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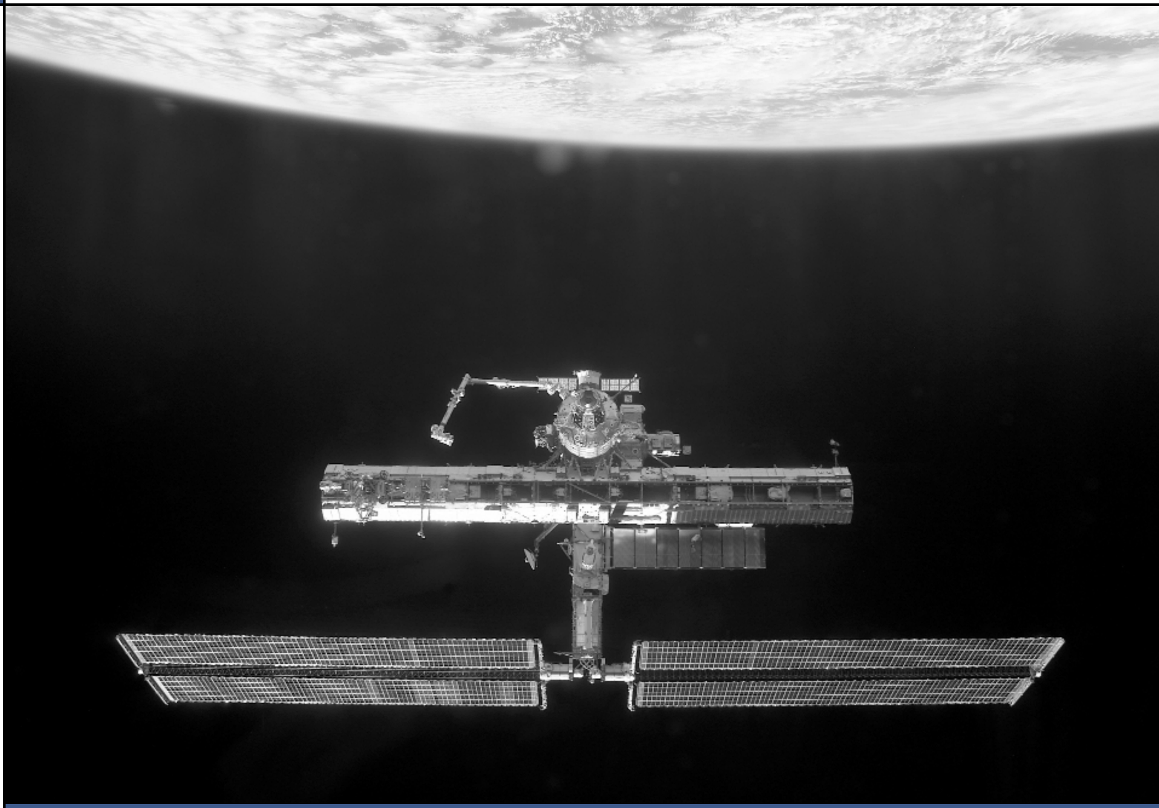
The Challenge of Coordinating "Big Science"



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IBM Center for
The Business
of Government

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Cover photo courtesy of NASA: Full view of the International Space Station (ISS)

TABLE OF CONTENTS

FOREWORD

On behalf of the IBM Center for The Business of Government, we are pleased to present this report, "The Challenge of Coordinating 'Big Science,'" by W. Henry Lambright.

In this report, Professor Lambright examines three large-scale research and development programs: climate change, nanotechnology, and the International Space Station. He analyzes the case studies from a unique perspective: how these programs were coordinated among several federal departments and agencies. In the case of the Space Station, international coordination was required.

A major premise of this report is that in the future, many governmental programs—not just large-scale research and development programs—will require similar coordination across departments and, in many cases, across nations. The research task undertaken by Professor Lambright was to find lessons from these three case studies that might be applied by other government agencies as they face the challenge of coordinating different programs.

In many ways, this report is a sequel to Professor Lambright's previous study for the IBM Center, "Managing 'Big Science': A Case Study of the Human Genome Project." In that study, Professor Lambright examined the challenge of coordinating the Human Genome Project across the government and internationally. In the case of the Human Genome Project, the National Institutes of Health was the "lead agency." In the cases of climate change and nanotechnology, there were no clear "lead agencies," and a coordination approach was required in each case. Anybody who has ever faced the task of coordinating "equals" knows that the challenge is a large one.

As in the case of the Human Genome Project, Professor Lambright found that a key success factor is the importance of setting a clear and focused goal. When the goal is clear and worthwhile, coordination becomes possible. Although some turf battles may occur, the mission often overrides turf concerns. Reflecting on his experience managing the Human Genome Project, Dr. Francis S. Collins, director of the National Human Genome Research Institute, commented that what helped that project succeed was "absolute, unquestionable shared commitment to the goal." In the three new case studies, Professor Lambright concludes again that shared goals and commitment are key.

We trust that this report will be helpful to executives at all levels of government who face the challenge of coordinating activities with other governmental organizations, including other nations and international organizations.

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EXECUTIVE SUMMARY

This study builds on an earlier work by the author that examined the leadership aspects of the Human Genome Project. Specifically, success in that project required the coordination of diverse parties spanning federal agencies within the U.S. and between the U.S. and Great Britain. This project tracks the evolution of three other large-scale research and development (i.e., Big Science) programs: climate change, nanotechnology, and the Space Station. The specific management question investigated—coordination—implies making the whole more than the sum of the parts. How is that done? Who does what? Who coordinates? Who is coordinated?

The programs studied cost in the billions of dollars and stretch over years. They represent not only national policy decisions but international efforts. All require management, but it cannot be the top-down hierarchical kind possible in one organization. Involved is a collection of multiple parties over whom the leader may have minimal control. Somehow the leader has to steer the group in a particular direction. None of the three programs detailed in this report are as successful as the genome project. They vary in their attainment of goals set for them and devices used (lead agencies, interagency committees, White House overseers, and "czars"). Climate change has seen success and frustration in its history. Nanotechnology is a relatively new activity and is off to a strong start as an interagency initiative. The Space Station is already of historic significance technically, but presents continuing managerial issues it may or may not overcome. These three cases, therefore, provide a range of experience from which to draw lessons.

The cases show that coordination is difficult, but attainable, where large-scale interagency programs are concerned. However, getting agencies to cooperate (especially across national boundaries) requires leaders to utilize various coordination strategies. They include: 1) setting a clear and focused goal; 2) emphasizing common interests; 3) attracting political support; 4) enlisting White House oversight agencies; 5) employing strong but diplomatic leadership; 6) retaining staff support; 7) using a threat from outside the group to get agencies to cohere; and 8) holding to an end while being flexible as to means.

Introduction

In 2002, the author wrote a report for the IBM Center for The Business of Government on the Human Genome Project.[1] This was the largest scientific and technological enterprise in biology's history. It cost approximately $3 billion, stretched over a decade and a half, and involved two federal departments in Washington, a major funding organization in England, and scientists in six countries. Universally hailed as a success, the project was also viewed as exemplifying the wave of the future in organizational terms. It was a monumental coordination activity in which diverse organizations came into a coalition, indeed partnership. The author examined the role of the National Institutes of Health (NIH) as the "lead agency" in the project. Lead agencies are not always successful, but NIH was in this case, owing to its dominance in funding, an astute top manager, and the spur of competition from a private company seeking to achieve the human genome sequence before the public enterprise. This study looks at other examples of coordination in "Big Science" programs for purposes of comparison and contrast in lessons learned.

Issues

The term *coordination* implies making the whole more than the sum of the parts. Typically, big programs that cut across agencies are fragmented and reveal gaps. They are less than the sum of the parts and their inefficiencies can lead to disappointing results. Almost everyone believes coordination is desirable, but hard to bring about. Many would like to be coordinators, few wish to be coordinated, and competition abounds. Managers seek mechanisms that combat centrifugal forces to achieve organizational coherence.

The following study looks at three Big Science programs. Two are in the research category; the other involves technological development. Two are national in scope and are implemented by several agencies; one is international in scale. Two go back many years; the third is relatively recent. They all are costly in terms of money. The two older programs have expended many billions over their lifetime. Even the youngest one has risen to $2 billion after just a few years in existence.

