AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

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INTRODUCTION

This is the last publication of the decade-long AIP Study of Multi-Institutional Collaborations[1] and we introduce it with a brief review of the circumstances surrounding the study's initiation and the range of its actions.

The mission of the Center for History of Physics of the American Institute of Physics (AIP) is to preserve and make known the history of physics and allied fields. The physicists who initiated the history program four decades ago envisioned achieving this mission through a documentation strategy. Put simply, the AIP Center would maintain close contacts with the physics community so that—as the community and its research structures evolved—the documentation strategy also would evolve. Through this process, the Center would continue to be in a position to provide guidance to those responsible for records: it would help to identify which records should be saved and it would work cooperatively with archivists to place valuable records in appropriate repositories. To make known historical source materials, it would bring collections of papers and records to the attention of historians and other users through what would be named the International Catalog of Sources for History of Physics and Allied Sciences. The documentation process worked smoothly—except when challenged by periods of dramatic change in the research community.

During the 1980s, the AIP Center became concerned about the many complexities and unknowns surrounding the documentation of multi-institutional collaborations (i.e., projects involving three or more institutions). Since World War II, such collaborations have increasingly been the organizational framework for scientific research. The impact was most visible in the field of particle physics. In this discipline, members of a single collaboration may currently number in the hundreds, come from a score of institutions based in several countries, take a decade to prepare and conduct an experiment at a unique accelerator facility, and then disband. The experimental results may significantly advance fundamental science or be of sufficient interest to excite the popular press and inspire the award of a Nobel Prize, so it was quite clear to us that future historians and other scholars would want to study the work. Equally significant multi-institutional research was conducted by teams in other fields of physics, in other fields of science, in major engineering projects, and in a growing number of other areas of modern society. In short, this type of work was a multi-billion dollar activity with tremendous impact on the development of science, of technology, and ultimately of society as a whole. There could be no doubt of the high importance of understanding how such work is, in fact, carried out. Yet the process of large-scale

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[1]There is a companion publication to this volume entitled *Highlights and Project Recommendations*. Final Report of the AIP Study of Multi-Institutional Collaborations. College Park: American Institute of Physics, 2001. Previous publications are: *AIP Study of Multi-Institutional Collaborations. Phase I: High-Energy Physics*. New York: American Institute of Physics, 1992; *AIP Study of Multi-Institutional Collaborations. Phase II: Space Science and Geophysics.* College Park: American Institute of Physics, 1995; and *AIP Study of Multi-Institutional Collaborations. Phase III: Ground-Based Astronomy, Materials Science, Heavy-Ion and Nuclear Physics, Medical Physics, and Computer-Mediated Collaborations.* College Park: American Institute of Physics, 2000. These reports are all available from the AIP Center for History of Physics; summary reports for each phase are also available on the Center's Web page (www.aip.org/history/).

collaborative research was (and is) not well understood by historians, sociologists, and other scholars. Although there had been scattered studies of individual collaborations, there were no systematic studies of this centrally important activity available to scientists, research administrators, and the public. At the time, the conclusive piece of evidence was that meaningful records of such transitory "mini-institutions" had not yet been secured for the use of scholars and others studying the research process. Even a decade later, records of only three collaborations had been included in the AIP Center's International Catalog of Sources for History of Physics and Allied Sciences.

By the early 1990s, warnings were being issued to the archival community that the world was operating more and more in the mode of large, temporary, multi-institutional projects—often referred to as "adhocracies." Archivist of the United States Don W. Wilson said "Archivists used to relying on organizational structure for the retrieval of information or for historical understanding will have to find other ways of ensuring that the deliberations and decisions of an adhocracy like this are recorded and preserved in a way that future users can understand them."[2] Tora Bikson, Rand Corporation sociologist, spoke to archivists of the increasing dominance of collaborative work—much of it carried out by adhocracies—in modern organizations; she concluded that the real challenge to documentation efforts is organizational sociology in real time.[3] Tom Malone, Director of the MIT Center for Coordination Science, also described new structures for the organization of work as adhocracies, virtual organizations, and "overnight companies."[4]

Organizational change, along with technological change, presents enormous challenges to archivists and others who must learn how to document the new phenomena. Past experience provides archivists with little guidance for coping with the complexities in modern science such as new technologies for generation and use of research data, increased involvement of several sectors in research projects, and growth of internationalism in scientific research efforts. To meet the challenge, the AIP Center has developed a new kind of research aimed at resolving archival problems; we call it "documentation strategy research"—i.e., research to expand the Center's understanding of the physics community and, thereby, to extend its documentation strategy. It was first used in the AIP Study of DOE (Department of Energy) National Laboratories which enabled the AIP Center to extend its documentation strategy to cover postwar nonacademic institutions. In the mid-1980s, the AIP designed a new documentation strategy research project to learn how to document multi-institutional collaborations.

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[2]As quoted in the column, "From the Archivist of the United States," *Society of American Archivist Newsletter*, July 1991, p. 6.

[3] The 2020 Vision sessions were published in a special issue of *The American Archivist*; see volume 57, no.1 (Winter 1994).

[4]"Inventing the Organizations of the 21st Century," a paper given on 3 November 1995 at the Symposium in Celebration of the Thirtieth Anniversary, 1965-1995, College of Library and Information Services, University of Maryland at College Park.

In order to address the problems of documenting these transient institutions, we knew we had first to understand the process of collaborative research and how collaboration members generate and use records. We decided to make a broad survey, the first of its kind, into the organizational structures and functions of research collaborations involving three or more institutions. To do justice to possible variations among scientific communities where collaborations thrive, we thought the study should examine a number of areas of physics and allied fields. During the decade-long study, the AIP Study of Multi-Institutional Collaborations examined patterns of collaborative research in the fields of geophysics (including oceanography), ground-based astronomy, materials science, medical physics, particle physics, and space science as well as an area we called computer-mediated collaborations. To assist in the design of our research methodology and critique our findings for each of the major phases of the AIP Study, we assembled working groups of distinguished scientists/science administrators, archivists, historians, and sociologists. A final AIP Study of Multi-Institutional Collaborations Working Group critiqued this final report on the long-term study.[5]

An AIP documentation strategy research project involves three important stages: first, systematic planning and field research; second, analytic studies to develop documentation aids; and third, a final period devoted to policy and programmatic issues. In a similar fashion, this final report of the AIP Study of Multi-Institutional Collaborations consists of three parts. In Part A, we describe our methodology and our historical and archival findings. Part B focuses on records appraisal in three ways: (1) an analysis of comparative organizational structures of the collaborations studied, (2) an analysis of particular functions of collaborations in terms of the records they generate, and (3) formal appraisal guidelines indicating the most valuable records of collaborations in the disciplines we studied. Part C concludes the report with a broad survey of existing archival practices followed by the project's recommendations for actions needed to document multi-institutional collaborations.

The AIP Study of Multi-Institutional Collaborations has been supported by the American Institute of Physics and through grants from the Andrew W. Mellon Foundation, the National Science Foundation, the National Historical Publications and Records Commission, and the Department of Energy (DOE). Joan Warnow-Blewett and Spencer R. Weart served as project director and associate project director throughout the AIP Study. The staff position of project historian was held by Frederick Nebeker during Phase I and Joel Genuth throughout Phases II and III. In the position of project archivist: Lynn Maloney served during Phase I, Janet Linde overlapped with Maloney on Phase I and with Anthony Capitos on Phase II, and Capitos continued as project archivist during Phase III until April 1997, after which time Genuth assisted Warnow-Blewett with these responsibilities. Major consultants to the AIP Study included historians: Peter

[5]Members of the Working Groups for Phases I, II, and III are in Appendix D; the Working Group for the Final Report is on the inside back cover.

Galison, John Krige, Frederick Nebeker, Naomi Oreskes, and Robert Smith; archivists: Deborah Cozort Day and Roxanne Nilan; and sociologists Wesley Shrum, Ivan Chompalov, and, for Phases I and II, Lynne Zucker. We also want to acknowledge the support of research assistant Martha Keyes. R. Joseph Anderson, now assistant director of the AIP Center, helped out with the work and—most importantly—provided an objective perspective on our draft documents. Martha Keyes and Kiera Robinson (Phase II), and Holly Russo (Phase III and Final Report) were responsible for publication layout and production of reports; each was assisted by Rachel Carter.

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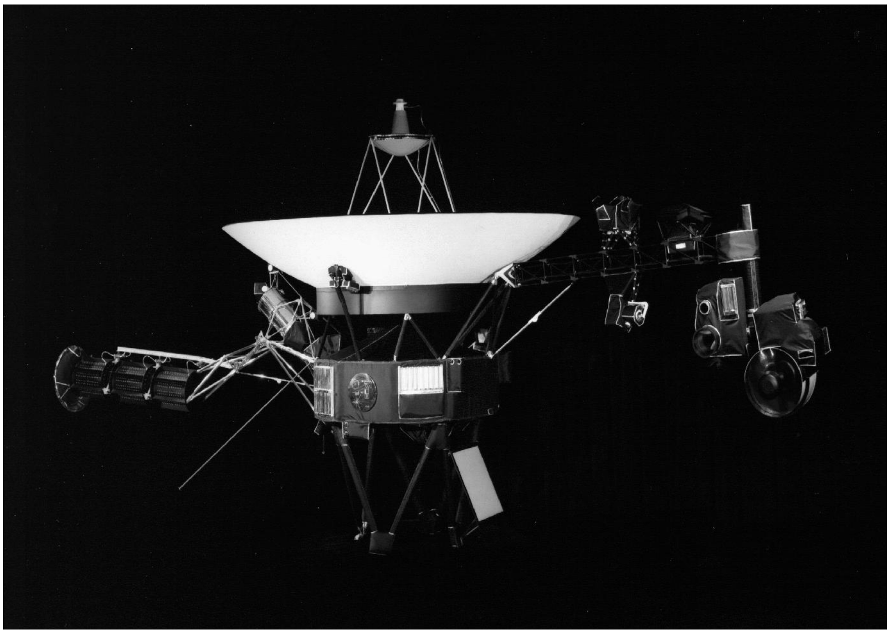

Voyager spacecraft. Photo courtesy of the Jet Propulsion Laboratory Picture Archive.

National flags in front of the Fermi National Accelerator Laboratory represent the countries of researchers currently conducting experiments. Photo courtesy of Fermilab Visual Media Service.

AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART A

SECTION ONE: HISTORICAL-SOCIOLOGICAL FINDINGS OF FIELDS STUDIED BY AIP

Joel Genuth

HISTORICAL-SOCIOLOGICAL FINDINGS OF FIELDS STUDIED BY AIP

I. *INTRODUCTION*

The stories of collaborations in the contemporary physical sciences constitute a fascinating tapestry of patterned diversity. Within each scientific specialty covered by the AIP Study, the researchers' quest for effective, feasible, and soul-satisfying organizational frameworks for querying nature has produced variations on classic themes. A full and definitive accounting of such frameworks was beyond the scope of the AIP Study, whose primary objective has been to generate empirically informed recommendations for how to document multi-institutional collaborations. However, for our program of interviews with participants in selected collaborations—we interviewed over 450 participants in nearly 60 collaborations to create the empirical foundation for our recommendations—we liberally interpreted our mandate in order to provide the materials for a first comparative assessment of the narratives of collaborations. Within each of the areas of physical research, we attempted to cover a range of characteristics in the collaborations we selected for investigation. We designed the interviews to obtain insights into processes that must be understood to begin imagining a documentation strategy and framing a historical investigation:

- How did the collaboration form and who made it form;
- Who provided the collaboration with funding and what obligations did the collaboration owe to its patron(s);
- How was the collaboration organized and managed and who took responsibility for the collaboration's administrative needs;
- How did the collaboration structure communication among its individual and institutional members;
- How did the collaboration divide labor and what was the role of the participating institutions in the collaboration;
- Who determined the timing, placement, and content of dissemination of scientific results stemming from the collaboration's activities;
- What were the opportunities, challenges, and obstacles to international participation in a collaboration; and
- What significance did the collaboration have for the course of scientific research and the careers of its individual participants?

The interviews thus provided at least skeletal information on the origins, organization, and legacy of each collaboration. The historical and sociological analyses of this information not only serves the cause of identifying those collaborators who were most likely to have records that document significant developments, but also can help archivists, administrators, and policy analysts to assess how collaborations generate and use records, why collaborations organize themselves in the ways they do, and why they seem more or less successful in the eyes of their participants.

There is, of course, no best way to run a multi-institutional collaboration; there is not even a best way to run a collaboration in most of the individual areas covered in the AIP Study. However, there are styles of collaborating that are appropriate to particular conditions or purposes that recur throughout the areas and the individual cases. The more intimately inter-dependent participants in a collaboration are, the more participatory and democratic a collaboration tends to be; particle physics collaborations, in which instrumentation components made by individual teams must all work well together to create meaningful data, most frequently practice this style. At the other extreme, collaborations create fewer and less intense inter-dependencies among scientists when their purpose is to develop and maintain research facilities that members of participating institutions compete to use. Such collaborations sharply distinguish "engineering" from "science," strive to make their facilities' engineering serviceable to many scientific interests, and employ elaborate organizational structures to insure their divisions of labor are suitable and that all the claimants on the facilities receive a fair hearing. The geophysics collaborations that "import techniques" and the ground-based astronomy collaborations that build observatories often practice this style. In-between these extremes are various shades of gray. The variations in how collaborations are managed, in the roles of participating institutions, and in the dependencies of the participating scientists underpin the archival analysis that follows this section.

II *GEOPHYSICS*

A. *Introduction*

For geophysics, AIP interviewed 106 participants in eight multi-institutional projects that began operations between the late 1960s and the late 1980s. In our choice of collaborations, the AIP staff and consultants consciously tried to cover a range of features: internationally and nationally organized collaborations, seismological, climatological, and oceanographic collaborations, smaller and larger collaborations, and collaborations supported by single and several funding sources. In our choice of interviewees, the AIP staff sought to cover all types of people involved with the collaborations, from administrators at funding agencies to graduate students at university departments.

In contrast to both particle physics and space science, though in ways that parallel ground-based astronomy, the geophysics collaborations we studied clustered around two types, which we call "technique-importing" and "technique-aggregating" projects. Three of the eight collaborations sought to import and adapt for academic geophysics established but expensive techniques that had proven their mettle in industrial research or other scientific fields. The other five sought to aggregate evolving geophysical techniques to study a site that offered a strategic window into poorly understood processes or a global phenomenon that outstripped the resources of any individual institution to capture. The organization of geophysics collaborations and their documentation problems are different for each kind of project.

B. *Project Formation*

- **Geophysicists did not have any institutionalized means of forming multi-institutional collaborations and relied on personal or intra-institutional contacts for the expertise needed to develop plans that collaborations carried out.**

- **Technique-importing projects were too expensive to be funded without high-level review from the funding agency; to have a chance of securing funding, their instigators had to unite behind a single proposal that balanced the need for unified project administration with multi-institutional project governance.**

- **Technique-aggregating projects contained too many interests to optimize data acquisition for all their individual members; to secure funding, their participants had to unite behind collective goals that justified compromising on individual interests.**

Geophysicists do not enjoy the services of institutions where scientists and engineers routinely unite to define field studies *for the broader community* to carry out; nor do geophysicists enjoy institutions that build geophysics facilities for outsiders to use. The enduring scientific significance of micro-level experimentation is well satisfied by geophysical research institutes, which combine the scientific and technical personnel needed to promote the field research of their own staffs. For large-scale innovations in research instrumentation, geophysicists have relied on the ongoing willingness of corporations and government agencies to develop highly expensive geophysics facilities, which academic geophysicists have parasitically used. Multi-institutional collaborations have been necessary in geophysics when scientific interest in field observations have outstripped the capabilities of individual institutes and when academic geophysicists have wanted to control facilities that were too expensive for an individual institute to develop.

Geophysicists have relied more on personal contacts than institutionalized relations to obtain the expertise they needed to plan large-scale field research or to develop highly expensive facilities. All the collaborations we studied included among their instigators scientists who had previously worked for industry, worked closely with engineers in research institutes, or had acquired logistical experience in previous research. Geophysicists have also had to find their own ways to frameworks within which they could propose and work on a multi-institutional project. Neither funding agencies nor national advisory bodies have provided organizational help.

The technique-importing projects among our cases—that is, the collaborations that formed to import for academic geophysics expensive techniques that industry or government had developed—were all funded by NSF; as projects whose purpose was to increase the capabilities of university-affiliated researchers, they were of interest only to NSF among funding agencies. The proposals for technique-importing projects were always out of scale for the norms of the particular NSF program handling them. Program managers thus had to obtain approvals from higher administrative authorities to fund these proposals, and preferred to have an endorsement from the National Academy of Sciences for the project. These requirements behooved the proponents of importing the technique to unite behind a single proposal lest they give the impression that there existed conflicting views on the value of the project or the strategy for pursuing it. A plausible, universally backed proposal required that instigators find an organizational framework that placed sufficient authority in one institution to simplify collaboration administration without excluding the other institutions from collaboration governance. In all cases, the instigators created a consortium. Sometimes administrative headquarters were made part of one of the participating institutions, and sometimes the consortium was incorporated to vest administration in a freestanding organization. But in all cases, substantive policy-making powers were vested in committees whose members were selected with no special regard for the headquarters institution.

For would-be instigators of technique-aggregating projects—that is, collaborations that aggregated independent scientists with a common interest to conduct research from the same vantage point—the challenge was to demonstrate that the whole would be greater than the sum of the aggregated parts. Including many techniques and scientific interests within a collaboration was necessary to justify exceptionally expensive field work, but inclusiveness guaranteed that no single specialty would be pursued to best advantage. Workshops were the usual forum in which scientists explored and debated the trade-offs that were needed to define a project that balanced collective coherence against the pursuit of individual specialties. Ideally, a workshop produced agreement on an outline, on justification for a project, and on who would be responsible for coordinating proposal writing and for project administration. Often, the range or expense of technique-aggregating proposals made them difficult for funding agencies to accept. Proposals to aggregate a wide range of techniques received peer reviews that judged individual experiments as contributions to the proposer's specialty rather than to the other experiments. Proposals that were expensive relative to a funding-agency manager's usual budget created pressure to develop new programmatic contexts. Instigators of projects that were both too broad and expensive for their usual patrons had to develop an interagency or international framework.

C. *Organization and Management*

- **Technique-importing projects organized as consortia to overcome inter-institutional rivalries among their members; technique-aggregating projects used Science Working Groups (SWG) to limit the centrifugal forces generated by their independent, competing principal investigators (PIs).**

- **Funding agency program managers were rarely involved directly in project management.**

- **Standing committees of technique-importing consortia addressed the projects' vital scientific issues.**

- **SWGs of technique-aggregating projects minimized their involvement in scientific issues in deference to the PIs and their teams.**

Participants in technique-importing projects commonly spoke of "consortia" that were responsible for appointing standing committees. These committees advised or directed collaboration executives, who made the arrangements that enabled researchers to exploit the imported technique. This structure helped the projects overcome the inter-institutional rivalries among their members by enabling all institutions to have an equal say in where, when, and by whom the imported technique would be deployed. Participants in technique-aggregating projects often identified Science Working Groups (SWGs), which were comprised of the collaboration's principal investigators, as responsible for setting the project's scientific strategy and balancing any conflicting interests among the PIs. Science Management Offices (SMOs), which one of the PIs directed, were funded to coordinate logistics for all the PIs. This structure, by insuring that the project's collective research strategy was subject to collective control, helped technique-aggregating projects overcome the centrifugal forces generated by their competing PIs. Neither type of project wanted funding agencies involved in their management. The agencies were passive towards technique-importing projects unless they failed to resolve major organizational issues or until they asked for additional money. Agency program managers also usually left technique-aggregating projects to govern themselves[6]

In technique-importing projects, the standing committees addressed the most scientifically important issues. They usually debated the general designs and specifications for the projects' major pieces of instrumentation and decided whether and when to apply the technique to a particular target. The importance of collaboration executives and consortium-wide governing committees depended on how activist the standing committees were and how successful they were at reaching consensus. Activist standing committees made collaboration executives their agents by assuming responsibility for producing detailed plans for a technique's use and for setting specifications for the instrumentation that the executives would acquire. Passive standing committees allowed collaboration executives to shape discussion of instrumentation design and use. Governing committees of technique-importing projects always made the major administrative decisions—such as the rights and obligations of membership, eligibility of individuals to participate, and when to recapitalize the project or go out of business—but governing committees did not address scientific or technical issues when a specialized standing committee reached consensus on the course of research and development.

In technique-aggregating projects, the Science Working Groups determined the boundary between collective collaboration business and business that the collaboration enabled individual participants or teams to pursue on their own. Some aspects of these projects obviously had to be handled collectively—e.g., scientists taking samples from ice cores had to agree on who took how much ice from which part of the core. But usually, SWGs tried to leave as much of scientific importance as possible in the hands of individual participants and teams. Even in collaborations in which some of the teams depended on each other to address important scientific questions, the SWG was never called on to adjudicate scientific disputes among participants, never regulated the content of scientific papers, and never successfully produced a scientific paper with collaboration-wide authorship.

The SWG also determined how much of what was deemed collective should be handled by the Science Management Office (SMO). Project logistics have usually absorbed SMO staff. The immense planning that geophysics field research required was only deemed intellectually significant in oceanographic projects, because planning where research vessels would go, how long they would stay there, and who could dangle how much apparatus in the water determined the parameters of the data sets that the PIs could hope to create. SMO personnel have also frequently created collaboration-wide databases. In almost all instances, however, participants did not independently work with data collected by someone else, and SMO staff have not actively brokered relationships among scientists.

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[6]An exception to this statement was a collaboration that stimulated the development of collective instrumentation that could prove useful after the collaboration disbanded. In this case, an agency program manager involved himself to represent the interests of future potential users of the collective instrumentation.

D. *Activities of Teams*

- **"Experiment," "team," and PI are clear terms in the context of technique-aggregating projects, but ambiguous in technique-importing projects; for the latter, we label the groups that deployed the imported technique as "teams," their activities as "experiments," and their leaders as "PIs."**

- **Teams in technique-importing projects conformed to requirements that the consortia set for properly using the techniques, including provisions for sharing and managing data.**

- **Teams in technique-aggregating projects were the product of varied efforts of their PIs to develop instrumentation, and their contrasting characteristics and needs were the source of most of the conflicts in these projects.**

The term "experiment," in the context of technique-aggregating projects, consistently refers to the activities that a PI oversees in order to obtain data and produce findings. Usually a PI's team has consisted of people from the PI's own institution, and usually a PI has either taken the institution's own data-acquiring equipment into the field or brought back samples from the field for laboratory analysis in the PI's home institution.

In technique-importing projects, data are collected by research parties, which the consortium selects to carry out specific deployments of its technique. Unlike teams in technique-aggregating projects, whose members are usually students, postdocs, or engineers selected by the PI, research parties are often comprised of independent scientists who individually competed to be part of the research party. Nevertheless, we view research party members as analogous to team members in a technique-aggregating project and a research party's designated leader as analogous to the PI. Equating the research party leaders with the PIs and the party members with team members reflects the level of initiative and intellectual investment among participants in the two types of collaborations. The independent scientists who joined research parties that used an imported technique adapted to the roles and tools provided by the consortium.

In technique-importing projects, the formation of experiment teams was determined by the activism of the consortium's standing committees. A consortium whose standing committees initiated and structured discussions of possible research sites empowered collaboration executives to select team members from formal proposals submitted by scientists. Consortia whose standing committees evaluated ideas raised by non-committee members either relied on external scientists to form their own teams to use the collaboration's instruments, or relied on collaboration executives to appoint team leaders who would include the external scientists in the work. Either way, only team leaders could hope to influence strategy for data acquisition, and team members lived with the decisions of the leaders and standing committees. Teams in all consortia have required members to share their data streams within the team. All of them published overviews of their initial primary accomplishments with a team-wide author list, and archived their data through the consortium. Further use of the data has been unregulated by either the teams or the consortium.

In technique-aggregating projects, each team controlled a particular scientific instrument. Would-be PIs have faced three inter-related technical difficulties (beyond the generic difficulties they share with strictly laboratory scientists): (1) achieving efficiency and user-friendliness in data acquisition in order to be less burdensome on a collaboration's communal resources and thus more welcome to participate; (2) achieving efficiency in data processing to increase their potential responsiveness to other PIs; and (3) making their equipment operate reliably in the field.

Geophysicists have employed combinations of four strategies to reach PI status. Some relied on adapting for geophysics the data taken from field instruments that others developed for other purposes. Some cultivated sophistication in operating standardized or communal instrumentation that geophysics institutes routinely supplied. Those with a taste for design researched and developed new instrumentation for measuring geophysical parameters. Finally, some purchased commercial analytic apparatus for determining concentrations of particular substances and customized the apparatus to accept samples acquired through geophysical field work. All the participants in the collaborations we studied had strongly specialized in particular types of measurements, but those who used standardized techniques appear to have had the most opportunity to "poach" on other specialists' turf.

