRF) is a modular facility comprising autonomous Materials Science Research Racks (MSRR) for research in the microgravity environment of the International Space Station (ISS). The facility will house materials processing apparatus and common subsystems and interfaces required to operate the apparatus. Each MSRR is a stand-alone autonomous rack and will be comprised of either on-orbit replaceable Experiment Modules, Module Inserts, investigation unique apparatus, and/or multi-user generic processing apparatus, and will support a wide variety of scientific investigations.

The Materials Science Research Facility is being designed to accommodate the current and evolving cadre of peer-reviewed science investigations which include solidification of metals and alloys, thermophysical properties, polymers, crystal growth studies of semiconductor materials, and research in ceramics and glasses.

This description provides a general characterization of the Materials Science Research Facility (MSRF), the Experiment Modules (EMs), and Experiment Module Inserts that could accommodate the current and future cadre of Materials Science Investigations. The information is preliminary and does not represent science or engineering requirements or design specifications. The specific Experiment Modules defined herein for potential follow-on development are in the conceptual definition stage only. Furthermore, many of the Materials Science investigations are immature and are in the early flight definition stage and are pending completion of the formal science review process. It is anticipated that specific hardware requirements as derived from the various Materials Science Investigations and necessary for the design of the various Experiment Modules and/or Module Inserts will be developed in the near future commensurate with completion of rack architecture studies and the maturing science requirements.

The MSRF concept consists of three modular autonomous Materials Science Research Racks (MSRR-1, MSRR-2, and MSRR-3) which will have phased deployment beginning with the third Utilization Flight (UF-3), and will accommodate materials processing furnaces and common subsystems and interfaces required to operate the furnaces. Each MSRR is a stand-alone rack and will be comprised of either on-orbit replaceable Experiment Modules (EMs), Module Inserts (MIs), investigation-unique apparatus, or multi-user generic processing apparatus, and will support a wide variety of scientific investigations. The EMs for each rack will be designed to be "smart" furnaces and will be comprised of the Furnace Module, Avionics, Control and Support Subsystems. The EMs for MSRR-2 and MSRR-3 will be designed consistent with the developing rack architecture and will incorporate optimum flexibility to support on-orbit maintenance and change out of key components. All MSRR-configurations will use the ISS Active Rack Isolation System (ARIS) system.

The MSRF racks will be designed for a minimum useful life of five years and a design goal of ten years. MSRF will interface directly with the ISS provided resources for its operation. The operational life of the EMs is planned for a minimum of five years. Crew interaction and telescience operational capabilities are provided.

1. First Materials Science Research Rack (MSRR-1)

The first Materials Science Research Rack is being developed to accommodate the NASA/ESA Experiment Module with multiple Module Inserts, Space Products Development Commercial Experiment Module, and follow-on Materials Science Discipline Experiment Modules. The NASA/ESA EM will be developed as a collaborative effort by NASA and the European Space Agency utilizing the ESA Materials Science Laboratory. This EM will accommodate various MIs which will be built both by NASA and ESA for on orbit changeout.

The first operations of the MSRR-1 as the first MSRF rack, will accommodate payloads for both NASA MSFC Microgravity Science and Applications Project Office and the Space Products Development Office (SPD). Following completion of the SPD on-orbit research activities, the SPD EM will be replaced with a Materials Science EM. The MSRR-1 rack configuration will use the ISS ARIS subsystem.

a. NASA/ESA Experiment Module

The NASA/ESA Experiment Module for the first Materials Science Research Rack (MSRR-1) is a multi-user, multi-purpose facility for accommodating Materials Science research in the United States Laboratory Module of the International Space Station (ISS). The NASA/ESA EM accommodation is modular, consisting of an Experiment Module and exchangeable Module Inserts. The inserts will process the sample and will contain heating elements. The Module Inserts (MIs) can be changed out on orbit. A variety of on-orbit replaceable MIs will be used to accomplish science investigations. Specifically, Bridgman-type crystal growth, isothermal processing, and solidification and quench processing accommodations are planned for MSL via specific MIs. NASA will develop a Quench Module Insert (QMI) and a Diffusion Module Insert (DMI) for the NASA/ESA EM. ESA will develop the Low Gradient Furnace Module Insert (LGF) as part of the International cooperative effort. The Solidification and Quench Furnace (SQF) which is under development by ESA for the Columbus Orbiting Facility is also a potential candidate MI for utilization in the NASA/ESA Experiment Module.

Features of the NASA/ESA Experiment Module support precise temperature stability and control, high resolution temperature resolution and measurement, furnace translation capability, mass spectrometer failure detection system, rotating magnetic field, current pulsing capability for sample interface demarcation, and shear cell motor drive capability. The Experiment Module will be designed for manual sample exchange.

The furnace inserts, with various heater types which are replaceable on-orbit, will be accommodated in a sealed furnace chamber. The EM core unit contains the module inserts and includes all items directly interfacing with the science Sample Ampoule /Crucible Cartridge Assembly (SACA). These include the furnace core, adiabatic zone, hot and cold zones, translation system, sample support structure, vacuum chamber, electrical equipment, and the supporting electrical, mechanical, vacuum, water, and gas supply lines. The temperatures and the axial temperature profiles required for sample processing are controlled by an assembly of furnace thermal zones and heat extraction zones. The furnace canister is designed to operate with either a vacuum or an inert gas environment.

Module inserts as well as science samples housed in suitable cartridges can be manually replaced during on-orbit operations by the crew. Telescience capabilities are provided, including sample thermocouple and resistance data, in addition to failure sensor data downlinked in real time to the PI team on the ground as well as being displayed on-board.

i. Quench Module Insert (QMI)

The Quench Module Insert provides for unique rapid quenching of the solidification interface not offered by other types of MIs. Rapid quenching capability is a key design requirement for satisfying certain class of solidification experiments

QMI Baseline Capabilities

This insert is a Bridgman type furnace with an actively cooled cold zone and gas quenching capability. The maximum temperature accommodated is 1400°C and helium is used as the quench medium. Gradients of up to 100°C/cm are required. An experiment-specific electronic package for resistance measurement is included. The MI envelope is 22 cm in diameter and up to 62 cm long depending on the translation stroke.

The furnace is planned to operate in a partial pressure gas environment. Key processing operations include sample melting and rapid quenching of the solidification interface. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands.

ii. Diffusion Module Insert (DMI)

The Diffusion Module Insert provides both precision isothermality in the heated zones and axial gradient between the zones to accommodate diffusion studies using the shear cell method. Both Fickian and Soret diffusion experiments can be carried out utilizing this Module Insert.

DMI Baseline Capabilities

The DMI is a Bridgman type furnace insert which will be designed to accommodate processing temperatures up to 1600°C. The requirements are for this module insert to have good isothermality and controllability An isothermal length of approximately 10 cm is provided in the heated zones. An adiabatic zone is used between the heated zones to achieve the desired axial gradient of up to 100°C/cm. Furnace translation capability is also provided. Both Fickian and Soret diffusion experiment can be carried out using a shear cell in which the diffusion process is allowed to occur inside the capillary tubes and the experiment is terminated by the shearing of the cell. The SACA incorporates a drive motor to accomplish rotation and shearing. The MI envelope is 22 cm diameter and up to 62 cm long depending on the translation stroke.

The Diffusion Module Insert will nominally operate in a vacuum environment. The shear cell motor is used to physically shear the diffusion cells to terminate processing. Furnace operation is fully automatic. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands.

iii. Low Gradient Furnace (LGF) Module Insert

The LGF is a low temperature Bridgman-Stockbarger furnace primarily intended for crystal growth experiments. The Low Gradient Furnace module insert provides for directional solidification processing with precise temperature and translation control. It also provides rotating magnetic field capability and current pulse interface demarcation. Optional features that can be incorporated include Seebeck voltage measurements, shear cell rotation, sample resistance measurements, ultrasonic pulsing and reservoir heating.

LGF Baseline Capabilities

The LGF Module insert is a vacuum furnace. It can accommodate processing temperatures up to 1600°C. The furnace has a booster heater zone and is mounted with enhanced cooling capability at this interface to act as a heat extraction zone. A fixed length adiabatic zone is provided. Axial gradient capability is limited to achieving up to 50°C/cm. The supporting subsystem provides for precise translation in the range 10^{-5} to 0.2 mm/sec along with rapid translation (pseudo quench) capability. Both thermocouples and thermo-optical sensors are used to provide precise temperature control (±0.1°C) and stability (± 0.02°C). A high degree of radial uniformity of temperature is also achievable. Current pulse interface demarcation capability is also available. In addition, controllable rotating magnetic field capability is provided. The design supports cartridge leak detection. The MI fits inside the standard envelope of 22 cm diameter and up to 62 cm long depending on the translation stroke.

Furnace operation is fully automatic with telescience operational capabilities provided. Crew interaction will be required for performing sample changeout. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands.

iv. Solidification and Quench Furnace (SQF) Module Insert

The Solidification and Quench Furnace module insert is optimized for metallurgical experiments requiring large thermal gradients and fast quenching of samples. Quench capability is provided via a Liquid Metal Ring that connects the cooling zone to the sample cartridge. It also provides rotating magnetic field capability and current pulse interface demarcation. Optional features that can be incorporated include Seebeck measurements and sample resisitivity measurements.