These programs have been deemed so compelling in national interest that they were announced or promoted through presidential decisions. While presidential priorities, they are managed by separate agencies—agencies that may even be in different nations. Who coordinates and integrates multiagency Big Science? Which strategies work and which fail? Why and why not?

To answer such questions, we look first at climate change. This program was born in a formal sense at the end of the Reagan administration in 1988. It was called the U.S. Global Change Research Program (GCRP), and continues to this day. It was proclaimed a "presidential initiative," a formal designation, by President George H. W. Bush in 1989. Under President George W. Bush, in 2001, it was subsumed under his Climate Change Research Initiative (CCRI). Perhaps as much as $25 billion has been spent on GCRP thus far, and more will be spent on the combined GCRP/CCRI.[2] For our

Acronyms

CCRI	Climate Change Research Initiative
CEES	Committee on Earth and Environmental Sciences
CENR	Committee on Environment and National Resources
CRV	Crew Return Vehicle
DOE	Department of Energy
EPA	Environmental Protection Agency
ESA	European Space Agency
FCCSET	Federal Coordinating Committee on Science, Engineering, and Technology
GCRP	Global Change Research Program
ISS	International Space Station
IWGN	Interagency Working Group on Nanoscience, Engineering, and Technology
NASA	National Aeronautics and Space Administration
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NNI	National Nanotechnology Initiative
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NSET	Nanoscale Science, Engineering, and Technology
NSF	National Science Foundation
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
OSP	Orbital Space Plane
OSTP	Office of Science and Technology Policy (White House)
PCAST	President's Council of Advisors on Science and Technology
RSA	Russian Space Agency
USGS	U.S. Geological Survey
WTEC	World Technology Division of the International Technology Research Institute

purposes, it is useful to think of them both under the rubric "climate change."

The second program studied is the National Nanotechnology Initiative (NNI). This program, established by President Bill Clinton in 2000, was augmented under President George W. Bush. A relatively new effort, it has spent close to $2 billion since 1997.[3] It has been hailed as key to the world's next great technological revolution.

The third is the International Space Station (ISS). This program is different from the first two in requiring coordination among space agencies in different countries. Announced by President Reagan in 1984, it is the biggest international civilian research and development (R&D) project in history, and today involves 16 nations. Approximately $35 billion has been spent on ISS by the U.S. alone, with other nations contributing many billions more.[4]

All three programs present significant management challenges. Each program has been shaped by the strategies and interplay of many actors. Our focus is on the leadership behind the program. This may be a "lead" agency, or an interagency committee, or some overarching entity in the White House or Office of Management and Budget (OMB). Its role is to steer and integrate as necessary. It also seeks to provide program change as required. National initiatives in science and technology that are big in scale and long in duration require multi-agency coordination. At best, coordination creates an organizational coalition or "virtual agency" around a program. Without it, a program often drifts, has internal conflict, and may even fall apart.

Acknowledgments

The author wishes to acknowledge support from the IBM Center for The Business of Government and from NSF grant SES-0114689 concerning space policy.

Climate Change

In 1987, the President's science adviser, William Graham, convened an interagency group with climate-change interests under the aegis of an existing but moribund mechanism, the Federal Coordinating Committee on Science, Engineering, and Technology (FCCSET). Tony Calio, the director of the Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), was his designee to chair the group. Calio made it clear to other agencies that NOAA would be the lead agency in a government-wide R&D program on climate change. Other agencies protested that prospect. An OMB representative at the meeting stated that even if the agencies got together and came up with a program, they could expect no additional money for their trouble. The meeting collapsed.[5]

Afterward, three senior managers from NOAA, the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA) met and decided to try to salvage the idea of a coordinated interagency initiative in climate change. Each ran a program relevant to the subject—climate research at NOAA, geosciences at NSF, and earth-monitoring satellites at NASA. All three wanted more resources for their own program and saw presidential support as essential to growth. They knew and liked one another, and believed they could do better in concert than separately.

With the support of their agency heads, they wrote a letter to OMB saying they would like the budgets that were designated for climate change of their respective agencies considered as a whole. OMB was surprised, but pleased. Having castigated agencies in the past for not coordinating, it saw an opportunity to encourage a positive step in government. Graham was brought into the process and, before long, the three agencies put together a planning document for what they called "The U.S. Global Change Research Program." The term *global change* allowed them to include more than climate change, but climate change was the primary driver.[6]

Becoming a Presidential Initiative

The report the three administrators provided carried over to the Bush administration. President George H. W. Bush had campaigned as the environmental president and told voters not to worry about the greenhouse effect because the "White House effect" would take care of it. Shying from regulation, Bush decided on more research to determine if there was a serious problem and if human actions had something to do with it. Moreover, he told his science adviser, Allan Bromley, to pick a few important areas of science and technology he could push.[7] Bromley selected global change—an obvious choice in terms of ripeness for decision—and it was proclaimed Bush's first "presidential initiative" in science and technology. Congress in 1990 followed suit, passing legislation that gave global change a legislative base. However, Congress indicated it wanted policy-relevant knowledge to come from the program. This element added a note of complexity—coordination meant not just integrating science, but also linking science to policy.

Implementation

Leadership was vested in an interagency committee under FCCSET, the subcabinet level coordination body headed by Bromley. There were approximately a dozen agencies represented on this committee, which came to be known as the Committee on Earth and Environmental Sciences (CEES). In addition to line agencies such as NOAA, NSF, NASA, and the Department of the Interior, the committee included representatives of OMB and the White House Office of Science and Technology Policy (OSTP), headed by Bromley. The chair of CEES was the director of the U.S. Geological Survey (USGS), the primary agency of the Department of the Interior concerned with GCRP. He was chosen because he was non-threatening to the dominant agencies— NOAA, NSF, and NASA. These three agencies held the real power on CEES, because they spent the most money and gave it the most time. A subcommittee of CEES headed by Robert Corel, geosciences director at NSF, provided intellectual direction on scientific strategy. To the extent there was a key individual, it was Corel, who saw the word *National* in National Science Foundation as an opportunity for inter-agency leadership. Thus, the reality of power was bottom up and agency driven, rather than top down, from the White House. However, the model was not the lead agency type. Agencies involved refused to use the term *lead*. The formal coordination mechanism was the *interagency committee,* and an informal group of managers worked behind the scenes to steer the operation.[8]

During the George H. W. Bush years (1989–93), the Committee on Earth and Environmental Sciences developed the reputation of an effective interagency organization and the Global Change Research Program a model interagency effort, receiving study at both Harvard University and Syracuse University. The scientific strategy was to build an "earth system science" that would take a holistic view of the planet. It would combine satellite and ground-based observations, with the goal of developing a "predictive capability" for climate and other earth changes.

Agencies would meet and jointly plan a program. They would engage in budget crosscuts to see how individual agencies could contribute to common endeavors. Plans were reviewed by the National Research Council (NRC). Unlike most interagency committees, CEES had real power. Once CEES did its interagency plan and made a crosscut of priorities, it bargained with OMB over a GCRP budget. OMB "fenced" the GCRP budget. That is, designation of GCRP as a "presidential initiative" carried with it special care. It was protected against cuts by the host agencies once a CEES-OMB decision was reached. Moreover, an agency not party to GCRP that wished to join in the collective effort had to go through CEES, which could apply "standards." Participation by the Department of Energy (DOE) was initially rejected because CEES saw its research plan as shoddy. The plan had to fit the CEES vision of a coordinated earth system science. CEES was not just a creature of the agencies (especially the "big three"); it was also a creature of OSTP and OMB. Bush had backed the decision to give climate-change research a funding boost. OMB's view was that as long as the budget was going up, it only made sense to see that it was managed well. Coordination, integration, and a strong interagency management system were deemed essential.[9]

The Committee on Earth and Environmental Sciences was powerful to the degree it was not perceived as powerful or going against the grain of what agency heads wanted. It was up to the representatives on CEES to make sure their respective administrative superiors were on board. CEES overstepped its bounds, however. The Secretary of the Interior was offended because he was constrained in reprogramming funds by CEES, an interagency committee whose head was his subordinate, the director of USGS. Also, a document was leaked to Congress by CEES that took a different position on a global change issue from that of the administration. Bromley fired CEES's head and put in his place an administration loyalist who happened also to be Corel's boss at NSF, obviously a way to restrain (but keep) the informal leadership of the enterprise.[10]

Nevertheless, the administration was satisfied with CEES and the presidential initiative model. With GCRP a precedent, Bromley established a handful of other initiatives on the GCRP design. As these began, he moved GCRP to "national program" status rather than presidential initiative. The primary difference was that OMB removed the fencing power. In addition, the administration created a small secretariat to help run the enterprise. Corel and his counterparts were doing interagency work on top of their regular agency assignments. As a national program, the budget continued to go up, although not as rapidly as before. Priority shifted to new presidential initiatives. Bromley, writing of his experience as George H. W. Bush's science adviser, called his work with interagency coordination his "most important accomplishment in Washington."[11]

The Clinton Transition

GCRP was maintained by the Clinton administration, whose vice president, Al Gore, was deeply interested in global environmental issues. However, it altered the management mechanism. The Bush White House had delegated much of the authority to steer GCRP to CEES, which meant the three dominant research agencies (NOAA, NSF, and NASA). That meant GCRP emphasized basic research to characterize the problem, even to determine whether climate change was a problem, rather than applied research to mitigate the problem. The integration of science into policy did not happen. The science agencies of CEES did not push; the Bush White House did not pull.

