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MATERIALS CHARACTERIZATION--VITAL AND OFTEN SUCCESSFUL, YET STILL A CRITICAL PROBLEM

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ABSTRACT

A 1967 report of the National Materials Advisory Board (NMAB) on "The Characterization of Materials" gives the definition of characterization as follows: "Characterization describes those features of the composition and structure (including defects) of a material that are significant for a particular preparation, study of properties, or use, and suffice for the reproduction of the material."

While it has now become evident that such characterization action as this is essential to build a stronger, more effective materials capability in this country, it is not yet as evident as to how best accomplish such work in the degree demanded.

This paper reviews some of the past history of materials characterization endeavors, the progress made toward the objective, the relevance of current and future scientific and engineering problems to continued and increased efforts, and the opportunities and roadblocks to progress in characterization.

INTRODUCTION

In today's world, ideally, the manager of a materials characterization laboratory should be able to open an unlabeled container, remove whatever material is within it, and make a series of measurements, which would tell what the material is. Given a second unlabeled container, he should be able to determine whether the material within it is the same material in the sense that it would have the same behavior for some set of properties or processes of interest. For gases or liquids the manager of a good laboratory is likely to be quite successful. For solid materials, complete success is still not always possible. With such materials a combination of knowledge about how the material was made and the best available characterization measurements on the material give more reliable results, but even this combination sometimes fails.

Are such failures due to the lack of available analytical techniques and instrumentation for performing the required characterization of the material? Or, have characterization methods only advanced, in general, to the point where they still merely give expedient and partial descriptions of the preparation method and property measurements? Have we procrastinated on bringing about the improvements in our abilities to describe adequately "those features of the composition and structure (including defects) of a material that are significant for a particular preparation, study of properties, or use, and suffice for the reproduction of the material?" Has characterization knowledge been understood and properly applied in engineering materials?

In an attempt to answer such questions, a review of some of the past history of materials work, various studies on materials characterization and the interdisciplinary nature of the problem appear in order as a basis for an assessment of the current and future status of the field.

HISTORICAL REVIEW

At an early period in history, man discovered that a variety of materials--stone, fired clay, cement, the common biological materials and various metals--were available for a wide range of uses. For example, the production of ceramics (the earliest inorganic material to be structurally modified by man) and copper beads date back to the 9th millenium B.C.; the smelting of minerals to 5000 B.C.; many metal alloys were made by the 3rd millenium B.C.; steel was made (in Iran) as early as 1200 B.C.; and cast iron was first produced (in China) around 500 B.C.

In the several centuries that followed such pioneering developments as these, materials were pretty much taken for granted and it was thought that they required no investigations for their wider range of uses--a situation that, unfortunately, still exists today in some circles.

The first real manifestation of a progressive upsurge of appreciation and knowledge about materials began in the 17th century. The scientific revolution that took place at that time formed the basis and triggered off many subsequent, significant discoveries and developments. Cyril Stanley Smith [1] has reviewed some of these. Professor Smith states:

> "...In 1772 Rene Ferchault de Reaumur published an outstanding work on iron, based on observed and hypothetical changes of structure on the level that today we associate with the microstructure. In the best scientific tradition he designed laboratory experiments aimed at checking and improving the theory and from these he developed an important industrial material, malleable cast iron. His work came, however, at the very end of the period during which Cartesian corpuscular theories could be taken seriously by scientists. Newtonian rigor displaced this kind of structural speculation; microcrystalline grains came back into science only at the end of the 19th century following the discoveries of microstructure of steel by Henry Clifton Sorby in 1864.
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> ...In 1912 X-ray diffraction was discovered and soon applied to the study of the structure of solids by Lawrence Bragg and his followers. It at once gave a measurable physical meaning to structure on an atomic scale, and made this as real as the larger-scale structures that had been revealed by Sorby's microscopic methods half a century earlier....
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> For a time the X-ray-diffraction results led to the construction of too idealized a picture. Then the role of imperfections was perceived, first chemical, then electrical, then mechanical errors in the building of crystals. The last served to explain the deformability of metals as well as the nature of the interface between crystal grains, the old grain boundary about which practical metallurgists had long speculated because of its' great practical importance.
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> Although still dominant, metals thereafter lost their unique position in scientific studies of materials. Ceramics combined all the interesting crystalline complexity of metals with the electrical interest of semiconductors. Organic chemistry had been developing rapidly in the 19th century as analytical methods became available. The awareness that many compounds with the same composition have different properties engendered the organic chemist's particularly fertile concept of structure. Molecular architecture began almost as a notational device but soon became a central part of organic chemistry and was ready to join with X-ray crystallography in guiding the development of the complicated structures that endow synthetic polymers with their properties..."