SQF Baseline Capabilities

The SQF module insert can accommodate processing temperatures up to 1600°C. The furnace has a booster heater zone and an adiabatic zone of variable size (diameter 11 to 30 mm and length 50 to 100 mm) which can be replaced on-orbit. The achievable axial gradient is up to 150°C/cm depending on the adiabatic zone configuration. The cold zone is actively cooled. Quench is accomplished by means of a liquid metal ring interface with the SACA. The design supports cartridge leak detection. The MI fits inside the standard envelope of 22 cm diameter and up to 62 cm long depending on the translation stroke.

Furnace operation is fully automatic with telescience operational capabilities provided. Crew interaction will be required for performing sample exchange. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands.

2. Second Materials Science Research Rack (MSRR-2)

The MSRR-2 rack configuration will be derived consistent with the outcome of the MSRR-2/3 Rack Architectural Studies currently being conducted at MSFC. It will be designed to accommodate a variety of on-orbit replaceable investigation unique Experiment Modules. MSRR-2 EMs are currently in the conceptual design stage and planned for future development. The EMs will satisfy the requirements of a class of investigations which include diffusion in liquid elements, segregation in alloys, interface pattern studies, vapor transport growth study of ternary compound semiconductors, and crystal growth.

MSRR-2 rack configuration will house the investigation unique apparatus and provide necessary subsystem elements for interfacing with the ISS resources and for autonomous operations. The apparatus size can vary and the maximum envelope is limited to a half-rack. It is envisioned that automatic sample exchange capability will be provided. MSRR-2 rack configuration will use the ISS ARIS.

3. Third Materials Science Research Rack (MSRR-3)

The third Materials Science Research Rack (MSRR-3) configuration will be derived consistent with the outcome of the MSRR-2/3 Rack Architectural Studies currently being conducted at MSFC. MSRR-3 EMs are currently in the conceptual design stage and planned for future development. This particular rack will be designed to accommodate a variety of on-orbit replaceable investigation unique Experiment Modules.

The MSRR-3 rack configuration will house the investigation unique apparatus and provide necessary subsystem elements for interfacing with the ISS resources and for autonomous operations. The apparatus size can vary and the maximum envelope is limited to a half-rack. It is envisioned that automatic sample exchange capability will be provided. The MSRR-3 rack configuration will use the ISS ARIS.

B. ADVANCED AUTOMATED DIRECTIONAL SOLIDIFICATION FURNACE (AADSF)

Developed for flight in the cargo bay of the Space Shuttle, the AADSF is a modified Bridgman-Stockbarger type directional solidification furnace. The AADSF gradient zone region is modified between missions to be optimized for the needs of a particular cadre of investigators. The AADSF was successfully operated on the Second United Stated Microgravity Payload Mission (USMP–2) in March 1994 and the Third United States Microgravity Payload Mission (USMP–3) in February 1996. A modification incorporating a sample exchange mechanism was flown on the fourth United States Microgravity Payload Mission (USMP-4) in November 1997. Three investigation samples were accomodated.

AADSF Baseline Capabilities. The AADSF Furnace Module is a five heater zone furnace, comprising a hot zone with an end guard heater, a booster heater between the gradient zone and hot zone, an unpowered gradient zone, a cold zone and a cold zone guard heater. The hot zone bore is approximately 2.5 cm diameter and 26 cm long. The cold zone bore is approximately 2.5 cm diameter and 12.5 cm long. The length and bore of the temperature gradient region is based on the thermal profiles required by the Principal Investigator. The gradient zone can be outfitted with a metal heat extraction plate and two ceramic insulating plates to modify the gradient temperature profile. The hot zone has been operated in ground test up to 1150°C; and the cold zone operated to 850°C. Up to six thermocouples of mixed type can be accommodated in the cartridge containing the sample ampoule.

The AADSF can be operated from the ground during the mission to change furnace set points and translation rates and current pulsing programs. Sample ampoule thermocouple data and furnace control and housekeeping data are downlinked in near-real-time during mission operations. The orbiter crew has the ability to boot up the computer from the orbiter in the event of a computer malfunction.

A sample exchange mechanism (SEM) was added to one of the AADSF flight units for the USMP–4 mission. This enhancement accommodates a maximum of three muffle tubes. Each muffle tube has typically contained one sample enclosed in an ampoule which, then, allows for up to three samples to be processed during a single mission. Muffle tubes have been configured with more than one sample. The samples will be loaded and retrieved on the ground. Current pulse interface demarcation, up to a current level of 20 amperes, has also been added to this unit.

C. CRYSTAL GROWTH FURNACE (CGF)

The CGF is a modified Bridgman-Stockbarger type directional solidification furnace capable of hot zone temperatures to 1600°C, and the exchange of experiment samples by the astronaut flight crew. The CGF system occupies two full Spacelab racks and comprises four avionics boxes and an Integrated Furnace Experiment Assembly (IFEA). The IFEA contains the Experiment Apparatus Container, which houses a Reconfigurable Furnace Module.

The CGF was successfully operated on the First United States Microgravity Laboratory Mission (USML–1) in June–July 1992, and performed flawlessly in processing all eight samples planned during the Second United States Microgravity Laboratory (USML–2) mission in October–November 1995. The CGF underwent significant modifications and upgrades for the reflight including the addition of current pulse interface demarcation capability.

CGF Baseline Capabilities.

The CGF Reconfigurable Furnace Module comprises three zones with a total of seven heater elements. The heated zones consist of a hot zone with redundant heater elements, a guard heater, a booster heater between the hot zone and gradient zone, an unpowered gradient zone, and a cold zone with redundant heater elements and a cold zone guard heater. The bore of the furnace is approximately 3 cm in diameter; the hot zone length is approximately 25 cm, and the cold zone length is approximately 16 cm. The length of the gradient zone is selectable pre-mission from 1.0 to 7.0 cm, based on the thermal profiles developed by the PI during ground based characterization testing. A Ground Control Experiment Laboratory or ground prototype of the CGF System is available to support pre-flight PI ground-based science testing activities. The gradient zone can be outfitted with a metallic heat extraction plate to assist in radial heat dissipation. The hot zone has been operated in ground test up to 1350°C; and the cold zone operated to 1225°C in support of previous flight investigations. Up to six thermocouples and up to four failure sensors can be located in the cartridge containing the sample ampoule. The furnace can be translated for directional solidification between 0.002 mm/min. and 8.3 mm/min. during processing; a rapid translation capability of up to 1200 mm/min. is also available. Sample ampoules/cartridges can be up to 2 cm in diameter and up to 20 cm in length. The current pulse interface demarcation system can deliver a coded string of current pulses of up to 40 amperes to the sample.

The CGF can be operated from the ground during the mission to change furnace set points, translation rates, and interface demarcation settings. Sample ampoule thermocouple data and failure sensor information, in addition to furnace control and housekeeping data, are downlinked in real-time and delayed near-real-time modes during mission operations, which provides a high degree of flexibility and interactive capability with the experiment operations for the PI and science team.

D. ADVANCED GRADIENT HEATING FURNACE (AGHF)

The AGHF is a multi-user tubular furnace for high temperature directional solidification research developed by the European Space Agency (ESA). It is currently configured for operations inside a Spacelab module on board the Space Shuttle. The AGHF was successfully flown aboard the Life and Microgravity Science (LMS) mission in June-July 1996. Several experiments were processed using shared operational time.

AGHF Baseline Capabilities. The AGHF is a Bridgman type gradient furnace consisting of a heated section with two individually controlled heaters acting on a common thermal diffuser, separated from a cooled heat extraction zone. The furnace is displaced relative to the sample. The AGHF is currently optimized for sample diameters of up to 20 mm, current pulse interface demarcation up to 30 amperes, and a high degree of thermal stability. Sample cartridges up to 32 cm long containing up to 28 thermocouples can be translated up to 14 cm in the furnace, from 0.6 mm/hr to 600 mm/hr. The AGHF can be commanded/monitored on Earth in a similar manner as the Crystal Growth Furnace.

E. MILLIKELVIN THERMOSTAT (MITH)

MITH Baseline Capabilities. This is a microgravity materials science and fluid physics apparatus capable of both autonomous operation and remote control operation through uplink and downlink communication. In its current configuration, this apparatus permits study of the solidification behavior of transparent organic materials, such as succinonitrile (SCN) or pivalic acid (PVA) in dendrite growth experiments.

A single sample can be repeatedly melted and supercooled with solidification observed at the center of a 4 to 6 cm diameter spherical test volume. Spontaneous initiation of solidification is minimized by using highly purified test materials, isothermal control during each solidification test cycle, and compatible stainless steel and glass test chamber construction.

The thermostat can measure and control the test chamber with high precision and accuracy by using an isothermal bath around the chamber. The test chamber allows orthogonal photography and digital imaging of the chamber test volume. The digital imaging system is a charge coupled device (CCD) camera which, in conjunction with three onboard computers, has three principal capabilities. First, the CCD cameras identify the first appearance of solidification at the center of the target sample volume and then activate the high resolution photographic system. Secondly, the CCD cameras store adjustable field-of-view images. Finally, CCD images are available for transmission to ground control and can be used to determine appropriate remote adjustments of some of the experiment parameters such as: photographic frame rate, undercooling temperature, etc. For postflight analysis, still-frame Schlieren photography provides up to 500 alphanumerically annotated, high resolution photographs from two 35 mm cameras. These photographs show orthogonal views of the test volume for accurate determination of random solidification growth direction.