Each strategy has its virtues and drawbacks. PIs who adapted others' data did not have to face the immediate technical problems of making the instrumentation work in the field, but at the cost of working with less-than-optimal data. PIs who used standard instrumentation in sophisticated ways also did not face technical problems, but they were caught between conflicting demands of their collaborators, who did not want to bother with more sophistication than they needed for their purposes, and their fellow specialists, who judged their work on whether it advanced the state-of-the-art in their shared specialty. PIs who developed their own instrumentation could claim the ability to measure geophysical parameters of generic importance, but always excited doubts over whether their instrumentation would prove balky or ineffective. PIs who used commercial analytic instrumentation were tightly limited in what substances they could measure, but they were able to adapt their instrumentation to handle samples from a variety of natural media; they served as a pool from which project instigators have sought recruits and as a source of demand for innovation or expansion of sample acquisitions.

Most of the social conflicts associated with technique-aggregating projects stemmed from the different time scales on which the participating specialists obtained meaningful data. Some experimenters obtained raw data in digital form suitable for immediate processing while others had to take raw data in the form of samples and then perform additional analytic work in a laboratory. Collaborations have struggled to find uniform rules that rewarded the teams' investments of effort in obtaining particular data streams while encouraging teams (and outsiders) to attempt innovative measurements that combined data streams. Experimenters have had the easiest time with each other in collaborations where everyone's data were digital at the time of acquisition. Participants in these collaborations, however, have found that outside users were inclined to reprocess the data to extract information that the data-takers were uncertain their instrumentation had reliably recorded. Collaborations that mixed digital and sampled raw data were, predictably, the most difficult. They have worked well only when digital data-takers have been willing to share their data in advance of sample-takers' ability to reciprocate while sample-takers have both reciprocated and welcomed "poaching" by digital data-takers.

E. *Dissemination*

- **Dissemination was controlled by teams in both kinds of collaborations, though technique-importing projects imposed more requirements on data management and archiving.**

In technique-importing projects, consortium committees and executives have never been involved in the dissemination of scientific findings acquired by deploying the techniques. The leaders of experiment teams, as soon after data acquisition as reasonable, have usually been required (or at least felt obliged) to produce a general overview of results, with other team members as authors, for publication in a relatively less specialized journal. Subsequent publishing in scientific journals and delivering papers at conferences has otherwise been an unregulated affair left to individual initiative. Interpretive disputes over the same data have not been regulated within consortia or teams.

In technique-aggregating projects, the individual PIs dominated dissemination of scientific findings. Beyond occasionally organizing special sessions at conferences or special issues of journals, the collaborations as a whole almost never played a role in disseminating results. In all of the cases we studied, papers were written on the basis of a subset of a collaboration's data streams, and author lists included only the people considered appropriate by the PIs in charge of the data streams.

F. *Funding*

- **The NSF was most prominent agency for multi-institutional geophysics collaborations, but was more essential for technique-importing than technique-aggregating projects.**

- **Technique-importing projects were funded by "block grants" with the result that they felt pressured to expand their memberships.**

- **Technique-aggregating projects were funded by individual grants to PIs plus a grant for a Science Management Office to deal with project logistics.**

The National Science Foundation figured most prominently as the funding agency in the geophysics collaborations we studied. That does not necessarily mean that NSF has been most prominent in geophysics generally. Rather, multi-institutional geophysics collaborations have been so oriented to the concerns of university scientists that usually NSF seemed the appropriate agency. For technique-importing projects, NSF has been the sole source of American funding. Technique-aggregating projects, because of their more limited objectives and diverse technical ranges, often obtained some of their funding—even all of their funding in two of our cases—from agencies other than NSF.

All the technique-importing projects we studied began with "block grants," which created consolidated administration of the acquisition and deployment of instrumentation. This structure stimulated jealousies among non-participating institutions, which lobbied consortia or NSF for changes. Collaboration administrators have often conceded the appropriateness of increased participation in collaboration governance and either expanded the number of participating institutions or abandoned block funding in favor of having NSF judge proposals for how best to deploy the consortium's instrumentation. When a collaboration's administrators resisted outsiders' interests, NSF has pressured the collaboration, in response to requests for ongoing funding, to put less stress on proposing wide-ranging explorations of the sites its standing committees deem worthy, and more stress on proposing site-specific studies in cooperation with the geophysicists of non-participating institutions.

For technique-aggregating projects, regardless of the agencies involved, funding was structured as a collection of individual grants to several PIs, with an additional grant to one PI to staff and operate an SMO. Because the several funding agencies that supported technique-aggregating projects had different traditions, the scope of the SMO's authority and jurisdiction have varied significantly. The collaborations we studied included instances in which (a) the funding agency left the SMO with next-to-nothing to manage, (b) the funding agency made the SMO's PI a (benevolent) despot for the collaboration, and (c) the funding agency made the SMO an active filter between participants and the agency.

G. *Internationalism*

- **Political necessity encouraged internationalism in geophysics collaborations.**

- **Technique-importing projects started nationally, but tended to become international in proportion to their novelty and the amount of labor required to process their data.**

- **International technique-aggregating projects were international from the start because of the organizational infrastructure provided by international agencies.**

The most important forces encouraging internationalism in geophysics collaborations has been a sentiment that nations should cooperate in the investigation of global processes, and the political necessity of including nations that control territory or resources that are essential to the investigation of a site or process. Other factors favoring internationalism were the desire to spread collaboration costs across governments and to broaden the expertise available to a collaboration. These forces combined most potently in technique-aggregating projects that investigated global processes and were least present in technique-aggregating projects that were site-specific.

Technique-importing projects all originated domestically and became more or less internationalized depending on how powerful the forces for internationalization were *vis à vis* the desire of collaboration administrators to keep management in familiar hands. When the United States alone was making a technique available to academic geophysicists or when post-acquisition data analysis was exceptionally labor-intensive, technique-importing projects internationalized. When other nations were not making a technique available to their geophysicists, that raised the value to other nations of joining in on what the Americans had started, and made it easier for Americans to negotiate terms that preserved what they considered proper management for the collaboration. The more labor-intensive the post-acquisition analysis of data, the harder it was for American scientists to keep pace with the rate of data collection, and the easier it was for them to share data collecting privileges with other nations' scientists. Formal internationalization, through the addition of other nations' scientific institutions to a consortium's membership, came at the cost of imposing additional rules to insure equity.

International organizations provide an infra-structure for defining technique-aggregating projects that are international from the outset. Workshops sponsored by the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO) have effectively spawned collaborations to study global processes. (Scientists in technique-aggregating projects that focused on a site rather than a global phenomenon were either indifferent to internationalism or found internationalism a contentious burden.) The leaders of successful workshops became the nuclei of future science working groups. ICSU and WMO have together created offices, staffed by "seconded" scientists from participating nations, to oversee an international SMO. However, WMO and ICSU only have funds for meetings and collaboration administration; the scientists in the proto-working group have to petition their national governments for resources to acquire and analyze data. Collaborations have been handicapped by national governments that were unwilling to contribute the resources that the international collaboration needed.

H. *Communication Patterns*

- **All collaborations had a hub-and-spoke structure; lateral communication among their several parts was unimportant until participants were ready to develop advanced findings.**

- **Technique-importing projects had information-absorbing hubs to consolidate sophistication in the design and maintenance of their complex, costly instrumentation.**

- **Technique-aggregating projects had information-absorbing spokes with hubs limited to the information needed for logistical coordination.**

All the geophysics collaborations we studied established communication hubs to collect information and pass it out to participating scientists at multiple institutions. However, in some collaborations, the hub has existed for the sake of the spokes while in others the opposite was true. In the former case, scientists at the spokes were prone to limit concentration of power at the hub and preferred to contribute only information that seemed necessary to the hub. In the latter case, scientists at the hub had to realize the importance of providing enough information to enable scientists at spoke institutions to satisfy their research interests. The principal factor that has determined the direction of information flows has been the expense and complexity of the communal collaboration resources entrusted to hubs.

Collaborations with expensive, esoteric communal resources had information-absorbing hubs. Technique-importing projects typically established information-absorbing hubs to consolidate the acquisition, maintenance, and use of the equipment. Outside scientists contributed well-heeded advice, but did not have responsibilities that required them to become large consumers of project information.

Collaborations with mundane communal resources had information-disseminating hubs. Technique-aggregating projects typically had information-absorbing spokes that used hubs to disseminate the information needed for knowledgeable discussions of each other's logistical needs. Administrators at the hubs were responsible for spotting possible problems, wringing the most from collaboration resources, and leading discussions of contentious issues, but they did not become thoroughly versed in the intricacies of the spoke scientists' methodologies.

After data were acquired, pressures to produce the best possible science usually impelled spoke scientists to allow the hub to collect and disseminate the collaboration's several data streams. However, lateral communication and data-sharing among spoke scientists with complementary scientific interests were common, effective, and often necessary for the proper handling of data streams. In no case we studied were hub scientists successful at organizing collaboration-wide authorship of a scientific paper. Publications involving scientists from multiple spokes were always the product of lateral communication.

I. *Social and Scientific Significance*

- **Research scientists in university-managed institutes often relied on "soft money" for their salaries and specialized strongly to maintain their competitiveness for funding.**

- **Technique-importing projects created postdoctoral positions that helped launch scientific careers.**

- **Failed start-up companies provided geophysicists and their projects with a pool of experienced engineers interested in working for salaries.**

The geophysics collaborations we studied were based on individuals pursuing three types of careers. First, obviously, geophysics collaborations needed research scientists who desired research opportunities that only a multi-institutional collaboration could support. Second, collaborations used geophysicists in administrative positions to form and manage collaborations. Third, collaborations needed engineers or industrial scientists who were willing to work for a collaboration-supporting institution rather than a for-profit business.

Of the 61 American geophysicists we interviewed because of their participation as researchers in our collaborations, roughly half either held non-teaching university appointments or performed their research at research institutes that were university-managed but not part of a university department. In general, these scientists often rely on grants for part or all of their salaries. The pressure to raise money probably accounts for the tendency of geophysicists to specialize in a particular kind of measurement, because through specialization a geophysicist can maintain competitiveness for the use of a technique-importing project's instrumentation or for a slot in a technique-aggregating project. For geophysicists who staked their careers on developing a type of measurement, inclusion in technique-aggregating projects has been a cherished sign that they and their technique had "arrived" as part of the panoply of accepted geophysical measurements.

Longer collaborations have been a mixed blessing for geophysicists. Long technique-aggregating projects provided participants welcome relief from fund raising but did not generate the steady stream of data sets needed for supporting dissertation writers or avoiding gaps in a publication record. Technique-importing projects, which have always endured if successful, often needed staff research scientists to help with the use of project instrumentation. Our information is sparse, but such positions have at least sometimes been viewed as good places to start science careers.

Career research administrators loom large in our sample of cases. All the technique-importing projects and six of the eight technique-aggregating projects originated under the aegis of a career program manager at a federal agency. Of the two collaborations that had administrative problems that affected scientific work, one originated under an agency program manager who was not a career research administrator, and the other originated not under a career program manager but in an agency that was overwhelmingly dedicated to in-house projects. Though any solid conclusion would require at least a comparison of successful with failed collaborations, it seems “no accident” that our case studies were largely shepherded through by program managers who left research permanently for administration in agencies with strong extramural research programs.

The high-risk, high-gain character of the oil business has made technical expertise available to geophysics collaborations. Veterans of failed start-up companies—or even veterans of successful companies who have tired of hustling for business—have been happy to leave entrepreneurship to work for a salary. Start-up companies that are not yet well established have been happy to work with collaborations as a way to demonstrate their services and products. Only a collaboration that reprocessed data originally collected for other purposes did not hire engineers to assist in collaboration administration.

III. *GROUND-BASED ASTRONOMY: OBSERVATORY BUILDERS*

A. *Introduction*

Only universities were charter members of all of the four collaborations we investigated, and all of these collaborations have allowed only universities to be full institutional members. In only one of our cases did the collaboration invent a less-than-full-member category in order to accommodate other scientific institutions. In all cases, the bulk of the funding for the collaboration came from university endowments and private sources. Government funding was an important supplement to the private funding in all but one case, but securing government funding was not a prerequisite to formalizing a collaboration and initiating work. All the projects were ongoing at the time of interviewing; AIP interviewed a total of 15 participants.

Our sample did not include any collaborations that involved national optical or radio observatories or that was managed by the Association of Universities for Research in Astronomy (AURA), which manages many of the national observatories. Our findings would likely have been different had such collaborations been included.

B. *Project Formation*

- **Universities needed each other for the capital to develop observatories that matched some of the capabilities of national observatories.**

- **Partners were difficult to find because universities with capital were usually hatching their independent plans.**

- **Formalization was essential because each institution was putting up substantial funds.**

- **Partners were entitled to observing time commensurate to their contributions.**

Aging, university-owned facilities and frustrations with the quantity and flexibility of the time to be won by competing for the use of national observatories have stimulated astronomers and engineers in university astronomy departments to consider the creation of new or re-capitalized observatories. Would-be instigators with promising ideas for a new observatory performed preliminary design studies (sometimes with "seed" funding and sometimes on departmental time) and convinced their departmental colleagues to be supportive. Collaborations became necessary when the department lost confidence in its ability to raise, on its own, sufficient funds to implement the instigators' ideas. The purpose of collaborating, in all cases, was to find enough monetary contributions to build the observatory.

Observatory-instigators used the scientific capabilities of national observatories as the context in which to argue for their plans. The collaborations we studied had all succeeded in identifying an appealing combination of features that partially distinguished them from national observatories and partially emulated national observatories. Lower construction cost estimations were the most common and obvious way for collaborations to distinguish themselves in an appealing way from national observatories, but lower costs were neither necessary nor sufficient to forming an observatory-building collaboration. In one case, a collaboration raised funds comparable to the construction costs of a national observatory on the promise of building an observatory that outperformed national observatories employing the same basic techniques. In the three cases in which the collaborations raised significantly less money than needed for a national observatory, they did not simply build lesser versions of national observatories but focused resources so as to match or outperform some of the capabilities of the national observatories. One collaboration accepted having lesser across-the-board observing power, but developed remote-user capabilities that enabled astronomers to carry out a wide range of schedules.[7] Another accepted having less angular observing range than has been typical, but sought at least to match the observing power of the world's best telescopes within its observing range. Another built a smaller-than-national observatory that covered a frequency range for which there was no dedicated national observatory.

Finding partners was an awkward exercise for the instigators. Ideally, they wanted astronomy departments whose members were frustrated with the quality of their available observing options and who were confident about their ability to raise capital, but who had not yet developed their own plans for capital improvements. Departments with the last two characteristics, we hypothesize, were rare; a department that had or believed it could raise capital funds was probably

[7] For example, one astronomer, to good effect, observed the same quasar for twenty minutes every other night for months on end. The astronomer could not have carried out such a program at a national observatory and discharged his other responsibilities.

a department performing research into developing its own observatory. These collaborations formed because the instigating department had links to a department that was ignorant about its university resources, disappointed in its research and development efforts, or internally split over the best type of observatory to develop. One collaboration became credible when a university's dean shocked its astronomy department by suggesting the university could partially finance development of an observatory, and a new faculty member familiar with the plans of the would-be instigators seized the moment and connected his new department with the instigators' department. In another case, deans and department chairmen who were frustrated with a local history of argument and uncertainty over how to recapitalize astronomy threw their weight behind collaborating with other universities that had well articulated plans for a new observatory. Finally, departments that lost scientific or technical confidence in the viability of home-grown plans for re-capitalizing their observatories were ripe for collaborating with instigators from other departments.

In all the cases we studied, once two universities had an informal agreement to provide half or more of the estimated money for the observatory, universities with less money were welcomed into the collaboration, and astronomy departments that had not been actively considering recapitalization became willing to invest modest funds to become minor partners in a major project. The collaborations were formalized through signed, legal agreements among the institutional members. (In two cases, the institutional members created a new corporation to build the observatory.) The agreements were usually difficult to negotiate, but no interviewee in any of the projects indicated that the difficulties involved matters of scientific or technological substance. The basic principle behind all the agreements was that collaboration members received observing time in proportion to their contributions. (When government agencies contributed, they issued requests for proposals to use the observing time they had acquired; scientists at collaborating institutions were eligible to apply for time within both the agency-sponsored competitions and whatever system their home institution set up for allocating time.)

C. *Organization and Management*

- **Formalization created consortia governed by Boards of Directors.**

- **Collaborations struggled with how much authority to unify under project management and how much authority to disperse among the participating institutions.**

- **Advisory committees of scientists from member institutions usually oversaw design of scientific instruments to be used with the observatory and deliberated on trade-offs between scientific capabilities and engineering burdens.**

Historically, astronomy has long been a "big science" in the sense of needing expensive facilities and engineering services, but its facility-builders have worked on a single-institution basis, and facility-users, even when they have cooperated across institutional lines, have had little need to formalize their organization. Recently, however, the facilities that have seemed worth building cost more than any single institution could raise. Thus, university astronomers have struggled with the trade-off between centralizing project management and maintaining their individual institutions' prerogatives and traditions.

On a broad level, all the observatory-building collaborations adopted similar organizational structures. All four vested ultimate intra-collaboration authority in a Board of Directors comprised of representatives from the member institutions. In one case, each member had a representative; in the rest, representation reflected the relative sizes of the members' contributions. The Boards met (face-to-face or by conference call) at least twice a year and as often as six times a year.

In all four projects, one individual was most responsible for the physical construction of the observatories. In two cases, the individual was an engineer and formally designated the "project manager." In one case, the individual was an astronomer and formally designated the "observatory director." In the last case, the leading scientist geographically closest to the observatory site was most responsible for construction, and he held the title "project director." In three of the cases, the collaboration organized advisory committees of scientists from the member institutions to deliberate on trade-offs between enlarging scientific capabilities and assuming engineering and financial burdens in the development of the observatory, to decide on broad specifications for additional scientific instruments for collaboration-wide use, and to plan a series of commissioning measurements to test the observatory's capabilities and shake down its component parts. In the fourth case, meetings of the Board of Directors came to include more individual participants and effectively served as a forum for general discussion of the collaboration's plans and prospects. Finally, in three, cases the Board of Directors occasionally commissioned external panels to perform design reviews of major observatory components.

Within this common structure of Board of Directors, principal administrator, intra-collaboration advisory committees, and external design-review panels, these collaborations varied mostly by the degree to which they chose to professionalize the development and construction of their observatories. Two of the collaborations were strongly professional, meaning the collaboration empowered a trained project manager to get the observatory built by contracting out for services to private corporations. One of the collaborations preferred self-management, meaning the participating scientists managed collaboration resources and relied more on university staffs and students than external contractors to design and build the observatory. Finally, one of the collaborations fell between these two extremes.

The professionally managed collaborations empowered their formally designated project managers to build an autonomous organization to carry out the development, construction, and integration of the major observatory components. The project managers operated mostly by contracting out for services. The activities of scientists at the member institutions were restricted to development and construction of scientific instruments that were peripheral to the observatory's systems engineering, to advising the project manager on the specifications for the contracts, and (when relevant) to building technologically novel components. Conflicts between scientists and project management were common over the degree of technical and financial risk to assume in the interest of achieving the highest possible scientific performance. Such conflicts were noticeably more intense in the memories of participants in a project where scientists were building a technologically novel component that was organic to the observatory's systems engineering. While both scientists and project management had equivalent administrative access to the Board of Directors for settlement of disputes, the burden of proof, as a rule, lay with the scientists. The Boards for these projects considered building observatories that embodied the scientists' original insights to be a sufficient challenge for project management, and they protected managers from pressures to continue pushing the state-of-the-art.

The moderately professionalized observatory-building collaboration, like the highly professionalized ones, operated mostly by contracting out for services, with an individual designated to keep the contractors centrally coordinated. However, in this instance, the Board selected a scientist from one of the member institutions to be the observatory director and the coordinator of the contractors without giving the director or his member institution the authority to hire the contractors. Instead, the contracting was spread across all the member institutions. When the collaboration succumbed to the temptation of accepting sizable technical risk (though at no additional cost) to achieve greater scientific capabilities than originally planned, and the contractor developing the technically risky component ran into difficulties, the collaboration as a whole suffered. As word of the problems of one contractor spread through the collaboration, the observatory director, given his lack of hiring and firing authority over the contractors, did not have the clout to keep the rest of the contractors from letting their schedules slip. The collaboration came to view this organization as inadequate, and in pursuing a second major project, it has added a project manager, who reports to the observatory director, to track and evaluate the progress of contractors.

The self-managed collaboration went beyond the moderately professionalized collaboration by not only letting the member institutions be the administrators of observatory development and construction but also by doing much of the work in-house. The division of institutional labor was part of the formal agreement that formed the collaboration. Initially, this collaboration was going to have an engineer serve as project manager, but the individual resigned early in the collaboration's life, and the Board of Directors decided not to hire a replacement. No single entity filled the vacuum in inter-institutional coordination. The Board itself used its meetings to identify collaboration-wide tasks and to assign sub-groups to carry out the needed work. An Executive Committee, consisting of one scientist from each institution, held conference calls every two weeks to assess development. The scientist whose institution was responsible for the bulk of the hardware development was designated "project director" and his institution oversaw activity at the observatory site. With money tight (and in the absence of professional project management to negotiate the best value for the needed design and construction services) the collaboration came to operate on a cash-conserving, build-it-yourself basis.[8] Graduate students and postdocs were heavily relied on to perform labor that could have been done by construction workers.

[8]There are multiple possible reasons for this collaboration's relatively paltry use of external services. The project director's institution had a tradition of building in-house, and the instrumentation did not represent such a technical challenge as to require employing professional services.

None of the collaborations we studied centralized project management to the point that its Board of Directors, comprised of representatives of each member institution, became a figurehead body. In all our cases, the Board of Directors was a vibrant, decision-making body.[9]

D. Activities of Teams

- **Scientists at member institutions autonomously built instruments for the more professionally managed collaborations.**

- **Participating institutions controlled observing time.**

- **Observers are expected independently to process and analyze the data they take, using technical documentation that the collaboration collected from instrument builders.**

In a highly or moderately professionalized collaboration, the scientists from member institutions participating in the collaboration's Science Steering/Advisory Committee were responsible for development and construction of scientific instruments to be used at the observatory. Once the Committee settled on the number and character of the instruments, and who from among the member universities' scientists would be in charge of designing and building each instrument, the instrument builders were able to proceed in near total autonomy, using the laboratories, machine shops, and contracting services of their employing institutions. The costs of the instruments compared to the rest of the observatory were too small to make them fiscally prominent within the collaboration,[10] their engineering interfaces with each other were trivial or nonexistent, and no interviewee reported any social, technical, or scientific issues surrounding their interfaces with the observatory. The instrument-builders sought to improve on the state-of-the-art for the type of instrument each was building, but nobody tried to develop a new technology or instrument design within the framework of these collaborations.

The self-managed collaboration relied on member institutions to build the observatory, and one component of another observatory built by a professionalized collaboration was too technically challenging to be developed outside the setting of a research laboratory. In these cases, a scientist at the institution responsible for the component took charge of the research and development. Though some of the construction of these novel components was contracted out, all the design work was performed within the research laboratory.

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[9]In selecting case studies, we considered AURA-managed national observatories to be single institutions and thus outside the scope of our study, and we focused on collaborations among universities as the most significant challenge for documentation research. Our finding would certainly have been different had our sample included collaborations that involved AURA-managed observatories with other observatories. AURA appoints a "project director" with the power to make decisions when the engineering and scientific leaders of a project clash. Boards of directors, when they exist, serve to set broad goals and to hold the project director accountable but not as vehicles by which the institutions contributing financially resolve intra-project disputes.

[10]Which is not to say that the cost of instruments is trivial. According to our Working Group members, the cost of instruments is increasing rapidly.

In all four of these observatory-building collaborations, the principal power retained by the member institutions was to determine how the observatory would be used. Each had rights to a share of observing time in proportion to the size of its contribution. In the highly and moderately professionalized collaborations, each institution has its own "Time Allocation Committee" to consider proposals from its own scientists. These committees worked independently without worrying about the possibility of duplicate observations. Only the self-managed collaboration centralized consideration of observing proposals. Scientists proposing similar observations were encouraged to consider jointly re-proposing, and when the reviewers' recommendations did not coincide with the allocation formula, the Executive Committee made marginal adjustments to preserve the formula.

