BPA News

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Driving Innovation Through Materials Research

by Paul Fleury, Chair, Solid State Sciences Committee

The 1996 Solid State Sciences Committee Forum, entitled "Driving Innovation Through Materials Research", was held at the National Academy of Sciences in Washington, D.C., on February 12–13, 1996. The meeting centered on policy issues surrounding the support, delivery, and impact of materials-related R&D as well as a representative look at recent accomplishments and the opportunities and challenges facing the community in coming years.

The first two sessions focused on the environment for the conduct and support of R&D in materials-related fields from a number of perspectives.

The keynote speaker, Thomas Weimer, Staff Director of the Basic Research Subcommittee of the House Science Committee, set the stage from a national perspective. [See an article based on his talk in this issue of *BPA News*.] He identified several themes and directions emerging from the current Congress and driven by geopolitical, social, and economic factors. These included the end of the Cold War, the U.S. budget deficit, the American public's dissatisfaction with government bureaucracy and institutions in general, and an increasing belief that the government and technology have not solved many of the societal problems we face. He noted the recent sea change in the makeup and viewpoints of the Congress. For example, 62 percent of the House Science Committee, which consists of 50 members, have less than three years seniority. There have been a record number of retirements already announced in the Senate, indicating a loss of senior members familiar with technology related issues. The debate on the restructuring of federal support for science and technology continues, as does experimentation with various relationships among industry, government, and universities as providers of R&D. All of these factors call into question long-held assumptions underlying societal support for R&D. Weimer challenged the science community to become involved at all levels in the education of the Congress and the public at large on the critical role of science and technology as investments in the long-term future of the country. He cautioned against taking a discipline-by-discipline approach and cited the need to emphasize the broad nature of investment in R&D.

The view from the Council on Competitiveness was presented by Erich Bloch, who detailed a number of recommendations from the Council to all the major sectors in the R&D community. While broadly aimed at the

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In this issue:

A Physicist Looks at Environmental Research

by Charles Kennel[1], former Associate Administrator, Office of Mission to Planet Earth, NASA

We are the first generation that can perceive the global dimensions of environmental change. We are the first generation that can characterize the state of the global environment. And we are the first generation that can begin to understand our own global environmental impact.

Our perception of the environment changed forever in 1968 when, for the first time, we began to see pictures of the earth viewed from space. These images made a varied network of environmental concerns coalesce in the public mind. By the late 1980s, a global science of earth systems had evolved, incorporating a huge range of scientific disciplines from atmospheric physics and chemistry to plant and animal ecology to human socioeconomics. Our conceptual model of this science is not yet formed clearly enough that we can make accurate long-term (10-100 years) forecasts of our planet's climate, but we have identified the elements that are needed to do this, and we have an indication of what talents need to be engaged. It has become very clear that this is one of the largest and most interdisciplinary efforts ever undertaken.

A pathfinder for the field has been our growing understanding of the science of stratospheric ozone depletion. That science has also led the way for international decision making on global environmental issues. A clear scientific

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[1] Before becoming the head of the Office of Mission to Planet Earth, Dr. Kennel chaired the Board on Physics and Astronomy. He has returned to the University of California at Los Angeles as Executive Vice Chancellor.

Committee on Condensed-Matter and Materials Physics Formed

The Board on Physics and Astronomy (BPA) is undertaking a series of reassessments of all the branches of physics as the foundation for a new physics survey. The survey will provide a broad picture of physics as a whole, identify issues that are common to its various subfields, and show the relationships among the different fields of physics and between physics and other areas of science.

As part of the new physics survey, the BPA's Solid State Sciences Committee (SSSC) is planning a study of condensed-matter and materials physics to assess scientific progress in that field and the impact of recent advances and developments.

The study will include the following:

- an illustrative recounting of the major research accomplishments of the field over the last decade,
- an analysis of the impact of this research on technology,
- an evaluation of the infrastructure and research modes of the field today, including both large facilities and principal-investigator research, with recommendations for increased effectiveness,
- an examination of demographics and career issues,
- an analysis of the implications of the above on student training and employment, with an emphasis on the university-industry interface,
- an assessment of the standing of the U.S. effort relative to that of other countries.

To conduct the study, a Committee on Condensed-Matter and Materials Physics has been established under the chairmanship of Venkatesh Narayanamurti of the University of California at Santa Barbara.