Clinton, and especially Gore, assumed there was a problem. The change in emphasis meant that other agencies on CEES—which was now called Committee on Environment and National Resources (CENR) and enlarged in membership—had more clout. Mitigation (and prevention) was what the Environmental Protection Agency (EPA) cared about, and EPA's hand on GCRP policy enlarged to a degree. The role of the land agencies (the Departments of Agriculture and Interior) expanded. The "earth system science" vision became less the focus of the program. To proponents of the change, it was a necessary broadening of scope; to opponents it was a dilution of goals.[12] Centrifugal forces began to pull the tight system constructed by the research agencies and Bush White House apart.

Similarly, the Bush administration had selected global climate change as one of a few initiatives to push, whereas Clinton-Gore had many more priorities. The FCCSET process was discarded, and a higher-ranking National Science and Technology Council (NSTC) took its place, charged with coordinating *all* federal science and technology. One of the associate directors of the White House Office of Science and Technology Policy, for the first time, had *environment* as a formal mission in his title. Environment, however, cut a very broad swath across the government. Robert Watson, OSTP's associate director for environment, told CENR that global change could no longer be as "privileged," as it had once been. What that meant in practical terms was that OSTP did not treat it as special, as either a "presidential initiative" or "national program." Other Clinton R&D initiatives were coming to the fore and getting more attention.[13] OMB, which had once been the power behind GCRP, now looked elsewhere in backing presidential priorities. Moreover, Watson pressed for useful policy outputs from GCRP, in line with administration emphases. He and Corel began competing for the intellectual leadership of the enterprise.

In 1995, the Republicans took control of Congress and began an assault on environmental R&D, especially climate change. The Congress, operating through specialized committees, was always a counter to interagency coherence. While budgets overall went up, there was room for agencies to make adjustments. Interagency transfers were made to keep joint initiatives on track. Coordination was harder when individual agency budgets were attacked. Agencies had to look after their own interests first. NASA, whose satellite program constituted one-half of the overall GCRP budget, made changes independently of GCRP. The Clinton-Gore administration managed to weather the Republican assault, and the budget for GCRP did go up incrementally. However, much of the energy for interagency cohesion was spent, as some of the founding fathers of the program moved on.[14] The Clinton-Gore administration, with the Kyoto climate meetings of 1997 a deadline-forcing event, gave increasing attention to emissions-control policy, and the research program suffered from "benign neglect." While power had gone up to the White House, the White House was not really running GCRP. The "vertical coordination" of Corel and Watson failed, and eventually both left government.

Reorientation under the Second Bush

By the end of the Clinton administration, independent evaluations of the Global Change Research Program were sharply critical. The vision of "earth system science" might have been acceptable when GCRP was young, but it was found to be too diffuse for a mature program by the National Research Council. When budgets got cut, NRC said, the vision proved too vague to serve as a guide to priorities—what to save and what to let go. In response to evaluations, the earth-system approach gave way to more emphasis on regional climate change. This was in line with administration concerns about vulnerabilities and mitigation, but it was a vision that added to the schisms in the program.

President George W. Bush inherited a GCRP in 2001 badly in need of revitalization and tightening. Its legislative mandate helped protect GCRP from termination, a course favored by some Bush advisers. Killing GCRP, however, became politically impossible after Bush made his decision in that year to withdraw from the Kyoto Protocol on climate change.

The logical course was to modify GCRP, but how? Bush decided to subsume GCRP within a Climate Change Research Initiative. GCRP continued as a basic research-oriented, longer-term effort. CCRI, however, was to focus on shorter-term issues in climate change and cope with the acknowledged science-policy gap.[15]

The most notable difference in management structure was that there was now an individual clearly designated as in charge of this interagency program—James Mahoney, Assistant Secretary of the Department of Commerce. His position is presidentially appointed and Senate confirmed. The Secretary of Commerce, a close friend of Bush's, instructed Mahoney to spend three-quarters of his time on GCRP/CCRI. The secretariat is under him, and he reports to an interagency committee of cabinet status. The Commerce Department is the de facto lead agency and Mahoney the lead person. Within Commerce, NOAA is the principal technical organization.

James Mahoney

Mahoney retained Richard Moss, staff director of the GCRP secretariat, as his principal associate. Together they prepared a strategic plan, which served as the basis in 2002 for a large Washington conference of stakeholders. Using comments derived from the conference, the strategic plan will be the roadmap for GCRP/CCRI for at least the remainder of the Bush years. Bush critics have called the Mahoney organization "smoke and mirrors," hiding Bush's lack of commitment. They see research as an excuse not to act (i.e., prevent or mitigate climate change). Others believe research is needed but it must be much more targeted and its results quickly assessed for policy.[16] Mahoney is running an old program that has spent a lot of money and produced a strong knowledge base. However, because of its maturity, results are expected that are useful to policy if the program is to have credibility. Mahoney is expected not only to integrate science but also to push toward policy. Critics doubt that Bush will provide the policy pull, however.

There is no research program in government more controversial than climate change, nor one that extends so widely across government. There is no central climate agency. Hence, coordination has always been a point of contention. The Bush I (George H. W. Bush) interagency committee model was seen to have worked because it was narrowly focused on "good science" goals and run by the science agencies most concerned. Behind the formal interagency mechanism was a close-knit group of senior managers who shared a common vision. Moreover, the interagency model was the chosen instrument of a science adviser anxious to make FCCSET effective. Finally, it had real power to augment and protect program funds, thanks to OMB's fencing strategy. Vertical and horizontal lines of authority intersected at the interagency committee. All those conditions eroded under Clinton; the program continued, but became the more typical and fractious interagency effort. With broader but more contentious goals, GCRP saw centrifugal forces overwhelm those that integrated. Whether the Bush II (George W. Bush) model, which appears to be a "czar" approach, will work remains to be seen. Czars need the backing of presidential power.

Nanotechnology

Nanotechnology is the study of structures and devices at the molecular level. A molecule is one-billionth of a meter, hence, a nanometer. Materials this small have found their way into production, but the process has been largely fortuitous. Today, there is science behind this technology and conscious design. It has been found that physics, chemistry, and engineering at the nanoscale have unique properties. Nanotech is not simply an advance in miniaturization. It represents a novel realm of research, development, and applications. Materials produced at the nanoscale can be made stronger, lighter, cheaper, and better.

The computer revolution, now limited by size, could in the future be not only extended, but enabled to go in novel directions. Diseases like cancer could be treated by attacking cells at the earliest stages, when only a few cells are damaged. Nano-robots could be soldiers in military campaigns. The applications seem limitless, and advocates speak of a second industrial revolution. There may well be considerable hype in these claims by proponents. However, there also appears to be a growing consensus that nanotechnology may be a revolutionary technology of vast implications—both positive and negative.[17]

There were no federal R&D programs specifically devoted to nanotechnology until very recently. Individual scientists did research on the subject, competing for grants from the National Science Foundation and other agencies. Work was scattered, fragmented, and uncoordinated, except through processes of communication in the technical literature.