In all cases, the collaborations have expected individual observatory users to process and analyze data on their own. Instrument builders have provided the technical documentation that users need, and users also increase their sophistication by talking about their experiences with other users and observatory operators. In three of our four cases, users have had no choice but to process and analyze their data themselves. These three collaborations have not been archiving their data, and in only one of these three did interviewees report the existence of any sentiment for standardizing data processing sufficiently to make archiving meaningful. In the fourth case, the collaboration did provide calibration and some processing software, and does archive the data. Nevertheless, the collaboration designed the observatory's data acquisition system to accommodate other software packages that observers might prefer to use on their data.

E. *Dissemination*

- **All dissemination of scientific results was left to the discretion of individual observers.**

None of the interviewees interpreted questions about dissemination as referring to articles produced in the course of telescope research and development.

None of these collaborations were involved in the dissemination of results stemming from the uses of the observatory. All decisions about publication and allocation of credit have been in the hands of observers.

F. *Funding*

- **The member institutions provided primary funding from their endowments or by finding philanthropists or private foundations.**

All four collaborations were principally funded by their member institutions, which tapped their endowments, philanthropists, or private foundations for money. Support from a federal agency was secondary. When an agency contributed to one of these collaborations, it was entitled to a commensurate share of observing time, and it organized its own system of allocating that time.

G. *Internationalism*

- **Collaborations sought foreign members only as a way to raise additional funds.**

All of these collaboration formed out of a core of American institutions. Three of the four included international participants as a way to raise more funds for construction and future improvements. Administrative arrangements were straightforward and involved no problems of logistics, policy, or culture for German and Taiwanese institutions. However, differences in political culture caused tensions within a collaboration that raised funds by adding a Japanese scientific consortium with funding from the Japanese government. The Americans had budgeted optimistically and wished to spend slowly to save money for an unexpected development; but the Japanese had budgeted pessimistically, expected the money to be spent promptly, and were prohibited from applying to the Japanese government for additional funding until their contribution to the collaboration had been spent.

H. *Communication Patterns*

- **Information on observatory design and construction funneled into the project manager, who kept the Governing Board and collaboration members apprized of developments.**

- **Information on observatory use remained within the member institutions.**

All of these collaborations strongly centralized communication concerning observatory design and construction in the office of the project manager (or his equivalent in the less professionally managed collaborations). Information from SWGs, instrument builders, and contractors flowed to the project manager, who kept the Governing Board and scientists at member institutions apprized of progress and developments. When collaboration members disputed a project manager's decisions, they directly communicated their concerns to members of the Governing Board.

Communication concerning observatory use for scientific research was strongly decentralized. Time allocation committees of member institutions usually did not inform each other of the proposals they received, and scientists who could benefit from coordinating their observations had to learn about each other and make arrangements on their own. The self-managed collaboration came closest to centralizing some communication concerning observatory use. Its Governing Board has considered trying to coordinate the efforts of several scientists in order to implement large observing projects that no individual scientist could readily carry out.

I. *Social and Scientific Significance*

- **The financial contributions of member institutions were so significant that no institution ever dropped out of any of the collaborations we studied.**

- **Less professionally-managed collaborations failed to finish observatories on time and budget.**

- **The quantity of time and character of effort needed to participate in design and development of observatories excluded junior faculty, postdocs, and students from meaningful roles.**

All of the member institutions of these collaborations invested significant amounts of their own money into building the observatories. Thus it is hardly surprising that no institution has dropped out of these collaborations. The collaborations have occasionally added institutions, especially foreign institutions, to supplement their finances in exchange for modest dilution of the original members' share of observing time.

Only one of these collaborations finished building its observatory on time and on budget, and it was one that had professionalized development and construction. The others either suffered from amateurism in their cost estimates, or outright considered a slower pace of construction less evil than creating a powerful organization that could build an observatory punctually by spending money quickly and efficiently. All of the collaborations succeeded (or apparently will) in building their observatories, though the ones that overran construction schedules have had problems operating well, because too many of the principal individuals in the development of individual components had become too busy with new work (taken on during the construction delays) to participate in observatory integration and shake-down. The observatories all have been or will be used for a wide variety of studies. The common contribution of the observatories to astronomy of three has been to show that part of a national observatory's capabilities can be built on a several-university budget; the fourth stands for the ability of several universities to build a general-purpose observatory around a technologically novel and challenging component when private philanthropists are willing to donate $100 million.

Observatory-building projects, in the opinion of nearly all interviewees, are for tenured professors who are uninterested in moving, because these projects absorbed scientists' time without generating scientific accomplishments needed for building a career in astronomy. Scientists in the more professionalized collaborations were prone to complain about the power and personality of the project manager, while scientists in the more self-managed collaborations were prone to complain about the quantity and pace of the work. However, such conflicts were not project-threatening, and none of the interviewees mentioned the possibility of empowering an individual to balance scientific and engineering interests. The interviewees implicitly understood that both professional management and self-management have their virtues, both come at a price, and there can be no fundamental mid-stream change in an organizational approach to managing observatory development.

IV. *GROUND-BASED ASTRONOMY: USERS OF OBSERVATORIES*

A. *Introduction*

The three collaborations we investigated were mostly comprised of radio-astronomy observatories with their parent institutions, plus an occasional university or observatory without its own radio telescope. Almost all the resources these collaborations needed were paid for within the budgets of the observatories the collaborations used. The dominance of institutions with radio-astronomy observatories in our sample may be an artifact of our selection of technically-aggressive collaborations that performed Very Long Baseline Interferometry (VLBI) at novel wavelengths, and collaborations that formalized relationships among observatories for VLBI observations at conventional wavelengths. None of the collaborations we studied performed sky surveys or interferometry with optical telescopes; our interviews provide no basis for describing the social characteristics of collaborations conducting sky surveys or optical interferometry.[11]

AIP interviewed nine participants in three collaborations: one from the 1970s, one from the 1980s, and one from the 1990s.

B. *Project Formation*

- **Technically aggressive astronomers used informal collaborations to explore interferometry at novel wavelengths.**

- **Observatories formed consortia to schedule interferometry observations at conventional wavelengths.**

- **A dedicated national facility for interferometry, the Very Long Baseline Array (VLBA), obviated the need for collaborations to make observations at wavelengths the facility covered.**

Exploiting the properties of radio waves has long been a fruitful pursuit for scientists and engineers, and interferometry involving multiple radio observatories could not possibly be pursued except through a collaborative framework. Circa 1970, informal collaborations of groups of technologically sophisticated astronomers and scientifically inclined electrical engineers working at different radio observatories succeeded in obtaining interference fringes by "correlating" their independently recorded data tapes. Success spawned imitation and competition. By the mid-1970s, the system of using informal collaborations to make observations that stayed within the state-of-the-art was evoking widespread discontent that was fueling desires for change. Competitive astronomers did not want to continue relying on one another to oversee the technicalities of making their observatories operate well enough to support interferometry; observatory directors, sensitive to the observing time lost while configuring an observatory for interferometry and reconfiguring it for independent observing, did not want to continue worrying how interferometry affected their observatories' productivity. To resolve these difficulties, astronomers resorted to forming two types of collaborations and a non-collaborative project. One form of collaboration involved formal arrangements among the radio observatories for scheduling and supporting interferometry; the second involved the continued use of informal collaborations for observations that attempted to expand the wavelength regime in which interferometry was possible. The former type of collaboration required the drafting and signing of a formal agreement and designated itself a consortium; the latter just required that the astronomers interested in participating propose the observation to their respective observatories. The non-collaborative project was the National Radio Astronomy Observatory's development of the Very Long Baseline Array, a user facility that freed astronomers from needing to deal with independent observatories in order to perform interferometry at centimeter wavelengths.

[11] The AIP's prior experience and input from the Working Group did provide limited guidance for archival analysis.

C. *Organization and Management*

- **Consortium had a chairperson to deal with observatory directors and a secretary to schedule observations, but no need for further structure because it was not responsible for performing the research it made possible.**

- **Informal collaborations had a scientific leader who saw to the collaboration's few administrative requirements, but needed no additional structure because all participants well understood their roles and responsibilities.**

Neither type of VLBI collaboration required much organizational structure, though the reasons for their small organizational needs were quite different.

The consortium had little organization because it did not generate new work that astronomers and engineers would have to perform and that its officers would have to manage. Its purpose was to re-channel in more productive ways the work that astronomers and engineers were already undertaking. A chairman lobbied observatory directors for observing time and resources for VLBI observations. A secretary centralized the collection and review of proposals for VLBI observations and then the scheduling of the highly rated proposals within a time period that all member observatories agreed to set aside for VLBI observations. A treasurer with a modest budget centralized acquisition of data tapes and other incidentals of VLBI research. An annual meeting, in conjunction with the American Astronomical Society meeting, sufficed for the community of VLBI researchers to elect officers and provide them with a collective sense of the most significant obstacles.

The informal collaborations had little organization because their members enjoyed a mutual understanding of what was needed to perform a successful VLBI observation. Among the participants for each particular attempt to observe a particular object at an unusual wavelength, one individual was acknowledged as having the deepest personal investment in seeing the observation performed. That individual moderated collaboration-wide e-mail discussions that produced an observing plan, dealt with the observatory directors to insure that the collaboration had the correct blocks of observing time at each observatory it wished to link, and made sure that each observatory had the equipment it needed to produce observations that met the (mutually understood) standards for post-observation correlation with the other observations. No further organization of tasks was required, and because the collaboration did not raise any dedicated funds for its use, no accounting of its activities was required. Individual members proceeded to take responsibility for preparing and operating the observatory each knew best. Once the data were taken and correlated, the most invested individual took on further data processing and analysis.

D. *Activities of Teams*

- **Teams for both the consortium and informal collaborations consisted of the people who took data at each observatory.**

- **Teams operated in near total autonomy, as each knew its observatory best.**

- **All work on instrumentation used in VLBI research was done outside the context of collaborative observing.**

For both kinds of collaborations, teams were best defined as the people who took data at each participating observatory. Setting up an observatory for VLBI observations and returning it to its standard configuration involved significant quantities of skilled labor that, in all cases, involved members of the observatory staff or astronomers intimately familiar with the observatory.

The consortium negotiated informal understandings between what outside observers could reasonably demand of particular observatories and what each observatory could be expected to provide given its telescope's age, its funding level, its staff size, and its in-house research program. In exchange for relief from the burdens of cultivating supporters within each observatory, observers were obliged to work with the support that the observatory directors agreed to provide. Observatory directors gave up a measure of autonomy over the management of their observatories, but in exchange, secured the support of VLBI users in intra-community discussions of funding priorities for astronomical facilities.

Teams within the informal collaborations operated in near total autonomy. These collaborations were composed to include astronomers and engineers who were sufficiently adept with instrumentation and sufficiently intimate with a participating observatory to believe in their chances of acquiring data at an unconventional wavelength. There was nothing for the collaboration as a whole to do, except to let each team do its best to prepare its observatory prior to the designated observing time.

Neither the consortium nor the informal collaborations designed or built the instrumentation it used. The collaborations relied entirely on the availability of instrumentation developed under other auspices. The radio observatories themselves conducted research and development into the electronics needed to receive and amplify signals at assorted wavelengths. Support for the development of the increasingly accurate clocks, tape recorders, and the "correlators" for playing back and combining the signals of two data tapes came (and continues to come) mostly from NASA to support geodetic measurements of continental drift. NASA-supported instrumentation was (and is) readily loaned for astronomical measurements, and astronomers interested in being part of informal collaborations to observe at unconventional wavelengths knew whom to call to borrow what they needed.

E. *Dissemination*

- **VLBI was unique in that participants cannot tell whether they were obtaining worthwhile data while they were taking them; the data streams had to be processed successfully through a "correlator" to be of scientific value.**

- **The consortium played no role in observers' correlation, analysis, and dissemination of the data.**

- **Informal collaborations made correlation a collaboration activity; participants who subsequently analyzed the correlated data were obliged to have their manuscripts**

reviewed by members of the other teams and to include those members as authors on any resulting publication.

VLBI observations differed from most other types of research we studied in that data acquisition and data analysis were entirely separate functions. Once acquired, the individual data sets from the participating observatories were of no value to the observers unless they could be successfully correlated. (Correlation generates the interference patterns that would have been produced had the observatories been hard-wired together to form a literal interferometer.) Taking data without having any way of knowing whether the data can be processed has made VLBI work stressful.

Because data acquisition involved considerable work and the data were considered without value unless the tapes could be correlated, correlation was the central drama of VLBI observations. Participants gathered at the site of the correlator for days or weeks of searching for a synchronized playback that would yield interference fringes above the level of background noise. When data streams were successfully correlated, the resulting data set was archived following NASA regulations. (All the tapes containing data from the individual observatories were recycled whether or not they played back well enough to be correlated.)

The data set of correlated data still required considerable processing before it could be the basis for a scientific interpretation. Within the collaboration, only the participants most interested in the objects being observed attempted to process the set of correlated data. This processing involved correcting for instrumental and environmental effects (using the logbooks kept at each observatory), calibrating the observations of the interesting objects against observations of reference objects, performing Fourier analysis to transform interference patterns into images, and processing the images to bring out the scientifically interesting properties of the observed objects. Participants who were more concerned with data acquisition and correlation than with the objects being observed did not consider the post-correlation processing to be worth their time. Outside scientists were considered too unfamiliar with the observing conditions and instrumentation to process correlated data.

The consortium and its officers played no role in the observers' use of the data, though the consortium did keep the quantity of VLBI observations in line with the capacity of the correlators to process the data. All decisions on disseminating scientific findings were in the hands of individual observers.

In the informal collaborations, the individuals who had done post-correlation processing and analysis drafted papers and circulated them for comment within the collaboration on the assumption that all scientists and engineers (but not technicians) involved in data acquisition would want to be listed as authors after the paper-drafter. In general, the other participants felt limited in their power to alter drafts because they were no longer intimate enough with the data to engage the paper-drafters in sophisticated discussion. Disputes, when they arose, were largely over the level of confidence with which the findings should be interpreted. Drafters had the final say on what was submitted to journals, and participants were entitled to request their names be removed from the author list.

All participating scientists and engineers were entitled to be authors on the first publication stemming from a particular set of observations. However, in subsequent papers, observing teams whose data had not correlated with the others' were not necessarily included.

F. *Funding*

Both types of collaboration required little or no dedicated funding. The expenses they entailed were covered by the budgets of the individual observatories.

G. *Internationalism*

- **Internationalism improved the quality of observations by extending the baseline of the interferometer.**

- **Coordination problems were minimal in international collaborations because teams operated autonomously and money was not transferred.**

Internationalism has been common in VLBI because the longer the baseline, the greater the angular resolution. Whatever the difficulties in international cooperation, "You never have enough angular resolution and you never have enough signal-to-noise ratio," as one interviewee emphatically made clear.

Swedish and German observatories were involved in the collaborations we studied, though only the Swedes participated in the informal collaborations that stretched the VLBI wavelength regime. The American government also allowed consortium observatories to collaborate occasionally with Soviet observatories on condition that Soviet scientists not be allowed to inspect American instrumentation.

Because teams were so autonomous in VLBI observations, international collaboration was only marginally more onerous on a logistical level than trans-continental collaboration within the United States. And because no dedicated funds were involved, international collaboration posed few extra administrative burdens. All that mattered was that the observatories agreed to a common research protocol: to observe the same thing at the same time at the same wave-length.

H. *Communication Patterns*

- **The consortium secretary was the focus for routine communication, and the consortium annual meeting was the focus for policy issues.**

- **The scientific leader of informal collaborations was the hub for communication concerning the collaboration's observing strategy, and issues that arose during the actual observing time.**

The consortium centralized communication concerning routine business in the office of the secretary. Scientists sent proposals to the secretary, who commissioned peer reviews and scheduled the highly rated proposals for observing time at the participating observatories. Communication concerning consortium policy and the relationships between users and observatories took place principally at the consortium's annual meeting and in subsequent discussions between the consortium chairman and the observatory directors.

The informal collaborations used their scientific leader as a communications hub. The leader led the collaboration's discussions of observing strategies leading up to the actual observing time, and the leader made real-time decisions during the observing time if the collaboration's strategy proved infeasible.

I. *Social and Scientific Significance*

- **Both formal and informal collaborations imposed only incremental burdens on permanent institutions and required minimal additional resources.**

- **Astronomers have evolved an informal system whereby informal collaborations of the technically aggressive explore prospects for observing at new wavelengths, formal consortia facilitate the use of extant observatories by the technically literate who wish to duplicate the successes of the technically aggressive, and national facilities enable all astronomers to perform interferometry without forming collaborations.**

Both the formal consortium and informal collaborations produced science by temporarily modifying the operations of extant, independent institutions. The incremental costs involved in their activities were so small that the informal collaborations did not even need dedicated funding and the consortium received little scrutiny from its funding agency.

These two types of collaborations, plus the Very Long Baseline Array (VLBA) facility, reflect a commitment to maintaining the ability of individual astronomers to claim credit for observations of astronomical objects. Ongoing, informal collaboration was the province only of the technically ambitious few, who hoped to expand the wavelength regime in which VLBI could be advantageously used. Their common interest in establishing the viability of VLBI at new wavelengths has enabled them to collaborate in making particular observations that only a few of them were interested in making. Subsets of these astronomers and engineers will likely continue to collaborate as they identify objects they wish to observe at unconventional wavelengths. However, once significant numbers of astronomers became convinced of the feasibility and fertility of performing VLBI at a particular wavelength, the reason for collaborating shifted. Instead of enabling astronomers to make particular observations, the purpose of forming a collaboration became to formalize relations among the observatories in the interest of freeing individual astronomers from the need to cooperate with competitors. And such formalized relations among observatories only remained necessary in the absence of a national user facility dedicated to making VLBI observations at wavelengths of widely accepted value. With the VLBA active at centimeter wavelengths, the informal collaborations have moved into millimeter wavelengths, and the formal consortium withered, though it could be revived should the technically ambitious whet the astronomers' appetites for VLBI observations at wavelengths that the VLBA facility cannot reach.

V. *MATERIALS SCIENCE*

A. *Introduction*

We originally distinguished materials scientists who collaborated to use accelerators from materials scientists who collaborated for other reasons, on the assumption that accelerator-using materials scientists would best be compared to scientists in other accelerator-using disciplines. That assumption was not borne out. Accelerator-using materials science collaborations are distinct in their organization from particle physics collaborations, which have historically been the chief users of accelerators. Consequently, we are here discussing all the materials science collaborations we researched. The collaborations that used accelerators and those that did not can be thought of as distinct types of materials science collaborations.

The eight collaborations in this category all included institutions from two of the following four sectors: universities, corporations, government laboratories, and federally funded research and development centers. In six cases, three of four sectors were represented, although in no case were all four represented. Universities participated in all the collaborations, but in one case their role was minor. Corporations participated in seven of these collaborations, and were major participants in all but one of these seven. In three of these collaborations, competing corporations jointly participated. Corporations would have loomed even more important had we been able to follow through on our plans to investigate another collaboration that was corporation-dominated. However, we had to drop the collaboration from the study because prospective interviewees were not willing to obtain all the clearances they would need to cooperate. In total, we interviewed 28 participants.

Materials science, outside its recent use of accelerators, has traditionally been "little science." Usually individual institutions petitioned funding agencies for support of their laboratories, and projects that meet our criteria for a multi-institutional collaboration are uncommon. However, outreach, especially to industry, is an essential activity for materials science laboratories in academic and government institutions. Thus much materials science research may be *de facto* multi-institutional even when *de jure* performed within a single institution.

B. *Project Formation*

- **Collaborations that did not use accelerators formed in response to new funding initiatives.**

- **These collaborations justified their formation by arguing the importance of researching particular classes of materials and by arguing that their collaboration included scientists from the right combination of disciplines and institutions from the right combination of sectors for performing the research.**

- **To include researchers from several sectors, these collaborations needed to negotiate an intellectual property agreement that divided what corporate participants could keep proprietary and what they needed to share with other participants.**

- **Collaborations that used accelerators usually formed in response to the construction of a new accelerator.**

- **These collaborations justified their formation by arguing the importance of their scientific interests and their ability to build a beamline that would serve the diversity of these interests.**

- **Accelerator-using collaborations had fewer formalization difficulties than the non-accelerator collaborations.**

All the collaborations that did not use accelerators owed their existence partly to ferment in the politics of funding agencies. Our sample does not include any cases of a collaboration forming to produce an unsolicited proposal. This is not to say that the government has foisted collaborations on an unwilling community, but rather that the political culture has stimulated the funding agencies to develop initiatives that favor multi-institutional collaborations in materials science. A new NSF program (Science and Technology Centers), change within NSF's Materials Science program, and new authority for the Defense Advanced Research Project Administration (DARPA) have all stimulated materials scientists to collaborate across institutions. Although materials scientists would not have formed collaborations in the absence of such agency initiatives, they have seized on the opportunities in order to support increased production of esoteric materials that they wished to research.

Every collaboration in the non-accelerator group named itself by identifying a class of materials it was investigating—not by identifying a theoretical perspective to elaborate, an experimental technique or research tool to develop, or a hypothesis to test. This form of naming was appropriate to the multi-disciplinary and multi-sectoral character of these collaborations. In every instance, the major institutions and individuals were already pursuing research into these materials, and their research within the collaboration was a direct outgrowth of their pre-collaboration research. In every case, the justification for forming a collaboration was to create a common administration over a range of perspectives, talents, and facilities that were needed to investigate a class of materials. These collaborations formed because the significance of studying particular materials and the prospects for acquiring significant government funds were together so alluring that the participating institutions agreed to bend their customary operations to accommodate each other.

Accelerator-using collaborations in materials science mostly formed in response to the opportunity to develop customized, novel beams and complementary detectors for examining classes of materials. Two of the four collaborations we studied were direct responses to funding-agency initiatives to build new accelerators that would provide a beam with unprecedented characteristics. A third collaboration formed to use an extant facility to produce a novel beam and an appropriate suite of detectors. Only one formed to conduct studies using extant accelerators and beamlines to examine a particular material.

Like the materials science collaborations that did not use accelerators, these collaborations were all comprised of scientists employed by institutions in more than one sector. However, they were not always multi-disciplinary, and their naming strategies reflected their compositions and purposes. A collaboration that formed to use established beamlines at a national laboratory came closest to resembling a non-accelerator-using collaboration; it established a common administrative framework over multi-disciplinary and multi-sectoral resources in order to pursue comprehensive studies of particular materials, for which it named itself. A collaboration that formed to develop a better beamline at a national laboratory than could be made at the members' home institution came closest to resembling a particle physics experiment; it united intra-disciplinary competitors for the development of a framework for experimentation and used the central element in its framework for its name. In between these two were collaborations that formed to develop customized beamlines at new accelerators. They were both multi-disciplinary and multi-institutional, but one was more oriented towards serving the interests of future beamline-users employed by its member institutions and the other was more oriented towards serving the interests of the scientists who built the beamline.

Geographic proximity was a significant factor in the formation of the non-accelerator collaborations. In every case, would-be instigators found prospective collaborators from other sectors by knowing researchers or administrators at close-by institutions. Personal relationships among scientists from different sectors were essential to the regional origins of these collaborations. In two cases, neighboring university and industrial scientists formed the nucleus of a collaboration; in one case neighboring university and FFRDC (Federally Funded Research and Development Center) scientists formed the nucleus; and in one case neighboring industrial and government scientists formed the nucleus. Regional collaboration had the obvious virtue of enabling participants to make use of each others' laboratories without burdensome or expensive travel. However, in three of the four cases, the collaboration expanded beyond its original region as a result of changes in employment of important researchers or out of a need for more kinds of expertise than the instigators' regions provided. Regional relationships thus appear to have been necessary to conceiving a collaboration, but neither necessary nor sufficient for formalizing or operating a collaboration.

Getting from a nucleus to a proto-collaboration with a plausible chance of winning funding involved using some combination of three techniques for these collaborations. First, the instigators networked at conferences and elsewhere to feel out other institutions with relevant resources about the prospects of working together. Second, they held semi-public workshops to gauge the level of interest among local institutions in working together on studies of classes of materials. Third, they submitted a proposal jointly with an inadequate number of collaborators and then followed the advice of agency program managers when the managers suggested they join forces with other independent proposers. In two of the cases, agency-assisted brokering, conference networking, or shifting employment of essential individuals made the final collaborations look more national than local.

Geographic proximity was far less important to the formation of accelerator-using collaborations—except insofar as having a participating institution close to the accelerator laboratory was obviously convenient. However, prior working relationships among prominent individuals were still often important to instigating a collaboration. Former colleagues, consulting relationships, and prior collaboration at another accelerator laboratory were foundations for initial discussions of prospects for developing a proposal. When instigators were unable to interest enough of their professional friends to develop a plausible proposal, they did not sponsor workshops in the hopes of engaging other institutions in the accelerator's region. Instead they took one of the more national approaches to finding additional collaborators—they either made their interest in acquiring more collaborators widely known and interviewed those institutions that expressed interest; alternatively, they submitted a proposal with fewer collaborators than seemed desirable and let the accelerator laboratory's management match them with complementary proposals.