The CCMMP's first activity will be a workshop that will bring together members of the science community and leaders of federal agencies that support research in this area for two days to discuss the forefronts of the field and issues that affect its progress.

The program for the workshop includes five sessions. The first, entitled "Federal Perspectives on Science and Materials" will feature talks by William Harris, who heads Mathematical and Physics Sciences at the National Science Foundation, and Pat Dehmer, who recently took up the leadership of Basic Energy Sciences at the Department of Energy. The future of condensed-matter and materials physics will be discussed in the second session.

The third session, entitled "Accomplishments and Opportunities", will feature talks on a number of forefront topics, including:

- theory and computational physics,
- surfaces, interfaces, and thin films,
- optical materials and phenomena,
- electronic/magnetic materials and phenomena,
- probe microscopies,
- nanostructures and nanophase materials,
- nonequilibrium phenomena,
- new materials.

The workshop will then break up into small discussion groups.

The fourth session will consider infrastructure and policy issues as well as major and smaller facilities. Talks on related topics will be followed by breakout sessions.

In the final session, reports will be heard from the breakout sessions and there will be general discussion of the implications, both for the field and for the conduct of the CMMP study.

To provide additional input to the Committee and also to provide a general forum for discussion in the community, a structured web discussion has been set up on the World Wide Web. It can be accessed through the CCMMP's website at www.nas.edu/bpa/cmmp.html, where current information on the plans for the study can be found. Everyone with an interest in this field is encouraged to contribute. ■

A Congressional Perspective on Federally Supported R&D

by Thomas Weimer, Staff Director, Subcommittee on Basic Research, Committee on Science, U.S. House of Representatives

In this discussion, I will try to identify themes emerging from the 104th Congress that have long-term implications for science and technology. Changing perspectives on science are reflected both in the Congress and in the broader debate on science, technology, and public policy.

Radford Byerly, a former colleague on the staff of the House Science Committee, has summarized these changes rather well in an article that appeared in *Science*[1]. Some of the key points that underlie the changes are as follows:

- The end of the Cold War has weakened the engine of the freight train that has pulled federal science and technology support since World War II. No replacement engine has emerged with political support like that of the national security engine.
- The American public is dissatisfied with its government and inherently suspicious of bureaucracy. This makes it ready to reduce government's size and reach.
- The public is calling for substantial deficit reduction.
- The public is increasingly dissatisfied that government and science have not solved societal problems. "Yes, science and technology helped win the Cold War, but what have they done to reduce crime, improve health care, combat racism, and prevent drug abuse?"

Byerly's conclusion? The Vannevar Bush social contract, which has defined the interaction between science and the rest of society for the past 50 years, may no longer be valid. Bush argued that (1) scientific progress is essential to the national welfare, (2) science provides a reservoir of knowledge that can be applied to national needs, and (3) scientific progress results from the free intellectual pursuit of subjects of the scientists' choice. These assumptions, though perhaps still necessary to sustain societal support in the post-Cold War era, are no longer sufficient. A national debate is needed to identify a new and sustainable paradigm that will define how science and technology contribute to the national welfare and how the troika of government and its labs, industry, and research universities can best work together to address societal goals.

The Political and Policy Environment of the 104th Congress

How does this thesis relate to the political and policy environment we have seen during the first session of the 104th Congress? The House of Representatives has been widely acknowledged as a leader in the debate on these issues, especially their nonmilitary science and technology aspects on which the House Science Committee has specifically focused. The ideological and party leadership changes, as well as the broadly-heard calls to balance the budget and downsize government, have been widely reported. However, other factors that have received less attention may have equally important ramifications. In particular, a major change is the turnover in the membership of the Congress. New members now constitute more than 50 percent of the House. On the Science Committee, which has 50 members, 22 are freshmen and 9 are sophomores, so that 62 percent of the members of the Committee have served for three years or less.

In general, new Science Committee members have little relevant education or experience that positions them at the outset to engage fully in the science policy debate. This is not new. What is new is that the large number of new members now constitutes a majority voting block. It is my personal observation that new members generally take one to three congresses to become sufficiently familiar with the issues that they can engage independently in science policy debates; obviously it takes time to educate oneself on complex issues.