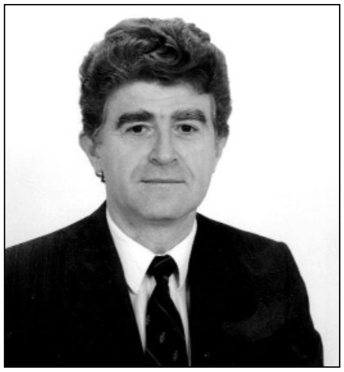
Getting on the Agenda: An Agency Advocate

The government official generally acknowledged as putting nanotechnology on the public agenda was Mihail (Mike) Roco, a former professor of mechanical engineering from the University of Kentucky, who came to the National Science Foundation in the 1990s to serve as a program manager in the engineering division.[18]

In 1995, Roco decided to build a sustainable research program in nanotechnology. What he needed was a decision by NSF to do so, but it would not be easy to get it. Universities accorded nanotechnology little priority, researchers were not pushing, and industry was not pulling. A nanotechnology initiative seemed a long shot.

Roco developed a dual strategy. That is, he worked for support within NSF and also sought allies outside the agency to try to get NSF to better appreciate the field. It was not that NSF as an organization was against nanotechnology; rather, the agency had a limited budget and tremendous pressure on that budget from many competing priorities, including some that appeared as promising, or more promising, than nanotech.

Roco turned to a private organization, the World Technology Division (WTEC) of the International Technology Research Institute. This organization did studies for NSF and other agencies of the status of particular fields. WTEC helped him identify what was happening or not happening in other agencies, as well as who were potential allies in those agen-



Mihail (Mike) Roco

cies. In 1996 Roco organized an informal group of like-minded research managers from NASA, the Departments of Defense and Energy, the National Institute of Standards and Technology (NIST), and the National Institutes of Health. They met periodically with Roco to talk about nanotechnology and strategy.[19]

The group decided to find out what was happening with nanotech in other countries. This meant that this group of federal managers had to contribute to a study by WTEC. There was a lot of "tooth-pulling," recalled Geoff Holdridge, then of WTEC, but \$400,000 was raised. In 1996, WTEC began a two-year survey, looking at Japan, Russia, and Western Europe.[20]

A White House Ally

Roco, meanwhile, "talked up" nanotechnology wherever and whenever he could. In 1997, another outside ally, absolutely critical in subsequent events, came to the fore. Tom Kalil, special assistant to President Clinton on the White House Economic Council, had been reading about nanotechnology and was intrigued. He was looking for some new technology that would fit into a Clinton policy to stimulate industrial advances. He heard about Roco and called Neal Lane, then director of NSF, requesting permission to speak to Roco. He wanted to learn more about the status of the field and what NSF and other agencies were doing.[21]

Within six months, the informal interagency group Roco headed was elevated to a formal Interagency Working Group on Nanoscience, Engineering, and Technology (IWGN). The IWGN was constituted as a committee under the National Science and Technology Council, the mechanism the Clinton administration used to coordinate cross-agency R&D initiatives. Kalil came at science and technology from an economics orientation, and he increasingly identified nanotechnology as a possible way to keep the U.S. high-tech economic engine running. He constituted policy "pull." The research "push" came from Roco, who was chair of the IWGN. Kalil was the co-chair, an arrangement linking the White House and the agency within the committee.

In 1998, Roco achieved success within NSF when the engineering division where he was based gave him the go-ahead for a special effort in nanotech. In the fall, Roco contracted with WTEC to organize a major workshop involving government, universities, and industry that would establish a vision for the field and give it a high-profile send-off. In doing so, Roco was acting as an NSF program officer, chair of IWGN, and partner of Kalil.[22]

Becoming a Clinton Initiative

In January 1999, the workshop took place, with Kalil as the opening speaker. The title of his address was: "Nanotechnology: Time for a National Initiative?" Kalil, in essence, challenged the assemblage to make the case for a national initiative. He emphasized the importance of separating fact from fiction.[23]

The workshop was highly positive, and leading industry officials as well as academic scientists pointed to the positive prospects. One industry executive indicated that the computer revolution would end unless nanotechnology devices were developed.[24]

Following the workshop, Roco returned to NSF and worked with IWGN on developing a vision document the White House wanted. However, it was not long afterward that Roco was hit by a major setback. The NSF engineering division had a new director who had other priorities. He wanted to move what discretionary money he had from nanotech, and he told Roco to bring his nascent nanotechnology program to a stop.

By this time, however, there was momentum and a constituency for nanotechnology outside NSF that had a life of its own. In April 1998, the President's new science adviser, Neal Lane (who had previously run NSF), had declared at a congressional hearing: "If I were asked for an area of science and engineering that will most likely produce the breakthroughs of tomorrow, I would point to nanoscale science and engineering."[25] Roco now had a second influential ally at the White House, in addition to Kalil.

Thus, even as he was told by his immediate superior to shut down his NSF initiative in 1999, Roco was encouraged by external allies to lead the fight for a presidential initiative. To become a presidential initiative, however, was not a foregone conclusion. There were competing priorities. Roco would have to make a case to a succession of review groups before the President would make it a formal White House–backed effort. NSF's top management knew of the White House interest, however, and decided to back Roco in making a pitch.

The process started with a hearing at the Office of Science and Technology Policy. Roco made a presentation along with other individuals from NSF and representatives from other agencies pleading their case for priority for particular fields. The others generally advocated incremental increases in budget. Roco pointed out how little was spent by the federal government on nanotechnology and argued for a half-billion-dollar augmentation. Afterward, one of the OSTP officials came up to him and said that he liked what he had heard and that Roco should start preparing a document justifying what the government should do.[26]

NSF wanted new money—all the agencies of IWGN did. They did not want the administration to earmark nanotech as a substantial initiative and then tell the agencies to find the money in their existing budgets. As 1999 moved on, the OSTP process of identifying possible initiatives the President could back was joined by the OMB budget preparation process—how much to spend? NSF authorized Roco to make his case for nanotech, but it also authorized others to speak on behalf of another budget increase in information technology (an existing Clinton initiative), as well as in biocomplexity. Biocomplexity was already an NSF initiative, one closest to the heart of NSF's new director, Rita Colwell, a biologist.

Roco recalls feeling like an underdog in briefing OMB, but he was later told by an OMB official that "only nanotechnology sparked excitement."[27] Roco used an interesting technique to get the attention of OMB. He provided a document with a brief of his pitch that had a "blank" cover. Puzzled, OMB staff closely perused the document looking for the title. Then, they got the point: The print on the front was so small, it could not be seen by the human eye. Roco had found a way to make the report stand out from the others, and his oral presentation did the rest. The tide seemed to be turning in nano's direction. By September, WTEC had finished surveying what other countries were doing and produced a report from the January workshop. There was now considerable ammunition in Roco's hands for a presidential initiative. The world survey showed there was a great deal going on in Japan, Russia, and Western Europe. While Japan in particular was in the lead in certain aspects, the central conclusion was: "This is an up and coming area of science. We're ahead. They're coming!"[28]

Now the President's Council of Advisors on Science and Technology (PCAST) heard Roco on nanotechnology. It held two hearings, and in November told him: "It is a pleasure to recommend nanotechnology as a national initiative." OSTP, OMB, PCAST—all were on board. All that was left was to give the initiative a name and decide how much would go into it the first year. Interestingly, there was a debate over the name. The issue was whether *science* should be part of the name. Roco held out for the original concept—nanotechnology—which put the emphasis on engineering. Obviously, the prospect of new money drew numerous possible claimants from various agencies. Inclusive labels provided broader room under the funding tent (*climate change* had been *global change* for most of its program life). Broader labels also diffused the effort. The push for nanotech came largely from engineers; the pull was from people like Kalil who wanted economic development. In the end, Roco got his way.[29]

As for budget, OMB met with IWGN and asked each agency how much it was spending on nanotech. The policy decision, OMB said, was made. The administration was going to double the existing budget. So each agency calculated what it was spending—and OMB reached a total federal number of $495 million. This represented not only nearly a doubling but essentially equaled the half billion Roco had requested—and which he had not expected to get.

Thus, in 1999, Roco had seen his own NSF program seemingly terminated by a division-level decision only to be rescued by much higher-level decisions. His inside-outside strategy of alliance building, begun in 1995, paid off. In January 2000, President Clinton traveled to Caltech, where the potential of nanotechnology had first been proclaimed by one of its scientists many years before, and declared:

> My budget supports a major new National Nanotechnology Initiative, worth $500 million ... the ability to manipulate matter at the atomic and molecular level. Imagine the possibilities: materials with 10 times the strength of steel and only a small fraction of the weight—shrinking all the information housed at the Library of Congress into a device the size of a sugar cube—detecting cancerous tumors when they are only a few cells in size. Some of our research goals may take 20 or more years to achieve, but that is precisely why there is an important role for the federal government.[30]

Getting Congressional Endorsement

The executive branch decision meant little if Congress did not go along. The National Nanotechnology Initiative was a program with a cross-agency budget of close to $500 million. Congress made decisions through committee, which provided funds agency by agency. There was no guarantee Congress would provide what the Clinton administration asked.