Defining a "complete" or "excellent" proposal was more ambiguous for non-accelerator collaborations than either accelerator-using collaborations or collaborations in the other fields we studied. Few, if any, of the specific tasks the non-accelerator collaborations proposed to do were intrinsically necessary to do within a collaborative framework. Thus, these collaborations all needed a way to counter the argument that they were old wine in new bottles or administrative fictions created to obtain funding that their members could not have individually obtained in the framework of national competition. They pursued one of two basic strategies to demonstrate their coherence and necessity. Some were "device-oriented" (in the words of one interviewee), meaning they sought to investigate novel materials in the context of making a device that could serve a technological purpose. Collaboration was justified by the need for a broad range of intellectual talents and institutional functions to develop the device's prototype. Others stressed the organizational obstacles mobilizing the quantity and quality of resources that research into the novel materials merited. Collaboration was justified by the need for a multi-institutional combination of personnel and facilities to investigate the materials.

Both forms of justification led to difficulties in formalizing the collaborations. The two device-oriented collaborations, which were DARPA-funded, included corporate laboratories with competitive economic interests, and one also included a government laboratory with a newly instituted incentive program that made collaboration with other institutions problematic. In these cases, after their proposals had been accepted but before work could begin, long and difficult negotiations were needed to reach a signed agreement about protection of proprietary information and the appropriate scope of the collaboration's affairs. The two collaborations that stressed the organizational obstacles to scientific progress were both NSF-funded. They had to negotiate terms among the collaborators and with NSF on the use of NSF funds to support activities at the non-university laboratories that were members of the collaboration. They also, in the process of writing their proposals, had to winnow their prospective participants (and thus the number of approaches to the study of the materials on which they were concentrating) to what could be well-supported within the fiscal limits that NSF had set for this type of award.

Formalization was never an issue for the accelerator-using collaborations. Even when competitive corporations were involved in a collaboration, the collaborators had no difficulty in establishing conditions for taking proprietary data or using proprietary instrumentation in conjunction with the collaboration's instrumentation.[12]

[12] While the taking of proprietary data did not strain relations within the collaboration, proprietary data were a source of tension between the collaboration's corporate members and the government agency that financed the accelerator.

C. *Organization and Management*

Non-accelerator collaborations:

- **usually vested ultimate authority in a Board of Directors, programmatic authority in a committee of leading researchers from each institution, and daily managerial authority in one of the leading researchers, who usually held the title "director."**

- **usually set up its own proposal-review system to judge the quality and appropriateness of particular lines of research to the topic the collaboration was addressing.**

Accelerator-using collaborations:

- **usually had no structure beyond designating a "spokesperson" to deal with high-level laboratory administrators and a technically adept participant at or near the laboratory to be responsible for keeping the instrumentation working.**

- **used their members' shared sense of what they wanted from their collective instrumentation as a source of managerial discipline.**

Ultimate authority for three of the four non-accelerator collaborations was vested in an inter-institutional board, which was usually called the Board of Directors. (In the fourth case, the collaboration was small enough not to need a formally delineated structure.) This top-level board included the research administrators responsible for each institution's participation in the collaboration (usually titled the co-directors) and usually other representatives from the participating institutions. Once this board set the broadest fiscal and personnel policies within which the collaboration was to operate, its principal purpose was simply to exist for the contingency that the collaboration failed to set substantive policy for itself. By contrast, only one of the accelerator-using collaborations vested authority in a Board of Directors. To the extent that the other accelerator-using collaborations had an authority structure, an individual scientist was designated to speak for the collaboration and usually held the title "spokesperson." However, the greater social homogeneity of the accelerator-using collaborations and their internally well-understood goal of creating a workable system for generating data made them less needful of some kind of board that could threaten to make decisions for the collaboration if the direct participants had trouble making decisions themselves.

Major policies for the non-accelerator collaborations' research were set by a committee below the Board of Directors. This committee, whose name varied from collaboration to collaboration (e.g., Program Committee, Executive Committee, Technical Representative Committee), again included the co-directors and, usually, the participating scientists with responsibility for parts of the collaboration's intellectual sub-structure. It embodied the collaboration's internal division of labor, and by reforming itself could change the division of labor. And it determined the collaboration's internal allocation of resources.

Accelerator-using collaborations usually did not need such a committee. In general, they designed their collective instrumentation in such a way that teams could use it independently for their own scientific interests, and in general each team had its own funding sources. Thus there were few occasions in which these collaborations needed to reconsider their internal working relationships and their internal allocation of resources, and correspondingly little need for a formal committee to deal with such matters.

Daily management of affairs in all the non-accelerator collaborations were vested in an individual, who usually held the title "director," and who also served as his institution's co-director. The director's institution was fiscally responsible to the funding agency and distributed the funding through contracts with the other participating institutions. The director's office was responsible for assembling the progress reports and collecting the administrative data necessary for dealing with the funding agency and other interested outsiders. Often he had an assistant director to help with the paper work. This arrangement reflected nothing more than administrative convenience and compliance with funding-agency accountability regulations. Within the collaboration, the director would chair meetings of the committee responsible for research policy, but participating scientists generally viewed him no differently from the other co-directors, and the director's institution neither sought nor been granted any privileges.

In the accelerator-using collaborations, a scientist at or near the accelerator laboratory had responsibility for routine daily affairs. Most of the time, the individual's qualifications were that he was technically adept with the instrumentation and socially adept at dealing with the accelerator laboratory's administration. However, in one of the four cases we studied, a scientist at the laboratory and a scientist from an institution near the accelerator laboratory were both considered leaders of the collaboration. This form of organization led to extreme difficulties, and the collaboration eventually reorganized itself to resemble the other accelerator-using collaborations.

Determining (and in some cases redetermining) an internal structure and allocating resources across the divisions it created were the central collective tasks for the non-accelerator collaborations. The two NSF-funded collaborations approached this matter in similar fashion. They both created, in the process of writing their proposals, multi-institutional teams for each research theme or topic they wished to address. All of the team leaders plus the institutional co-directors became the nucleus of the committee directly concerned with budget and research policy. (This committee was variously named the Program or Executive Committee.) Drawing up a collaboration budget involved potentially tricky conflicts between supporting the most promising-looking research and maintaining the traditional balance of funds going to each participating institution. In these successful collaborations, the balance on this committee between scientists representing research specialties and scientists representing their institutions yielded consensual decision-making that left the Boards of Directors with little to do. Annual or semi-annual collaboration-wide workshops were the primary formal occasions in which everyone could hear of each other's progress and discuss the wisdom and efficacy of the collaboration's internal arrangements in light of the latest results. NSF site visits and applications for ongoing funding forced the collaborations to assess their progress and the prospects for their several lines of research. Both collaborations also had external advisory committees whose meetings stimulated ferment. The advisory committees included scientists and administrators from institutions and sectors not represented in the collaboration; they were probably most useful for encouraging the collaborations to pursue research lines that complemented or supported what was going on outside the collaboration's earlier purview. At the time AIP interviewed participants, one of these collaborations had undergone a substantial reorganization, and the other expected to do the same in preparation for an upcoming site visit.

The two DARPA-funded collaborations—compared with the NSF-funded collaborations—organized themselves so that categories of research activities were more identified with particular participating institutions or with groups of institutions that had previously worked together informally. Both of the DARPA-funded collaborations included corporate competitors, and dividing labor along institutional lines made it easier for the corporate scientists to participate without releasing information their corporations wished to keep proprietary. However, the principles on which the two collaborations divided their tasks differed. One took a pipeline approach to the development of a device. It divided the work into materials development, miniaturization, design, and integration. The competing corporations led separate stages, and the governing committee, which met weekly by conference call, found it could discuss and deal with the technical problems at the interfaces between the stages without intruding into the techniques and practices that each corporation wished to keep secret. The other divided the research and development by using prior specialization in experimenting with a sub-class of the materials the collaboration was investigating. Each corporation worked with the sub-class of materials it knew best, and the main purpose of collaboration meetings was for everyone to evaluate their accomplishments and prospects in light of the others' results. However, the participants felt that this system did not optimize free discussion, perhaps because in comparing the properties and performance of related materials, the corporate participants could not help but be interested in each other's processes as influences on the quality of the materials each made.

As with the NSF-funded collaborations, the DARPA-funded collaborations operated by making one institution accountable to DARPA and having this accountable institution subcontract to the other participants. As with the NSF-funded collaborations, decisions were generally made by consensus within the committees and boards set up to govern the collaborations. And, as with the NSF-funded collaborations, the higher-level boards and their members became less active in collaboration affairs as the lower-level committees proved capable of reaching consensus on the conduct of collaboration affairs. DARPA program managers annually reviewed the collaborations, but these collaborations had no external advisory committees. The DARPA reviews did force participants to look critically at their arrangements, but the difficulties in negotiating the initial intellectual property agreement inhibited any efforts to reform the collaboration's internal structure, even in the collaboration that was dissatisfied with the level of open discussion within the collaboration.

The central collaborative tasks of most of the accelerator-using collaborations were to develop and maintain the combination of beamline and detection instrumentation that would serve the needs of the members. In two of our four cases, corporations assumed responsibility for the health and progress of the collaboration, and the corporations insisted on the option of using the beamline for proprietary research or for other independent purposes that would not be subject to oversight by the other institutions in the collaboration. However, these two collaborations adopted distinctive approaches to allocating responsibility for building the beamline and to creating autonomy for experimenters using the beamline.

In one case, the collaboration's institutional members centralized their financial contributions to the collaboration and created a Board to manage the funds and to oversee a professional staff charged with designing and building a beamline to meet the needs of interested scientists at the member institutions.[13] The staff director was responsible for dealing with the accelerator laboratory administration and for reaching an understanding about what the beamline should do with the interested scientists at the member institutions. Annual Board meetings were the principal form of oversight for assessing staff progress, for setting any new directions necessitated by the need to comply with laboratory regulations, and for addressing any conflicts that staff and member-institution scientists had not been able to resolve on their own.

In another case, the collaboration's institutional members did not formally centralize their financing of the beamline and did not create an authority to oversee the use of funds. Instead it relied on *ad hoc* self-management for beamline development and construction. The scientists interested in using the beamline preferred to build the beamline themselves and had the experience to do so. The collaboration designated as "spokesperson" the leading scientist from the institution that took responsibility for providing the most challenging beamline component. The engineer recruited by the spokesperson to design and procure this component took charge of overall beamline construction. The spokesperson represented the collaboration to the accelerator laboratory's administration, but wielded little authority within the collaboration—in part because there were so few collaboration-wide issues once the beamline was operational.[14] Each team built its own "end station" for its own experiments with its own instrumentation. An annual collaboration meeting in conjunction with the accelerator's Users Committee meeting was sufficient to keep the collaboration coordinated. (A laboratory-employed scientist served as "beamline manager" and handled daily scheduling and routine repairs.)

One accelerator-using collaboration pursued integrated studies of materials using extant beamlines and detection instrumentation. It needed no significant management. The number of participants was small enough, their roles so self-evidently clear, and the needed facilities so easily tapped that nobody even had to organize a meeting of all the participants.[15] A postdoc, who was carrying out the brunt of the physical studies, and his supervisor were able to hold the collaboration together by communicating (by visits and e-mail) with the concentration of chemists who had synthesized the materials, and by meeting individually with the relevant beamline experts at the national accelerator laboratory. The chemists and beamline experts never had to meet or coordinate in order for their efforts to contribute to the development of a satisfying model for the structure of the synthesized materials.

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[13]These arrangements most resemble those of professionalized telescope-building collaborations as described in the essay on ground-based astronomy. Effectively, the collaboratively built beamline became a sub-facility which individuals working for a member organization could propose to use.

[14]The term "spokesperson" is also common in particle physics, where it has very different meanings and connotations. See section VII, Particle and Nuclear Physics, below.

[15]In many respects, this collaboration resembles astronomy collaborations performing Very Long Baseline Interferometry observations.

D. *Activities of Teams*

- **In the non-accelerator collaborations, teams were groups of specialists, usually from more than one participating institution, concentrating on a substantive problem.**

- **Teams took all data in non-accelerator collaborations, mostly using the extant instrumentation in their home institutions; acquisition of new instrumentation was a secondary priority.**

- **The degree of autonomy with which teams worked in these collaborations varied too widely to frame any generalizations.**

- **Teams in accelerator-using collaborations most often referred to the efforts of each participating institution to build and take data with its own end-station instrumentation, but there were instances in which "teams" had different or multiple meanings.**

- **Once the beamline was operating, teams usually took data autonomously.**

"Teams" in the non-accelerator materials science collaborations referred to a multi-institutional group of researchers concentrating on a substantive problem. All data in these collaborations were taken as part of team activities. None of these collaborations collectively built instrumentation with which to take data streams for the use of everyone in the collaboration. None of the teams and individual scientists in these collaborations have had to build up their instrumentation from scratch, because their collaboration researches have involved using the techniques they employed in their pre-collaboration researches. Data were mostly taken within the home laboratories of the participating scientists with instrumentation the laboratories had already acquired.

Though development of instrumentation was not a principal activity of any of the non-accelerator materials science collaborations, three of the four did directly support the acquisition of new instrumentation by member institutions. (In the fourth, a corporation-dominated collaboration, the corporations counted their purchase of collaboration-relevant instrumentation towards their cost-sharing obligations.) The new instrumentation was invariably purchased—sometimes by contract in which the purchasing institution specified novel features for the maker to incorporate. (We heard of no instances in which materials scientists developed instrumentation within their research laboratories while working within a collaborative framework.) In the NSF-supported collaborations, most instrumentation acquired with collaboration support was available for the use of everyone in the collaboration. The same was not true of the DARPA-supported collaborations, but it is unclear whether instrumentation was not shared as a point of policy or whether instrumentation was not shared because the roles of the participating institutions were so sharply divided that they had no need for each other's instrumentation.

The teams operated at diverse levels of autonomy in these collaborations and the diversity did not coincide with their funding agency. In the DARPA-supported collaboration that organized itself in pipeline fashion, the teams required frequent communication to keep abreast of each other's developments and to discuss the significance of each other's developments for project administration. Because the device the collaboration hoped to develop was based on a novel material, the collaboration decided not to set specifications in advance for what each team needed to accomplish in order to make a functioning device; instead the teams had to keep adjusting their goals as they learned more about the material and its behavior under various conditions. By contrast, in the DARPA-supported collaboration that organized itself along its institutional members' prior specialization the teams worked in near total autonomy between the meetings at which they shared findings and plotted further research strategies.

Teams in the NSF-supported collaborations operated with more intermediate autonomy. The participants were all building on their individual prior research, which as a rule they had pursued autonomously, but the participants also knew that collaboration administrators and NSF officials would judge the collaboration on the basis of whether it stimulated research that might not have been done had the collaboration not existed. The most overt indicator of an individual scientist's adherence to collaborative values were data jointly taken with collaboration members, and collaboration administrators especially esteemed joint data-taking among members of different teams as an indication of the collaboration's efficacy in stimulating research that independent proposal-writing would not have generated. Both collaborations balanced participants' desires to build on their prior individual research programs against the need for more collaborative approaches by operating their own internal funding system; members of the participating institutions interested in being part of the collaboration proposed research to collaboration administrators, who considered the likelihood that the research would lead to the joint taking of data within the collaboration as well as the technical soundness of the research.

In accelerator-using collaborations, "teams" had several meanings. For the self-managed beamline-building collaboration, "team" referred to the institutional member(s) responsible for a particular end station, which the team equipped for a particular style of experiment. For the formally managed beamline-building collaboration, team had two meanings: (1) the member institutions that set up their own in-house system for determining how their beam-time was to be used; and (2) the multi-institutional groups of similarly specialized scientists that worked with the collaboration staff to determine what beamline and detector parameters best met the needs of each specialty. "Team" initially had no meaning for the beamline-building collaboration that initially organized itself like a multi-component detector collaboration, and then came to have the same meaning as for the self-managed beamline-building collaboration after the collaboration reorganized itself. In the collaboration that pursued integrated studies of materials, intellectual specialization and institutional boundaries coincided so precisely that there was no need for the collaboration to make a formal designation of teams.

Teams in self-managed beamline-building collaborations focused on developing and using their independent end-stations. They were autonomous from each other in all operations save allocating the beam among the end stations, though pairs of teams have been prone to pursue joint experiments when their interests overlapped. Some teams have used their autonomy to develop unprecedented end-station instrumentation in their home-institutions' laboratories and workshops; one team has treated its end station like a vacation home—using the end station occasionally and often renting it out to others in exchange for time on a facility better suited to its current interests.

Such autonomy has not consistently been a prescription for tranquil relationships. In one of our cases, the presence of an end-station tenant, who competed with the research programs of other end-station teams without contributing to the construction and ongoing development of the beamline, caused hard feelings.

We collected little information about teams (as either multi-institutional groups of similarly trained specialists or as single-institution organizations for allocating beam time) in the formally managed beamline-building collaboration. The multi-institutional groups of specialists were not powerful because of their relative lack of experience in accelerator-based research as compared to the beamline builders. Because the beamline had not been completed at the time we did the interviews, the participating institutions had not yet set up systems for deciding on how to allocate their beam time.

E. *Dissemination*

- **In non-accelerator collaborations, the only collaboration-wide review of manuscripts was to ensure adherence to a collaboration's intellectual property agreement.**

- **Only the accelerator-using collaboration that collected data on already-existing beamlines succeeded in making dissemination a collaboration-wide function.**

Almost none of these collaborations maintained ongoing collaboration-wide policies for the reliability of results, when or where to present results at conferences or publish them, or how to allocate credit to individuals working within the collaboration. Dissemination was usually in the control of the teams or individual data-takers, who on an *ad hoc* basis could decide to take data jointly and publish together. In collaborations that included corporate competitors, manuscripts were internally reviewed for compliance with the collaboration's intellectual property agreement; nobody reported ever experiencing a problem with the reviews. Most accelerator-using collaborations did not publish papers with a collaboration-wide author list (except for papers reporting on beamline design and performance).

F. *Funding*

- **Corporations always either funded themselves or cost-shared with a government agency.**

- **NSF and DARPA both funded non-accelerator collaborations; they differed in their requirements and willingness to influence a collaboration's composition.**

- **DOE funds the accelerator laboratories at which collaborations take data, but not the collaborations themselves.**

Funding arrangements varied significantly across materials science collaborations. Government agencies were a direct source of funds for all but one of the collaborations, but the legal arrangements they employed varied. Some collaborations were funded by contract, some by grant, and some by "cooperative agreement," which provides the funding agency with more oversight authority than a grant but less than a contract. Corporations, in general, shared costs with the funding agency; in one instance, a corporation was the principal source of direct funding.

G. *Internationalism*

- **International participation was unimportant to all these collaborations.**

None of the materials science collaborations we studied initially included institutions from outside the United States. The DARPA-funded collaborations were required to involve only American institutions. In one case, the purchase of a corporate participant by a Japanese holding company nearly derailed the collaboration until the corporation's management convinced DARPA program managers that the holding company had none of its employees on site and that the originally American-owned firm effectively had a wall protecting the technology within the company.

The NSF-supported non-accelerator collaborations and the accelerator-using collaborations did not operate under such strict requirements. However, none formed with institutional international participation.[16] One of the non-accelerator collaborations developed an informal arrangement with a German research institution, but both collaborations consisted initially of geographically proximate institutions, and neither has shown enthusiasm for becoming more far-flung. In two of the accelerator-using collaborations, foreign institutions became prominent participants only as the original institutions encountered difficulties in raising funds for the beamline or in dedicating personnel to use it. It is not clear whether these collaborations have not pursued international collaborators out of a sense of nationalism or out of a preference for localism (including the possibility of using each other's laboratories) that precluded intense involvement with distant American institutions as well.

H. *Communication Patterns*

- **For scientifically significant information, materials science collaborations stress lateral, point-to-point communication among teams over hub-and-spoke communications between headquarters and the teams.**

Neither kind of materials science collaboration set up a powerful communications headquarters to collect and distribute scientifically important information. In non-accelerator collaborations, lateral communication among teams was a *raison d'etre* for the collaboration, and a duty of collaboration-wide administrators was to make sure the collaboration was organized so that such communication took place. Accelerator-using collaborations centralized communication concerning the desirable characteristics of beamline components and the schedule of beamline use, but the teams were so scientifically autonomous and so self-sufficient in the operation of the beamline that there was no need for a central channel for collaboration-wide communication.

[16] One did involve a scientist working for a foreign institution as an individual participant; the scientist eventually took a position in the United States.

I. *Social and Scientific Significance*

- **These collaborations have been most significant as experiments in the organization of materials science research; no single result of any of these collaborations has greatly affected scientific knowledge.**

- **All of these collaborations have had very stable memberships with few institutions being added and even fewer leaving.**

- **Non-accelerator collaborations have tended to reorganize themselves in response to evolving opportunities for research and the interests of their members (except when reorganization would have necessitated renegotiation of an intellectual property agreement); accelerator-using collaborations have only reorganized themselves when they encountered major problems or conflicts.**

The non-accelerator materials science collaborations we studied have been granted funding commitments for as short as two years and as long as 11. Their funding levels for research are difficult to compare because some collaborations carried significant burdens for educational outreach, and because some collaborations leveraged their funding through cost-sharing with participating corporate or government laboratories. The accelerator-using collaborations were open-ended in time; they existed (or will exist) for as long as their participants successfully pursued funding. The collaboration that used extant beamlines was far shorter than the others. Obviously, the more effort collaborators put into acquiring instrumentation, the more time they will want for using the instrumentation.

Once formed, all materials-science collaborations have had stable institutional memberships. Only one collaboration dropped an institutional member, and that was because of the retirement of the institution’s leading scientist. Only two have added organizations; one because a founding administrator took a new job at a different institution, and one because it needed more funds and labor than its current members were capable of generating. However, the accelerator-using collaborations have been far more likely to be organizationally stable for long periods of time than the non-accelerator collaborations, which tended to be organizationally dynamic when they lasted for longer than two years.

Success for the accelerator-using collaborations meant creating conditions that enabled its members to take data and publish papers—preferably while remaining within the originally proposed schedule and budget. (An exception to this generalization is the collaboration that used extant beamlines to pursue integrated studies of materials; it only lasted 18 months and only produced one publication.) These collaborations’ participants were presumed to know what their scientific interests were and to be capable of independently satisfying them once the collaboration provided the necessary instrumentation. Thus these collaborations’ internal organizations revolved around obtaining and maintaining the instrumentation. Until a collaboration sought funding for recapitalizing a beamline, there was no need for organizational reform.

The premise among the non-accelerator collaborations, by contrast, was that their participants could not independently satisfy their scientific interests and perhaps were constrained by their individual institutional arrangements from even realizing what their best interests were. The DARPA-funded collaborations presumed that competing corporations had to work together in order to realize scientific objectives. These collaborations were internally stable, because even when participants felt dissatisfaction, the difficulty of reopening negotiations over the intellectual property agreement seemed prohibitive. One went out of business at the end of its initial funding, rather than try to recast its intellectual property agreement to take into account the shifts in interests among its members; the other did not need to continue as a collaborations because of a merger among its major corporate members. The NSF-funded collaborations presumed that the extant framework for research would not advance the investigation of particular materials with broad scientific or technological significance. These collaborations were designed to be internally malleable because part of their original purpose has been to experiment with research categories and institutional relations; even when these collaborations have operated to the satisfaction of the participants, the prospect of a major NSF site visit or a requirement to re-propose for more funding has prompted self-examination and reform. They needed longer lives than the DARPA-funded collaborations in order to have a chance to demonstrate that they could generate enduring lines of research.

As a group, these collaborations have been most significant as attempts to find satisfying working relationships among institutions from different sectors. The accelerator-using collaborations functioned smoothly because they left the participating institutions with the latitude to decide what to examine and who to involve in its examination. The non-accelerator collaborations attempted a more organic integration of university, industrial, and government science. When competing corporations were involved, as was the case in the DARPA-funded collaborations, scientists from at least one sector had complaints. University participants felt their role was too circumscribed in a collaboration that the corporations dominated; in another, university participants felt that the corporate scientists were too circumscribed out of fear of releasing proprietary information. Corporate scientists were usually dismayed at the amount of in-house arguing needed to obtain permission to collaborate; and government scientists were dismayed when a collaboration they brokered fell apart because a corporate merger of the participating firms led to the elimination of one of the participating research groups.

Interviewees have all expressed satisfaction with the intellectual quality of their participation. At minimum, these collaborations enabled participants to define and acquire the means to pursue a post-collaboration research direction individually. Most have been the source of enduring work relations at least among individual participants. All are credited with wisely bringing together experts with different perspectives but common interests in a class of materials, and also with deepening researchers' appreciation of the difficulties in mastering the relations among the structure, properties, synthesis, and use of new materials.