The MITH is currently designed for location in the open shuttle bay on the USMP carrier. It is thermally isolated in a conditioned N_2 atmosphere and is isolated from astronaut physical access during flight.

F. MIDDECK GLOVEBOX (MGBX).

The Middeck Glovebox is a multi-user and multidiscipline facility that provides an enclosed working space for experiment manipulation and observation. The MGBX occupies two standard lockers in the Space Shuttle middeck. The Middeck Glovebox door opening to insert or retrieve investigation hardware is 20.3 cm by 19.4 cm, with a working volume of 35 liters. The Glovebox working volume is approximately 39.0 cm wide, 25.0 cm deep, and 23.0 cm high. Forced air cooling can withdraw a maximum of 60 W of investigation generated heat. Up to 60 W of 24, ±12, and 5 VDC power is available for experimenter apparatus.

The MGBX can be used in various modes of pressure and air circulation. The working area can serve as a sealed environment that is isolated from the crew cabin atmosphere, as a constantly recirculating atmosphere that is maintained at a pressure slightly lower than the middeck ambient, or as a working area open to the middeck. Multipurpose filters exist to remove particles, liquids, and reaction gasses from the recirculated air.

Due to limitations of the Space Shuttle middeck, there is no standard data or video downlink. There is the possibility of some near-real-time video downlink (from the Shuttle Camcorder), but this will be decided on a mission-by-mission basis. Three video recorders provide data storage, with digital data stored in the audio channels; an additional connector records 10 channels of data (five analog and five digital) to the interface frame data recorder. An adjustable light switch, video port plugs, a backlight panel, and cutout window covers provide illumination.

The overall philosophy of the Glovebox program is to provide the ability to conduct less complex science investigations or technology demonstrations in a microgravity environment in a faster, better, and cheaper manner. The hardware development cycle is approximately 2 to 3 years. Currently ten glovebox investigations in the disciplines of materials science, fluid physics, biotechnology and combustion science are under development for flight, and additional Glovebox flight opportunities for new investigations are planned on a frequent basis from 1996 through 1999.

G. GLOVEBOX LASER LIGHT SCATTERING HARDWARE

A compact instrument has been designed that is capable of both static and dynamic light scattering measurements. This instrument was designed to operate in the Space Shuttle glovebox facility and occupies the volume of an 8” cube. It accepts cylindrical test cells with an outer diameter of 10 mm. A translation motor enables interrogation of a 2 cm length of a test cell with a translation velocity of either 24 µm/sec or 0.6 mm/sec. It is equipped with a pigtailed laser diode which delivers approximately 6-8 mW of power at 780 nm to the test section. A fiber optic pickup at 90 degrees delivers scattered light to an avalanche photodiode detector. A glovebox facility camera can be positioned to record static light scattering data incident on a semi-cylindrical diffuse screen (approx. 30 degrees – 160 degrees). Test samples can be oscillated about the cell axis with a fixed 2 degree amplitude. The instrument is capable of inducing single impulses or sinusoidal oscillations with variable frequency (15–70 Hz). The instrument is controlled via software resident in a laptop computer which also contains a digital correlator card to compute the temporal autocorrelation function from the avalanche photodiode output. The instrument should be able to interface with the ISS Microgravity Science Glovebox facility with minor modifications.

G. SUPPRESSION OF TRANSIENT ACCELERATION BY LEVITATION (STABLE)

STABLE is an actively controlled vibration isolation system which has been baselined to control 50% of the U.S. allocation of payloads to be flown on ISS. Designed to operate on the component level rather than the rack level, it has been successfully proven on USML–2 in late 1995 with a small simple system to study materials processes in microgravity that are applicable to crystal growth mechanics. The STABLE system operates by the application of dual axis wide-gap electromagnetic actuators with feedback from accelerometers.

II. FUTURE DIRECTIONS

The evolving focus of the MRD emphasizes the development of modular payloads that can be configured (or easily reconfigured) to accommodate specific investigations and their experiment-unique equipment. In addition, NASA has developed descriptions of candidate MSRF Experiment Modules perceived as suitable for a subset of the research described in Appendix A. These general hardware capability descriptions are included as a point of departure for researchers to consider the type of capabilities that might meet their science requirements; researchers should not, however, feel limited by these capabilities. The descriptions are concepts for guidance only, as some of the NASA systems given have not been committed for development. The proposals received in response to this NRA will be used to more accurately determine the capabilities needed in future flight hardware. These Experiment Modules, now in the early concept definition stage, could, if developed, be available for flights in 2002 and beyond.

A. MATERIALS SCIENCE RESEARCH FACILITY (MSRF) EXPERIMENT MODULES

In addition to the existing materials science apparatus described in Appendix B Part I of this NRA, NASA is conducting studies of potential follow-on MSRF Experiment Modules based on the preliminary performance specification of PIs selected from the Microgravity Materials Science formal peer selection process through the 1996 NRA. The materials science Experiment Modules described here are in the conceptual design stage and have not yet been approved for development. In addition, coordination of plans for microgravity materials science apparatus development is underway with our international partners to insure that identical research capabilities are not inadvertently duplicated on the ISS. The final selection of initial MSRF Experiment Modules will be based on the needs of the individual research projects which successfully complete a SCR; a mix of investigation-unique and multi-user Experiment Modules is probable. Additional MSRF Experiment Modules are anticipated, and will be based on the results of future Microgravity Materials Science NRAs.

Concepts for the required Experiment Modules which satisfy the goals and objectives of the Materials Science program are being developed. No containerless positioning or levitation devices are currently planned for incorporation into the MSRF. It is anticipated that the useful life of each rack will be from a minimum of five (5) years with a design goal of up to ten (10) years. The operational life of the Experiment Modules (EM) is planned for a minimum of five (5) years. The EMs will be designed to be serviceable and maintainable on orbit for their operational duration and will satisfy unique scientific investigations. Flexibility is to be included in the design of Orbital Replacement Units (ORU's) for key components in order to extend useful life of the Experiment Module.

1. First Materials Science Research Rack (MSRR-1)

a. Pattern Formation and Coarsening Research (PFCR) Experiment Module

This experiment module, known as EM-2, will provide a platform for pattern research beyond that flown as part of the Isothermal Dendritic Growth Experiment (IDGE) on the United States Microgravity Payload series of Spacelab Missions. There will be three EM-2 inserts that are projected to serve the varying needs of anticipated investigators. Solidification and coarsening characteristics will be studied by melting a transparent model material in an isothermal bath, lowering the temperature of the isothermal bath to a controlled undercooled state and then instigating solidification. Growth and coarsening of the material will be observed and recorded by optical wavelength imaging on two orthogonal axes.

The basic EM will provide the thermostat temperature and pressure control and data acquisition systems. The investigation unique MilliKelvin Thermostat (MITH) inserts will each include the thermostatically controlled bath and the PI-unique sample growth chamber. The thermostat will be capable of establishing and maintaining a constant temperature in the range of 40° - 70°C with high precision and accuracy over long time periods. Temperature measurement will be of equally high fidelity. The EM will also incorporate the optical imaging system, including lasers, lighting, digital photography, and photographic and holographic film capability.

Depending on the length of the experiment, crew time may be required to change out holographic film. Telescience operational capabilities are provided. It is currently planned that EM-2 will replace the SPD Commercial EM. It will remain on orbit and accommodate the replaceable MITH Inserts.

Enhancements to the MITH development include variable photographic magnification and field of view, greater video field of view, and increased frame rate. Video enhancements may allow study of transient phenomena during flight. Other possible enhancements include a new sample chamber with multiple moveable, independent dendrite initiation sites

2. <u>Second Materials Science Research Rack (MSRR-2)</u>

a. <u>Self-Diffusion in Liquid Elements/Thermophysical Properties (SDLE/TPP) Experiment Module</u>

This experiment module is envisioned as a self contained, semi automatic, sealed, and multiple temperature apparatus. The EM will provide for diffusivity studies in low gravity on a variety of elements and binary and ternary compounds.

All furnace components, samples, sample exchange mechanism, electronics/ microprocessors are within or on the sealed experiment container. The SDLE experiment container is divided into a processing volume and a non-processing volume. Major components housed within the processing volume are: a measurement cell which contains the platinum core, heater and thermal shields and cooling structure, diffusion sample cartridges/cartridge container, radiation detector modules including their support electronics, sample translation system, and radiation shielding and support structure. The experiment container will provide for either a vacuum or an inert gas environment surrounding the measurement cell. The non-processing volume contains the avionics and control system components including data acquisition system, signal conditioning, power conditioning and power distribution. The Experiment Module diffusion sample cartridge container will be designed to be changed out on-orbit to accommodate multiple runs of up to 5-10 samples each. Processing temperatures up to 1400°C can be achieved.

The apparatus will be able to continually operate over multiple increments with sample replenishment or to refly on separate increments. Telescience operational capability will be provided. Crew interaction for sample changeout will be required.

b. <u>High Gradient Directional Solidification (HGDS) Furnace Experiment Module</u>

The HGDS will be a directional solidification furnace supported by its own subsystems for operation. The module is designed to support studies involving crystal growth processes, segregation in alloys and interface pattern selection criteria.