The Senate is lagging in this generational transition, in part because of its longer election cycle, but by the time of the Forum in February 1996, it had already seen 13 announced retirements, the highest number in over 100 years. Clearly the generational transition is occurring in both houses.

What conclusion do we reach from this observation? The science community needs a continuing program to educate new members and their staffs on federal investment in science. Everyone involved must take part in crafting and delivering the relevant messages as "civic scientists." Information delivered by constituents is often the most effective, but all messages must reinforce each other and resonate if they are to have the desired impact. Site visits within a member's district and visits with young researchers are very effective methods of delivery.

Federal Budget Trends

Many people are unaware of the trends in aggregate federal R&D spending (both defense and civilian) since World War II. In inflation-adjusted dollars, federal support rose annually through 1966 and then declined in the aftermath of the Apollo program and the Vietnam War. The trough occurred in 1975, 28 percent below the 1966 peak. After 1975, federal support once more rose steadily to a new peak in 1987. It has been declining since that time. In other words, after adjusting for inflation, there have now been eight successive years of declining federal support,

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[1]R. Byerly, Jr., and R. A. Pielke, Jr., "The Changing Ecology of United States Science", *Science* **269**:5230 (September 15, 1995), 1531.

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entire U.S. R&D enterprise, the Council's study *Endless Frontier, Limited Resources* contains lessons, themes, and recommendations that are applicable to the materials community. The central finding was "that R&D partnerships hold the key to meeting the challenges of transition our nation now faces." If the policy recommendations from the study are followed, the climate for such partnerships will improve, industry will increase its participation in R&D, and a greater sharing of costs, resources, and experiences among all sectors will result.

Arden Bement of Purdue spoke about the changes needed in the research university in the coming years:

- the changing demand for and character of graduate and undergraduate degrees (particularly in science and engineering),
- the evolving demands of industry away from the narrowly focused research Ph.D., to personnel adept at problem solving, communications, and leadership, with the ability to work in an adaptable and interdisciplinary manner, and
- the growing importance of the master's degree in science and engineering.

The use of collaborations, both within the United States and globally in both education and research, will increase. There will be more minors and dual-degree programs and a greater emphasis on industry-friendly positions in matters such as intellectual property. There will be an increased use of distance learning and an increased need to serve and retrain the mature technical work force as technology continues to shift rapidly.

Research from the industrial perspective was described by Charles Shanley of Motorola, who used three case studies to illustrate the importance of materials research to his industry: engineered ceramics, gallium arsenide circuits, and optical fibers for data transmission. He also described different modes of successful operation for researchers or innovators and emphasized particular themes which worked in his company.

The national laboratories were discussed by Al Narath of Lockheed Martin who detailed the complexity and diversity of capabilities and missions within the DOE laboratory system. These range from the generation of new science enabled by large facilities to the defense responsibilities borne by the complex, multi-program weapons laboratories. The DOE laboratories are undergoing an unprecedented reexamination of their missions, their cost effectiveness, and their future roles in addressing national needs. The reaction to shrinking support has led to some tension between research universities and laboratories as potential competitors. The promising interactions with industry growing out of CRADA-like partnerships appear threatened. Nevertheless, Narath's message was upbeat—there is progress toward a truly integrated system of laboratories with complementary and cooperative strengths that will better address a broad variety of national needs through an improved set of partnerships with both the industrial and academic sectors as well as among government organizations.

Neal Lane of the National Science Foundation echoed an earlier stated theme that R&D support from the Federal government peaked in real dollars in 1987 and has been declining steadily every since, with a projected decline of another 30 percent over the next six or seven years. While the NSF commitment to materials is firm, the field will not be exempt from the NSF retrenchment. He called for the development of the "civic scientist" to articulate the value that R&D delivers to the country and to lead an increasing involvement of scientists in defining the future, not only of our scientific research but of our technology. The importance of educating congressional and political leaders on the need for continued R&D investment for the good of the country cannot be overemphasized. He urged the research community to engage in a new and active dialogue in all levels.