VI. *MEDICAL PHYSICS*

A. *Introduction*

The three collaborations in this category were all ongoing at the time of interviewing. They included as institutional members medical schools and their affiliated hospitals[17] (with researchers

[17]We will use the phrase "medical center" to refer to medical schools and affiliated hospitals.

drawn from radiology, biophysics, and statistics groups), university physics groups, national laboratories, corporate laboratories, and medical professional societies. Radiologists participated in all the collaborations, but no collaboration consisted entirely of radiologists. Who else was essential to the radiologists depended on the degree to which the purpose of the collaboration was to develop new procedures versus testing state-of-the-art procedures. Developing procedures required more collaboration with physical scientists and engineers; testing procedures required more collaboration with statisticians and professional societies.

The AIP Center had less experience documenting medical physics than all the other specialties covered in the long-term study. As a result, we had the least success eliciting the cooperation of participants in medical physics collaborations, and we do not have a robust empirical foundation for making general claims. Radiologists were less well represented among our interviewees than desirable because many of the radiologists with whom we sought interviews were unwilling to grant them, and those that did grant interviews often declined to meet for more than 45 minutes.[18] AIP conducted a total of 12 interviews. Two of the collaborations were oriented towards diagnosis of cancers; both were funded principally by the National Cancer Institute with modest cost-sharing from corporate participants. The third was cardiology-oriented and had support from a philanthropic foundation, DOE, and the National Institutes of Health (NIH).

B. *Project Formation*

- **The collaborations in our sample were all oriented towards diagnosis, not treatment.**

- **Our sample did not show a pattern for how these projects were conceived and how their instigators recruited participants.**

- **All the collaborations had difficulties in formalizing their arrangements; it appears that medical physicists's institutions have not formed multi-institutional collaborations frequently enough to have smooth procedures for doing so.**

All of the collaborations in this group were oriented towards diagnosis rather than treatment of medical conditions. Though three cases seems a paltry sample on which to make broad generalizations, this stress on diagnosis seems consistent with the recent widespread concern in the United States with controlling costs of medical care by identifying diseases earlier, when they are easier to treat.

The instigation of these collaborations varied widely. At one extreme was a collaboration that originated as an effort of university and national laboratory physicists to use new research tools for bio-medical purposes. At the other was one that originated because policy makers were uncomfortable with the paucity of information for assessing diagnostic modalities. In between was one in which a funding agency's desire to satisfy an interest group dovetailed with research efforts that were already underway in bio-physical circles.

[18] Radiologists paid on a fee-for-service basis considered our requests for two-hour interviews an excessive imposition on their time.

Word-of-mouth and geographic proximity were essential for collaborators to find each other when university physicists sought to pursue medically relevant adaptations of physical research instrumentation. The instigators assumed that intellectual intimacy would be necessary among the various specialists who had no previous history of working together. Collaborating with locals made it easier for participants to get to know one another and to adjust when an individual proved incompatible. Nearly the opposite was the case for the collaboration that originated with policy-makers' discomfort at the available information for assessing diagnostic modalities. Word-of-mouth did play a modest role in stimulating radiologists at prominent medical centers to draft proposals to participate in studies comparing modalities, but the funding agency made the final selection of the participants for each study and selected which participant would be the scientific leader of each study. Instead of aiming for intellectual intimacy in order to develop a new diagnostic tool, this collaboration aimed for an impersonal consensus on the effectiveness of various diagnostic tools. The collaborators' lack of choice in whom they worked with contributed to the plausibility of their studies. The collaboration that originated in the intersection of interest-group pressures and research developments again occupied an intermediate position. While location was unimportant to the participants, their familiarity with and respect for each other's work led them to seek funding collectively, even though each understood that his proposal would have to pass individual scrutiny by the funding agency.

No matter the intellectual origin of these collaborations, their instigators faced significant problems in formalizing arrangements. The university physicists and medical-center physicians interested in investigating the bio-medical prospects of a tool of physical research did not fit well into an established funding program within the federal government, and the participants were always seeking (sometimes conflicting) strategies for funding their activities. The policy makers interested in assessing diagnostic modalities kept needing to find sets of similarly equipped medical centers willing to dedicate their instrumentation and personnel to assessing extant instrumentation rather than to developing diagnostic novelties. The funding agency that wished to stimulate research in response to interest-group pressure sponsored a workshop that succeeded in establishing the credibility of an area of research as likely to yield significant improvements in diagnosis; but the funding agency was accustomed to funding individual-investigator proposals and did not adjust its procedures to review these proposals in a unified fashion. The fact that these collaborations all had formalization hurdles to clear may be more significant than the fact that they managed to clear them. Our sample indicates that the institutions that support medical physics do not welcome the formation of multi-institutional collaborations and do not encourage their formation often enough to have smooth procedures for handling collaborative proposals when they are generated.

C. *Organization and Management*

- **Our sample did not show a pattern for how these collaborations were organized.**

- **Medical physicists sometimes needed a rigidly organized collaboration to insure its members adhere to collaboration standards, sometimes needed a minimally organized collaboration to insure its members fully explore their preferred lines of research, and sometimes organized themselves strongly enough to insure the integration of instrumentation and perspectives of their multi-disciplinary members.**

- **In spite of the different traditions of physicians and physicists, managerial difficulties were rarely based on disciplinary identities.**

The organization of these three collaborations ran the full range from rigidly organized in response to external pressures, to self-organized in response to perceived needs, to barely organized in response to perceived lack of need. Such diversity seems indicative of a lack of traditions for collaborative research in medical physics.

The rigidly organized collaboration was the one formed by the funding agency to compare the effectiveness of different diagnostic modalities. Its intellectual leaders were the head of the statistics group, which defined what constituted a meaningful test of the modalities, and the radiologist that the funding agency appointed "coordinator" (by virtue of being the principal investigator (PI) for what the agency considered the strongest proposal). The collaboration's administrative functions were vested in a medical professional society staffed by technical personnel with no scientific interest in the designs and outcomes of the studies. The central collaborative challenge occurred before data collection began—when the participating radiologists, the other medical specialists each radiologist recruited from his/her medical center, and the statisticians held a workshop to devise a research protocol that would yield statistically significant results within the boundaries set by technical feasibility and medical ethics. Once the protocol was established, the medical centers began collecting data and sending them to the professional society, which was responsible for daily management of collaboration affairs. The medical professional society performed some preliminary data processing; and the society, using its control of the funds to reimburse the medical centers for their expenses in collecting data for the collaboration, held each medical center to the standards for data set by the protocol. In the event of a dispute, the coordinator had authority to judge whether a medical center was meeting the standard.

At the opposite extreme was the collaboration that originated at the intersection of scientists' research interests and an interest group's lobbying efforts. The collaboration created a minimal managerial structure, because the collaborators had a ready-made division of labor based on a combination of working relationships they had established prior to the collaboration and interests they had made known at the initiating workshop. Each participant had been working on developing a capability relevant to a new and potentially more powerful system for diagnosing a disease. Being in a collaboration, with the discipline of semi-annual meetings to discuss their work, made the participants responsible for comparing their results and addressing the interfaces among their emergent capabilities. The scientist who had recruited the participants to propose jointly as a collaboration held the title "project director," but once the proposals were in and an agreement reached on how to divide the collaboration's budget among the participants, he did little beyond organizing the meetings. All interviewees, including himself, viewed him as a coordinator with no more authority than any of the other senior members of the collaboration and viewed the collaboration as operating well without a collaboration-wide intellectual leader.

The self-organized collaboration was similar to the minimally organized one in that it too had a ready-made division of labor based on the previously acquired skills of the major participants.

However, it had to make sure that instrumentation produced in different laboratories would interface properly; reach a collective assessment on how best to collect data; schedule beam time on a synchrotron radiation facility at a national laboratory, and guarantee the national laboratory that it operated within the regulations that the accelerator laboratories have had to enforce for the exposure of people to radiation for medical purposes. It made one of its intellectual leaders the administrative leader, and he used the data runs and the initial geographic proximity of the participants as opportunities for collaboration meetings. The meetings (which were minuted) were the principal means by which the collaboration coordinated itself. When meetings became logistically more difficult and less frequent (because of turnover in personnel and a change in operations site to a new, superior facility in a different location) a collaboration-threatening misunderstanding developed. Participants were able to resolve this crisis and became more careful about keeping each other informed about their plans.

The very name “medical physics” evokes cross-disciplinary exchanges and the corresponding possibility of conflict based on different scientific orientations as well as different financial expectations, cultural expectations, and institutional affiliations. However, in none of these collaborations were scientific orientations an issue. Financial expectations were only an issue in the collaboration that used reimbursements as the means for holding participants to collaboration-wide standards. Contrasting cultural expectations—centered around the degree of difficulty of specialists’ tasks, the amount of time required to complete them, and the amount of explanation owed the practitioners of other specialties—troubled participants in the self-managed collaboration but did not threaten the collaboration’s existence. Only the institutional affiliation problem was an issue in more than one collaboration, and only in the self-managed collaboration did it become a serious issue. This collaboration did not have a secure niche in a funding agency’s program, and the addition of new institutions led to uncoordinated and potentially conflicting efforts to raise funds. (The minimally managed collaboration and its funding agency had to address how much a corporate participant should share in the costs of its involvement.)

D. *Activities of Teams*

- **Teams in medical physics collaborations could be functionally differentiated to cover all facets of developing a diagnostic tool or functionally equivalent to standardize procedures used on patients.**

- **Differentiated teams performed research and development that was constrained by the goal of producing an integrated system. They shared data to facilitate comparative assessments of each other’s performance.**

- **Equivalent teams did not perform research and development but were autonomous and self-sufficient in collecting data through standardized procedures. They did not share data with each other but sent data to the statistics teams to insure data acquisition remained unbiased.**

Sets of teams in medical physics collaborations were of two types. One type was comprised of functionally differentiated teams in order to cover the range of skills and specialties needed to create an effective diagnostic system. The other type used functionally equivalent teams in order to standardize diagnostic procedures over a statistically significant portion of the population and thereby assess the efficacy of the procedures.

The functionally differentiated teams filled niches within the diagnostic system that the collaboration hoped to develop. Each was responsible for the research and development of the instrumentation, algorithms, or clinical evaluations required for its task. (Academic physicists, physicists at national laboratories, and physicists in industry built instrumentation in-house; physicists working for medical centers built prototypes and contracted out for final design and construction of instrumentation worthy of full-scale clinical testing.) The collaborations we studied included an instance where the teams worked in near total autonomy and another where they worked in close coordination. In the former case, the physicists worked for medical centers or for corporations with a history of supplying medical instrumentation, and each team developed its own form of a diagnostic technique. The teams shared data as they saw fit; in practice, that meant the teams shared data liberally because the diagnostic techniques were technically different enough that none of the participants saw any advantage to keeping their information proprietary. In the latter case, the physicists worked in university departments and national laboratories. The teams shared all data, which sometimes led to conflicts because practitioners of one specialty occasionally resented having their work questioned by practitioners of another specialty. We hypothesize that when medical possibilities are perceived in the work of physicists employed by medical centers, the physicists will have designed the work to fit within medical niches and that a collaboration trying to develop a diagnostic system will not need high levels of coordination to bring about a meshing of clinical and laboratory practices. By contrast, physicists employed outside bio-medical organizations probably did not initially consider medical possibilities and had no pressures to incorporate medical possibilities into the designs of their work. Consequently, in the latter case, a collaboration incorporating physics apparatus into a diagnostic system will likely need to integrate their teams' activities in order to bring about an adjustment of laboratory and clinical realities.

The functionally equivalent teams were designed to standardize diagnostic services to patients willing to participate in the collaboration's research. Tinkering with instrumentation or procedures was expressly forbidden by the research protocol the collaboration established at its initial meetings. The collaboration determined what data to take; each team was then self-sufficient in gathering its share of the data. Both teams and individuals were kept deliberately ignorant of what others were finding. All data went to the administrative unit for processing and then to the statistics group for analysis. The teams never had access to all the data streams until the statistics group was confident that further data acquisition would not be biased by the teams seeing the extant data. When the statistics group's findings were wanting in timeliness or quality in the eyes of the teams, team members were prone to question the viability of the research design.

E. *Dissemination*

- **The more rigidly managed a collaboration, the greater the controls on publication and the more inclusive the author list for published articles.**

The barely managed collaboration indeed barely managed the collaboration's dissemination activities. The teams published independently, just citing the collaboration's support; on the few occasions that have called for public presentations representing the entire collaboration, the project director has drafted the paper and circulated it for approval within the collaboration.

Both of the more heavily managed collaborations managed dissemination on a collaboration-wide basis. In the self-managed collaboration, the unwritten but well understood rules were that a physicist oversaw the writing of papers aimed at physics audiences, and a physician oversaw the writing of papers that were aimed at medical audiences. Manuscripts were circulated among the participants, who all understood their roles well enough that there was never a dispute over the author list. In the collaboration with externally imposed management, paper writing had to await the completion of the statisticians' analysis, which had to await the collection of the full data set. The written rule was that the "coordinator" drafted the first important paper presenting the substantive results, circulated it among the PIs, and was listed as first author. The rights of team members below the level of PI to be authors on these papers was disputed, since the task of team members was only to follow the collaboration's instructions on the acquisition and submission of data.

F. *Funding*

- **Bio-medical funding agencies were oriented towards individual investigators and did not adapt well to reviewing or supporting multi-institutional proposals.**

- **Physics-friendly funding agencies were uncertain when to initiate support of medically oriented physics research and when to withdraw support to let the research be judged entirely on its medical potential.**

Administrative procedures at the National Cancer Institute and the other NIH institutes that support bio-physical research are designed to elicit and review proposals from individual investigators. Two of the three collaborations existed, in the eyes of their funding agency, as aggregations of individual grants (even though, in one of these cases, the collaborators had found each other and produced a set of cross-referenced proposals). In our one case of a collaboration between physicians and physicists with university or national-laboratory affiliations, the participants struggled to maintain funding. The agencies that traditionally supported physicists and the agencies that traditionally supported physicians had no means to coordinate their support and to decide when the collaboration's activities were appropriately judged as contributions to the development of physical instrumentation and when as contributions to medical diagnostics.

G. *Internationalism*

- **Internationalism was unimportant, which is to be expected given the importance of national standards for medical practice.**

Given the importance of national standards for medical practice, it is not surprising that internationalism was not prevalent in medical physics collaborations. Only one of the collaborations included a non-American institution—a Canadian institution that was a world leader in developing a particular line of diagnostic instrumentation. And that collaboration was organized to transfer the completed instrumentation to an American medical center for clinical testing.

H. *Communication Patterns*

- **Each collaboration's communication system was idiosyncratic.**

Our sample was too small and the collaborations in our sample too varied to infer whether any pattern to communication exists for medical physics collaborations.

I. *Social and Scientific Significance*

- **Collaborations researching and developing new diagnostic tools had more stable membership than those investigating the efficacy of diagnostic tools.**

- **All collaborations struggled to balance standardizing practices in the interest of testing them clinically and tinkering with practices in the interest of discovering superior methods.**

The costs of medical physics collaborations are difficult to assess because of their occasionally disjointed funding, cost-sharing with corporate participants, and the participation of physicists without dedicated funding. However, the costs of performing clinical trials to assess the efficacy of diagnostic systems dwarfed the cost of developing the systems.

The collaborations developing diagnostic systems have been more stable than the collaboration assessing the efficacy of diagnostic techniques. As the latter has switched its focus from organ to organ, it has made close to wholesale changes in institutional participants, with only the professional society and the statistics group participating in each and every study. The collaborations developing diagnostic systems have either not changed membership at all or added institutions to take advantage of new and better facilities for supporting their research.

These collaborations have all had stable internal organizations. However, one of the system-developing collaborations has been planning to make organizational changes in anticipation of changing from development to clinical testing of their systems.

The small number of cases examined, AIP's lack of familiarity with the field, and the diversity in formation and management among these collaborations all make it difficult to draw general policy lessons. Also, new policies at NIH to attract experts in computation to bio-medical research has the potential to make NIH more receptive to funding multi-institutional collaborations in medical physics. However, one problematic condition these collaborations had in common was a struggle with the trade-off between standardizing practices in the interest of testing practices clinically and tinkering with the components of diagnostic systems in the interest of discovering obviously superior practices. Conflicts were most significant in the collaboration that froze practices. When the data-gathering teams could not accrue patients quickly enough to enable the statisticians to reach robust results before equipment manufacturers produced their next generation of systems for acquiring data, the data-gathering teams considered the collaboration's results obsolete upon publication. Some interviewees expressed an unwillingness to participate again in such research.

VII. *PARTICLE AND NUCLEAR PHYSICS*

A. *Introduction*

In the first phase of the long-term study, AIP interviewed approximately 150 participants in 19 high-energy physics experiments that were approved between 1973 and 1984. In the third phase we interviewed five participants in two heavy-ion experiments, which included both high-energy and nuclear physicists and were funded by the nuclear physics programs at DOE and NSF. The heavy-ion collaborations fit readily into the patterns we found in high-energy physics. Furthermore, nuclear physicists on our Working Group informed us that our findings for high-energy physics conform to practices in nuclear physics. We therefore have merged high-energy, heavy-ion, and nuclear physics under the designation "particle and nuclear physics."

In selecting experiments for investigation, we consciously included a variety of types: larger and smaller experiments, fixed-target and colliding-beam experiments, experiments using proton, electron, and heavy-ion beams, and experiments from the four most important accelerator laboratories in the United States (Brookhaven National Laboratory, Fermi National Accelerator Laboratory, Stanford Linear Accelerator Center, and Cornell's Newman Laboratory) plus a parallel study of the European laboratory, CERN. In most cases, interviews were conducted by project staff in the interviewee's office using question sets standardized for each interviewee category: physicists, graduate students, and engineers and technicians. Additionally, project staff and consultants conducted more in-depth investigations of one experiment at FNAL, one at SLAC, one at Cornell, and one at a major manufacturer of instrumentation for high-energy physics. These investigations involved almost 100 additional interviews.

B. *Project Formation*

- **Design and construction of accelerators occurred outside the framework of our collaborations' tasks of detector design and construction.**

- **Accelerators set the technical environment in which collaborations form, and construction of a new accelerator has been the primary stimulus to form new collaborations.**

- **Accelerator laboratory administrators have been the most important gatekeepers between a would-be collaboration and beamtime.**

- **Collaboration instigators sought just enough American groups to be credible with laboratory administrators.**

- **However, they have also made a point of recruiting accelerator-laboratory research groups and foreign groups with special expertise.**

Since the 1930s, physicists have conducted experiments on the elementary constituents of matter at "accelerator laboratories"—large facilities where scientists, engineers, technicians, and construction workers have assembled the enormous apparatus needed to accelerate charged particles to the high energies needed to overcome the forces that hold subatomic particles together. Accelerators vary by the particles they accelerate and, since the early 1970s, they have also varied by the kind of experimental layout they support. Some accelerators send particles down “beamlines” where they crash into stationary targets, causing the release of particles that physicists detect with apparatus laid out linearly behind the target; other accelerators collide two beams of particles traveling in opposite directions, causing the release of particles that physicists detect with apparatus concentrically nested around the collision point. For fixed target experimentation, physicists have come to prefer electronic apparatus, which produce digital signals that can be immediately manipulated with computers; only electronic apparatus has been used in colliding-beam experiments.

Collaborations of particle physicists have formed to perform experiments by building “detectors”—more or less elaborate combinations of instrumentation, computers, and software that together enable physicists to detect subatomic particles released when accelerated beams either collide or smash into fixed targets. Accelerators have been designed prior to and independently of the design of individual experiments. Would-be collaborations have petitioned national laboratories for access to their accelerators and the laboratories’ administrations have appointed advisory committees whose recommendations are critical for deciding who gets “beamtime” and space at the laboratories. Collaboration members also have petitioned funding agencies, usually through their home institutions, for the money they needed to participate. The general sentiment among interviewees was that if the laboratory granted beamtime, the agencies would provide funding. However, in the more recent collaborations in our sample, the member institutions only paid for the salaries and travel of their individual employees; the cost of materials and construction were funded through a central collaboration account that the funding agency set up at the accelerator laboratory. In this arrangement, the relative importance of the physics advisory committee and the funding agency in determining whether an experiment gets performed has tilted towards the funding agency.

The construction of a new accelerator has proven to be a sure way to stimulate a shake-up in the pattern of working relations among particle physicists. Our sample encompassed or was proximate to the opening of Fermilab and the subsequent development of its tevatron, the development of the SPEAR and PEP colliding-beam accelerators at SLAC, the development of the Cornell Electron Storage Ring, the use of the SPS synchrotron at CERN to collide proton and anti-proton beams, the use of the Alternate Gradient Synchrotron at Brookhaven to accelerate heavy ions, and the beginning of construction of the Relativistic Heavy-Ion Collider at Brookhaven. Most of the collaborations in our sample formed to take advantage of a new accelerator. As an oversimplified first approximation, collaboration formation in particle physics has been “new-accelerator-driven.”

The instigators of an experiment at an American laboratory understood that they needed to attract enough physicists to convince laboratory administrators that the experiment, if approved, could be built and run as proposed. That condition drove physicists to form collaborations to match the scale of their experiments rather than the norms of the past. Instigators almost always had to find collaborators from outside their circle of physics friends. Except when a non-American institution possessed unique technical capabilities, experiment instigators tended to worry about getting the right number of collaborators for an experiment rather than putting together a complementary blend of skills and sub-specialties. American physicists assumed that they were all familiar with, if not expert in, all phases of an experiment, and that a university's particle physics group encompassed all the skills needed for an experiment. Throughout our sample, physicists wrote their experiments' computer programs and built instrumentation in their home institutions' laboratories and shops. The lone strategic element in fleshing out a collaboration has been that instigators have usually wanted to include physicists on the staff of the accelerator laboratory in their collaborations. Relations with a laboratory's staff were facilitated by having in-house physicists in the collaboration, and in-house physicists provided an avenue by which the collaboration could tap other laboratory resources, such as computers for data acquisition.

No central authority has mandated roles to be filled and titles to be used in collaborations of particle physicists, but participants have come to adhere to a few norms. A collaboration has been represented by its "spokesperson" when it has to deal with the management of an accelerator laboratory or other external powers. The leading physicist from each of the institutions participating in a collaboration has been the "group leader." The other faculty, post-doctoral scientists, and graduate students brought into a collaboration by a group leader from a university have been known as a "team."

C. *Organization and Management*

- **Particle physics collaborations maximized participation in scientific discussions and minimized the powers that collaboration administrators exercised over the members.**

- **To varying degrees, all collaborations used the accelerator laboratory as a headquarters, divided labor along institutional lines, and created a collaboration-wide information pool.**

- **Collaborations blended these organizational strategies principally in response to technical needs, though institutional, historical, and logistical factors also influenced structure.**

- **A spokesperson's role depended on whether the collaboration built a multi-purpose detector with elaborate and challenging systems engineering or a more specialized detector with few systems challenges.**

Particle physics collaborations sought to maximize participation in discussions and decisions concerning the basic strategies for designing, running, and producing results from their experiments. Instigators kept their collaborations as small as possible without sacrificing credibility in order to minimize the need for formal administration. They used data runs at the accelerator laboratory as opportunities for collaboration-wide meetings, and even the ones that created relatively elaborate administrations used collaboration-wide meetings as the forum for scientific discussions. The number of institutions, more than the number of physicists, created the greater organizational challenges to collaborations. Because academic particle physicists in the U.S. were funded as university groups, whose size and budgets were limited by both university and governmental dynamics, and because accelerator-laboratory groups were fewer in number, collaborations could become larger only by including more domestic academic institutions or foreign groups. The addition of institutions brought collaborations both extra resources and organizational complexity. This fundamental trade-off was probably the greatest source of daily friction within collaborations.

Collaborations could not readily deal with their organizational complexities through the creation of an intra-collaboration authority because collaborations had no claims to the powers that could significantly reward or discipline their faculty-level members. Promotions, pay raises, hiring privileges, the administration of research grants, and access to a machine shop or research and development laboratory rested with the institutions that employed the collaborators. When collaborations suffered acute conflicts, the conflicts usually resulted from the collaboration being unable to acquire the power to deal with its organizational complexity.

Collaborations nevertheless managed to conduct daily business because of widespread acceptance of how experiments could be performed and how participants should build careers within their home institutions. Every collaboration made the accelerator laboratory something of an organizational headquarters because that was where detector components were assembled and data taken. Every collaboration divided and duplicated labor along the lines of the participating institutions to avoid overloading a spokesperson with supervisory burdens and to enable group leaders to demonstrate their importance to a collaboration within their home institutions. And every collaboration set up information pools to enable members to work with hardware and software that others had developed. How collaborations combined or compromised among these organizational principles varied with their technical, institutional, historical, and geographic circumstances.