The HGDS will be an investigation unique apparatus. The furnace can accommodate processing temperatures up to 1600°C and includes a reconfigurable gradient zone length from 1 to 5 cm in order to be able to achieve an axial gradient of 50 to 150°C in the sample. The processing atmosphere can be either inert gas or vacuum. A precise translation drive is provided. Quench capability from either water or gas or phase change collet will be provided to achieve quench rates up to 100°C/sec in the sample. An automatic sample exchange capability (up to 20 samples) with provision for crew interaction is provided. Sample size up to 2 cm in diameter and 20 cm long can be accommodated. Higher gradient, accommodation of larger size samples, provision of an automatic sample exchange capability distinguishes this furnace module from the Quench Module Insert.

The HGDS will be designed for on-orbit installation. The design will allow for on-orbit maintenance and changeout of key components with ease. Telescience operational capabilities will be provided. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands. The processing software will also be capable of being modified and/or reloaded on-orbit.

c. Directional Solidification and Vapor Transport (DSVT) Experiment Module

This Experiment Module provides capabilities for both directional solidification and vapor transport crystal growth processing. In addition, it will provide current pulse interface demarcation, very precise and extremely low translation rates, and in situ optical measurement features.

The DSVT will be an investigation unique apparatus. The furnace can accommodate processing temperatures up to 1400°C and includes a reconfigurable gradient zone length from 1 to 5 cm. The processing atmosphere can be either inert gas or vacuum. A very precise and extremely low translation (0.028 to 0.058 µm/sec) drive is provided. An automatic sample exchange capability (up to 20 samples) with provision for crew interaction is also provided. The sample will be contained in ampoules housed in special cartridges to obtain a single level of containment. Sample size up to 2 cm in diameter and 20 cm long can be accommodated. Programmable current pulses up to 100 A are required. Video capability includes resolution comparable to NTSC TV at a frame rate of about 1 per second.

The HGDS will be designed for on-orbit installation and a design life of five years. The design will allow for on-orbit maintenance and changeout of key components with ease. Telescience operational capabilities will be provided. Processing of long duration (up to 7 days/run) are anticipated. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands.

3. Third Materials Science Research Rack (MSRR-3)

a. Directional Solidification Furnace with Pulsing (DSFP) Experiment Module

This Experiment Module is planned to be a modified-Bridgman furnace with actively cooled cold zone to achieve a low temperature with the hot zone operating at a moderately high temperature. It provides for in situ Seebeck voltage measurements and current pulsing with a high amperage long duration pulse capability.

The DSFP will be an investigation unique apparatus. The multizone furnace can accommodate processing temperatures up to 1000°C and includes an actively cooled cold zone that can achieve a low temperature of 50°C while the hot zone is set to 650°C. The gradient zone is reconfigurable with 1 to 10 cm length. A translation drive is provided for processing and rapid positioning of furnace. An automatic sample exchange capability (up to 20 samples) with provision for crew interaction is also provided. The sample will be contained in ampoules housed in special cartridges to obtain a single level of containment. Sample size up to 2 cm in diameter and 20 cm long can be accommodated. Programmable current pulses up to 100 A and long duration (up to 300 sec) are required. The DSFP furnace module will be installed within the half-ISPR envelope.

The DSFP will be designed for on-orbit installation and a design life of five years. The design will allow for on-orbit maintenance and exchange of key components with ease. Telescience operational capabilities will be provided. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands. The processing software will also be capable of being modified and/or reloaded on-orbit.

b. High Temperature Bridgman Furnace (HTBF) Experiment Module

This Experiment Module supports high temperature processing of semiconductor materials. Significant features include accommodation of processing temperatures up to 2300°C and provide high degree of isothermality in the heated zones specially to conduct Fickian diffusion studies in doped silicon.

The HTBF furnace will be an investigation unique apparatus to support diffusion studies of doped silicon using the shear cell method. The conventional Bridgman furnace can accommodate processing temperatures in the range 1000°C to 2300°C and support high axial gradients. Translation drive is provided for processing and rapid positioning of furnace. A high degree of isothermality is provided in the heated zones. An automatic sample exchange capability (up to 20 samples) with provision for crew interaction is also provided. The sample will be contained in ampoules housed in special cartridges to obtain a single level of containment. A shear cell drive motor is included in the sample cartridge to enable physical shearing of diffusion cells following completion of diffusion. Sample size up to 2 cm in diameter (up to 5 cm cartridge diameter) and 20 cm long are planned to be accommodated.

The design will allow for on-orbit maintenance and changeout of key components with ease. Telescience operational capabilities will be provided. Preprogrammed processing profile tables which are event and/or timeline based will be used for nominal operation and key software control functions will be operable by direct uplink commands. All table parameters are modifiable by uplink commands. The processing software will also be capable of being modified and/or reloaded on-orbit.

B. ISS MICROGRAVITY SCIENCE GLOVEBOX (MSG)

Planning for a larger version of the glovebox for ISS has begun. Utilities similar to the Middeck and Mir Gloveboxes are envisioned, but with a larger work area, more power (up to 1000W), and increased data handling capability for the investigations to be performed within the glovebox. The MSG will be developed by ESA and available for use in the U.S. Laboratory Module of the ISS. A detailed description of the Microgravity Science Glovebox can be found on the website http://floyd.msfc.nasa.gov/msg/

C. ACTIVE RACK ISOLATION SYSTEM (ARIS)

Some of the experiments scheduled to be performed on board the future International Space Station (ISS) will be sensitive to motion and vibration. In order to not disturb these experiments, researchers have developed a system that isolates these experiments from disrupting vibrations which could reduce the likelihood of a successful experiment. The ARIS is designed to isolate certain classes of science experiments from major mechanical disturbances that might occur on the ISS, essentially acting as a shock absorber. The ARIS isolates the research payload from motion disturbances through a sophisticated electronic sensing and control system as well as umbilical cables and actuators, allowing the rack to float within a half-inch clearance in all directions in the space station. The umbilicals provide power, data, fluids, gases and vacuum conditions needed to support science experiments conducted in the rack. The umbilicals also allow some of the transport module's vibration to disturb the rack. The control system will use accelerometers to sense rack vibration and generate response signals to the rack actuators. Then the actuators in the ARIS rack will counter those vibrations by pushing between the rack and the space station module. ARIS is expected to isolate payloads from low frequency vibrations. This system is expected to be implemented at approximately half of the Microgravity investigations processing locations on board the future ISS.

D. EXPEDITE THE PROCESSING OF EXPERIMENTS TO SPACE STATION (EXPRESS) RACK

The ISS Program Office has developed an extension of the Space Station accommodations for small and modular-type subrack payloads. Known as the EXPRESS Rack, it provides simple and standard interfaces for the integration of payloads, and will allow for the operation of subrack, experiment-unique materials science equipment in the ISS.

The EXPRESS Rack provides the interfaces to accommodate middeck locker payloads and Standard Interface Rack (SIR) drawer payloads. Two configurations of the EXPRESS Rack are provided: one accommodates fifteen four-panel-unit SIR drawers or multiples thereof, the other accommodates eight middeck lockers and two SIR drawers. Because of the modular accommodations, multiple payload disciplines can be accommodated and operated simultaneously in each EXPRESS Rack. Resources that may be provided to the payloads are 28V electrical power, air and liquid cooling, RS422, Ethernet, analog and discrete data interfaces, video, vacuum, and nitrogen.

The physical integration needs of payloads are reduced due to the standard and simple interfaces. In addition, a streamlined analytical integration process is under development by the ISS Operations and Utilization Office for the EXPRESS Rack users to manifest and integrate standard payloads in eleven months or less before launch.

E. ELECTROSTATIC LEVITATION FURNACE (ELF)

An Electrostatic Levitation Furnace is being developed for the Japanese Experiment Module (JEM) in the ISS, which will be operational after the year 2000. The National Space Development Agency of Japan (NASDA) has been developing the JEM and a variety of experiment facilities for the ISS. The ELF is one of the facilities under development for materials science research in the JEM's microgravity environment.

Containerless processing is a key technology in material science research for investigating the formation of metastable phases and nucleation phenomena and for measuring thermophysical materials properties such as heat capacity, surface tension, thermal conductivity, and viscosity of molten samples. The ELF is an experimental system required for scientific investigations in such fields under microgravity. The facility enables containerless sample processing by means of electrostatic levitation. The ELF also has heating capability, gas environment control capability, non-contact temperature measurement capability, and automated sample exchange capability.

The levitation section consists of two sample position detectors, an ultraviolet lamp, upper and lower electrodes and a position control unit. The sample in the chamber is charged by the UV lamp, and position is achieved by adjusting the balance between the sample inertia and coulomb forces generated by two electrodes. The heating section consists of a chamber, four heating lasers and their power control unit. According to the current design, four laser diodes with 0.80 µm to 0.81 µm wavelengths are employed, and a total power of 1,000 W will be applied. The four lasers are controlled independently, creating the capability for heterogeneous sample heating as well as homogeneous heating.

The ELF has a pyrometer, a thermal imaging system and a video camera to monitor the sample condition. The pyrometer will be used to measure the temperature center of the sample surface, while the thermal imaging system is for measurement of the temperature distribution of the sample. In the thermal imaging system, the thermal image of the sample is divided into pixels, and the average temperature of the pixel will be sent to the ground. A video camera will be used to observe the sample. From this image, we can understand the status of the sample, status of levitation and positioning, and status of the experiment.