Arati Prabakhar of NIST, Anita Jones of DoD, and Martha Krebs of DOE focused on examples from their agencies of impacts which materials research has had upon their agency missions. They were uniform in their support for and recognition of the value of materials R&D in enabling the missions of the Departments of Commerce, Energy, and Defense to be met. Nevertheless, all emphasized the need for increased accountability and measurement of research impact relative to the historical past. Programs which have significant impact on the mission of the agency will be the ones to survive. The struggle between the long- and short-term views which industry and laboratories are facing is evident as well in all of these missions agencies that are responsible for so much of the funding of R&D in the materials field.

The agency presentations were followed by a lively panel discussion involving the speakers of the afternoon session and several congressional staff members. Many of the day's issues were explored in terms of experiments in partnership such as technology transfer from federal laboratories to industry, partnerships between laboratories and universities, and direct government funding of research in industrial settings. A lively discussion centered on the recent change in political climate and its effects on the laboratories' technology transfer programs, the Technology Reinvestment Program, and other similar programs. While the panel was divided as to which of the programs were more or less worthwhile, there was general agreement that every program must have a set of criteria against which success can be measured over a period of a relatively few years to determine whether not to continue making the investment. Some panelists felt that the government participation in such programs smacked of "corporate welfare", in that if an activity were really beneficial to a company, then the company could be expected to fund it. "Any company that fails to invest properly in R&D deserves to go out of business," said one panelist. When the panel was asked whether the same might be said about a country (in light of Dr. Lane's projections), it had no answer. It was emphasized, however, that the criteria for continued support should be tailored to the individual programs, because they have generally different objectives. There was also general agreement that there is a need for a new social R&D contract, that funding will continue to shrink, and that a national debate on the structure, strategy and substance of federally supported R&D must be pushed forward.

On the second day, the Forum turned to representative accomplishments of materials R&D in driving industrial innovation. The amazing explosion in information-carrying capacity of high-speed networks based on optical communications was detailed by William F. Brinkman of Lucent Technologies. Glass fibers of unimaginable transparency with exquisitely tailored waveguide properties permit transmission of billions of bits per second over thousand-mile distances without the need for intervening electronics. Semiconductor laser sources and detectors allow simultaneous sending of many carriers at different wavelengths over the same fiber.

The equally prodigious and longer-term growth of semiconductor and magnetic materials, which form the basis for computing and information storage, were vividly demonstrated by in Michael Polcari's talk. Materials for gate insulators, metallic interconnects, and ever-smaller-scale circuit elements are enabling the industry's continued exponential increase in computer processing power and semiconductor memory capacity. Equally exciting new magnetoresistive materials are enabling a 100-fold increase in magnetic disc memory capacity.

In tracing the influence of materials research in the automobile industry, Norman Gjostein emphasized the societal and competitive drivers for lower cost, more efficient, and more environmentally benign motor vehicles. The materials challenges in these fields range from developing cheaper, stronger, and lighter-weight materials to understanding the materials science of the combustion process to creating recyclable materials for both components and entire vehicles. Cost synergy with other industries such as the aircraft industry was emphasized and the clear value of materials technology in U.S. automotive competitiveness was detailed.

Jeffrey Frey's talk on technology development in Japan emphasized the special culture of the island nation, which drives their approach to education, work, research, development and manufacturing. He emphasized the differences in formal education, job training and work methods between Japan and the United States. Differing approaches to industries, laboratory structures, and the training and mobility of the technical work forces were also highlighted.

The final forum session was devoted to future opportunities in materials research. Dave Moncton of Argonne National Laboratory described the major photon facilities utilizing synchrotron radiation for materials research. New sources like the Advanced Photon Source put us on the threshold of qualitatively different abilities to characterize and modify materials using light whose wavelength ranges from the subangstrom to the submillimeter. Structural biologists, polymer chemists, and others are joining the physicists, chemists, and materials scientists as the user communities expand into the many thousands. As elsewhere, the United States finds itself in hot international competition with respect to photon sources, where our investment and position are competitive and at the forefront.

With neutron sources, on the other hand, we are not on the forefront in either metric. Mike Rowe of NIST reviewed the situation for neutron sources and neutron science in the United States. He began by emphasizing the properties of neutrons themselves. These properties make them uniquely powerful probes of molecular and condensed matter. They are also necessary to create required amounts of medically vital isotopes.