STUDIES ON MATERIALS CHARACTERIZATION

In the 1930s basic work on materials gathered momentum. Such work, including progress on characterization, influenced and enriched the empirical development of new and improved materials. By 1964, many new alloys and nonmetallic materials had been so developed and new analytical techniques for the scientific investigation of the materials had come into existence. However, even though variations in the composition, structure, and defects--features of the atomic world that can effect the properties and behavior of the materials--could be then better appreciated, they were not always understood. As a result, empiricism and empirical predictive testing of materials for most engineering applications was still prevalent in the early 1960s. Such techniques were necessary and valuable, but their limitations became increasingly troublesome. In short, characterization became more important to scientists as the understanding of properties became more sophisticated. At the same time, characterization became more important to technology as engineering materials became more complex and possessed higher performance. A small variation in the character of a relatively low performance material usually is unimportant because such materials are used with a considerable factor of safety. Use of a large factor of safety with a high performance material removes much of its advantage. Modern designs use materials closer to their limits and leave less room for variability in materials properties. Good quality control based on good characterization is very important. Much progress in characterization and quality control has since occurred but progress has been and still is impeded by several critical types of ignorance. One type is ignorance of how to measure subtle aspects of character such as microcracks of a few microns in a microstructure with other features of similar or larger size. Another type is ignorance of the many features of character that are critical to some properties or processes. For example, just which of many trace components are critical to sintering behavior in a particular ceramic?

The seriousness of this lack of understanding was recognized in the 60s, but a major stimulus to do something about the situation arose when it became increasingly apparent that there was a very definite requirement to find improved methods for somehow tailor-making materials having reliable, uniform and reproducible properties. This need constituted a problem of great national importance since serious impediments to progress in a variety of areas such as atomic energy and a spectrum of defense technologies, in particular, were deemed to be materials limited. In short, the reliable performance of devices and systems and the development of new devices and systems were directly dependent on progress in the materials area.

With this background, the Materials Advisory Board (now the National Materials Advisory Board) of the National Academy of

Sciences--National Research Council was requested by the Department of Defense in February 1964 to form a study committee on the Characterization of Materials. The findings of this landmark study were reported in March 1967.

Basically, the major conclusion of the committee was the confirmation that there existed an urgent need in this country to find ways to better characterize materials. By "better" it was meant that the significant internal or atomistic features of a material (structure, composition, and defects) must be identified, quantified, and these correlated to the physical or behavioral properties that the material exhibits. (An extended abstract of this report, "Characterization of Materials," MAB-229-M, is in Appendix A). Some 16 subsequent NMAB studies conducted to date since 1967 and notably those on electronic device materials, massive glasses for structural applications, IR laser window materials, IR transmitting materials, ceramic processing, rapid solidification processing, cobalt conservation, amorphous semiconductors, structural ceramics, organic polymers, dynamic compaction of metal and ceramic powders, etc. have all endorsed such a national materials need in research and development. Specific recommendations on the direction of such R&D and other suggestions for the implementation of a viable approach to the characterization of materials are summarized in Appendix B. These are taken from some of the various aforementioned NMAB reports.