The ELF for ISS is in a fundamental design phase; key technology development and overall configuration design are in progress. Ground-based tests of levitation and heating have been conducted on a breadboard model. During these tests, a YAG laser with 100 W power has been employed as a heating device. Thus far, samples of pure aluminum and zirconium, with 2 mm in diameter have been successfully levitated and melted in vacuum conditions. Functional tests in a reduced gravity have also been performed by using parabolic flights and will be conducted on a TR–1A sounding rocket.

F. ADVANCED TEMPUS

An advanced TEMPUS electromagnetic levitation facility is under consideration as a bilateral development with NASA for the International Space Station. In contrast with the TEMPUS apparatus currently available for a possible flight on Spacehab the Advanced TEMPUS facility planned for the Space Station pursues an "experiment container changeout" concept: up to 9 samples with comparable properties and processing requirements are grouped into one sample magazine and may be processed sequentially. Required experiment specific hardware and environmental conditions such as a coil system (highly efficient and without obstructing the view onto the sample), sample holders, gas atmosphere, special needs for illumination, etc. are realized within the container and do not affect the Space Station rack-installed peripheral infrastructure , e.g. pyrometers or vacuum and cooling modules. In addition tailor-made video equipment could be flanged to the container from the outside. Experiments with varied requirements are conducted by in-orbit changeout of the respective containers.

G. SpaceDRUMS

The Canadian Space Agency is developing an acoustic levitator known as SpaceDRUMS (Dynamically Responding Ultrasonic Matrix Sonar). The facility uses 20 narrow beam transducers operating at 64kHz positioned at corners of a dodecahedron to position the sample. PID control via cameras has demonstrated the ability of the system to react to some extreme g-jitter during parabolic trajectory low gravity flights and to levitate in a stationary position a 4 cm sample. The force necessary is of the order of mN. Static field control is also possible. Various configurations of heating are now being studied, including laser heating, a spherical furnace and mirror furnaces.

H. DISPOSITIF POUR L'ETUDE DE LA CROISSANCE ET DES LIQUIDES CRITIQUES (DECLIC)

DECLIC is a new, modular, multi-user facility currently being designed and built by the French Space Agency, CNES for use aboard the International Space Station, initially in the US Laboratory followed by the Japanese Experiment Module, the Columbus Orbital Facility or the Russian module. The facility is being designed to conduct microgravity investigations in critical phenomena and directional solidification of transparent alloys.

Specifically, DECLIC will accommodate microgravity investigations in morphological stability and pattern formation during crystal growth in transparent alloys. Experiments can be conducted under controlled temperature gradient conditions or conditions provided by an isothermal thermostat that can be controlled with millikelvin precision. It will also accommodate chemical-physical studies of supercritical pure fluids (CO_2, SF_6, Xe) and solutions (H_2O and aqueous solutions). In addition, investigations in condensed matter physics requiring a long term microgravity environment can also take advantage of the capabilities offered by DECLIC.

DECLIC is the follow-on to the ALICE-2 facility, still onboard the Russian MIR space station, but will accommodate wider classes of experiments. The facility provides advanced optical diagnostics, including wide field imaging, microscopy, interferometry and small angle light scattering as well as highly accurate measurements of thermophysical parameters (pressure, temperature). All experiments can be conducted within a very stable and accurately thermally controlled environment. Operation of the facility is via quasi real-time telescience.

More detailed information about DECLIC and its capabilities can be obtained at the CNES web site: http://www.cnes.fr/espace_pro/declic/declic.html

I. UNIVERSAL MULTIZONE CRYSTALLIZATOR

An advanced version of the Unversal Multizone Crystallizator (UMC) has been developed by the University of Miskolc, Hungary for crystal growth on long duration space missions. A collaborative intensive test study of an earlier version, involving participants from US and Hungarian investigators has been completed at MSFC. The UMC furnace consists of 25 1.5-cm thick individually controlled heating zones of tungsten/rhenium. It operates in vacuum at up to 1500ºC. Isothermality of ±0.4°C with a gradient of 100°C/cm are attainable in the furnace bore. Sample dimensions of up to 45 mm in diameter and 250 mm length can be accommodated. Directional solidification is achieved by systematically reducing the power to individual zones. The UMC has been tested on the ground and has successfully produced materials by physical vapor transport, travelling solvent zone, electronic gradient freeze, and float zone techniques. Geometric shapes such as turbine blades have also been produced. More details of the prototype UMC can be found in Proceedings of SPIE volume 2809, "Space Processing of Materials," pp. 358-366, Denver, CO, 1996. The UMC has been configured to fit into a half rack on ISS with its own vacuum system. Details can be found at URL http://www.matsci.uni-miskolc.hu/umc.htm.

J. Low Temperature Furnace with Quench

A small low power furnace for temporal and spatial isothermal holding (±0.1°C typical) has been equipped for water quenching. The cartridge is constructed of aluminum with integral heaters for ease of control, good heat transfer, and rapid quenching. The Lewis Research Center (LeRC) developed furnace and controller/recorder fit into the middeck glovebox facility and are consistent with glovebox provided utilities. It could be mounted in a rack or Get Away Special (GAS) environment. Specimen volume is about 9 cc, maximum temperature is 200°C, and quench rate is approximately 30 degrees per second.

K. Surface Light Scattering Hardware

NASA's Advanced Technology Development (ATD) program is sponsoring the development of surface light scattering hardware. This instrument is designed to non-invasively measure the surface response function of liquids over a wide rage of operating conditions while automatically compensating for gross surface movement. The surface response function can be used to compute surface tension, properties of monolayers present, viscosity, surface tension gradient, and surface temperature and its gradient. The instrument uses optical and electronic building blocks developed for the laser light scattering program at NASA LeRC along with several unique surface light scattering components and new algorithms.

L. Laser Light Scattering Hardware

A versatile, miniature, modular light scattering instrument has been developed at NASA LeRC for the use in microgravity. An enhanced multi-angle Laser Light Scattering (LLS) facility is in the process of being developed. LLS can be used to measure microscopic particles in the size range of 30 angstroms to above three microns. It is a non-invasive technique that can determine particle structure, weight-average molecular weight, and particle-particle interactions. A Space Shuttle glovebox version of this instrument has been used on orbit to measure PMMA hard spheres concentrations in an index matched solution to determine the order-disorder phase boundary. This technique is also appropriate for studying protein crystal growth, spinodal decomposition, aggregation, diffusive transport, critical phenomena. Etc. Design and development of flight hardware for accommodation in the EXPRESS rack on Spacelab have already been started. The hardware will be capable of making static and dynamic light scattering measurements. Specific capabilities include: Bragg diffraction and photon counting from 10 degrees to 170 degrees with

0.25 degrees resolution; small angle scattering from 0.10 degrees to 10 degrees with 0.25 degrees resolution; Bragg scattering from 10 degrees to 60 degrees; and ability for sample rotation and oscillation. Flight hardware for use on the ISS is in the planning phase.

III. GROUND-BASED FACILITIES

Investigators often need to conduct reduced gravity experiments in ground-based facilities during the experiment definition and technology development phases. The NASA ground-based reduced-gravity research facilities that support the MRD materials science program include an array of specialized laboratory apparatus, such as laboratory equipment (i.e. furnace systems, special diagnostic tools and equipment, etc.), an evacuated drop tube at MSFC, a drop tower at LeRC, and parabolic flight research aircraft. A variety of specialized test apparatus have been constructed and used to conduct a wide range of materials science research. In general, these apparatus have been developed to accommodate specific individual investigator's requirements. In addition, other hardware and facilities have been developed which have the potential for use by investigators. Investigators should denote any additional facilities needed for their research, and such facilities, if available, can be made accessible on a limited basis.

A. 105 METER DROP TUBE

A 105 meter long by 25 centimeter diameter drop tube located at the Marshall Space Flight Center provides 4.6 seconds of low gravity process time. The facility, primarily intended for containerless processing applications, can maintain a vacuum level of 10^{-6} torr or can be backfilled with various gases to increase cooling rates. Two heating methods are currently available: an electron-beam furnace and an electromagnetic levitator. Other heating methods are possible. Samples are viewed through ports located at eight meter intervals in the tube. The drop tube has been used for the study of undercooling, nucleation, and solidification phenomena in molten metal samples. However, the facility could also accommodate studies of semiconductor, ceramic, or glass materials.

B. 5.18 SECOND ZERO GRAVITY FACILITY

The 5.18 second Zero-Gravity Facility has a 132 meter free fall distance in a drop chamber which is evacuated by a series of pumpdown procedures to a final pressure of 1 Pa. Experiments with hardware weighing up to 450 kilograms are mounted in a one meter diameter by 3.4 meter high drop bus. Residual acceleration of less than 10^{-5} g is obtained. At the end of the drop, the bus is decelerated in a 6.1 meter deep container filled with small pellets of expanded polystyrene. The deceleration rate is typically 60 g (for 20 milliseconds). Visual data is acquired through the use of high-speed motion picture cameras. Also, other data such as pressures, temperatures, and accelerations are either recorded on board with various data acquisition systems or are transmitted to a control room by a telemetry system capable of transmitting 18 channels of continuous data. Due to the complexity of drop chamber operations and time required for pump-down of the drop chamber, typically only one test is performed per day

C. PARABOLIC FLIGHT RESEARCH AIRCRAFT

The aircraft can provide up to 40 periods of low gravity for 22 second intervals each during one flight. The aircraft accommodates a variety of experiments and is often used to refine spaceflight experiment equipment and techniques and to train crew members in experiment procedures, thus giving investigators and crew members valuable experience working in a low gravity environment. Qualified observers or operators may fly with their experiment packages. The aircraft obtains a low-gravity environment by flying a parabolic trajectory. Forces twice those of normal gravity occur during the initial and final portions of the trajectory, while the brief pushover at the top of the parabola produces less than one percent of Earth's gravity (10^{-2} g). The interior of the aircraft bay dimensions are approximately three meters wide and two meters high by 16 meters long. Several experiments, including a combination of attached and free-floated hardware (which can provide effective gravity levels of nominally 10^{-3} g for periods up to 10 seconds) can be integrated in a single flight. The aircraft can supply a total of 80 amps of 28 volt dc, 90 amps of 115 volt ac 60 Hz and 30 amps open each phase of 3 phase 115 volt ac 400 Hz. These are maximum powers available to all users. Instrumentation and data collection capabilities must be contained in the experiment packages.