Reactor and spallation sources at home and abroad are utilized by thousands of scientists. But there is a striking contrast between U.S. neutron facilities and those in Europe. Although neutron scattering was pioneered in the United States (as recognized by the 1994 Nobel Prize for physics) we have fallen behind Europe for the last two decades in terms of investment, with the result that the leading sources (of both reactor and spallation neutrons) are European.

A fitting climax to the research opportunity segment was provided by George Whitesides' address on "Molecular Self Assembly and Nanostructured Systems." By letting nature take its course toward thermodynamic stability, materials can be manipulated to assemble themselves into desired aggregates, structures, or replicas. Micro contact printing and micro molding were two examples of the new vistas opened by the "bottom up" approach to fabricating complex and useful structures.

The wrap-up session was an energizing event. It was unusual in two ways. First, it was focused on actions and next steps rather than a mere review of the material presented at the forum. Second, it was attended by a substantial majority of the participants who attended the opening session. Factors influencing this attendance include the high degree of engagement and discussion throughout the forum by all attendees, and an unusual degree of candor among all speakers in raising issues. The community appears to have moved beyond the "denial" phase in recognizing the profound charges that have occurred in the nation's attitude toward R&D, in accepting that austerity and accountability will henceforth be a way of life, and in stepping up to the responsibility to articulate the values of the nation's R&D investment.

There was unusual openness in discussing plans and programs either already launched or contemplated from ordinarily competing elements within the

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Congressional Perspective (continued from Page 3)

extending through three Presidents and five Congresses, and amounting to a cumulative decrease to date of approximately 10 percent. Under the current budget scenarios of the Administration and the Congress, this declining trend will continue for six more years. AAAS projections based on the FY 1996 budget resolution predicted a decline of approximately one third over that coming period. Of course, the actual percentage will depend on the performance of the economy and many other factors.

Thus the debate in Washington is not over the overall direction of federal R&D support, which is continuing downward, but rather over the pace of the reduction and the ratio of research versus development and military R&D versus civilian R&D. The message is that science is being treated no differently, at this time at least, than any other discretionary programs. But this message should be a warning: as the discretionary appropriations pie gets smaller and smaller, science is competing directly with all the other discretionary programs, many of which have strong advocacy groups that are skilled in Congressional lobbying. The science community needs to get involved in the education of the Congress (and the public at large). Scientists must explain, in nontechnical terms, the long-term benefits to society of investment in science and technology.

Restructuring the Federal S&T Support Infrastructure

Driven in part by these budget trends, there has been renewed discussion of restructuring the federal science and technology support infrastructure within government. The Department of Science proposal has been renovated as one possible approach to addressing efficiency of administration and budgeting issues, albeit with the loss of pluralistic funding sources. This debate was not fully engaged this past year, in part because of ongoing strategic realignments at NASA and DOE, but it does not appear to be over. Discussions over the restructuring of the infrastructure, such as those concerning the future of the Commerce and Energy departments, will continue into the second session of the 104th Congress. The fundamental question is, with continuing diminished federal resources as a given, "Do we have the best and most efficient government infrastructure in place for delivering scarcer dollars to the actual research performers?"

Restructuring Government-Industry-University Relationships

Achieving better relationships is clearly going to be critical to the performance of science and technology. I've been struck in visiting national laboratories over the last year at the signs of changes I see and by the way they are doing business. These changes include both technology transfer and laboratory-university partnerships. Congress remains in favor of Cooperative Research and Development Agreements (CRADAs) as long as they are mission-oriented and the money comes from programs and not from set-asides. Industrial research has declined in the last three years. The decline in basic research has been rather precipitous. Consequently, interactions between industry and the other sectors are more important than ever. Within government, indirect avenues of enhancement, such as tax and regulatory changes, must continue to be examined for opportunities for improvements.

For universities, there is a need to confront cultural barriers against industrial partnerships, where they exist, and to further drive interactions outside the university. Another change that is growing in importance is that of state-federal partnerships that identify and invest in strategic science and technology areas and define economic development goals.

Summary

In summary, the generational turnover in Congress is a new and significant change with a potential for having a long-term effect on S&T policy. The science community should get involved in the education of Congress (and the public at large) regarding the critical role that science and technology investments play in the well being of the country in the long term.

Members of Congress often learn first from other members, then from the Washington establishment, and third from their constituent base. The latter may have the greatest long-term impact.