In 1999, there had been hearings by the congressional science committees that touched on nanotechnology. One hearing was devoted entirely to nanotechnology. Roco communicated formally and informally with Congress in 2000. For a while, it appeared Congress might not act, given its open war with Clinton.

At this point, support for the Clinton initiative came from an unexpected source—former House Speaker and long-time Clinton adversary Newt Gingrich. Gingrich strongly endorsed the initiative, writing an open letter to the Republican congressional leadership, thereby giving the program a bipartisan embrace.[31] The Republican Party leadership helped influence individual committee decisions. The result was that Congress wound up appropriating $422 million, less than that requested but still a very substantial increase for nanotech. The program got the legitimation and money its advocates sought. The process of adopting a national initiative was complete.

Anticipating Threats

While the White House, Congress, and agencies agreed to go forward with a major initiative on nanotechnology, a new threat was raised. In fact, one of the virtues of a "managed" interagency program was the ability of leaders to anticipate threats and make early decisions to avert them.

In April 2000, Bill Joy, cofounder and chief scientist of Sun Microsystems, and co-chair of the Presidential Commission on the Future of Information Technology Research, published an article in *Wired* magazine that gained great notoriety. Joy echoed predictions issued in the 1980s by futurist Eric Drexler of self-replicating assemblers and pondered the dark side of this major technical advance. He wrote of nano-robots as potential "engines of destruction" and pointed out that man was making a "Faustian bargain in obtaining the great power of nanotechnology." He discussed how it could be used in terrorist and military applications—the "gray goo problem," in which humans created "masses of uncontrolled replicators ... able to obliterate life."[32]

Joy could not be dismissed as an alarmist Luddite. He was a top technical entrepreneur. His point was that nanotechnology was going to be like biotechnology or atomic energy—powerful. But, unlike atomic energy, it would be propelled not only by governmental but also commercial interests, thus much harder to control.

Roco and his allies in the agencies and the administration had been promoting the technology, obfuscating its potential dangers. Drexler could be dismissed to some extent, although he had set up a think tank specifically to deal with nanotechnology and other futuristic technologies, but not Joy.

The result was that as IWGN developed an implementation strategy in 2000, it realized that the program had to look at all aspects of societal impacts. As people became more aware of nanotechnology, certain individuals and groups would oppose its advance. Better to conduct research on these impacts from the outset. Hence, the implementation plan that eventuated in 2000 included a section on societal dimensions, much as the Human Genome Project had years before.[33] Most of the program, by far, would be technical, but the decision was made that some small portion would be aimed at social scientists and perhaps ethicists.

The implementation plan projected six agencies would lead the nanotechnology initiative: NSF, with most of the funding, followed by the Departments of Defense and Energy. Then, at lesser levels, were NASA, NIST, and NIH. In addition, the White House (Kalil), OSTP, NSTC, OMB, Transportation, and Treasury were represented on IWGN. Other agencies were on IWGN that were possible users of nanotech. A secretariat for coordination was planned and provision was made for external review. However, just as the nanotech initiative got under way, came a change in presidential administrations.

There was a point during the campaign of 2000 when Al Gore considered citing nanotechnology as an example of the progressive outlook of the Clinton-Gore administration. Gore was personally interested in futuristic technologies. But proponents of nanotech dissuaded him, arguing that they had managed to give it the cachet of bipartisanship and wanted to maintain that image.

A Boost by Bush

When George W. Bush became president, Kalil left government along with other advocates in the White House, such as science adviser Lane. Many OSTP officials left, but a number of mid-level OMB staff stayed, providing institutional memory and linkage to Roco, who remained at NSF. The IWGN interagency mechanism continued. Roco's strategy was to keep going along the trajectory planned under Clinton, and to keep a low profile while awaiting some sense of where the new administration was headed. It took half a year for Bush to appoint a science adviser. The science apparatus of NSTC, PCAST, and OSTP continued, but was slow to get in gear. The IWGN did not develop an implementation plan in 2001. Roco waited.

In the fall of 2001, Roco met with a Bush appointee at OSTP. He was told: "Go forward."[34] For FY 2002, the Bush administration increased nanotech's budget again, to $604 million. NSF, meanwhile, promoted Roco to "senior adviser" at NSF, within the Directorate of Engineering. The new title reflected his expanded role as lead administrator within the de facto lead agency for a national initiative. He was spending a great deal of time external to NSF, communicating with Congress and working with other agencies on the initiative. The planned secretariat was established to support IWGN agencies. Its role was to help produce documents, share information among agencies, and help the enterprise take a trans-agency view.

As the U.S. moved forward, so did other countries. The decision by the U.S. under Clinton to launch the National Nanotechnology Initiative, and evidence of a continuing push under Bush, stimulated the European countries, Japan, and others to step up their own work in the field. International competition became more intense.[35]

Aiding nanotech's heightened visibility, but in a negative way, was Michael Crichton's novel *Prey*, which came out in November 2002. Taking off from Drexler and Joy, Crichton wrote of clouds of nanoparticles or "microrobots" that escaped from the laboratory and threatened havoc on the world. While negative in its view, the book underlined nanotech's reputation as an important and powerful new technology.[36]

The FY 2003 budget for nanotech went up to $710 million. Roco's advocacy strategy was slightly different with Bush than with Clinton. Under Clinton, the emphasis was economic development. For Bush, it was basic research in aid of industrial competitiveness. Also, in the post–September 11 world, national security implications were getting increased attention. NSF still led in funding, but Defense was a close second.

The management of NNI continued as before, spearheaded by an interagency committee. The group reported, as under Clinton, to NSTC. It was composed of senior officials from line agencies and the White House. One difference was that IWGN's name was changed to the Nanoscale Science, Engineering, and Technology (NSET) committee.

Also, the composition of NSET was enlarged from IWGN. Represented were Defense, Energy, Justice, Transportation, Agriculture, State, Treasury, EPA, NASA, NIH, NIST, NRC, OMB, OSTP, and NSF. The real continuity was Roco, who stayed as chair and guided the expansion. EPA's presence reflected the new sense of environmental impacts. However, no one took Kalil's place as co-chair.

This fact (the absence of a co-chair from the White House) reflected Bush's decentralized management approach. NNI had been primarily agency-driven under Clinton, but needed strong White House support to become a presidential initiative and receive a substantial rise in funding. Now it apparently didn't need a topside champion as much. It had been accepted by the new administration along with the interagency committee approach to its management.

An Early Assessment

In June 2002, an independent assessment of the program by the National Research Council (NRC) was completed. It provided an early view of how NNI was going, with attention to coordination. Though only two years old at the time, NNI already had reached the $1 billion plateau in overall spending, was growing, and was seen as Big Science, albeit about "little" devices.

NRC complimented NSF for its leadership in pulling together other agencies and giving the program a sense of coherence. Each agency had its own list of objectives, but there were common themes and a set of "grand challenges." These were larger-scale ventures that involved more than one agency. Such crosscutting efforts had one agency as a "champion," with others contributing. The agencies, however, retained their autonomy and control of funds. There was no "fencing" of money for crosscutting or national activities.

The NRC noted that NSET members sought to communicate with industry, universities, states, and others. They held joint workshops, met regularly, and engaged in planning and efforts to identify areas of research need and possible ways to better coordinate. From what NRC said, there was no question that the work of NSF in particular in providing leadership across government had improved on the fragmented efforts of the past. The de facto lead agency model of coordination had taken NNI some distance toward a coherent program.

However, NRC saw plenty of room for improvement. It called the agencies' focus on their own missions "strong and unapologetic," an attitude that worked against the NNI's goal of having the whole being more than the sum of its parts. To counter impediments to coordination, NRC recommended more White House leverage. Specifically, it called for OSTP to play a larger role, setting up an outside board of science advisers to take a broad look at scientific strategy. OSTP, contended NRC, should also manage a special grant fund to support areas of cross-agency research that might be of national priority, but which fell short of being agency priorities.[37]

Thus, as a relatively new interagency initiative that survived a change in administrations, nanotechnology illustrates what it took to get a presidential decision and national program under way. Strategically located individuals at the agency level and in the White House combined forces, using an interagency mechanism as a meeting ground and leverage on the larger system. Vertical and horizontal lines of coordination made the program possible. The issue is how to maintain the momentum and coherence in the face of an inevitable desire by agencies to go their own way—often in competition with one another for funds.