D. LOW GRAVITY AIRCRAFT MATERIALS SCIENCE APPARATUS.

1. Automated Directional Solidification Furnace (ADSF)

This furnace is based on a prototype of the Grumman ADSF that flew sounding rocket and Space Shuttle experiments with Mn–MnBi alloys. The furnace uses a basic Bridgman furnace configuration. It been optimized for use in parabolic flight aircraft and has been fitted with a water spray interfacial quench device. The furnace has been employed extensively for KC–135 solidification experiments on metals and semiconductors over a 10 year period. It is also compatible with the DC–9 platform. Representative materials that have been investigated using this apparatus include metal alloys, plastics, superconductors, and metal matrix composites. From one to four samples, 0.5 cm in diameter and 6–15 cm in length, are processed per flight. Containment is typically alumina or quartz ampoules. Maximum operating temperature is 1500°C; temperature gradients of approximately 100°C/cm are achievable in metal alloy systems. The furnace can be translated at 0.1 to 100 cm/min. over a distance of 8 cm. The quench rate is typically 100°C/sec. Instrumentation supports acquisition of two sample temperatures, furnace temperature, cold end temperature, accelerations on three axes (mounted to furnace), and furnace position.

2. Isothermal Casting Furnace (ICF)

The ICF is designed for multidimensional solidification (bulk casting) during a single aircraft parabolic maneuver. The sample thermally soaks at a predetermined temperature for a specific length of time and is then quenched by a stream of helium gas during the low gravity period of the parabola. The furnace has been used for aircraft experiments for 10 years. Typical experiments include the testing of crucible wetting characteristics for immiscible alloys or semiconductors during solidification under low gravity conditions. Previously processed materials include iron-carbon alloys, immiscible metal alloys (e.g., aluminum-indium), and cadmium telluride. Sample dimensions are typically 0.9–1 cm in diameter by approximately 2 cm in length. The furnace operates over a range of temperatures from 100 to 1350°C. Quench rates range from 1°C/sec to 50°C/sec. Up to three sample temperatures can be recorded along with acceleration along three axes.

3. Quench Furnace With X-Ray

A Quench Furnace with X-Ray is also available for ground-based low-gravity research at LeRC. This three zone, end chill, directional solidification furnace with a water quench can reach a maximum temperature of 700°C. It was developed to study the solidification of metal samples during low-gravity testing in research aircraft. The liquid-gas and solid-liquid interfaces are recorded using x-ray scanning and high resolution CCD camera.

4. SpaceDRUMS

The acoustic levitator described in section IIG can also be accomodated on the parabolic aircraft.

IV. SPECIALIZED GROUND BASED REASEARCH CAPABILITIES

In addition to the specialized ground based microgravity capabilities such as drop tubes and drop towers, and parabolic aircraft, NASA is able to support selected Principal Investigators with state-of-the-art laboratory equipment, sample preparation facilities and computing support. These facilities are offered on an as available basis, through the Microgravity Science and Applications Division of the Marshall Space Flight Center, who have available trained personnel to assist all experimenters.

A. MSFC ELECTROSTATIC LEVITATOR (ESL)

A new containerless electrostatic levitation research facility for materials and fluids is being established at MSFC, derived a system donated by LORAL. The facility uses electrostatic forces to levitate specimens in a vacuum chamber, then a high power infrared laser heats and melts these specimens. A 60 W YAG laser is available for metallic specimens and two 50 W CO_2 lasers are available for oxides and ceramic specimens. By isolating a material from all but its radiation environment, the disturbing influences of container walls and impurities are removed. The electrostatic forces will levitate a wide variety of materials: conductors, semiconductors, and insulators.

The specimen's position is controlled using a sophisticated three-dimensional digital feedback system manipulated through an intuitive and convenient computer interface. All of the controls over the specimen's motion and heating can be handled by a single user sitting at the control terminal.

Specimens are typically spheres, 2-3 mm in diameter. Once a specimen is levitated and melted, the ESL can apply a range of measurement techniques to measure the material's thermophysical properties, such as specific heat capacity, density, surface tension, viscosity, and optical emissivity, all as functions of temperature. At a given temperature, density is measured through analysis of a digitized silhouette image, and viscosity and surface tension are obtained from the frequency and rate of decay of shape oscillations.

B. High Magnetic Field Solidification Facility

Built at MSFC, the High Magnetic Field Solidification Facility includes two 5 Tesla superconducting magnets each with a vertical, 25 cm diameter room temperature bore. The use of a strong magnetic field can suppress fluid motion, thus simulating some of the effects of low gravity. By this means some important parameters can be determined which enable better use of the valuable and limited processing time in space. Resistance heated tubular furnaces capable of temperatures to 1200°C with bore diameters up to 2.5 cm are available and include thermal control and translation mechanisms. With appropriate inserts, the thermal environment of flight furnaces such as CGF and AADSF can be closely approximated. During FY96, ground based studies for two flight experiments, plus 2 other funded ground based studies have used the furnace. Prospective PI-specific modules would be considered for adaptation for this facility.

C. MAGNETIC DAMPING FURNACE

A prototype ground-based Magnetic Damping Furnace is expected to be a directional solidification Bridgman-Stockbarger furnace with or without magnetic damping. The major design characteristics of this device will include the application of a 0–0.2 Tesla magnetic field over the melt/solidification process if desired. The three zone furnace will operate at temperatures from 200 to 1175°C in the hot zone, 200–1200°C in the booster zone, and 150–950°C in the cold zone. A variable gradient zone of 0.5–5 cm length with a thermal gradient of up to 70°C/cm and an isothermality of ±0.1% is planned. The translating furnace will be capable of processing a sample from 12 to 20 cm in length with a diameter of up to 1.5 cm.

D. STEREO IMAGING VELOCIMETRY (SIV)

A system of hardware and software has been designed to allow acquisition of three-dimensional vectors describing flow simultaneously throughout an experimental volume. Used for ground-based and flight experiments, the quantitative results may be compared directly with numerical or analytical predictions of flow velocities. The system requires a transparent fluid seeded with particles large enough to be viewed as a full pixel on a video screen. Two synchronized orthogonal views provide the raw data. While generally used with light, the algorithms for velocity vectors could also be used with x-ray images of suspended particles. The SIV system has worked for sample volumes between eight cc's and two cubic meters. For experiments planned for the ISS, the Fluids and Combustion Facility will contain orthogonal video cameras which can record the data required for three-dimensional velocity analysis.

E. COMPUTATIONAL CAPABILITIES

NASA has the capability to provide the research community numerical modeling analysis (such as SINDA, HEATRAN, COSMOS, FIDAP) of material/fluid flows as influenced by thermal gradients, concentration gradients, surface tension, magnetic fields, gravitational acceleration, g-jitter and other driving forces. The emphasis is on physically based models giving quantitative flow descriptions. The facilities have commercial and specialized software operating in a workstation environment with access to mainframes.

F. X-RAY MICROSCOPE

This instrument is designed to view in situ solidification of thin, light samples with high resolution. The technique uses direct x-ray projection from a point source. The divergent beam passes through the sample. With a furnace permitting solidification to within a few mm of the x-ray source, in situ interfaces can be visualized at a resolution of 30 µm.

G. SPREADING RESISTANCE MEASUREMENT

A Solid State Measurements model 150 spreading resistance apparatus is available at MSFC. To use this instrument an investigator is expected to provide his/her own set of measurement probes.

H. OPTICAL AND ELECTRON OPTICAL MICROSCOPY LABORATORY

The equipment of a modern microscopy laboratory is available, including:

1. A Zeiss Axioplan 2 optical microscope equipped for reflection/transmission microscopy with Nomarski interference contrast, dark field, image processing, filar eyepieces for precise measurement, and automated and large stage capabilites. In addition and older Zeiss Ultraphot III optical microscope is with an infrared camera system is available.
2. A Zeiss scanning electron microscope, model DSM 960, equipped with a Link energy dispersive x-ray analysis system and beam controlling software. The collection of quantitative chemical analysis data can thus be automated. The system also includes an OPAL electron back scatter detector, which can be programmed to determine grain orientation over large sample areas. Other accessories include a cold stage and electron beam induced current imaging (EBIC).
3. A JEOL JXA 8900R electron microprobe analyzer equipped with three spectrometers for wavelength dispersive x-ray analysis, and a Noran energy dispersive x-ray system. Both of these systems permit quantitative light element determination. The microprobe is fitted with a large specimen stage.

All three of these systems are linked to the internet.