THE INTERPLAY OF SCIENCE AND ENGINEERING IN CHARACTERIZATION AND THE INTERDISCIPLINARY NATURE OF THE PROBLEM

At least two things are quite apparent in this matter. One, the kind of materials characterization suggested in the first MAB report (MAB-229-M) on the subject is not an easy task. Second, and partly because the job is not easy, materials characterization tends to mean something quite different to people of different backgrounds. To the solid state physicist the interpretation may be quite different from that of the materials scientist or that of the engineer. And, this phenomenon is also quite interesting since in the fulfillment of the objectives of each of these types--materials act as the common denominator in scientific and engineering achievement. Moreover, as Walter Kohl observes [2]:

> "...We should now ask in what sense material science differs from solid state physics, which had come into its own as a discipline in the 1930s after the revolutionary concepts of wave mechanics and quantum mechanics had been introduced by De Broglie, Schrodinger, and Heisenberg and applied to the study of atomic systems. It is indeed difficult to make a sharp distinction. If solid-state physics is concerned with the study of electrical, optical and magnetic properties of crystalline solids, materials science embraces the study of all properties of all types of material-crystalline or noncrystal-

line... If solid-state physics is a discipline, materials science is many disciplines; indeed, its interdisciplinary nature is one of it's main characteristics... One may also say that solid-state physics applies existing knowledge to existing materials in an attempt to understand their properties. Materials science does that too, but it reaches out farther and attempts to apply this knowledge to the creation of new materials in which desirable properties of several components are combined with beneficial results... Many such innovations require the introduction of new techniques for fabrication and processing. That also is a special domain of materials science, although the materials engineer will be more particularly concerned with applications..."

As long as we are quoting here in this paper, we may as well add still another interesting quotation on the subject. This one comes from Sir Peter Hirsch of Oxford University. Professor Hirsch recently stated [3]:

"...In the 40s, 50s, and 60s we lived through a period in which the development of solid state physics led to a revolution in understanding of crystalline solids. In the field of mechanical properties of solids dislocation theory developed rapidly and in the same period electron microscopy and microanalytical techniques became available, which allowed materials to be characterized in unprecedented detail and on a fine scale, and which helped, inter alia, to establish dislocation theory on a firm basis. The general advances in electron theory of solids led to the revolution in semiconductor device technology, while the development of new polymers and plastics has led to impressive growth and diversity in application of these materials. The science of composite materials has been largely worked out and composites are likely to become of increasing importance in the future...

Over the last ten years or so, there has been a growing realization that in the universities in the U.K. the interface between materials science and engineering has been neglected: the motivation for much of the advances in materials science and physical metallurgy had been to achieve a better understanding of basic mechanisms controlling microstructure-property relationships and work aimed at solving engineering problems, particularly relating to manufacturing technology, had not been emphasized sufficiently. In the case of microelectronics research this problem has not arisen; the development of new devices requires sophisticated processing and methods and monitoring by advanced, often electron optical techniques, areas in which the engineering interface is at the frontier of knowledge. Consequently in this area the universities and industry collaborate closely together, and the materials "science" fulfills its proper function of an enabling technology...

Inevitably in a period of financial constraint...it will be more difficult to find support for research projects aimed at furthering our basic understanding of some property if this is not clearly related to achieving some engineering objective, or for developing some new material if there is not recognized need for it. While a shift in emphasis is undoubtedly necessary, it must not go too far..."

CURRENT STATUS OF MATERIALS CHARACTERIZATION

The landmark report of 1967 on Characterization of Materials can still be read with profit today. Its concepts still are sound and many of the recommendations of the report remain to be fully carried out.

On the other hand, certainly significant progress has been made in characterization. Every laboratory manager knows that whatever expensive and sophisticated piece of characterization equipment he buys will satisfy his staff only briefly, and that within a few years he will begin to hear how outmoded it is and at what a disadvantage his people are working. Advances in surface analysis and in electron microscopy alone are dazzling examples of the pairing of advances in science and in engineering of instruments. The availability of powerful, inexpensive microcomputers and minicomputers has revolutionized data collection and analysis. Access to national facilities for synchrotron radiation, neutron scattering, ion implantation, etc. is now vital to progress in many aspects of materials. Analytical chemistry has advanced in many ways and the advance shows no sign of slowing down.

Considering these developments, one might conclude that all is well and that steady progress toward the goals of the characterization report is being made. However, several recent reports seem to reflect a general view that some serious problems remain. For example, reports of the National Materials Advisory Board identify specific characterization problems in the fields of metal and ceramic powders, HgCdTe materials, high purity silicon, organic polymers, and composites. This list of characterization problem areas is certainly not exhaustive.