International Space Station

The International Space Station illuminates the biggest of Big Science programs. It is an R&D program that requires coordination in a national and international context, and a program with a lead agency/lead nation. It is the oldest of the three programs discussed in this report and by far the most complicated from a policy perspective.

The birth of the International Space Station program was driven not by a societal problem (climate change) or technological opportunity (nanotechnology). Instead it was driven primarily by bureaucratic need. NASA's identity as an organization that manages large-scale engineering programs that put men and women into space depended on having a new program to succeed the space shuttle. The shuttle moved from R&D to operations in the early 1980s. For years, NASA had contemplated a space station facility in which to do research and manufacture unique devices and that would serve as a staging outpost for deeper space probes. The agency needed a presidential decision to get such a program under way. James Beggs, then NASA administrator, appealed to President Reagan's geopolitical interests. The Russians had a space station program and were well ahead of the U.S. A space station was projected as a way to demonstrate U.S. leadership in space technology. The arguments provided societal advantages as selling points (pride, prestige, national security), but it was NASA's bureaucratic interest in survival that generated action in the short run.[38] Beggs was aided in making the case to Reagan by Gil Rye, a staff member of a White House interagency council concerned with space policy.

Adoption by Reagan

The space station was announced by Reagan as a presidential initiative in his 1984 State of the Union address. While initially a national program, propelled by national interests, the space station was envisioned by Beggs and adopted by Reagan as a program with international scope. The U.S. wanted to stay in control, but have other space-faring nations—Japan, Canada, and European countries—participating. Such participation would help in bolstering the program politically through a linkage to foreign policy. It would also help pay for the space station, although the U.S. was seen as the dominant funder by far. Prior to the Reagan decision, NASA had already initiated discussions with the European Space Agency (ESA)—a confederation that had come into being to coordinate the resources of European space agencies for cooperative projects. Japan and Canada were also approached. In announcing his decision, Reagan said he would invite other nations to join the program.

The *Freedom* Design

The implementation of the space station program turned out to take much longer and be far more tortuous than anyone contemplated in 1984. Reagan wanted a space station up in 10 years at a cost of $8 billion. That is what NASA said was possible. After the first 10 years, NASA had spent approximately $10 billion and placed no hardware in space. The reasons had to do with unforeseen technical difficulty, political turmoil, and delays caused by the *Challenger* accident of 1986 and its aftermath.[39]

There were actually two space station programs. The first, called *Freedom,* ran from 1984 to 1993. It involved NASA and the space agencies of Europe, Japan, and Canada (all signed on by 1988). *Freedom* used the lead agency approach with foreign participation. The basic concept for *Freedom* was that the U.S. would build the main framework of the station and other nations would add specialized modules. Components were largely separable, much like a Lego set. The U.S. was not dependent, technically, on the international partners, but the partners were dependent on the U.S. They joined because the space station was the "next big project" in space. Not to be part of it was to be left behind. The perception was that there would be technical and political benefits from being part of the world's most important, cutting-edge space project, even though the benefits were distant, vague, and uncertain. Reagan was succeeded in 1989 by George H. W. Bush. Bush maintained the space station *Freedom* project, but was concerned about its growing costs and slowness in implementation.

Clinton and the International Space Station

Everything changed for the space station with the arrival of Bill Clinton in 1993. Two factors were involved where Clinton and the space station were concerned. The first was foreign policy. The Cold War had ended in 1991 with the fall of the Soviet Union. President George H. W. Bush had seen space as an area where peaceful cooperation would be possible, but he had not moved far in achieving major agreements. Like Bush, Clinton wished to link Russia and its military/technical capability to the U.S. rather than see it transfer to U.S. adversaries. The second factor influencing policy was that Clinton wanted to cut the budget deficit and find money for new domestic priorities, and the space station faced a billion-dollar overrun when Clinton assumed office.

Soon after taking office, Clinton was told that Russia was engaged in a possible transfer of rocket (missile) technology to India. Clinton looked for ways to head off a weapons proliferation issue. At the same time, he saw the space station *Freedom* program with costs going up and no hardware in space. His budget director advised that this was an opportune time to kill the space station and make available funds needed for worthier programs. Clinton ordered NASA to engage in a major redesign to save significant money or risk losing the program altogether.[40]

While NASA frantically looked for ways to downsize *Freedom*—and Clinton's national security officials tried to come up with incentives to prevent the India rocket deal—the Russian Space Agency (RSA) intervened. It recommended to NASA a merger of the space station programs of the two countries. NASA's administrator, Dan Goldin, calculated that with Russia's know-how and hardware, NASA could build a bigger, better, and (for the U.S.) cheaper space station. Everybody would win, or so it seemed.[41]

The international partners were unhappy, however. Adding Russia lowered their status and delayed their possible participation. Nevertheless, they saw no alternative to going along. By the end of 1993, Clinton had endorsed the concept of a new International Space Station (ISS), and Congress had agreed. *Freedom* was ended and a new design for ISS adopted. Russia would get $400 million (at least) for agreeing not to transfer rocket know-how to India, joining the anti-proliferation Missile Technology Control Regime, and providing technical know-how to NASA based on its *Mir* space station.

ISS involved more than a change in technical design. The implications for management were enormous. First, ISS was now linked directly to Clinton's post–Cold War foreign policy and thus became suddenly much more important to him; secondly, Russia was seen as being more equal as a partner than Europe, Japan, and Canada. Russia was important to Goldin from the space policy perspective: It could help NASA get a better space station in orbit sooner.

The space station implementation plan was radically revised in 1994. Implementation would now have three phases:

1. Shuttle-*Mir* phase—when astronauts and cosmonauts would learn to live and work together, with Russians getting shuttle experience and the U.S. *Mir* experience

2. U.S.-Russian assembly phase—when a U.S.-Russian space station core would be developed and deployed
3. Completion phase—when the international partners would attach their modules to the main frame ISS, i.e., the U.S.-Russian system

The Clinton/NASA decisions had the effect of putting the U.S. and its existing partners in a dependency relationship with Russia. Most components of ISS could not be deployed until Russia had put centerpiece hardware into space. Critics pointed out that Russia was now on the "critical path" to space station development. NASA said the Russians would be good partners and speed the program. Critics maintained that Russia could also delay the program, and delays meant cost escalation.

The political dynamics were such that bringing Russia aboard may have saved the program from termination in 1993. Congress was in a cutting mood and killed the superconducting supercollider. Russia provided a "swords into plowshares" symbol that brought new excitement to a program badly in need of an updated rationale. Thus, a new organizational model came into being: the U.S. (NASA) was in the lead; Russia (Russian Space Agency) was the senior partner; and other nations (via their space agencies) were junior partners. No one used terms reflecting power, but the pecking order reality was obvious. The existing formal agreements among nations were rewritten to reflect the entry of Russia. Similarly, regular policy meetings among the space agency heads now included Russia.

Coordination took place not only through the policy meetings, but also through numerous technical groups. Parts of the space station would have to be designed in different countries and be joined together in space. International travel was a time-consuming responsibility for managers and technical personnel. Because of the international policy dimension, the respective foreign policy agencies of the countries became involved when necessary. A special commission under Vice President Gore and his Russian counterpart, Viktor Chernomyrdin, served as an overarching policy-coordination mechanism for the relationship.

Phase One: The Shuttle-*Mir* Phase

During the first phase of ISS, U.S. astronauts and Russian cosmonauts learned one another's language, cultural traits, and technologies. They cooperated in space. Scientists and engineers on the two sides shared knowledge. There were conflicts to be sure, but generally the mutual learning was positive. However, in 1997, a series of mishaps on *Mir* caused considerable anxiety in the U.S. and put the U.S.-Russian partnership in jeopardy. One of the accidents, a collision between *Mir* and a Russian cargo vehicle, risked lives. An influential congressional critic of the U.S.-Russian relationship demanded termination of the Shuttle-*Mir* phase.

NASA Administrator Goldin had two independent panels study the risks, and they reported the risks were manageable. He decided to move forward, a decision backed by Clinton. All went well and the Shuttle-*Mir* program concluded in 1998. Even the mishaps in 1997 were deemed useful learning experiences relevant to the future of ISS.