Every experiment has a "spokesperson," who has, narrowly speaking, been an administrative convenience—an individual designated to speak for the collaboration to the laboratory and to inform collaborators of laboratory requirements. However, the role of spokesperson has also carried connotations of scientific initiative and leadership. The nature of the spokesperson's leadership and the relationship between leadership and administration has varied with the organizational structure the collaboration adopted; technical factors have figured most prominently in how collaborators have chosen to organize themselves.

When construction and integration of an experiment's detector did not involve severe systems engineering challenges, a spokesperson rarely relinquished the role, even though several commented on the burden of becoming and staying cognizant of all aspects of the experiment. This was typically the case in fixed-target experiments performed as one in a "string" of experiments. Strings consisted of a core of physicists who continued to obtain beamtime with new proposals that called for using some or all of the apparatus they had previously used, or for building new apparatus that recapitulated and embellished on the design of their previous detector. The spokesperson for a given experiment was typically the collaboration member who convinced enough fellow-members that he had the best ideas for new measurements to be made with incremental changes in their components or the components' configuration. Spokespersons were thus possessive of their positions as evidence of their leadership and scientific judgement and obliged by their positions to maintain the documentation needed for future experiments in the string.

When a detector posed severe systems-engineering challenges, spokespersons were more likely to change and the collaboration more likely to create additional administrative positions to handle collaboration business, especially the designation of a technically minded physicist or engineer to track the development of the components and deal with systems engineering and integration issues. Such has been the case in colliding-beam experiments, where physicists surround the point of collision with concentrically nested sets of detector components. Leadership in these collaborations has been based on the ability to imagine a detection strategy that will garner meaningful information across much of the accelerator's energy range and that can be used to investigate several distinct physics topics. Once a colliding-beam detector was built, its instigator became just one of several participating research physicists who each had personal preferences for physics topics to address. Shifting spokespersons may reduce social tensions in these internally divided collaborations by keeping resentments towards any individual from accumulating. A byproduct has been that the "office" of the spokesperson has been more important for the collaboration's records than any one spokesperson's records.

D. *Activities of Teams*

- **Teams were responsible for individual components, including read-out circuitry and processing software.**

- **Teams were usually self-sufficient in designing whatever could not be purchased "off the shelf."**

- **Teams assumed responsibility for components principally on the basis of past experience.**

- **Responsibility for a component influenced only the initial members' choice of analysis topics, because all data streams and processing software were communal.**

Teams were principally responsible for design, construction, and maintenance of individual detector components. This usually included the circuitry to read out the component's data and the software to process the data. Physicists with prior success in building a particular component tended to recapitulate their earlier success in their later experiments. Rarely did an interviewee speak of wanting to build a particular component because of the component's connection to the particular physics topics the interviewee wished to address, because all data from all components were the communal property of the collaboration. (Collaborations typically merged their data streams in the creation of data summary tapes.)

Sub-contracting with industry has not played a significant role in the development of new detection technologies in the United States. (The same was not true for Europe, partly because the CERN policy to spend its funds in the various member states fostered subcontracts to industry.) However, there have been American firms, such as Lecroy Electronics, that have concentrated on developing general-purpose apparatus to sell to particle physicists. Its business strategy fit well with American experimentalists' penchant for keeping collaborations as small as possible and requiring participants to build the detectors themselves.

A large task for most teams was the reconstruction of its component's signals into categories and events that physicists could use to make calculations or measurements. The quantity of work that went into writing these one-of-a-kind software programs usually induced collaborations to treat them as communal property that all collaboration members should use as the starting point for all their data analyses. However, on occasion collaborations produced multiple reconstruction programs for processing raw data. Such collaborations struggled with conflicts over the virtues of the several reconstruction programs and over the commensurability of results reached by using different programs.

Initially, the physics topics addressed by collaboration members usually followed from their detector responsibilities. Individuals intimately involved in the development of a component wanted to see their efforts in instrumentation "pay off," and they had a comparative advantage over the rest of the collaboration in addressing topics that made heavy use of their component's data stream. However, such a "team-centered" approach to data analysis did not endure as the "first generation" of students and postdocs left the collaboration. New members chose topics without comparable commitments to the development of a particular component.

E. *Dissemination*

- **Both conference talks and journal articles were regulated by the collaboration as a whole with collaboration members entitled to dispute the validity or importance of findings and the proper attribution of credit for findings.**

Collaborations in particle physics usually regulated the dissemination of their experimental results. Conference talks, though not always a rare commodity, were carefully distributed within collaborations to confer credit and grant exposure to the collaboration's lesser-known members. Drafts of journal articles were almost always subject to a collaboration-wide review with all members entitled to suggest changes; thus the extraordinary length of the author lists for papers produced by large collaborations. Any disputes over the reliability and interpretation of results were resolved in the intra-collaboration review and were not reported in public forums. In a few instances, collaborators have removed their names from author lists because they thought the particular topic was not worth investigating. In none of the experiments we studied did any interviewees report that any participants asked to be removed from author lists out of distrust of a paper's results, though some interviewees had heard of or been involved in experiments where that happened.

At least five of the 21 collaborations we studied tried to highlight an individual's contributions to a particular analysis by placing the person at the head of the author list for the paper that presented those results. Ambiguity over who belonged in that position invariably provoked acrimonious discussions, especially when two students were vying for the prize.

F. *Funding*

- **Funding for collaborations was funneled through physics departments of member institutions, which were held accountable for use of funds.**

- **More recent experiments on colliding-beam accelerators funneled funding through the accelerator laboratory to strengthen the laboratory's role in insuring that systems-engineering problems were identified and solved.**

In the U.S., units in university physics departments, continuing a tradition that goes back to World War II, hold contracts with either DOE or NSF for the support of their particle physicists. There are at least two powerful reasons for using this framework: collaborations have been transitory while universities are stable fixtures in the institutional landscape; and university units may want to regulate the activities of individual faculty in the interests of maintaining a mix of activities that best serves the university and its students.

The experiments done on the PEP accelerator at SLAC and collider experiments that are larger and more recent than those covered in our sample have not conformed to this tradition. Instead, the government has provided the accelerator laboratory with funds for detector development, and the laboratory has distributed the money to collaborations with approved experiments. This laboratory-centered approach to funding experiments appears to be part of a trend to make the laboratories responsible for disciplining the collaborations that perform large, expensive experiments with intricate systems-engineering challenges in the design and integration of their detectors.

G. *Internationalism*

- **International collaborations were rarely desired but often necessary.**

International collaborations were children of necessity. None of the international collaborations in our sample became international as a result of prior personal or professional contacts, though they often led to lasting friendships. From the perspective of U.S. experimentalists (which is the perspective of most of our interviewees) any of four factors behooved experimentalists to seek foreign collaborators:

(1) A foreign group had developed an experimental technique that U.S. physicists wished to use and learn;

(2) An experiment required more manpower and money than could be readily raised domestically;

(3) A laboratory director spotted common interests in proposals from domestic and foreign collaborations and brokered a merger of the two; and,

(4) In one case, U.S. experimenters brought in foreign collaborators as part of an arrangement to move a working detector from an American to a foreign accelerator when the U.S. accelerator would no longer provide the beam time the experimenters wanted.

H. *Communication Patterns*

- **A collaboration's communication pattern depended on how it drew on basic organizational strategies.**

- **Collaborations have increasingly used electronic communication, but the collaboration meeting has remained the medium in which fundamental scientific issues are decided.**

Basic institutional and intellectual conditions of particle physics experiments required that all collaborations draw on three organizational strategies, each with a characteristic pattern of communication. (1) All collaborations treated the accelerator laboratory as an organizational headquarters; (2) all divided and duplicated labor to increase efficiency and to have a foundation for checking the reproducibility of puzzling or controversial findings; and (3) all collaborations needed an information pool that enabled members to take advantage of what others had developed.

In collaborations with strong headquarters—as was typically the case when the detector's components were difficult to integrate into a readily operated system—detailed information flowed from the outlying institutions to the laboratory, where a collaboration administrator tried to spot and defuse any problems in how the work done in outlying institutions would fit together. In collaborations that stressed the division and duplication of labor—as was typically the case when individual components were more of a challenge than overall detector integration—the teams did not want to deal with the details of each other's components, and the collaboration only collected what information was needed for each team to understand what the other had done. In collaborations that stressed the creation of an information pool—as was typically the case when conventional detector components were used with an innovative beamline or target—teams wanted the details of each other's components and relied on frequent inter-institutional communication (through meetings, phone calls, faxes, telexes, or e-mails) to keep up to speed on the technical developments of all parts of the experiment. Each collaboration idiosyncratically blended complementary organizational strategies and compromised among conflicting strategies in order to have the best chance of handling its toughest difficulties.

Viewed over time, our sample brings out one major trend and two major continuities. The creation of intra-collaboration information was increasingly formal (e.g., collaboration-wide mailings and memoranda) and increasingly electronic in the larger, more recent experiments. However, collaborations continued to divide labor, and the collaboration meeting remained the forum for discussions that led to decisions concerning the tactics and results of experiments.

I. *Social Significance*

- **Particle physics' distinctive political culture enabled collaborations to extract much work while exercising little power.**

- **The time scale of experiments was a main source of difficulties for careers in particle physics.**

Particle physics collaborations have been remarkable in that they extract large amounts of work from their members but possess few powers. Their peculiar blend of centralized institutional politics, egalitarian instincts, and competitive pressures account for this paradox. Collaborators have been obliged to agree on an organizational structure at the time of the collaboration's formation because of their need to convince central authorities (i.e., an accelerator laboratory's administration) that they were properly organized to produce what they promised. With respect for internal structure thus secured in advance, collaboration administrators have not required powers to maintain order and have granted broad rights of participation to all members of the collaboration, from graduate students to senior faculty. Such Athenian-style democracy has produced publications rather than cacophony because competition for discoveries and for career-advancing recognition limit the collective tolerance for intra-collaboration discussions.

The principal stress on particle physics collaborations has been coming from divergence in an experiment's time scale from the norms of academic careers. The construction times for large experiments have made it nearly impossible for students to build hardware for and analyze data from the same experiment and difficult for junior faculty to demonstrate they deserved tenure to faculty members outside particle physics.

VIII. *SPACE SCIENCE*

A. *Introduction*

For space science, AIP interviewed approximately 100 participants in six multi-institutional projects that were all launched between 1975 and 1985. (In the terminology of the field, "project" refers to the effort to launch, operate, and analyze data from spacecraft; we will use "project" in the space scientists' sense in this section.) These figures include the projects and interviews undertaken in our study of NASA and our parallel study of the European Space Agency (ESA). AIP staff and consultants consciously tried to cover a range of features in the selection of projects to investigate: projects managed by different space flight centers, projects whose participating scientists came from a variety of institutions, international and nationally organized projects, astrophysical and planetary science projects, and smaller and larger projects. In our choice of interviewees, the AIP staff sought to cover all the types of people who might be vital to the documentation of scientific work, from administrators at funding agencies to graduate students at university departments. However, the perspective of flight-center scientists and engineers is strongest, because they turned out to be the best sources of documentation of space science projects during the period we studied.

B. *Project Formation*

- **Design and construction of scientific instruments were done in conjunction with design and construction of the spacecraft, which was the most expensive part of a space science project.**

- **Space flight centers were the principal, but not the only, institutions that combined expertise in both spacecraft and instrument design and construction.**

- **Collaboration instigators needed a sponsor at funding-agency headquarters to champion the cause of acquiring funds.**

- **The funding agency has had the authority to decide on the participants in the project.**

In the first decades of government-sponsored space science, an enduring framework developed for dividing responsibilities for facets of space science projects. Rocketry, spacecraft structure, thermal balance, power supplies, spacecraft operations, and telemetry all came under the control of engineers. Problems of instrumentation and data analysis came under the control of scientists.

To participate in the design of a space project, scientists have needed engineers for their up-to-date familiarity with the capabilities of spacecraft.

The NASA space flight centers and the European Space Research and Technology Center (ESTEC), the lone ESA space flight center, have made it their business to house the expertise needed to design space science projects. They have placed a modicum of bureaucratic formality on the formation of projects. In "Phase A," studies have been commissioned to ascertain the technical feasibility of a project that has attracted interest through informal study. Desirable results have led to "Phase B," in which spacecraft designs are refined and construction costs estimated, with the goal of receiving an authorization to build and launch a spacecraft equipped with scientific instruments.

While flight centers have been the most significant incubators of space science projects, a few other laboratories have also combined spacecraft-construction capabilities with scientific expertise in the design of research instruments to be flown on spacecraft.[19] Scientists in university departments, however, lacked the resources to play a role in the creation of our selected projects.[20] Our evidence suggests that individual universities have specialized in the design and use of research instruments. Conversely, aerospace firms have specialized in spacecraft construction.

Project instigators working at a flight center had routine organizational channels through which to bring their plans to the attention of headquarters. When outside scientists instigated projects with little or no help from a flight center, their principal difficulty was to find a route into the politics of the agency's budget.[21] The existence of the projects we have studied attests to the wisdom, flexibility, or luck of their instigators in dealing with the representatives of engineering, scientific, and institutional interests in the politics of funding.

To flesh out ideas to the point of obtaining Phase A authorizations, scientists within the flight centers have informally lobbied center administrators and pitched their ideas to center engineers in order to recruit enough talent to acquire credibility. When flight centers have wanted to push their engineers' ideas for science projects, they have needed external indications that a scientific community supported their plans. ESA officials have acquired such assurances from specialized

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[19]In Europe, national governments have enabled such research institutes as Rutherford-Appleton Laboratory and the Max Planck Institute for Extra-terrestrial Physics to design space science projects, including the spacecraft. In the United States, the Defense Department has enabled such laboratories as the Johns Hopkins Applied Physics Laboratory and American Science and Engineering to do the same.

[20]This result may be an artifact of our selection of case studies; one obvious counter-example is the role Lyman Spitzer of Princeton played in creating the Hubble Space Telescope. See Robert W. Smith, *The Space Telescope: A Study of NASA, Science, Technology, and Politics.* New York: Cambridge University Press, 1989.

[21]Furthermore, it appears that flight centers have become less important for initiating projects. Officials at both NASA Headquarters and Goddard Space Flight Center cite the importance of "discipline scientists" at NASA Headquarters and their "Working Groups," committees of flight-center and external scientists, as the initial proposers of desirable projects.

working groups that report to ESA's Space Science Advisory Committee. NASA officials have turned to the National Academy of Science's Space Studies Board or to one of the advisory boards of external scientists created by NASA's Office of Space Science.[22]

Whether a project originated with space-flight scientists having ideas for making better measurements or space-flight engineers having ideas for making better spacecraft, project instigators have cultivated an agency headquarters scientist to promote the project within the agency's budget deliberations. Headquarters scientists, whose sense of accomplishment has depended on successfully promoting projects, have been receptive but discriminating consumers of suggestions. They have consistently used "working groups"[23] to judge or refine the outlines of projects. For projects that were small enough to be funded from an established line-item in the agency budget, working group deliberations have been the principal hurdle to initiating project construction. For projects that were large enough to require explicit authorization, obtaining working group support has been one major step on a longer path to approval.

The reward to the headquarters scientist who succeeded in agency budget politics has been to participate in drafting an Announcement of Opportunity (AO) to elicit proposals for instruments to be flown on the project and then to lead in the selection of proposed experiments. This selection was influenced by the comments of peer reviewers, engineering assessments of the proposals, and the sensibilities of the headquarters scientist's administrative superiors. In some projects, working groups drew up "straw-man payloads" to guide the competition for slots on the spacecraft.

Two projects were instigated with minimal flight center support; their principal hurdle to formation was the lack of a straightforward route into the agency's deliberations. Both sets of instigators used the tactic of persuading leaders in relevant experimental techniques to sign onto integrated proposals under a self-invented title other than principal investigator, which was reserved for the instigators themselves. The point, according to one of the recruits, "was to present to NASA something that was too good to turn down... [viz.] the participation of [all] the major players... so that there wouldn't be any serious competition from outside." The result was a partial subversion of a headquarters scientist's normal prerogatives. In principle, the agency could have broken up the self-made collaboration and reconstituted the project with multiple principal investigators (PIs), but chose not to.

C. *Organization and Management*

- **Space agencies have created a standard structure to balance the demands of scientists and engineers.**

[22]The name and precise responsibilities for this office have changed over time, but it has always been responsible for NASA's science projects.

[23]"Working Group" is a loosely and frequently used term in space science. In this section, it refers to standing or *ad hoc* advisory committees of scientists. In the next section, which analyzes the organization of fully formed projects, "Science Working Group" refers to the scientists who design and build a project's experiments plus others the scientists choose to include in their collective meetings.

- **Scientists discussed their collective concerns in a Science Working Group chaired by the project scientist; the breadth of what they deemed collective varies but never has included considering the content of scientific papers.**

- **Project managers have been in charge of budget, schedule, and integration of spacecraft, which included the payload of scientific instruments; managers's relations with scientists were best when SWG's concerns were narrow.**

- **Headquarters officials tracked expensive projects closely, but did not influence the substance of the project except when project participants could not resolve a conflict.**

NASA has imposed a formal structure on space science projects. Program managers at NASA Headquarters, engineers by training, have overseen project managers, also engineers by training, at NASA space flight centers. Project managers have overseen the design, construction and integration of spacecraft, including their payloads of scientific instruments. The PIs, scientists by training, have designed and built scientific instruments. A project scientist, typically an employee of the space flight center, has advised the project manager on spacecraft engineering options that could affect the project's scientific capabilities and has kept the other PIs informed of spacecraft engineering developments. To discuss and resolve collective scientific concerns, the project scientist has led meetings of a "Science Working Group" (SWG) of PIs and select members of their teams. The project scientist has also reported to a program scientist at NASA Headquarters, who has been able to bring scientists' concerns to the program manager at Headquarters or their mutual superiors.

These arrangements have attempted to manage an intrinsic tension in the concept of space science projects: which is the more difficult and significant challenge—sending and operating equipment in space, or satisfying criteria of scientific value? All space projects have had common problems of design and operations, and project managers are expert in building apparatus that will function in space. However, science projects, whether pursued in space, the natural earth environment, or the laboratory, have been valuable only if they yielded new or improved data. By providing scientists with their own line of communication to higher authorities, NASA has reminded project managers that they must serve as well as manage the PIs. Projects vary in how they cope with this tension.

1. *The Scope of the Science Working Groups*

Science Working Groups in our sample varied in how much business they handled. Scientists appear to have been torn between limiting the scope of the SWG, and thus maximizing their autonomy from each other, and expanding the scope of the SWG, and thus maximizing their unity in dealing with project engineers and outside scientists. The policy of scientists in any particular project depended on the project's origins and the way in which the project's participants joined. Projects that originated within the space flight centers and that were staffed with PIs chosen through a competition organized by NASA Headquarters had relatively circumscribed SWGs in comparison to projects that originated in outside laboratories and that were staffed with scientists recruited by the projects' scientific instigators.

In an extreme case, the SWG in one of our case projects was initially ceremonial and never became an important body for determining the design of the project or the science it made possible. Most commonly, the SWG restricted itself to dealing with collective issues that were engineered into the project's initial design, such as problems of interference between scientific instruments or the protocol for coordinating the operations of the instruments. At the other extreme, the SWGs for the two projects that originated outside flight centers felt the need to expand their scope in order to secure or maximize the project's scientific values. These two projects suffered through more conflicts than the others we studied, because the SWGs wanted responsibilities that the project or program manager considered their province.

Even the projects with expanded SWGs kept significant areas of science activity in the control of their projects' experiment teams and outside the SWGs' jurisdictions. Experiment (i.e., instrument) builders almost always cared principally about the spacecraft's capabilities and their individual interfaces to it rather than the capabilities and designs of other experiments. Individual teams decided when, where, and what to publish. When scientists within a project reached different conclusions about the same topic, they almost always disseminated their views individually without attempting to reach an intra-project consensus.

2. *The Scope of Flight Center Officials*

In every project, the flight center project manager was responsible for the project's money and schedule and was usually the most powerful individual in the project *during its design and construction*. In most cases project managers imposed their flight center's customs on the project. Most issues were resolved in communiques between PIs (or their engineers) and the project manager (or a staff member the project manager assigned to track science payloads). Even when the PIs resented the flight center's culture or the project manager's style, they usually accommodated each other. Only in the projects that originated outside the flight centers did conflicts between scientists and project management escalate to Headquarters.

During mission design and construction, the needs of the project manager consistently determined the scope of the project scientist's work. When the SWG dealt with collective science issues without requesting additional resources, the project manager needed the project scientist's guidance on when engineering expediency might upset the scientists' planning. When the SWG incubated conflicting ambitions that the spacecraft could not handle, the project manager needed the project scientist to adjudicate conflicts among the scientists and mediate between the scientists and project management. In the projects that formed outside the flight centers, the lead instigating scientist from outside the flight center overshadowed the project scientist in dealings with the project manager.

After the launch, project scientists administered project funds for data analyses and fielded proposals from members of science teams that were pursuing longer-term research on their data sets. Once funding for the project ceased, science teams had to obtain funding for analyses in the general competition for NASA program grants.

3. *Coordination Among Flight Centers*

The cases we studied included three international, multi-flight center projects: two multi-spacecraft projects in which one spacecraft was built at each flight center, and one single-spacecraft project in which the flight centers each built part of the spacecraft. The multi-spacecraft projects were consciously organized to minimize inter-flight center engineering interfaces, to maximize the project managers' individual and collective latitude, and to leave coordination of the project's greater-than-national capabilities to the province of the SWG, which operated as an international body in both these projects.

In the case of a single spacecraft that had systems built by multiple flight centers, the project staffs communicated heavily to discover and solve the integration problems before the scheduled launch, but the nations still had their own SWGs, which operated autonomously. Each flight center's SWG had designated blocks of time in which it could specify how the spacecraft should be operated.

4. *The Scope of NASA Headquarters Officials*

Once Headquarters had selected a flight center, selected the PIs, and initiated the flow of money for a project, its officials lost most, but not all, ability to exert daily influence over a project. Whether they continued to be active in a project depended on the project's budget and the intensity of conflict between scientists and project management. When a project was unusually expensive, or when conflict within the project was sufficiently intense, Headquarters officials were influential. Even when not interested in exercising influence, program managers often collected excellent records, because project managers were careful to report thoroughly and to invite program managers to important meetings. To do otherwise was to risk exciting a program manager's suspicions that a project harbored hidden problems. Program scientists only became significant when participating scientists and project managers could not resolve their conflicts.

D. *Activities of Teams*

- **Teams were responsible for individual instruments and almost always built upon past successes because of difficulties in "space-qualifying" an instrument.**

- **New instrumentation was usually developed by adapting laboratory instrumentation for use in space.**

- **Teams were comprised of a stable nucleus of instrument-builders and a shifting cadre of scientists with ideas for how best to use the instrument.**

- **Teams had proprietary rights to their data for one year, and teams attempted to be self-sufficient in addressing scientific topics.**

"Experiment" in the terminology of space science has referred to the design, construction and operation of an instrument plus processing and interpreting the signals the instrument returns. For purposes of design and construction, an instrument was often broken down into self-contained "boxes," whose mechanical interfaces were cleanly and simply specified at the start of the project and whose digital interfaces could be worked out over the course of construction. The head of a team usually has the title “principal investigator” (PI), and that is how we will use that term.[24] Other team members with independent standing as scientists usually held the title “co-investigator.” The significance of that title, as will be seen, has varied.

Scientists interested in carving out a niche for themselves in space experimentation must “space qualify” an instrument by demonstrating that it can survive the rigors of launch and operate in the harsh environment of space. Experimentalists have routinely employed two strategies to meet these difficult challenges. First, they consciously looked for laboratory instruments they thought could be adapted for use in space without compromising too severely on the instruments’ scientifically valuable features. Second, they have relied on components that have proven their reliability in commercial or military use[25] and rarely attempted to develop and use technical novelties unless an industrial firm was interested in taking up the novelty’s manufacture. Once experimentalists have space qualified an instrument, they usually have not even considered diversifying into a new area of instrumentation because of the competition they would face from established specialists.

Experiment teams have usually had a center-periphery structure. At the center has been a small number of institutions overseeing hardware development and basic data-processing software. On the periphery are scientists, often from other institutions, providing additional expertise in the science analysis of the data. In this manner, work on the many technical problems of space-based instrumentation have been efficiently centralized without wasting data on experimentalists unaware of all the ways the data could be used.