We would like to enlist your help in assessing the nature and extent of such characterization problems. To this end, we ask that you fill out the questionnaire that has been distributed to you. Please return your completed questionnaire to the Conference Director, Dr. James McCauley, as soon as possible so that the results of this poll can be given at the Workshop Panel Session on Friday, August 17, 1984. To help "prime the pump" on your thinking we offer the following classification of types of problems. However, we emphasize that we want to have your thoughts rather than a reflection of ours. Also, we desire specific examples rather than general statements. Our suggested general framework for characterization problems is as follows:

1. Inadequate knowledge of which features of character are important to the properties of interest. For example, on which types of point defect in a given material should characterization development be centered if the interest is in lower optical absorption? In longer carrier life? In improved sintering behavior? In reduced long-term creep?

2. Inadequate ability in fundamental scientific terms to measure the aspect of character, which is needed. For example, how should one determine which green (i.e., shaped but unfired) ceramics contain defects that will persist through firing and cause unacceptably low strength in final parts?

3. Inadequate use of existing techniques. For example, they may simply be too costly. Or, they may require adaptation that is clear in principle but the field of application may be too small to motivate instrumentation firms to adapt their equipment and procedures.

4. Inadequate knowledge of available techniques. The list of modern techniques is so long, their individual strengths and limitations are so complex, and the field is so compartmented into different specialist groups that many investigators may be lagging seriously behind in their knowledge of what can be done.

We have structured our questionnaire with these thoughts in mind, but we have also left openings for your own viewpoints. Please let us have them. We believe you will find the exercise interesting and the cumulative results of this poll quite revealing and useful.

REFERENCES

1. C. S. Smith, Materials, Scientific American, Vol. 217, No. 3, September, NY (1967).
2. W. Kohl, Personal Communication.
3. P. B. Hirsch, An Enabling Technology. MRS Bulletin of the Materials Research Society, Vol. VIII, No. 6, November-December, Pittsburgh, (1983).

QUESTIONNAIRE

1. Please list your own fields of scientific endeavor and/or engineering interest (e.g., precipitation hardening, superalloys for gas turbines, etc.):

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2. Is inadequate characterization a major problem limiting either scientific progress or engineering applications in your fields of interest? If the answer is YES, please give one or more examples, and also answer the next question.

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3. What percent of characterization inadequacy is due to:

   o Lack of sufficiently powerful techniques. _______

   o Lack of use of existing and adequate techniques. _______

   Please give examples.

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4. Is inadequate knowledge of characterization techniques a problem? If the answer is YES, please answer the next two questions.

______ (YES) ______ (NO)

5. What percent of the characterization knowledge problem arises from a lack of broad knowledge of the whole range of techniques including their capabilities, limitations and costs? Is there a need for good survey articles for the whole field?

6. What percent of the characterization knowledge problems is specific to techniques, and is of the nature of "how to get the job done" rather than "what techniques shall we use?"

7. What, if any, additional national or regional characterization facilities are needed (e.g., more synchrotrons, high-voltage electron microscopes, high-field NMR, etc.)?

8. What areas appear to be the most scientifically promising for improved characterization (i.e., those that offer opportunity)?

9. Do you believe that foreign countries, i.e., Japan, Russia, Germany, have carried out significant work in materials characterization? If so, give a few specific examples.

10. Several well-known scientists have recently stated that today materials science, engineering and technology together represent a unified, coherent field. Is this an idealized view considering the real world of current work in materials? If you feel that we have only scratched the surface of the opportunities for a convergence or unification of the field, the role that more emphasis on the characterization of materials can play is vital to this end. Do you agree or disagree? Comment briefly.

NOTE: Please turn in your completed questionnaire to Dr. James McCauley, the conference director. The results of this survey will be discussed on the final day of the conference and documented in the proceedings.

APPENDIX A

A landmark study (NMAB-229M) was the first to outline the guidelines for the development of a science of materials that would afford predictable and reliable results in devising new materials for high performance applications. The cornerstone for such a science is characterization, defined as describing, "those features of the composition and structure (including defects) of a material that are significant for a particular preparation, study of properties, or use, and sufficient for the reproduction of the materials." In the execution of the study effort, five panels were set up on composition, structure, defects, polycrystals, and polymers. The first three covered methods used to improve characterization generally, while the last two were specific to the unique problems of two materials classes. The study assessed the situation surrounding some of the greatest needs for characterization, i.e., better techniques and instruments, or more and better use of existing techniques and instruments; better characterization for improved preparation of materials, or improved study of materials, or improved use of materials; and more accurate and detailed characterization of materials in general.