Phase Two: The U.S.-Russian Assembly Phase

While the Shuttle-*Mir* phase was under way, the U.S. and Russia were busy developing hardware essential to phase 2—construction of the initial components of the space station's core. NASA had its troubles, but they were modest in comparison to the obstacles faced by RSA. The Russian economy declined drastically, and the Russian government curtailed expenditures for its space agency. An absolutely critical component, Russia's *Zvesda* service module (based on a second-generation *Mir* concept), was severely delayed. Construction in space called for two basic modules to go up first, one launched by Russia, the next by the U.S. They would be linked in space. These were on schedule. The third element, *Zvesda*, Russia's responsibility, was not.

Zvesda would provide space for astronaut living quarters and long-term propulsion capability to keep ISS in proper orbit while further assembly took place. The U.S. would provide most of the equipment subsequent to the first three elements, including a laboratory. But the U.S. could not go to "core complete" without *Zvesda* going up first.

Indeed, without *Zvesda,* the first two modules would eventually fall from orbit. Russia was not a contractor; it was a sovereign nation. NASA could cajole, plead, and badger, but could not order RSA to do anything.

The period 1998–2001 was one of enormous controversy in the U.S.-Russian relationship. NASA had to spend money to develop contingency hardware in case Russia did not come through. The resulting cost increases for ISS eventually caused Congress in 2000 to put a cap on what NASA could spend to put its part of the station in orbit. OMB kept a small model space station on hand to keep track of the parts that were going on or coming off, and the cost implications each part had for the whole. NASA headquarters used OMB as leverage against the center responsible for technical management, the Johnson Space Center, which had a tendency to overspend. The delay/cost issues were aggravated by Russia's refusal to deorbit *Mir*—as it had said it would. Finally, reports surfaced that Russia was transferring weapons-relevant technology to Iran. An angry Congress prohibited the U.S. from spending money for Russia on ISS unless the President certified Russia was not engaged in transfers contrary to U.S. national security interests.

RSA did come through in 2000. *Zvesda* went up, *Mir* came down, and the U.S. was able to move forward with the next steps in construction. That did not end the conflict or controversy. NASA Administrator Goldin vociferously complained when Russia in 2001 used some of its room on the U.S.-Russian space station to house an American, Dennis Tito, who reportedly paid the Russian space program $20 million to be the first paying "space tourist."

Phase Three: Toward Completion

Goldin left NASA in 2001 amidst controversy over a projected $4.8 billion overrun that would explode the congressional cap of $25 billion for the period 1993 through assembly. News of the cost projection came to the new Bush administration as a profound shock.[42] George W. Bush placed Sean O'Keefe, then deputy director of OMB, at NASA as the new administrator to bring ISS expenses under control. Hardware in development was cancelled, including a Crew Return Vehicle (CRV) that NASA was developing. But cancellation of the CRV meant NASA and the other international partners would have to depend on Russian *Soyuz* spaceships for escape vehicles.

Since the *Soyuz,* parked at ISS in accord with an agreement between Russia and the U.S., could take only three passengers, it limited the number of ISS crew to three. Scientists said three were not enough for good science on ISS, given the time crew spent simply to maintain the facility. In 2002, O'Keefe started development anew on a more advanced rescue vehicle, the Orbital Space Plane (OSP). Until that was ready, perhaps 2010, *Soyuz* remained critical.[43] In short, the U.S. and its international partners were dependent on Russia whether they liked it or not. Meanwhile, O'Keefe set 2004 as the date when the core station would be complete and phase 3, when the international partners would add their modules, could begin. However, the *Columbia* shuttle disaster on February 1, 2003, put all schedules in question. A sound recovery from *Columbia* would test the partnership's cohesion. What the disaster brought home with searing clarity was the degree to which the 16 nations involved were all in the same space station boat together.

Thus, ISS shows that coordination among agencies within a nation is easy compared to that among agencies of sovereign nations. RSA and NASA could make deals, but they meant nothing if the government of Russia would not fund RSA. Of course, the international partners (Europe, Japan, and Canada) thought they had an arrangement with the U.S., and then the U.S. changed everything when it brought Russia into the program. Sovereignty matters hugely. There is no leverage from above—OMB, the Office of Science and Technology Policy, the President—to get nations to coordinate. Their self-interests often get in the way of larger collective goals. The *Columbia* tragedy, therefore, poses a supreme challenge to the ability of nations to coordinate to keep the International Space Station viable.

Conclusion

Discussed here have been the organizational dynamics of large-scale science and technology (Big Science) programs. These are programs that cost billions and extend over years, involving national interests and multiple agencies. The emphasis in this report has been on lessons learned about coordination, although the cases offer other useful guides, such as how to get a program anointed a presidential initiative.

At the outset, the author noted that this project was stimulated by previous work on the Human Genome Project (HGP). Here I extended my research to cover climate change, nanotechnology, and the space station. In this section I make assessments of success or failure and account for the reasons these programs had those outcomes. In ongoing programs of the kind studied, judgments must be quite preliminary and guarded. Seldom can a program be judged a clear instance of success or failure. Most are somewhere in between, or have elements of both, at one point or another in their histories.

Thus, the Human Genome Project provides a useful baseline because it most clearly succeeded in achieving its goal—a working map of the human genome—on time and within the cost projected at the outset. The reasons had to do with the fact that these goals were technically realistic, the program well funded and well led, and the team of organizations effectively coordinated. A critical factor in getting the parts to congeal, the agencies and research performers to cooperate, was the threat of competition from a private sector entrepreneur to achieve the goal first. This threat strengthened the hand of the leader, who was already extremely well positioned at the National Institutes of Health. NIH was a strong lead agency because it dominated funding in the multi-party relationship that extended over national boundaries. It had not only the money, but also prestigious scientific leadership and stable political backing. Politicians provided NIH the money needed and left it to NIH leadership to make key technical judgments. Goals, organization, political support, competition, and leadership combined to move coordination to an ideal: a coalition or partnership. None of our present cases is so blessed.

Climate Change

Climate change has a mixed record. Its goals were dual: to provide a good science base and useful policy guidance. The former made the latter possible. Most observers believe the Global Change Research Program got off to an excellent start in building science. The Bush I years were marked by effective leadership and close coordination among three lead agencies working through a large interagency committee. The informal relations among the senior managers were a critical factor in this early interagency success. Also critical was the achievement of presidential initiative status, which earned GCRP not only more money but also OMB "fencing." Fencing meant that once the three agencies (and more) agreed on a cross-agency program, and OMB went along, the respective agency heads could not subsequently reprogram money on the basis of narrower agency interests. When the money was "new," the agency heads were less likely to object.

In the Clinton years, there was a widespread impression that the GCRP continued to do some "good science" but that in many ways it drifted and coordination lapsed. No longer was GCRP a presidential priority; no longer did it have OMB fencing; no longer did the three key managers work together closely, in part because they either moved on in their careers or were undercut by their agency heads, who had other priorities. Also, the principal agency leader of GCRP had competition from OSTP. It was not clear who was in charge, and they did not share a common view on GCRP direction. In the Bush I years, there was horizontal (interagency) cohesion and vertical (agency/White House) coherence. Not so under Clinton. To the extent GCRP produced good science over these years, this was less a result of successful interagency coordination than the work of specific agencies. The whole was less than the sum of its parts.

Moreover, because GCRP was an increasingly mature program, more was expected in the way of policy-relevant science, the second goal of the program. In the Clinton years, there was a disconnect between GCRP and the policy activity of the Clinton White House. The creation of the Climate Change Research Initiative on top of GCRP under Bush II is in part a function of this concern, as well as the President's political need to act in the wake of his Kyoto decision. Also, the leadership gap may have been addressed in CCRI by the designation of a specific person in charge at the agency level. High ranking, he nevertheless will be tested by the inherent agency spread of the issue—he must work through an interagency committee. His agency base—Commerce Department—is not necessarily as strong as it needs to be if he is to be a czar. Moreover, in making good science better coordinated science, and thus more useful science, he will be in a political thicket. There was topside political support for science-oriented GCRP under Bush I. Under Clinton, the program sometimes had support, sometimes was neglected, and sometimes featured competition for control. The nature of White House support for climate change under Bush II remains to be seen. More useful science will be more politically controversial science, and perhaps not welcome information.