“Co-investigators” has been the common term both for scientists who contribute to an instrument while working at a different institution from the PI and for scientists who increase a team’s scientific breadth. When co-investigators contributed to instrument design and construction, the PI had to decide on the allocation of the experiment’s spacecraft resources among the instrument’s components and was responsible for keeping the several parts compatible. Co-investigators who were included to increase scientific breadth never influenced the technical development of an experiment; they were chiefly of symbolic importance, demonstrating the existence of outsiders’ confidence in the scientific value of a proposed experiment.

In all the cases we studied, the engineering of the mission forced participating scientists to work out a more or less elaborate policy for acquiring data. In most of the projects, the individual teams were united in the data-acquisition strategy each team preferred, and the PIs straightforwardly represented their teams’ interests in SWG discussions. Occasionally, a project’s teams included divergent scientific interests and, instead of PIs negotiating data-acquisition

[24]In projects that formed outside the space flight centers, PI referred to the overall project instigator and leader, and another term, like principal scientist, was used for the scientists in charge of building particular instruments.

[25]The military context in which the parts and materials of space instrumentation originated has not noticeably hindered space scientists. They have used them successfully without needing to know their internal workings or the manufacturing processes used in their fabrication.

strategies for their teams, the project formed inter-team interest groups to consider data-acquisition strategies.

Once data were collected, the funding agencies granted teams a limited period (usually one year) in which the teams had proprietary rights to their data; then the agencies required teams to turn over the data to an archives. In most cases, experiment teams strove for, and occasionally achieved, self-sufficiency in their ability to perform scientific analyses. Projects usually left PIs to dispose of their data during proprietary periods and provided neither technical nor moral supports nor impediments to inter-team data sharing or analyses. When teams were unable to achieve scientific independence, they more or less easily arranged to exchange processed data, with the understanding that borrowing scientists would have the lending PI check the borrower's work before the borrower disseminated results based on the loaned data.

The utility of archived data varied greatly. In one case, the project supplied and regularly upgraded data-processing software, which enabled outside scientists to use the archived data. In one case, a team developed and used its own software for processing the raw data taken by other teams' instruments. But in most cases, scientists who have wanted to work with data taken by others have sought the cooperation of the PI.

E. *Dissemination*

- **The contents of publications and presentations were team matters, not project matters; teams usually determined the timing of publications and presentations.**

- **There were no formal rules on who was an author, but common courtesy and fear of errors insured that writers consulted and then recognized the relevant collaborators.**

Teams were responsible for producing findings based on their data. They operated autonomously except when a journal issue was devoted to a project's results—and then teams still controlled the content of their own submissions. Fear of errors in analysis and common courtesy have insured that team members circulate manuscripts and recognize others' contributions (from both within their teams and from other teams when they have worked with multiple data sets). Public differences in interpretation of data have been considered normal, and team members have published papers without achieving team-wide consensus on the meaning or significance of their findings.

F. *Funding*

- **NASA's science office has had separate programs for funding projects and the research and development into spacecraft and for funding the use of extant data and research and development into instrumentation; ESA only funded projects, and individual nations funded their scientists' research and development.**

- **NASA projects with estimated costs below a mandated limit have been funded under the "Explorer" program, while larger projects required the creation of a new budget line; ESA's science office operated under a five-year budget plan that did not distinguish large and small projects.**

- **NASA's programs have covered both spacecraft and scientific instrumentation; ESA's has covered only spacecraft, with individual nations supporting their scientists' contributions to scientific instrumentation.**

In the U.S., NASA has been the sole supporter of space science. NASA's Office of Space Science has two types of programs: on the one hand, grants programs to support analyses of extant data or research and development into instruments for taking data; and on the other hand, contract programs to support the construction of spacecraft and their payloads of scientific instruments. In Europe, the participating nations have their individual means for supporting research and development. ESA's Science Directorate has contract programs to support construction of spacecraft for science projects. In both the U.S. and Europe, the separation of support for research and development into instrumentation from the support of instrument construction for space projects has encouraged technical specialization and conservatism in projects. PIs have been expected to figure out how to "space-qualify" an instrument outside a project context and to propose appropriately tailored versions of space-qualified instruments for projects.

To fund a project, NASA must either acquire from Congress a budget line for a contract program, or the project must be inexpensive enough to fit in its "Explorer," "Discovery," or "Earth Probes" programs—established budget lines that receive an annual appropriation. Project instigators have usually wanted to fit into these programs in order to avoid the uncertainties of higher political reviews that accompany the creation of a new budget line. The ESA Science Directorate has resembled an enlarged Explorer Program. With its budget set on a five-year basis, with individual projects funded within a determined budget envelope, the ESA Science Directorate does not face a political hurdle equivalent to acquiring a new budget line every time space scientists unite behind a major project.

While project managers control the funding for both NASA and ESA projects, the agencies differ in the scope and options they grant project managers. NASA project managers have had the option of either contracting out construction and integration of the spacecraft to an aerospace firm or directly overseeing assembly and integration in-house. ESA project managers have always had to contract out for spacecraft construction and integration. NASA project managers fund construction of both the spacecraft and its payload of scientific instruments. ESA project managers only fund construction of the spacecraft, and scientists building instruments for the payload must acquire funds from their national governments. ESA projects have been the most structurally contentious, since the project manager and PIs have drawn their funds from different sources and thus have no direct incentive for keeping each other's costs down.

G. *Internationalism*

- **Space science has been international at both project and experiment levels.**

- **Project-level internationalism had several benefits but can require some participants to deviate from their normal policies.**

- **Experiment-level internationalism had some similar benefits but it forced participants to coordinate their development efforts.**

Space science has been international at two levels. Projects have combined the efforts of flight centers and scientists in multiple nations, and experiments have been built by multi-national teams of scientists and engineers. Only multi-national experiments, not projects, have been a crucible for the creation of enduring working relationships.

1. *Internationalism in Projects*

Four forces were responsible for making projects international: the desire to combine technical specialties that had become better developed in different nations; the desire to broaden the base of scientists competing to participate in a project; the desire to spread the costs of a project across governments; and the desire to use a quasi-diplomatic agreement to make projects more difficult to cancel. Mundane logistical difficulties of meeting and communicating accompanied the internationalization of all the projects, but more serious difficulties occurred when the idiosyncracies of a project conflicted with the policies of one of the space agencies or flight centers. For example, NASA has funded the experiments that American scientists fly and has required that PIs archive their data, but ESA has not funded experiments and thus has not regulated how PIs handle their data. Consequently, American PIs have viewed sharing data among teams in a project as only a modest infringement on their prerogatives while European PIs have viewed sharing data as a much greater infringement.

2. *Internationalism in Experiments*

Five of the six projects we studied in space science had formal international collaborators on one or more experiment or user teams. While we lack data from which to measure the prevalence of this internationalism over time, the qualitative impression of interviewees is that social and technical forces are encouraging the internationalization of experiment teams.

International experiment teams had the obvious fiscal advantage of spreading costs and the political advantage of being able to designate as PI the member in best favor with the agency funding the spacecraft. But these advantages came at the cost of taking on the interface and integration problems associated with the dispersed development of instrumentation. It is a testament to the power of internationalism's advantages that experiment teams treated these problems as challenges to technical cleverness.

H. *Communication Patterns*

- **Projects communicated in hub-and-spoke fashion.**

- **But hubs and spokes shifted over the course of every project.**

- **Across projects, the same office was not always the hub at the same stage of the projects.**

The space science projects we studied always structured formal communication in a hub-and-spoke fashion. However, the office at the hub varied and the importance of the hub in comparison to the spokes shifted with stages of the project. Consequently it is difficult to cast trustworthy and meaningful generalizations.

The most important communication hubs during the conceptualization of space science projects have been the NASA and ESA space flight centers. However, other institutions in both the United States (Johns Hopkins Applied Physics Laboratory, American Science & Engineering) and Europe (Rutherford Appleton Laboratory, Max Planck Institute for Extra-terrestrial Physics) have also successfully functioned as hubs for conceptualization. (More recently, the "Working Groups" that advise "discipline scientists" at NASA Headquarters have become pro-active in the design of science projects.) The "spokes" in this initial stage have been experimentalists with hopes of tailoring a project to fit their instrumentation expertise.

Once a project was conceived, a "discipline scientist" or "division chief" at agency headquarters became the hub for project communication. Project instigators fed information to their agency advocate. Spokes consisted in this stage of members of the agency's advisory panels (and in the United States, the National Academy's Space Studies Board) that compared the virtues of projects vying for funding.

When headquarters secured funding for a project, it declared a project manager and a project scientist at a space flight center to be the communications hubs. The project manager received and passed on the information the PIs needed to build instruments that were technically compatible with each other and the spacecraft. The project scientist received and passed on the information the PIs needed to develop their data acquisition strategies. In the event of an irreconcilable conflict, each had a contact at agency headquarters. The project manager was the more important hub during design and construction; the project scientist became more important after launch.

This sketch of intra-project communication describes projects that flight center scientists or engineers have advocated far better than it describes projects that scientists outside the flight centers planned. In the latter cases, the outside scientists have wanted their own institution's engineers to be the communications hub for technical information and the main instigating scientist to be the hub for data acquisition strategies.

I. *Social and Scientific Significance*

- **The high-risk, high-gain character of space science projects made participation in design and construction problematic for scientists who needed a secure source of data.**

- **Space scientists have needed enough flight opportunities for participants to recover from misfortunes or enough career rewards for participating even if the project failed for reasons beyond an individual scientist's control.**

Space science collaborations have been high-risk, high-reward ventures for their participating scientists. When projects have succeeded, participants obtained unprecedented data. When they have failed—and failure can easily be due to factors beyond scientists' control—participants have still had to continue to compete for career rewards with disciplinary peers obtaining data in safer fashion. Increasing participants' nervousness has been their impression that the number of flight opportunities has been decreasing and the time spent in their design and construction has been increasing. Instrument designers on university faculties feel most threatened, because long, risky undertakings are not well suited to graduate students. By contrast, university scientists without direct responsibility for instrumentation have happily prospered when they have been able to learn enough about an instrument to use its data with imaginative sophistication.

As economists have long noted, failure must be tolerable for people to accept risks. The challenge for space science communities will be to keep failure from becoming intolerable for scientists. If flight opportunities for experimentalists are few, then there must be career rewards for those who successfully provide desirable space instrumentation for projects that fail. If professional productivity is judged by the quantity and quality of papers published in journals of astronomy and planetary science, then there must be enough flight opportunities for experimentalists to recoup from project failures. Recent NASA policy has favored more frequent launchings of smaller scientific projects.

IX *COMPUTER-MEDIATED COLLABORATIONS*

A. *Introduction*

We decided to assume the responsibility of investigating computer-mediated collaborations because collaborating around the new capabilities made possible by advances in computation seems likely to increase in the future. Enthusiasm for computation, electronic communication, and their union has reached high-level policy circles that have the power to call for project proposals that develop or use these capabilities. For example, both the High Performance Computation and Communication legislation passed by Congress with the support of the Clinton administration and the National Academy report touting "national collaboratories"[26] have influenced physical scientists in the traditional areas covered by AIP.

As a preliminary attempt to see whether the concepts and categories we have developed for collaborations in longer-standing research specialties are applicable to computer-mediated collaborations, we selected three collaborations for investigation. Most of the participants were university faculty, but non-university scientists—at national laboratories, super-computing centers, or independent research institutes—were essential to each of these collaborations. All of these collaborations were government-funded, but none was funded from within the traditional programs of the government funding agencies. In all these projects, software development was a major goal. In one case it was the principal goal; the other two used problems in physics as an opportunity to develop software that would further physical research *and* be applicable for other purposes.

All the projects were ongoing at the time AIP conducted interviews. We interviewed a total of 13 scientists.

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[26]*National Collaboratories: Applying Information Technology for Scientific Research.* Washington, D.C.: National Academy Press, 1993.

B. *Project Formation*

- **Funding agency initiatives stimulated computer and physical scientists to look for common interests that could become the basis for a proposal, but our cases include one instance of a physical scientist seeking assistance from computer scientists and support from a computer science funding program.**

- **Proposal writing was complicated by uncertainties over the standards of judging explicitly multi-disciplinary initiatives.**

Two of these projects were responses to the creation of new funding agency programs and probably would never have existed had the agency not undertaken (or been pressured to undertake) a reform of its organization. The third originated in shifts of employment that happened to bring a field scientist, without a teaching appointment, to a university whose information scientists had plans for expansion. When the field scientist realized that the information scientists were interested in developing software that would relieve the difficulties that he and his colleagues had in operating remote instrumentation, they began investigating the possibilities of drafting a proposal.

These collaborations had different kinds of problems in forming, depending on whether or not they were the product of funding-agency fermentation. The two that responded to new funding programs knew where the money was, but struggled to find the right combination of participants and justifications for bringing the money to them. One collaboration resulted from the merger of two competing proposals. The other had its proposal twice fall slightly short in the competition for funds and finally succeeded when one of its members convinced the rest to add more computer-science people and more of a computer-science dimension to the proposal. The collaboration that originated with scientists discovering common interests knew who the people were, but not where the money was. An NSF program officer[27] liked the proposal and had a need to disburse discretionary funds before the end of a fiscal year, but he released the funds to start the collaboration only after he had assurances that a program in the Geophysics Directorate would help to support the collaboration in future fiscal years.

In all three cases, the drafting of a proposal was the central act that tied the collaborators together, and the acceptance of the proposal made the collaboration a reality. No formalities that were independent of submitting the proposal and receiving the funding were necessary for these collaborations to form.

C. *Organization and Management*

- **These collaborations struggled to find an organization that could cope with the diversity of intra-collaboration interests; each took a different approach.**

[27]Unfortunately, this individual has died. It is plausible to believe that his enthusiasm for the proposal stemmed partly from the ferment in the National Academy and political circles for computer-mediated collaboration. But we could collect no evidence bearing on this hypothesis.

- **The strategies pursued included ignoring the problem by increasing the autonomy of the teams; reducing the problem by reducing the collaboration's size and diversity; and declaring one set of interests most prominent, and living with the fall-out.**

The inclusion of both computer and physical scientists in these collaborations made coping with a diversity of interests the collaborations' central managerial task. All struggled to find an appropriate organizational structure for this task. None succeeded entirely. One avoided the problem by increasing the autonomy of participants and decreasing the role of collaboration leader, another eliminated the problem by reducing the number of participants and interests in the collaboration, and the third lived with the problem and the toll it took on the collaboration's morale and future viability.

The collaboration that avoided the problem was the most peaceful. Its most prestigious physicist was its titular head, but two of the less senior physicists, who were more familiar with computer science and had better ties to the collaboration's computer scientists, shouldered much of the collaboration's administrative burdens. Initially, collaboration workshops resembled "a Chinese firework factory [with] a lot of tables with people huddled around" independently working on their fireworks and looking over to see how the people at the other tables were faring. After spending the majority of their funded time working in this mode, the collaborators agreed to launch a coordinated effort to simulate a physical process. This *laissez-faire*, bottom-up approach precluded any conflict between physicists and computer scientists. It also meant that for most of its existence, the collaboration was really a collection of individual research projects on related topics.

The collaboration formed by merging two independent collaborations had too many interests for its managerial structure. The merger created a larger collaboration covering more research areas than anyone had initially conceived. The large size spurred the participating institutions to create various intra-collaboration and external committees to manage the collaboration. The collaboration's Executive Committee, which was and remains the collaboration's most powerful body, was initially comprised of representatives of the participating institutions. In this form, it seemed unable to disentangle scientific from institutional interests when it considered the collaboration's research directions. On the recommendation of an external advisory committee, the number of scientific areas covered in the collaboration was reduced, and membership on the Executive Committee expanded so that the (remaining) scientific areas were explicitly represented along with the institutions. The representatives of scientific areas on the Executive Committee became successful "middle managers" who mediated between those researchers working in their areas (regardless of which institution the researcher worked for) and the collaboration's director, who was fiscally responsible. Executive Committee meetings, held in conjunction with annual collaboration-wide workshops, were regular opportunities to assess the collaboration's collective goals, strategies, and internal organization. The collaboration thus became productive at the cost of decreasing its breadth of coverage.

The collaboration that lived with the problem had its leadership determined from the outside. At the insistence of the NSF computer science program officer, who provided the initial funding, the collaboration made a computer scientist rather than the instigating physicist the collaboration's initial director. The director promptly made his institution the focal point for software development. This decision alienated the institution that managed the scientific instruments that the software was to help the physicists use. The intra-collaboration rivalries and resentments led to low-quality communication that resulted in poor decisions that were later reversed or abandoned. The collaboration's survival was testament to the scientific efficiencies to be gained by operating and coordinating field instrumentation remotely.

It is difficult to design a manageable collaboration that creates cross-fertilization between distinct disciplines. These collaborations sometime precariously balanced how strongly the collaboration should integrate its members' ongoing research, how broadly the collaboration should reach across the possible topics it could investigate, and how centered the collaboration should be within one of its institutional members and participating disciplines. Their survival and success demonstrate the importance of computational sophistication for progress in physical science, and the importance of empirical challenges for progress in computer science.

D. *Activities of Teams*

- **The nature of "teams" varied across these collaborations; some were defined by disciplinary affiliation, some by the scientific problems being worked on, and some by their means of acquiring data.**

- **In all cases, teams, rather than the collaboration as a whole, were primarily responsible for the creation of scientific results.**

The basis for defining a team varied idiosyncratically among these collaborations. In the collaboration formed by merging two proposals, teams were multi-institutional groups of computer scientists interested in the same topic, and teams (rather than the collaboration as a whole) performed all the collaboration's research. Each team leader was a member of the Executive Committee and mediated between individual researchers and collaboration-wide management. In the other two collaborations, the computer scientists were one team, and the physical scientists divided labor either by responsibility for instrumentation or by the topic each principal investigator was analyzing. In these two collaborations, teams were too small to have any noteworthy structure. The individual teams each performed their own research, but in both collaborations, there was occasional collaboration-wide coordination of teams in the interest of pursuing an agreed-upon research strategy or topic.

E. *Dissemination*

- **Teams usually published results autonomously, and no collaboration set up formal rules for dissemination of collectively generated results.**

In general, teams in these collaborations publish their research autonomously. Collaboration-wide research has been sufficiently rare that none has set a policy for how to manage the dissemination of collectively generated results.

F. *Funding*

- **NSF was the principal source of support, but often used "cooperative agreements" rather than grants to support these projects.**

NSF has been the principal source of funds for all the collaborations in our sample. However, DOE has also explicitly included research combining the interests of computer and natural scientists in its mathematical programs.

In two of our three cases, NSF used "cooperative agreements" as the support mechanism for these collaborations. Cooperative agreements provide NSF with greater oversight than grants without imposing all the burdens of contracts. Their use reflects uncertainty over the viability of research directions in this area.

G. *Internationalism*

- **International participation was rare and never prominent.**

Only one of these collaborations had any international participation. The funding programs did not encourage or did not allow international participation in the other two.

H. *Communications Patterns*

- **Lateral communication among teams was the basis for informing computer scientists of the computation problems encountered by physical scientists.**

- **Lateral communication among teams was also the basis for generating scientific results, but the teams informed collaboration administrators of their activities in order help justify the collaboration's continued existence.**

The physical scientists in these collaborations communicated their computation problems directly to the computer scientists. A collaboration headquarters was not used to facilitate or channel such communication.

Likewise for the generation of scientific findings, these collaborations' teams either worked independently or made their own lateral connections. However, these collaborations needed to demonstrate to their patrons that they were truly working towards an integration of their diverse interests and not continuing their independent research under a new aegis. Therefore, they had their teams report scientific developments to collaboration administrators. Developments that stimulated cooperation between teams were prized as evidence that the collaboration was being effective in bringing about a union of physical and computer science.

I. *Social and Scientific Significance*

- **These collaborations attempted to bring together physical and computer scientists without losing the benefits of independent disciplinary traditions.**

- **The successes of these collaborations plus ongoing funding from NSF and DOE suggest that computer-mediated collaborations will become more prominent in American science.**

It has become a truism that we live in the "Information Age," and future historians will no doubt debate whether developments in the sciences were causes or effects of the proliferation of computation and electronic communication. To facilitate this debate, archivists in the present and near future will have to find ways to select and save new forms of ephemera. Chat rooms, Web sites, and electronic bulletin boards all contain enlightening documentation amidst much trivia.

The utility of computation in so many sciences (to say nothing of other parts of society) poses obvious organizational conundrums. There are advantages and disadvantages to encouraging the computationally gifted to become specialists in computer science. Identity with a discipline of computer science has the virtue of focusing computer scientists on topics of general significance to their disciplinary colleagues and the disadvantage of reducing their concern with topics of significance to other scientific disciplines. There are mirror-image advantages and disadvantages to encouraging the computationally gifted to become natural scientists. Such scientists will use their computational skills to advance their fields but may have little incentive to recognize and then develop the general significance of their computational work. These collaborations represent an attempt to have it both ways: to create intellectual intimacy between computer and natural scientists without losing the intellectual power that comes from specializing within a disciplinary tradition.

The fact that these collaborations hung together despite the tensions they internalized suggests that "grass-roots" support for multi-disciplinary collaborations between computer scientists and physical scientists is developing. A tradition of support for computer-mediated collaborations appears to be emerging at both NSF and DOE. While individual funding-agency programs are constantly being invented and terminated and individual agency offices are always acquiring new names to reflect shifts in their responsibilities, program officers and scientists see continuity in their efforts to develop constructive synergy between computer science and the natural sciences.

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART A

SECTION TWO: ARCHIVAL FINDINGS OF FIELDS STUDIED BY AIP

Joan Warnow-Blewett

ARCHIVAL FINDINGS OF FIELDS STUDIED BY AIP

I. *INTRODUCTION*

This report is based on a number of sources: (1) archival analysis of over 450 interviews on the nearly 60 selected cases for the disciplines included in the AIP Study; (2) the patterns uncovered through the historical-sociological analysis of these interviews; (3) discussions with archivists at the home institutions of interviewees; (4) site visits to discuss record-keeping with administrators and records officers (especially at federal funding agencies) involved with our disciplines; (5) discussions with National Archives and Records Administration appraisal archivists for the federal agencies; and (6) the AIP Center's general knowledge of archival institutions in various settings.

With the exception of our selected collaborations in ground-based astronomy, all of the projects studied by the AIP were funded by federal funding agencies and subject to the reporting requirements of the agency. Federal agencies are required to retain successful proposal files, including the proposals and budget requests, peer and panel reviews, and progress and final narrative and fiscal reports. Because of these requirements, a bare bones minimum documentation—far less than desirable—of these projects is at the federal funding agencies (and is supposed to be transferred later to the National Archives).[28]

II. *FIELDS STUDIED BY THE AIP*

A. *Geophysics*

The best locations to find the records of geophysics projects, according to the interview subjects, are the Science Management Offices (SMOs) and the consortium headquarters; they are, for example, the most likely locations for collaboration-wide mailings. SMOs provide the likely locations for records of project administrators, Science Working Groups (SWGs), and executive committees. Similarly, consortium headquarters have the records of the project's chief scientist (director, president, etc.), its standing committees (and, perhaps, subcommittees), and its Executive Committee. Other key players at consortium headquarters are staff scientists or engineers who work with each scientific party. For example, for the Ocean Drilling Program, one of the staff scientists assists the co-chief scientists with the planning and ship-board administration. Because of these responsibilities, records of the staff scientists would provide valuable documentation. However, at SMOs and consortium headquarters, there were typically no formal record-keeping requirements imposed by the collaboration. In certain geophysics or oceanography projects, the ships' logs provide a central record of a project, and perhaps even metadata concerning the conditions under which data were collected. These logs are often considered to be institutional records; their value in documenting projects is sometimes overlooked.

Because projects in geophysics have a longer, more political prefunding period, our investigations located additional categories of records at policy-making bodies. These records were at the National Academy of Sciences in the United States and, at the international level, the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO).

[28] Requirements are not always met, unfortunately; for further information, see Current Archival Practices, Part C, Section One of this report.

We found a variety of circumstances that affected the creation of records:

- The structure of the collaboration had an impact on records creation, with records most likely to be created by consortium administrators and committees and—to a lesser extent—by the more informal arrangements of administrators and working groups of science management offices (SMOs).

- Our findings indicate there is a higher percentage of e-mail use by the technique-aggregating projects than in the technique-importing ones. 80% of the members we interviewed in the technique-aggregating projects mentioned their use of e-mail compared to 55% in the technique-importing projects.

- Technique-aggregating projects, in general, seem to be shorter in length, larger in size, and more international in scope than technique-importing projects.

- Technique-importing projects, with their more formal administrative structure and use of consortia, provide a more formal mechanism for communication.