I. X-RAY DIFFRACTION LABORATORY

X-Ray diffraction capabilities include a Philips Materials Research Expert Diffractometer which operates on a Rigaku rotating anode x-ray generator. This instrument is available for the measurement of rocking curves and for reciprocal lattice mapping. Other x-ray equipment available includes a Rigaku powder diffractometer, a Blake Industries Laue camera and a Bede double axis diffractometer.

J. CONTRACTED FACILITIES

Other facilities available include the use of the National Synchrotron Light Source (NSLS) Synchrotron facility at Brookhaven National Labs and the use of the triple axis x-ray diffractometer at the University of Wisconsin – Madison. These two facilities are under contract to support NASA PIs through FY1999. For projects requiring such services beyond this date, PIs should include separate line items to cover the availability of these facilities.

1. NSLS Source The use of the X–19C beam line at Brookhaven is available through a grant to Professor Michael Dudley of University of New York at Stony Brook to examine NASA samples. This

facility uses white beam radiation and can provide x-ray topographies in both reflection and transmission.

2. Triple Axis Diffractometry Under the same grant, Professor Richard Matyi of the University of Wisconsin – Madison is contracted to examine NASA single crystal material. This work is done in close conjunction with the white beam x-ray topography and has proven to be a unique combination of facilities for quantifying the perfection of crystals.

ACRONYM LISTING

AADSF	ADVANCED AUTOMATED DIRECTIONAL SOLIDIFICATION FURNACE
ADSF	AUTOMATED DIRECTIONAL SOLIDIFICATION FURNACE
AGHF	ADVANCED GRADIENT HEATING FURNACE
ARIS	ACTIVE RACK ISOLATION SYSTEM
ATD	ADVANCED TECHNOLOGY DEVELOPMENT
CCD	CHARGE COUPLED DEVICE
CGF	CRYSTAL GROWTH FURNACE
DMI	DIFFUSION MODULE INSERT
DSFP	DIRECTIONAL SOLIDIFICATION FURNACE WITH PULSING
DSVT	DIRECTIONAL SOLIDIFICATION AND VAPOR TRANSPORT
ELF	ELECTROSTATIC LEVITATION FURNACE
EM	EXPERIMENT MODULE
ESA	EUROPEAN SPACE AGENCY
ESL	ELECTROSTATIC LEVITATOR
EXPRESS	EXPEDITE THE PROCESSING OF EXPERIMENTS TO SPACE STATION (Rack)
HGDS	HIGH GRADIENT DIRECTIONAL SOLIDIFICATION
HGFQ	HIGH GRADIENT FURNACE WITH QUENCH
HTBF	HIGH TEMPERATURE BRIDGMAN FURNACE
ICF	ISOTHERMAL CASTING FURNACE
IFEA	INTEGRATED FURNACE EXPERIMENT ASSEMBLY
ISPR	INTERNATIONAL STANDARD PAYLOAD RACK
ISS	INTERNATIONAL SPACE STATION
JEM	JAPANESE EXPERIMENT MODULE
JPL	JET PROPULSION LABORATORY
LeRC	LEWIS RESEARCH CENTER
LGF	LOW GRADIENT FURNACE
LLS	LASER LIGHT SCATTERING
LMS	LIFE AND MICROGRAVITY SCIENCE (Spacelab Mission)
MGBX	MIDDECK GLOVEBOX
MirGBX	MIR GLOVEBOX
MI	MODULE INSERT
MITH	MILLIKELVIN THERMOSTAT
MRD	MICROGRAVITY RESEARCH DIVISION
MRPO	MICROGRAVITY RESEARCH PROGRAM OFFICE
MSFC	MARSHALL SPACE FLIGHT CENTER
MSG	MICROGRAVITY SCIENCE GLOVEBOX
MSRF	MATERIALS SCIENCE RESEARCH FACILITY
MSRR-1	FIRST MATERIALS SCIENCE RESEARCH RACK
MSRR-2	SECOND MATERIALS SCIENCE RESEARCH RACK
MSRR-3	THIRD MATERIALS SCIENCE RESEACH RACK
MSL	MATERIALS SCIENCE LABORATORY
NASA	NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASDA	NATIONAL SPACE DEVELOPMENT AGENCY (of Japan)
NRA	NASA RESEARCH ANNOUNCEMENT
NSLS	NATIONAL SYNCHROTRON LIGHT SOURCE
PFCR	PATTERN FORMATION AND COARSENING RESEARCH
PI	PRINCIPAL INVESTIGATOR
PVA	PIVALIC ACID
QMI	QUENCH MODULE INSERT
SACA	SAMPLE AMPOULE/CRUCIBLE CARTRIDGE ASSEMBLY
SCN	SUCCINONITRILE

SCR	SCIENCE CERTIFICATION REVIEW
SDLE/TPP	SELF DIFFUSION IN LIQUID ELEMENTS/THERMOPHYSICAL PROPERTIES
SIR	STANDARD INTERFACE RACK
SIV	STEREO IMAGING VELOCIMETRY
STABLE	SUPPRESSION OF TRANSIENT ACCELERATION BY LEVITATION
SQF	SOLIDIFICATION AND QUENCH FURNACE
TEMPUS	TIEGELFREIES ELEKTROMAGNETISCHES PROZESSIEREN UNTER SCHWERELOSIGKEIT
USML	UNITED STATES MICROGRAVITY LABORATORY
USMP	UNITED STATES MICROGRAVITY PAYLOAD

THE REQUIRED APPLICATION FORMS MUST BE DOWNLOADED SEPERATELY FROM
http://peer1.idi.usra.edu/peer_review/nra/98_HEDS_05.html

INSTRUCTIONS FOR RESPONDING TO NASA RESEARCH ANNOUNCEMENTS

(JANUARY 1997)

A. General.

(1) Proposals received in response to a NASA Research Announcement (NRA) will be used only for evaluation purposes. NASA does not allow a proposal, the contents of which are not available without restriction from another source, or any unique ideas submitted in response to an NRA to be used as the basis of a solicitation or in negotiation with other organizations, nor is a pre-award synopsis published for individual proposals.

(2) A solicited proposal that results in a NASA award becomes part of the record of that transaction and may be available to the public on specific request; however, information or material that NASA and the awardee mutually agree to be of a privileged nature will be held in confidence to the extent permitted by law, including the Freedom of Information Act.

(3) NRA’s contain programmatic information and certain requirements which apply only to proposals prepared in response to that particular announcement. These instructions contain the general proposal preparation information which applies to responses to all NRAs.

(4) A contract, grant, cooperative agreement, or other agreement may be used to accomplish an effort funded in response to an NRA. NASA will determine the appropriate instrument. Contracts resulting from NRA’s are subject to the Federal Acquisition Regulation and the NASA FAR Supplement. Any resultant grants or cooperative agreements will be awarded and administered in accordance with the NASA Grant and Cooperative Agreement Handbook (NPG 5800.1).

(5) NASA does not have mandatory forms or formats for responses to NRA’s; however, it is requested that proposals conform to the guidelines in these instructions. NASA may accept proposals without discussion; hence, proposals should initially be as complete as possible and be submitted on the proposers' most favorable terms.

(6) To be considered for award, a submission must, at a minimum, present a specific project within the areas delineated by the NRA; contain sufficient technical and cost information to permit a meaningful evaluation; be signed by an official authorized to legally bind the submitting organization; not merely offer to perform standard services or to just provide computer facilities or services; and not significantly duplicate a more specific current or pending NASA solicitation.

B. NRA-Specific Items. Several proposal submission items appear in the NRA itself: the unique NRA identifier; when to submit proposals; where to send proposals; number of copies required; and sources for more information. Items included in these instructions may be supplemented by the NRA.

C. Proposal Content. The following information is needed to permit consideration in an objective manner. NRAs will generally specify topics for which additional information or greater detail is desirable. Each proposal copy shall contain all submitted material, including a copy of the transmittal letter if it contains substantive information.

(1) *Transmittal Letter or Prefatory Material.*

(i) The legal name and address of the organization and specific division or campus identification if part of a larger organization;

(ii) A brief, scientifically valid project title intelligible to a scientifically literate reader and suitable for use in the public press;

(iii) Type of organization: e.g., profit, nonprofit, educational, small business, minority, women-owned, etc.;

(iv) Name and telephone number of the principal investigator and business personnel who may be contacted during evaluation or negotiation;

(v) Identification of other organizations that are currently evaluating a proposal for the same efforts;

(vi) Identification of the NRA, by number and title, to which the proposal is responding;

(vii) Dollar amount requested, desired starting date, and duration of project;

(viii) Date of submission; and

(ix) Signature of a responsible official or authorized representative of the organization, or any other person authorized to legally bind the organization (unless the signature appears on the proposal itself).

(2) *Restriction on Use and Disclosure of Proposal Information.* Information contained in proposals is used for evaluation purposes only. Offerors or quoters should, in order to maximize protection of trade secrets or other information that is confidential or privileged, place the following notice on the title page of the proposal and specify the information subject to the notice by inserting an appropriate identification in the notice. In any event, information contained in proposals will be protected to the extent permitted by law, but NASA assumes no liability for use and disclosure of information not made subject to the notice.

Notice

Restriction on Use and Disclosure of Proposal Information

The information (data) contained in [insert page numbers or other identification] of this proposal constitutes a trade secret and/or information that is commercial or financial and confidential or privileged. It is furnished to the Government in confidence with the understanding that it will not, without permission of the offeror, be used or disclosed other than for evaluation purposes; provided, however, that in the event a contract (or other agreement) is awarded on the basis of this proposal the Government shall have the right to use and disclose this information (data) to the extent provided in the contract (or other agreement). This restriction does not limit the Government's right to use or disclose this information (data) if obtained from another source without restriction.