A summary of the various recommendations made in this study are:

Technical

1. Composition
   Greatly enhance capability for determination of major element stoichemistry. Improve analysis techniques for determination of O, N, C, S, B, and other anions. Improve valence state determinations. Develop methods for the location and analysis of inhomogeneities at the micron level. Develop survey techniques for the $\leq$ 1 ppm range.

2. Structural
   Fund greatly increased activity in optical methods (especially those utilizing coherent radiation) of structural characterization. Maximize the utility of x-ray diffraction by increasing the quality of the powder data file and extracting the maximum structural information from such data. Develop new high pressure and high temperature x-ray apparatus. The rapid utilization of the scanning electron microscope should be sponsored. Megavolt-range electron microscopes and pulsed-neutron spectroscopy likewise offer promise and deserve support.

3. Defects
   Absolute point defect determination (concentration and structure) needs substantial support. Methods for surface defects need development.

4. Polycrystals
   For characterizing polycrystalline systems, methods and theories of measuring internal stresses (micro and macro) are most important. Research on determining homogeneity and structure on the finest scale (< 1000 Å) should be supported. Characterization of dislocation structures in heavily cold-worked and shock-hardened metals is needed. Quantitative metallography is needed for surface and transmission microscopy. Improve thinning techniques for transmission microscopy.

5. Polymers
   In the polymer field, research should be supported in: rapid methods of molecular weight distribution; determination of supermolecular order in amorphous polymers, and in semicrystalline polymers; analysis of network structuration; methods to separate polyblends into their components; studies of nonpolymeric analogs (low molecular weight) of polymers; methods for characterization at the molecular level in presently intractable polymers.

Finally, there is an urgent need for immediate attention to all of these recommendations and action on as many as can be initiated in line with current requirements.

General Recommendations

1. The term: characterization, should be used as defined herein.

2. A substantially larger fraction of the funds available for materials research should be allocated and used for characterization.

3. Government agencies concerned with materials work should take positive steps to ensure that characterization is given greater emphasis and the continuity of support that are required to advance materials science.

4. Greater awareness of the basic need for better characterization (of more and better materials) should be promoted by sponsors, faculty, supervisors, and participants in work on materials research, development, and engineering.

5. Editors, referees, and policymakers of technical societies should insist on characterization of materials whose measured properties are submitted for publication.

6. A strong and sustained effort should be made to increase the effectiveness and status of those who work on characterizing materials.

7. Government agencies, such as the National Bureau of Standards, should be encouraged to exhibit stronger leadership in advancing characterization and its beneficial uses, especially in providing characterized reference materials.

8. Government agencies should encourage and support the growth of several strong centers of excellence in characterization of materials.

APPENDIX B

In Appendix A an extended abstract of the Materials Advisory Board report (MAB-229-M) on "Materials Characterization" is given. This abstract contains the recommendations of the study, which was published in 1967.

Since 1967, the National Materials Advisory Board (the successor of the Materials Advisory Board) has conducted a number of committee studies on various materials systems wherein the need for better characterization of materials was stressed in the findings. A sampling of some such studies include the following:

NMAB-223, "Ceramic Processing," Feb. 1968.

NMAB-284, "Fundamentals of Amorphous Semiconductors," Sept. 1971.

NMAB-332, "Organic Polymer Characterization," 1977.

NMAB-362, "Preparation and Characterization of Silicon for Infrared Detectors," Oct. 1981.

NMAB-368, "Rapidly Solidified (RS) Aluminum Alloys--Status and Prospects," 1981.

NMAB-377, "Assessment of Mercury-Cadmium Telluride Materials Technology," Sept. 1982.

NMAB-394, "Dynamic Compaction of Metal and Ceramic Powders," Mar. 1983.