A discipline-by-discipline approach to arguments in support of S&T is risky. It is better to emphasize the broad nature of investments in science and technology.

Although most people believe that federal spending in S&T is indeed an investment, the difficult argument comes when one tries to decide how much is enough or how much can be cut. Such issues do not have simple answers, and it is primarily through the experience gained from years of involvement that members arrive at the conclusion that investments in S&T are critical and become strong supporters of it. ■

Forum (continued from Page 5)

materials community. Everyone invited all others to contribute ideas, join in studies, submit proposals for joint projects, etc. Since all sectors (universities, industry, labs, agencies, and congress) were represented, we came away with the hope—and perhaps even an conviction—that we will address the issues of priority, accountability and partnership in more effective ways than ever. If so, this the 1996 SSSC Forum was indeed a success. ■

The Proceedings of the 1996 SSSC Forum are available from the Board on Physics and Astronomy (202-334-3520).

Environmental Research (continued from Page 1)

understanding of the ozone depletion problem was developed over many years based on the combined results of a ground-based monitoring network, measurements from aircraft, and measurements from satellites in space. The Montréal Protocol, which set a schedule for eliminating the use of ozone-depleting chemicals, would not have been possible without this clear understanding, and it is both significant and reassuring that the international agreement came into being very quickly once the scientific understanding did become clear. Even more reassuringly, the scientific evidence is now mounting that the Montréal Protocol is being complied with, and that its hoped-for positive impact on the ozone layer is indeed taking place. There is still no international agreement, however, on continuing space-based monitoring of ozone concentrations or on maintaining the ground-based ozone monitoring network.

At our present level of understanding, the immediate challenge in earth system science is to learn to predict climate variations, on a regional scale, from month to month (seasonally) or year to year (interannually). This is a richer, more complicated science than understanding the concentration of stratospheric ozone, largely because of the intricate interlocking between scientific and social factors. A good example is the development of models of El Niño, a pattern of ocean temperature and currents that develops in the Pacific in some years. These models are now about 70 percent accurate at predicting the large-scale changes in temperature and, to a lesser extent, precipitation, that take place in El Niño years. The next step in this intermediate-scale challenge will be to incorporate our understanding into an integrated prediction process that will allow farmers to change their planting strategies and, in general, prepare for and mitigate the effects of natural hazards. An international research institute has recently been formed to coordinate El Niño modeling efforts with impact assessments and adaptation strategies.

In the longer term, we would like to learn to predict regional climate changes over periods of 10-100 years. Prediction of global warming is only a small part of this scientific challenge. Note also that although data on greenhouse gas emissions and behavior are important, many other diverse types of data are also essential, from sea levels to the thickness of ice sheets to the extent of land cover by vegetation. As yet we have not even identified the important parameters. What combination of factors is most useful in understanding the behavior of our climate? We don't yet know.

Given the widespread public uncertainty about the whole complex of global environmental issues, there will be some resistance to accepting long-term assessments. Successful seasonal and year-to-year forecasts will be important public confidence builders for the longer-term science. Another important issue in the long term is our stewardship of meteorological data, which needs to be preserved and calibrated to allow checking of long-term model simulations.

Ultimately we want to understand how all the many parts of the global ecosystem interact. Because of the number of interlocking factors involved, this will be a very hard problem. Solving it will require changing how scientists work. For example, ecologists are very new to "big science". They are only now beginning to develop strategies for integrating their understanding of ecological behavior at the single-plot and local level to an understanding of regional and global issues.

We are only beginning to understand the global environment, but the issues are so important that we owe the next generation the capability to think clearly about them. Developing that capability will require a historical data set, an adequate scientific infrastructure, and a collaborative scientific and policy community.■

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U.S. National Committees[3]

[1] In cooperation with the Space Studies Board.
[2] In cooperation with the National Materials Advisory Board.
[3] See www.nas.edu/bpa for more information.

Recently Completed Studies:

- *Proceedings of the 1996 Solid State Sciences Committee Forum.* Available from the Board on Physics and Astronomy (202-334-3520).
- *Opportunities in Cosmic-Ray Physics and Astrophysics.* Available from the Board on Physics and Astronomy (202-334-3520).
- *Cosmology: A Research Briefing.* Available from the Board on Physics and Astronomy (202-334-3520) and on the BPA website.

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