(3) *Abstract*. Include a concise (200-300 word if not otherwise specified in the NRA) abstract describing the objective and the method of approach.

(4) *Project Description.*

(i) The main body of the proposal shall be a detailed statement of the work to be undertaken and should include objectives and expected significance; relation to the present state of knowledge; and relation to previous work done on the project and to related work in progress elsewhere. The statement should outline the plan of work, including the broad design of experiments to be undertaken and a description of experimental methods and procedures. The project description should address the evaluation factors in these instructions and any specific factors in the NRA. Any substantial collaboration with individuals not referred to in the budget or use of consultants should be described. Subcontracting significant portions of a research project is discouraged.

(ii) When it is expected that the effort will require more than one year, the proposal should cover the complete project to the extent that it can be reasonably anticipated. Principal emphasis should be on the first year of work, and the description should distinguish clearly between the first year's work and work planned for subsequent years.

(5) *Management Approach*. For large or complex efforts involving interactions among numerous individuals or other organizations, plans for distribution of responsibilities and arrangements for ensuring a coordinated effort should be described.

(6) *Personnel*. The principal investigator is responsible for supervision of the work and participates in the conduct of the research regardless of whether or not compensated under the award. A short biographical sketch of the principal investigator, a list of principal publications and any exceptional qualifications should be included. Omit social security number and other personal items which do not merit consideration in evaluation of the proposal. Give similar biographical information on other senior professional personnel who will be directly associated with the project. Give the names and titles of any other scientists and technical personnel associated substantially with the project in an advisory capacity. Universities should list the approximate number of students or other assistants, together with information as to their level of academic attainment. Any special industry-university cooperative arrangements should be described.

(7) *Facilities and Equipment.*

(i) Describe available facilities and major items of equipment especially adapted or suited to the proposed project, and any additional major equipment that will be required. Identify any Government-owned facilities, industrial plant equipment, or special tooling that are proposed for use. Include evidence of its availability and the cognizant Government points of contact.

(ii) Before requesting a major item of capital equipment, the proposer should determine if sharing or loan of equipment already within the organization is a feasible alternative. Where such arrangements cannot be made, the proposal should so state. The need for items that typically can be used for research and non-research purposes should be explained.

(8) *Proposed Costs.*

(i) Proposals should contain cost and technical parts in one volume: do not use separate "confidential" salary pages. As applicable, include separate cost estimates for salaries and wages; fringe benefits; equipment; expendable materials and supplies; services; domestic and foreign travel; ADP expenses; publication or page charges; consultants; subcontracts; other miscellaneous identifiable direct costs; and indirect costs. List salaries and wages in appropriate organizational categories (e.g., principal investigator, other scientific and engineering professionals, graduate students, research assistants, and technicians and other non-professional personnel). Estimate all staffing data in terms of staff-months or fractions of full-time.

(ii) Explanatory notes should accompany the cost proposal to provide identification and estimated cost of major capital equipment items to be acquired; purpose and estimated number and lengths of trips planned; basis for indirect cost computation (including date of most recent negotiation and cognizant agency); and clarification of other items in the cost proposal that are not self-evident. List estimated expenses as yearly requirements by major work phases.

(iii) Allowable costs are governed by FAR Part 31 and the NASA FAR Supplement Part 1831 (and OMB Circulars A-21 for educational institutions and A-122 for nonprofit organizations).

(9) *Security*. Proposals should not contain security classified material. If the research requires access to or may generate security classified information, the submitter will be required to comply with Government security regulations.

(10) *Current Support*. For other current projects being conducted by the principal investigator, provide title of project, sponsoring agency, and ending date.

(11) *Special Matters*.

(i) Include any required statements of environmental impact of the research, human subject or animal care provisions, conflict of interest, or on such other topics as may be required by the nature of the effort and current statutes, executive orders, or other current Government-wide guidelines.

(ii) Proposers should include a brief description of the organization, its facilities, and previous work experience in the field of the proposal. Identify the cognizant Government audit agency, inspection agency, and administrative contracting officer, when applicable.

D. Renewal Proposals.

(1) Renewal proposals for existing awards will be considered in the same manner as proposals for new endeavors. A renewal proposal should not repeat all of the information that was in the original proposal. The renewal proposal should refer to its predecessor, update the parts that are no longer current, and indicate what elements of the research are expected to be covered during the period for which support is desired. A description of any significant findings since the most recent progress report should be included. The renewal proposal should treat, in reasonable detail, the plans for the next period, contain a cost estimate, and otherwise adhere to these instructions.

(2) NASA may renew an effort either through amendment of an existing contract or by a new award.

E. Length. Unless otherwise specified in the NRA, effort should be made to keep proposals as brief as possible, concentrating on substantive material. Few proposals need exceed 15-20 pages. Necessary detailed information, such as reprints, should be included as attachments. A complete set of attachments is necessary for each copy of the proposal. As proposals are not returned, avoid use of "one-of-a-kind" attachments.

F. Joint Proposals.

(1) Where multiple organizations are involved, the proposal may be submitted by only one of them. It should clearly describe the role to be played by the other organizations and indicate the legal and managerial arrangements contemplated. In other instances, simultaneous submission of related proposals from each organization might be appropriate, in which case parallel awards would be made.

(2) Where a project of a cooperative nature with NASA is contemplated, describe the contributions expected from any participating NASA investigator and agency facilities or equipment which may be required. The proposal must be confined only to that which the proposing organization can commit itself. "Joint" proposals which specify the internal arrangements NASA will actually make are not acceptable as a means of establishing an agency commitment.

G. Late Proposals. A proposal or modification received after the date or dates specified in an NRA may be considered if doing so is in the best interests of the Government.

H. Withdrawal. Proposals may be withdrawn by the proposer at any time before award. Offerors are requested to notify NASA if the proposal is funded by another organization or of other changed circumstances which dictate termination of evaluation.

I. Evaluation Factors.

(1) Unless otherwise specified in the NRA, the principal elements (of approximately equal weight) considered in evaluating a proposal are its relevance to NASA's objectives, intrinsic merit, and cost.

(2) Evaluation of a proposal's relevance to NASA's objectives includes the consideration of the potential contribution of the effort to NASA's mission.

(3) Evaluation of its intrinsic merit includes the consideration of the following factors of equal importance:

(i) Overall scientific or technical merit of the proposal or unique and innovative methods, approaches, or concepts demonstrated by the proposal.

(ii) Offeror's capabilities, related experience, facilities, techniques, or unique combinations of these which are integral factors for achieving the proposal objectives.

(iii) The qualifications, capabilities, and experience of the proposed principal investigator, team leader, or key personnel critical in achieving the proposal objectives.

(iv) Overall standing among similar proposals and/or evaluation against the state-of-the-art.

(4) Evaluation of the cost of a proposed effort may include the realism and reasonableness of the proposed cost and available funds.

J. Evaluation Techniques. Selection decisions will be made following peer and/or scientific review of the proposals. Several evaluation techniques are regularly used within NASA. In all cases proposals are subject to scientific review by discipline specialists in the area of the proposal. Some proposals are reviewed entirely in-house, others are evaluated by a combination of in-house and selected external reviewers, while yet others are subject to the full external peer review technique (with due regard for conflict-of-interest and protection of proposal information), such as by mail or through assembled panels. The final decisions are made by a NASA selecting official. A proposal which is scientifically and programmatically meritorious, but not selected for award during its initial review, may be included in subsequent reviews unless the proposer requests otherwise.

K. Selection for Award.

(1) When a proposal is not selected for award, the proposer will be notified. NASA will explain generally why the proposal was not selected. Proposers desiring additional information may contact the selecting official who will arrange a debriefing.

(2) When a proposal is selected for award, negotiation and award will be handled by the procurement office in the funding installation. The proposal is used as the basis for negotiation. The contracting officer may request certain business data and may forward a model award instrument and other information pertinent to negotiation.

L. Cancellation of NRA. NASA reserves the right to make no awards under this NRA and to cancel this NRA. NASA assumes no liability for canceling the NRA or for anyone's failure to receive actual notice of cancellation.

APPENDIX D
NRA-98-HEDS-05

NASA RESEARCH ANNOUNCEMENT (NRA) SCHEDULE

MICROGRAVITY MATERIALS SCIENCE: RESEARCH AND FLIGHT EXPERIMENT OPPORTUNITIES

All proposals submitted in response to this Announcement are due on the date and at the address given below by the close of business (4:30 PM EST). NASA reserves the right to consider proposals received after this deadline if such action is judged to be in the interest of the U.S. Government. A complete schedule of the review of the proposals is given below:

NRA Release Date: ....December 16, 1998

Letter of Intent Due: ....January 26, 1999

Proposal Due: ....March 16, 1999

Submit Proposal to:

Dr. Michael J. Wargo
c/o Information Dynamics Inc.
Subject: NASA Research Proposal (NRA-98-HEDS-05)
300 D Street, S.W., Suite 801
Washington, D.C. 20024
Telephone number for delivery services: (202) 479-2609

Final Selections: ....September, 1999

Funding commences: ....No sooner than October, 1999
(dependent upon actual selection and procurement process)