A brief synopsis of each of the seven above-mentioned studies is as follows:

Ceramic Processing (Report NMAB-223)

In the field of ceramics, the NMAB has conducted several major studies. The first concerned the Processing of Ceramics (NMAB-223) and emphasized that a detailed examination of ceramic processing was a necessary step toward obtaining reliable high-integrity ceramic materials with superior properties. Technical recommendations given in the report are that (1) starting materials should be fully characterized as should each step in processing, (2) new tools and techniques should be provided to characterize material in process and the final product, (3) particular attention should be paid to the character of the ceramic surface, (4) standardized lots of starting materials and standard test methods should be made available, (5) the scientific approach should be used to overcome limitations in size without sacrificing reliability, and (6) improved understanding of character-property relationships must be developed. The report states that these essentials should be brought forcefully to the attention of all concerned, with interdisciplinary programs developed including consortia among universities, research laboratories and industry; to address the problems in a pragmatic manner.

Fundamentals of Amorphous Semiconductors (Report NMAB-284)

The study of glasses has been important historically because of their usefulness. Members of a comparatively new class of these materials, the amorphous semiconductors, have evoked interest in the last few years because they exhibit certain unique properties (semiconductivity, photoconductivity, low sensitivity to high-energy radiation, and ease of undergoing phase changes). Such properties are of considerable technological significance. In the report of this amorphous semiconductor study (NMAB-284), it was recommended that increased efforts be made in the gathering of data on physically realized glass structures, development of better methods of material preparation and characterization, investigations leading to better understanding of structure control and radiation hardness, and research aimed at the technological exploitation of unique properties.

Organic Polymer Characterization (Report NMAB-332)

This report attempts to define those properties of organic polymers that are critical to their use in current and advanced structural applications. It discusses and evaluates the characterization methodology that is available to measure and control those properties. It suggests some specific areas in which this technology can be employed to achieve improved performance and reliability through its application to procurement and quality control procedures. Case studies are presented to illustrate the utilization of characterization. Conclusions and recommendations are presented. A list of more than a hundred useful methods of characterization and commentary on use and limitations is given in an appendix.

The Preparation and Characterization of Silicon for Infrared Detectors (Report NMAB-362)

In this report materials and processing requirements for IR-type silicon were analyzed and defined. The status of the related processing technology was reviewed and deficiencies were identified. The major subjects addressed are:

- Device needs.
- Materials characterization.
- Preparation of polycrystalline silicon.
- Preparation of single-crystal silicon.
- Device process-induced contamination.

Materials requirements for high-speed, high-sensitivity IR detectors are significantly beyond the present capability of crystal growth technology. The preparation of ultra-high-purity polysilicon can be achieved in principle by upgrading or modifying present purification procedures. However, the preparation of both ultra-high-purity and homogeneous uncompensated In-doped single-crystal silicon, either by Czochralski growth or by float-zoning, with the established procedures is impossible. Substantive modifications of conventional crystal-growth procedures and the development of appropriate alternative approaches to silicon crystal growth, now in the research stage, are mandatory to meet the materials requirements.

Included in the recommendations of this study is the following:

> "All sponsored work pertaining to IR-device development and fabrication should include a strong materials characterization component. This procedure could insure the advancement of pertinent characterization techniques and contribute to the establishment of as-yet-unknown cause and effect relationships between materials deficiencies and device yield and performance. Such knowledge ultimately could remove much of the empirical element in materials processing..."

Rapidly Solidified (RS) Aluminum Alloys--Status and Prospects (Report NMAB-368)

This study was conducted to evaluate the potential of particulate (rapidly solidified) aluminum alloys for a broad range of structural applications. The study included analysis of current experimental and near-term production alloys; selection of representative target properties and analysis of structural performance in representative aircraft systems; evaluation of alternative methods for producing sheet, plate, extrusion and forging mill products with emphasis on approaches for processing particulate directly to mill products; assessment of structural fabrication and assembly processes and potential associated problems; review of the metallurgical state of the art of these alloy systems; and extensive examination of potential applications in aircraft, military, and space systems and commercial products. Significant conclusions and recommendations are presented that identify the future work required to support adequately the continued development of particulate aluminum alloys and to ensure the eventual availability of large-scale production quantities of these alloys. Among these recommendations was the following:

> "Present knowledge concerning phase relationships, metastability of alloy microstructures, and microstructure-property relationships in RS aluminum alloys is inadequate. This lack of knowledge extends to the relative importance of particulate cooling rates, particulate sizes, grain and dendrite sizes, solid solution decomposition kinetics, and alloy composition. Recommendation: A continuing, long-range basic research program should be undertaken to provide adequate support for current developmental and application activities. This program should stress the generation of fundamental structure-property relationships and the understanding of alloy systems and behavior rather than the development of specific RS alloys..."