Nanotechnology

Nanotechnology is a young and rapidly growing program. Under Clinton it achieved presidential priority, which was affirmed by Bush. Critical to its establishment under Clinton was the support of a strong White House staff member. Under George W. Bush, an interagency committee runs the program without the same tight White House connection. Another critical factor in nano's early success was the role of NSF as a de facto lead agency and the role of an entrepreneurial senior manager, Mihail Roco, at NSF in guiding the lead agency. He is widely praised and is regarded as a founding father of the government's nanotechnology initiative.

It is noteworthy that this leader rejected changing the name of the program so as to mention technology only, rather than science and technology. This decision not only kept the enterprise more sharply focused, but also clearly under engineers' control. Nanotechnology, like GCRP, has goals that go beyond good research to useful research. It is helpful in economic development and other practical applications (which are widely favored).

The leader of nanotech and his interagency allies thus have a "pull" on this program they can use to advantage. The engineering-research push and economic-development pull seem to have reinforced one another. They have moved the program in the same direction, giving support and providing a coherence of purpose across agencies. Still, an independent assessment recently argued that the agencies involved pursued their own goals first and had limits on their willingness to coordinate.

Like climate change, nanotech has a secretariat that provides staff support to the interagency endeavor. This device is essential for coordination because agency participants invariably find they must accomplish interagency work on top of regular agency assignments. In addition, nanotech will likely get a legislative base, like GCRP. This not only shows congressional support, but it helps keep the program going as administrations change.

Space Station

How is the space station to be judged from a coordination standpoint? The original goal was to get a space station up within a decade at a U.S. expenditure of $8 billion. The current estimate for the U.S. is closer to $35 billion ($10 billion for *Freedom,* $25 billion for ISS), with a complete station still years away. International partners other than Russia will be investing $9.5 billion on ISS. The Russian financial contribution is also substantial, but the exact amount hard to determine.[44]

The original goals were not technically realistic. In fact, the original *Freedom* design was abandoned in 1993 for a new design using the Russians. The ISS design has been technically successful in setting up the rudiments of a station capable of permanent human occupation. It is not a success in money and schedule terms, but certainly is a technological achievement on a grand scale even in its truncated form.

International partnership has helped more than it has hurt, thus far, in getting the space station to its present point. Having international partners—and especially the Russians—helped save the station in 1993, when it could easily have been terminated. The *Columbia* disaster underlies the importance of Russia and other partners keeping the station occupied when the space shuttle is grounded. The only rescue vehicle available is a Russian vehicle.

The space station is so complex that it defies easy categorization as success or failure. It is both at once, depending on the measure. Probably the central lesson brought out is that however difficult it is to get agencies to work together in one country, it is even harder to do so across borders. Sovereignty allows agencies to do what they want; there is no vertical (White House, OMB) pressure to make them. International projects do not usually save money, but they provide other benefits, such as the foreign policy values that come with international cooperation.

What also provide incentives to coordinate are shared goals and resource dependency. If each agency knows it cannot succeed in its purpose without the help of others, it will cooperate. Even the U.S. realizes the need for partners in the space station endeavor. It was the common need in bringing billions of pieces of information together to create the human genome map, in the face of competition, that kept the U.S. and England working together. The need in that case was technical and financial. For the space station, it is both and more. There is a stark political need. As a purely national project, it would probably not have survived this long. While international competition (Cold War) got the space station started, international cooperation has kept it going in the 1990s and into the 21st century. It is a symbol, for better or worse, of international collaboration in post–Cold War science and technology.

What climate change, nanotechnology, and the space station (as well as the Human Genome Project) reveal graphically is that coordination is not the work of an invisible hand. Rather, it takes the conscious attention of leaders committed to a cooperative enterprise. For whatever reason, they put a systemic goal ahead of parochial goals—or find a way the parochial goals are enhanced by the larger ones. The price of Big Science is an organization of organizations. Making them perform harmoniously is a colossal test of administrative skill. Leaders who coordinate well build interorganizational mechanisms around informal coalitions of people who share similar visions. Such visions can transcend agencies and even nations. The coalitions are most effective when they have horizontal and vertical dimensions, where interagency groups have external political support and pressure to cohere, and there are clear incentives to work together instead of competing for resources. Whether a project is national or international, nothing is more important to its fate than deft leaders who see the larger picture in which their organization fits. That kind of perspective makes coordination—and occasionally true partnership—possible.[45]

Recommendations: Leading Coordination

Leadership is essential in large-scale (Big Science) R&D programs. But where the programs are interagency (and even international) there are special problems involved. Quasi-independent organizations must be brought into alignment. Relations among such organizations are not hierarchical, although various outcomes require joint action. Fortunately or unfortunately, it appears that programs involving many agencies (and nations) are the wave of the future in major science and technology endeavors. Leadership may take the form of lead agencies, or lead people, or some other mechanism. Whatever the form, the leader of a joint program is perforce a coalition builder whose power lies largely in persuasion. What coordination strategies are available? Based on the previous case analysis, the following are relevant:

1. **Set a clear and focused goal.** Coordination is always difficult where many agencies with different stakes in an enterprise are involved. Ambiguous goals exacerbate confusion and conflict.

2. **Emphasize common interests.** The key interest to promote in most science and technology endeavors is more funding overall. Agencies need a positive incentive to cooperate, and more resources are basic. To get the resources and put them to proper use, organizations must cooperate. However, there are other non-financial interests that can make for cohesion, such as appeals to foreign policy, economic development, health, and pride of accomplishment.

3. **Attract political support.** These larger interests help attract political support. If the technical agencies exert a push, the politicians (and their surrogates) constitute a policy pull. For domestic and international programs, the brass ring leaders can seek is the status of a presidential initiative. In addition, congressional legislation undergirding a collective interagency activity can sustain the program across presidential transitions, and should be sought.

4. **Enlist White House oversight agencies.** Among the surrogates, White House operatives, including OSTP and OMB, are critical. It is useful to include these agencies on interagency committees so as better to forge vertical as well as horizontal alliances. OMB fencing of funds for interagency activities can be an enabling tactic for implementing joint decisions via separate agencies.

5. **Employ strong but diplomatic leadership.** The leaders of Big Science endeavors should be proactive, but understand the limits of power. Separate agencies (as separate nations) have power bases independent of the would-be coordinator, who is more likely to get joint action through consensual tactics than coercion.

6. **Retain staff support.** There is an "overhead" to joint activity—considerable time and effort beyond what individuals do in their home institutions. Leaders need the help of secretariats or their equivalents—staff devoted to facilitating the joint activity, such as meetings and the preparation of interagency documents.

7. **Use an external threat for internal cohesion.** The leader should use an external threat to get the interagency enterprise to better mesh. The threat can be domestic or international competition, as was seen in the genome and nanotech cases. It can be some dire calamity in the future (climate change). It may be survival of an entire area of R&D (Space Station). The leader stresses strength in union and defeat in division.

8. **Hold to the end, but be flexible as to means.** Achieving the goal of a Big Science endeavor can take many years. The leader helps the enterprise to adapt while keeping the end in sight. The successful leader has a strategy, but is flexible as to tactics. As noted, it is useful to think of the joint activity as an exercise in coalition building. The leader adapts the coalition to changing conditions, stressing interdependence, and holds to the goal through mutual adjustments over time. The leader needs attainable interim goals to provide morale-building victories and reasons for the participants to stay in alliance.

Endnotes

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12. Lambright, "The Rise and Fall of Interagency Cooperation," 40-41. The following agencies were represented on CENR in 2000: NOAA, OSTP, FEMA, NASA, Veterans Affairs, DOT, DOE, Department of Labor, DOD, CIA, CEQ, Department of the Interior, Smithsonian Institution, TVA, USDA, NSF, HUD, NSTC, EPA, HHS, State Department, OMB, Office of Federal Coordinator for Meteorology.

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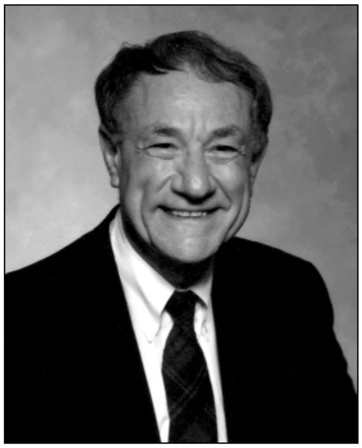

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