Assessment of Mercury-Cadmium Telluride Materials Technology (Report NMAB-377)

This report surveys the material requirements and existing material limitations for HgCdTe in its varied applications as a photovoltaic detector. This primary emphasis throughout this report has been the status of the material used for detection of infrared radiation in the 3- to 12-μm wavelength band. The status of the knowledge of the basic semiconductor properties of HgCdTe relevant to the operation of photovoltaic detectors is reviewed and related to device and focal plane performance and future needs. The material preparation aspects of HgCdTe are given primary consideration in this report. This includes a review of the phase relations in HgCdTe required for crystal growth, and a discussion of the defect chemistry of this material system. The crystal growth covers all aspects from derivation of the raw materials to the existing crystal growth techniques. With the current emphasis on epitaxial growth for HgCdTe, the status of substrate growth is also reviewed. The characterization techniques most commonly used in conjunction with the growth are reviewed and critiqued in detail.

Dynamic Compaction of Metal and Ceramic Powders (Report NMAB-394)

In this study on Dynamic Compaction of Metal and Ceramic Powders the state of the art and the technological potential for the dynamic consolidation of metal and ceramic powders was assessed. The fundamental consideration of dynamic consolidation, consolidation phenomena during dynamic compaction, dynamic compaction and conditioning of metal and ceramic powders, characterization of dynamically consolidated metal and ceramic powders, computer codes applicable to dynamic compaction, practical and potential applications, problem areas, and the current position of the United States in dynamic compaction were examined.

In the findings of the study it was recommended that a systematic study of the dynamic compaction process should be conducted; existing techniques should be improved and new ones developed to permit the monitoring of the dynamic events as close to the microscale as possible for temperatures, shock velocities, pressures, and particle motion; data and information from the systematic experiments recommended above should be utilized to form data information for the modeling codes; coordination among those investigating dynamic compaction should be maintained; a sufficiently funded, sustained, coordinated, and concentrated research and development effort should be initiated to strengthen the United Sates position in the dynamic compaction field. Such a R&D effort includes the recommendation that at least four types of characterization are needed to understand the details of dynamic compaction of metal and ceramic powders:

1. Characterization of the starting powder (including chemical, particle and crystallite dimension, X-ray lattice measurements, surface area, density of particles, shape distribution and distributions, etc.).

2. Characterization of the initial pressed powder contained in the die fixture (including green density, porosity, and texture details).

3. Characterization of the experiment in terms of the pressure-time-temperature relationship (in real time) of the projectile or explosive on the pressed powders.

4. Characterization of the resulting compact both axially and radially (including density versus position and the grain size data and shape observations based on detailed metallographic as well as X-ray TEM studies).

In addition to the aforementioned seven studies, a current (1984) study in progress is:

<u>Nondestructive Examination for Characterization and Quality Assurance During Manufacturing and Processing</u>

This study is being conducted to critically assess the current and future role of characterization and evaluation techniques in materials processing and manufacturing. Due to the broad nature of the topic, the scope has been focused by studying one or two model systems, and where possible, drawing generic conclusions.

Metal and ceramic powder production and consolidation are used as model systems since these are undergoing revolutionary changes primarily through new processing techniques that result in vastly improved properties. For instance, rapid solidification of aluminum, iron, and superalloy powders has received a great deal of attention in the past several years. Major efforts are underway by government and industry in the development of quality components for airframes, engines, spacecraft and missile structures, and other applications. Ceramics have also come to the forefront in recent years and have been used in critical applications primarily due to advances in processing. High technology applications are being explored and already exist in electronics, cutting tools, and automotive engines, among others.

In summary, this study will (1) define the state of the art of powder characterization and evaluation techniques, their applications and limitations as applied to metal and ceramic powder production and consolidation; (2) define current and future application needs and concomitant research and development; (3) examine federal roles and mechanisms for effective coordination among federal agencies; and (4) assess the technology transfer and educational requirements.