Geophysics projects—like others in the field sciences—generate electronic data of long-term usefulness for scientific research. In addition, samples taken in field research (such as cylinders of sediment and rock) are often preserved for future research. Although our study did not focus on the final disposition of the data created by these projects, we know there are many electronic data centers for these disciplines. The largest holder of geoscience data in the United States is the National Oceanic and Atmospheric Administration (NOAA) with a number of facilities across the country (e.g., the National Geophysical Data Center in Boulder). In the cases we studied, it may not always have been mandatory for individual investigators to deposit their data into a data archives. By and large the trend is for more stringent requirements. We are aware that some electronic data are found by archivists in the records of individual scientists; when this happens, archivists should notify the appropriate data center.

B. *Ground-Based Astronomy: Observatory Builders*

We found that the patterns of organization and management of all telescope-building collaborations are quite similar. All four collaborations included in our case studies vested authority in a Board of Directors, and made one individual most responsible for the physical construction, usually with the title of project manager but occasionally another title. In most cases they organized Science Advisory/Science Steering Committees of scientists from the member institutions to develop scientific instruments and advise the project manager on the trade-offs between scientific capabilities and engineering and financial burdens. In the construction collaborations in which national observatories were members, management has been unified, giving decision-making power to a project manager when the scientific and engineering leaders clash and lessening the authority of the Board of Directors as representatives of member institutions. Virtually all of the individuals holding these positions are on university faculties where archival repositories are available.

Despite these similarities, the difficulties of documenting the work of telescope-building collaborations are distinctive among the disciplines covered by the long-term AIP Study, and this is true for the building of both academic and national observatories.

In the case of academic observatories, funding is mostly from non-federal sources —private university endowments, state university allocations, and private foundations; support from federal funding agencies exists in some cases, but has been limited in its scope, e.g., to support site development. Private funding usually means less stringent records requirements. Collaboration proposal files, progress reports, correspondence with grant officers, and other related records may never have been created or—when they have—may be more difficult to find in university administrative files or in records of private foundations. When considering which university should be most responsible for saving records of an observatory's design, construction, and operation, we look to the university with which the observatory was affiliated; in most cases this will also be the university that has the largest membership on the collaboration's Board of Directors (reflecting the size of its obligation).

Documenting the building of national observatories is complicated by the records policies of the National Science Foundation (NSF)—the agency that supports the building and maintenance of the national observatories in the U.S.[29] Unlike the Department of Energy's contract laboratories, the NSF's contract laboratories and observatories do not create federal records; accordingly, these national observatories are not required by law to maintain records management programs or secure records of archival value. While at least some national observatories retain records, we are not aware that any of them have archival programs. To make matters worse, national observatories are not affiliated with universities or other organizations with archival programs and thus lack natural repositories.

C. *Ground-Based Astronomy: Users of Observatories*

If it is difficult to document the building of observatories, it seems virtually impossible to document collaborations of observatory users—at least radio telescope users.[30] The reason is straightforward. They leave a scanty paper trail (except for observational data) because they:

- Neither design nor build the instrumentation they use;
- Require little or no dedicated funding; and
- Require only minimal organizational structures.

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[29]The AIP Study's four case studies of telescope-building collaborations did not include any collaborations involving national optical or radio telescopes. As a result, our archival analysis of this category of collaborative building is based on previous experience of the AIP Center, the AIP Study's site visits, and input from the Working Group rather than the usual combination of these elements and oral history interviews conducted by the AIP Study.

[30]The AIP Study's four case studies of telescope-using collaborations did not include any collaborations conducting sky surveys or, indeed, any collaborations of optical telescope users. Accordingly, our archival analysis of collaborative research in the uses of optical telescopes and in conducting sky surveys is severely limited; it is based solely on the previous experience of the AIP Center and input from the Working Group, rather than the usual combination of these elements and oral history interviews conducted by the AIP Study.

The best documentation of a given collaboration is to be found in the lead scientist's proposal for use of a participating observatory's telescope and his/her collaboration-wide correspondence. For minimal documentation, then, we need radio observatories to have policies to preserve their proposal and evaluation records. For a richer record, we are dependent upon lead scientists to save their papers and their employing institutions to accession them for their archives.

It is highly unlikely that the scientific data of VLBI (Very Long Base Interferometry) collaborations will be useful for future research. As we learned, the data streams from each of the participating observatories had first to be successfully correlated. Although these correlated data are preserved following NASA regulations, considerable processing is required before correlated data can be the basis for scientific interpretation; further, our interview subjects agreed that this processing required too much familiarity with the original observing conditions and instrumentation to be useful to anyone who had not been involved with the data acquisition.

All participants in the radio observatory-user collaborations we studied were either on academic faculty or staff.

D. *Materials Science*

Our historical analysis of collaborations in materials science makes distinctions between those that make use of accelerators for synchrotron radiation and reactor facilities at DOE National Laboratories and those that do not. Our archival analysis is strikingly different for these two categories.

Collaborations that do not use national laboratory facilities present documentation challenges whether managed by universities or corporations. In two of three instances of university-managed collaborations, the collaborations made final funding decisions on institutional members' research; all three cases lacked a physical location beyond their offices at the fiscally accountable university. In a field with strong participation of corporate organizations, it is not surprising that our case studies included an instance in which the collaboration was managed by a corporate member which no longer exists because it was merged into another corporation. Such mergers confront corporate historians and archivists with questions concerning successful transfers of records; we can only urge corporations in such situations to be responsible for adequate transfer of archival records.

As usual, support by federal science agencies generates some core documentation. However, a cautionary note is in order. NSF centers (the Science and Technology Centers and the Materials Research Science and Engineering Centers) have emerged in recent decades on university campuses; most, if not all, of the centers make the final decisions on which researchers at member institutions get funded. This delegation of some authority from NSF to its centers diminishes the detail of documentation at NSF Headquarters; thus, it is important for university archives to take responsibility for securing their NSF centers' records of long-term value.

The characteristics of those collaborations that did make use of accelerators or reactors at DOE National Laboratories (half of our case studies) are quite different from those materials science collaborations that did not. For one thing, they had some attributes similar to those we were familiar with from other studies involving DOE National Laboratories: they were all required to submit both technical and managerial plans to the Facility Advisory Committees (our generic term for a variety of titles) of the laboratory facility, and they all had a liaison with the DOE Laboratory facility (whether called spokesperson, staff director, or an untitled member who played the role). These characteristics assure preservation on the part of the DOE National Laboratories of some core records and help us locate documentation for significant collaborations. On the other hand, we found that the collaborations rented space for offices at the synchrotron laboratories, that these offices are freestanding and impermanent, and that the collaborations do not create federal records unless the DOE laboratory is a formal member of the collaboration. We also found that each institutional member of a collaboration raised its own funds; typically academic institutions go to NSF and corporate members use internal funds.

Locations for records of materials science collaborations vary, depending upon their managing institutions and/or use of DOE facilities.

E. *Medical Physics*

It is virtually impossible for us to assess with any certainty the archival situation in the area of medical physics. The reasons are several. The AIP Study experienced difficulties in persuading individuals in the discipline to participate fully (or at all) in our interview program and found that even the more eminent leaders of the community were not at all familiar with questions of documenting their discipline for historical and social science studies. Also, the AIP Center has had little experience in documenting the research activities of medical schools or other medical research centers, in saving papers of individual practitioners,[31] or in dealing with the key funding agency—the National Institutes of Health (or its constituent parts, such as the National Cancer Institute).[32] Consequently, the AIP Study's Appraisal Guidelines and Project Recommendations to funding agencies and research institutions in the field are—for the most part—merely suggestive.

F. *Particle and Nuclear Physics*

1. *Introduction*

The initial phase of our long-term study of multi-institutional collaborations was devoted to high-energy physics. During our third, and last, phase of the project we examined briefly the area of heavy-ion physics. We found the characteristics of the disciplines to be so much the same that (with the agreement of the Working Group) we have combined our findings as collaborations in particle physics. Moreover, we have been told that our findings conform to those in nuclear

[31]The AIP Member Society most relevant to medical physics is the American Association of Physicists in Medicine which joined the AIP in 1973—a fairly recent affiliation compared to other AIP Member Societies. This, combined with the fact that the Association does not represent the full scope of medicine-related disciplines included in our selected case studies, may account for the fact that most practitioners we encountered during the course of the AIP Study lacked knowledge of the documentary concerns, responsibilities, and services of the AIP Center.

[32]Our ignorance about the NIH presents a major obstacle to our advocacy for effective preservation activities; e.g., we learned from our Working Group that the proposal process—so valuable in providing core documentation of collaboration plans and progress—varies among the institutes of the NIH.

physics experiments. Thus, this disciplinary category is now titled, particle and nuclear physics. Before going further, we need to point out that our study of high-energy physics was far more extensive than our study of heavy-ion physics. We carried out 19 case studies, as compared to two, and we conducted detailed studies (probes) of the discoveries of the psi particle at SLAC and the upsilon at Fermilab and of the CLEO collaboration at Cornell's CESR accelerator. In addition, we were able to draw upon data on all high-energy physics experiments from the *Experiments* database and the *HEP Publications* database made available to us at SLAC. As expected, in-depth work on the selected probes proved to be particularly valuable for issues regarding appraisal of technical documentation. The census—with such basic data as the number of experiments approved for each accelerator, number of teams and participants for each collaboration, and much else—combined well with project findings; for example, it gave us names of key institutions and individuals that we could approach for practical preservation work.

It is interesting to note that in the brief period between the time the high-energy physics projects we studied in Phase I were conducted and those heavy-ion physics projects we studied in Phase III were conducted, there were some management changes. In addition to the numerous well-known roles from high-energy physics, we found management structures in heavy-ion physics more familiar to us from collaborations in other disciplines—in one a project engineer and in the other a project manager—as well as a technical committee and a board made up of representatives from member institutions. These structures may indicate emerging complexities in the various areas of particle and nuclear physics collaborations that archivists should be on the lookout for.

2. *Archival Analysis*

In particle and nuclear physics collaborations, some types of valuable records are created by necessity. Notable examples are designs of detectors and components, experiment logbooks of data acquisition, data analysis records, and—more recently—Letters of Agreement and Memoranda of Understanding specifying arrangements between the collaborations and the laboratories.

In addition to these operational records, high-energy physics collaborations create intra-collaboration mailings—including minutes, technical reports, and other memoranda. The interviews on the earliest collaborations of our selected case studies (originating in the mid-1970s) show that some collaborations did not feel the need for intra-collaboration mailings and the decisions to create these records reflected to some extent the style and personal inclinations of the spokespersons. For decades now, intra-collaboration mailings have become standard elements in the documentation package, although their formats have changed from paper to electronic mail to collaboration Web sites.

Particular circumstances affect records creations; two may be especially pertinent to high-energy physics collaborations:

- The greatest bulk of records was created during the construction stage of an experiment when documentation is critical to later users of the detectors. Apart from experiment (or "running") logbooks, the least documentation was created during running, when the greatest number of collaborators were at the laboratory site and could communicate face-to-face. Records creation increased during the analysis stage, but records were not shared or distributed as extensively as during construction.

- Experiments in which the detector was designed to study a broad range of physics problems (such as the multiple-purpose four-pi detector experiments) resulted in arguments regarding the selection of physics problems and standards of analysis; this led to creation of more records.

The main locations of records appear to be in the hands of spokespersons; at the laboratories; and, to a lesser extent, with group leaders. We focus here on records with spokespersons and at the laboratories.

a. *Spokespersons*

Spokespersons, in nearly all of the cases we studied, had the most complete documentation. We found that the larger the collaboration, the more likely the spokesperson was to have kept the proposal and related materials. In addition, most spokespersons have some unique materials, e.g., correspondence with laboratory administration.

With larger numbers of people and institutional members, the role of spokesperson has come to encompass managerial tasks. There is, for example, ample evidence that intra-collaboration mailings correlate with the larger, more recent collaborations; responsibility for such mailings falls largely on spokespersons. In the best cases we've seen, their "archives" were well-organized and covered all aspects of the collaboration's work, including minutes of collaboration meetings (technical reports from group leaders and others on their assignments for detector development and data analysis, etc.), technical memoranda, and other intra-collaboration mailings. In other cases, spokespersons appeared to have kept many of these files but they were literally in piles all over their offices and may be difficult to extract from other, unrelated materials. Conversely, collaborations with fewer than 30 people and four or five groups, as was common in the 1970s, communicated more by telephone and in less formal meetings, resulting in far thinner documentation.

While the role of the spokesperson provides the single most promising location of intra-collaboration mailings and other records, we must be aware that where collaborations had co-spokespersons—or a practice of rotating spokespersons—the process of locating a full record will be more complex.

b. *Accelerator Laboratories*

The AIP Center was aware from its earlier study of DOE National Laboratories that these laboratories were the best source of documentation on the activities of their Physics Advisory Committees. (There are variations on the title of these committees; we refer to them generically here as PACs.) Site visits during the current project established that the laboratories still retain a full set of PAC records, including proposals from collaborations for experimental work and accelerator beamtime and minutes of the PAC's decision-making process.

The AIP Study of Multi-Institutional Collaborations provided evidence for other significant documentation of collaborations at the laboratories. During the 1980s, more detailed agreements emerged covering the responsibilities of both the laboratory and each of the institutional members of a collaboration. These responsibilities range from detector development and construction to provision of computer facilities and financial commitments. The most detailed of these agreements today are called Memoranda of Understanding.

There has been a very significant shift of responsibilities from individual investigators and universities to the laboratories. Recently, the laboratories have been exercising tighter control over experiments—at least the larger, more expensive ones. For one thing, major funding for large detectors is now likely to come directly to the laboratories from DOE and NSF, rather than to the institutional groups. In addition, there are increasing and widespread demands for accountability on the part of DOE in such areas as fiscal matters and health and safety. In some cases, the need for tighter control on the part of the laboratories may be reflected in the spokesperson being a laboratory staffer; in other cases, the spokesperson may be required to remain on site during the entire construction period of the experiment. Finally, there was evidence of yet another shift from academic laboratories to accelerator facilities—for fabrication of detector components; in addition, as detectors become bigger and more complex, laboratories tend to have more permanent staff in order to maintain detector components. Overall, the trend is for the laboratories to be the location for many technical records.

In sum, we found five categories of records that form a core and, taken together, provide basic evidence of the process of collaborative research for virtually all experiments. Our investigation located three of the categories at the accelerator laboratories: laboratory directors' files, records of the PACs (including proposals to the laboratories and contracts between laboratories and collaborations), and special databases on high-energy experiments and literature available at the Stanford Linear Accelerator Center. Apart from the databases, most of these records were still in office space; however, the laboratories obviously had some appreciation of their value and retained them all. We have confidence that they will eventually be formally secured by the laboratories and made available for research use. The remaining two categories are proposals to federal science agencies and Ph.D. theses (widely available on microfilm).

G. *Space Science*

In the field of large space science collaborations in the United States, NASA provides virtually all of the funding and much of the technical and managerial expertise through its space flight centers. Space science projects have formal record-keeping requirements related to the organizational structure NASA imposes on its projects. Also, since participating scientists create individual instruments which have to be integrated into a single spacecraft, considerable formally documented interaction between flight centers and the experiment teams takes place. The situation is very similar for the European Space Agency (ESA) and its flight center. For these reasons, substantial documentation is virtually always created by space science projects. The creation of records does not, of course, equate with saving those records. Outside of NASA, creating and saving records is largely based on the personal inclinations of participants.

The bureaucratic structure imposed by NASA—especially at the flight centers—means that certain offices are held responsible for specific aspects of NASA projects and are expected to create specific categories of records. Because of this, records are created almost regardless of the circumstances of the particular instrument-building team (such as number of member institutions and geographical distribution). At the NASA Headquarters level, however, more documentation is generated for joint projects with space agencies abroad, and for missions funded from budget lines that attract annual congressional scrutiny.

Scientific electronic data are useful in most cases for many scientific purposes; however, in some cases (e.g., where instrumentation incorporates technical novelties) outside users may still find it necessary to contact the original principal investigator (PI) in order to best understand peculiarities of instrumentation. Investigators are required to place their data in the National Space Science Data Center in a form useable by other scientists and this was the case for all but one of the projects we studied. The exception collaboration has deposited its data at the International Halley Watch Archive. We are aware that some electronic data are found by archivists in the records of individual scientists; when this happens, archivists should notify the appropriate data center.

The best documentation for information concerning scientific aspects of the mission, according to the scientists who responded to our questionnaires, are the records of the Science Working Group. These materials are normally located with the project scientist, who chairs this group of principal investigators. In two of our case studies, space science projects were instigated from outside NASA Headquarters and led by one or a few PIs. For these particular cases, we found that most collaboration members point to the records of the instigator(s) as containing the best documentation of the scientific aspects of that particular mission.

Finally, our investigations located a small number of categories of records (about 10) that, taken as a whole, provide adequate documentation for all multi-institutional collaborative research in space science. For any one project, these records are located at several settings. The main locations of records in the United States are at the National Academy of Sciences in its Space Studies Board records (previously the Space Science Board);[33] in the hands of discipline scientists, program scientists, and program managers at NASA Headquarters, project scientists and project managers at NASA flight centers, and PIs of project experiments (instruments). At ESA the important policy groups to document are the Science Programme Committee and the Space Science Advisory Committee and its two working groups: the Astronomy Working Group and the Solar System Working Group. Additional records are those of the European Space Science Committee of the European Science Foundation; it synthesizes, promotes, and coordinates advice on European space science and policy from the space science community in Europe. Finally, funding agencies of the several nations involved in each mission independently pass judgement on proposals to build experiments for ESA projects.

H. *Computer-Mediated Collaborations*

In the third and last phase of the long-term study, the AIP determined that it should deliberately examine a new category of collaborations that might well become more dominant in future collaborative research. The principal characteristic our three case studies in this category have in

[33] Projects in space science, like those in geophysics, have a long, more political, prefunding period; the National Academy's Space Studies Board has been the most important policy-making body for space science in the U.S.

common is the central role of computer science and technology—hence the name for this group, Computer-Mediated Collaborations. In this area, the AIP sought to learn of the relative health of these new kinds of projects: would they continue and thrive over the near future? We also needed to obtain a clearer picture of the ways, if any, the focus on computer science and computer techniques would affect a collaboration's organizational structure and the records the collaboration generated, as well as which records should be preserved.

Our sample focused on NSF-funded collaborations (although we also made site visits to DOE to learn about similar funding programs there). The NSF Center for Research in Parallel Computation, in addition to its focus on an aspect of computer technology, gave us experience with a second case of the new NSF program of Science and Technology Centers (STCs). The Grand Challenge Cosmology Consortium was funded through a new NSF program devoted to using computation for theoretical problems. The Upper Atmospheric Research Collaboratory (UARC) is referred to as a testbed for a National Collaboratory. The concept of a "collaboratory" (which would focus on access to remote instrumentation and improved communications of researchers) emerged in the late 1980s out of experiments in telescience, designs for electronic environments, and a conference held at Rockefeller University.[34] Although never a formalized program of its own at NSF or DOE, projects that serve as testbeds for a national collaboratory received considerable attention at both agencies in the climate of Clinton-supported Congressional legislation for High Performance Computation and Communication.

Would these new computer-mediated collaborations prosper in the near future? From our site visits to NSF and DOE and the meeting of our Working Group, the resounding, general answer must be yes. For one thing, the NSF STCs appear to be thriving and we can believe some of them will be devoted to research in computer science and technology. The Grand Challenge is no longer a formal NSF program unto itself, but it seems reasonably clear that such projects will be considered under the Knowledge and Distributed Intelligence (KDI) program under development at NSF. Collaboratory-style projects will also fall within the KDI at NSF and continue receiving support at DOE under its Mathematical Division, which—under various names—has been the organization within DOE for high-end computing. It is important to note that collaboratory techniques are now implemented by projects in a wide range of disciplines from electronics to research in AIDS.[35]

As to the second point—would the focus on computer science and techniques have an affect on a collaboration's organizational structure and the records the collaboration generated, as well as those that should be preserved?—the answer is mixed. The impact on organization structure and

[34] The National Academy of Sciences also issued an influential report, *National Collaboratories: Applying Information Technology for Scientific Research*. Washington, D.C.: National Academy Press, 1993.

[35] For an example of a recent overview, see "*Internet-Based 'Collaboratories' Help Scientists Work Together*," The Chronicle of Higher Education, Vol. XLV, No. 27 (March 12, 1999), p. A22. Just this year the following report appeared on the Web, "Report of the Expert Meeting on Virtual Laboratories," organized by the International Institute of Theoretical and Applied Physics, Ames, Iowa with the support of UNESCO. It explores the use of the collaboratory far beyond science and technology (Web site: http://www.iitap.iastate.edu/reports/vl/).

on records creation is not apparent in the case of the NSF STC and the Grand Challenge projects in our sample. But the impact on collaboratory-style projects such as UARC is a different matter.

There are typically two purposes for collaboratories: to operate scientific instruments by remote control and to provide researchers a venue for discussion and debate. We could not see in our study of UARC that the introduction of remote control of instruments had a distinctive impact on organizational structure and related records creation. But the electronic venues for discussion and debate generate a plethora of records—far more than can be saved, even for significant projects. At this point in time, the records generated by these discussion chatrooms require analysis by social scientists; this in itself has an impact on the collaboration's organizational structure and management as well as the records created.

III. *The Web and Other Electronic Records*

A. *Impact of the World Wide Web*

The World Wide Web was just becoming prominent when the AIP Study began. Simple searches of the Web made it obvious that many of our selected projects were using the Web to keep collaboration members informed. Also clear was the use of passwords to limit access to sections of Web sites.

The impact of the Web on collaborations is serious. We are aware that Web page delivery of information on collaborations is so efficient that it has reduced the number of face-to-face meetings required to maintain a collaboration. In one sense (and especially in some disciplines), the use of Web sites encourages good record keeping, in that minutes of meetings and key aspects of the collaboration (how to access data, for instance) are posted very quickly. On the other hand, some collaborations keep a good Web site instead of keeping good archives.

Our concerns about Web sites and passwords made the topic a central issue that we discussed with scientists (representing the disciplines covered in the AIP Study) at our last Working Group meeting in September 1999.[36] Essentially all these scientists agreed that collaborations in their disciplines are moving from e-mail-based exchanges of information to larger Web-based distribution of records. The use of Web sites has affected the ways collaborations work internally, making collaboration easier from the point of view of transmittal of information. Most collaboration members seem to really like the Web as a mode of exchange; the only conflict we learned of had to do with a collaboration's decision not to post some informal meetings. One scientist suggested that the Web is more democratic than e-mail because, with the Web, everyone has access to information at the same time. What gets posted and what does not get posted can tell you a lot about a collaboration's organization and power.

Discussion of the use of passwords at our meeting covered points of when and why they are used and their impact on archival preservation. It seems that passwords may be used, on the one hand, to protect vendors and the proprietary rights of corporate members and, on the other hand, to

[36] A small group of historians and other scholars were also at the meeting. An archivist reported that the National Archives considers Web sites the big, new area for appraisal. It is beginning several actions, e.g., scheduling Web sites for the federal agencies and appraising the potential value of usage statistics.

protect collaboration groups from "outsiders" gaining access to their analyses of collaboration data.[37] However, use of passwords is not the central issue for archival preservation. The real problem—according to the scientists—is that many collaborations update their Web sites without preserving all the previous documents on the site, whether or not they were protected by passwords.

We shared our concerns about collaboration Web sites with the larger group of archivists and records managers on our Working Group. The important message from their perspective is that archival intervention is critical if Web sites are to be documented. Only a fraction of the data will be needed to document even the most significant collaborations. As with any set of records, archival appraisal of Web site records is required to make an appropriate selection of the files for historians and other secondary users. Given the current state of Web technology, archival appraisal decisions should not be made on data after the fact or after the project, but should be made up front. Knowledgeable archivists/records managers should be accepted as partners with the system design people as project software/systems are first being configured. As this partnership determines what things (activities, transactions, people, etc.) to instruct the system to capture, we recommend they make liberal use of the AIP Study's Appraisal Guidelines (see Part B, Section Three, of this report). For those collaborations already underway, collaboration leaders should consider having their Web site administrators employ the latest Web site technology to periodically capture the most important documents on their Web sites. Archivists would provide valuable assistance, particularly in transferring knowledge of the AIP Appraisal Guidelines for selecting valuable records.

B. *Electronic Scientific Data*

The AIP Study did not go into any details in terms of what electronic scientific data should be saved—beyond learning that these data are not useful for *historical* research.[38] We took the position that if scientific data have long-term usefulness for scientific purposes, the scientists themselves would see to it that they are preserved.[39] We found the following proved to be generally true for physics and allied disciplines:

- In the laboratory sciences—where scientists control their experiments and can improve the data with better instruments—scientific data are not useful for long-term scientific purposes; and

[37]We heard a vivid illustration of the urgent need for passwords during the data analysis stage of very large high-energy physics collaborations. In this case, some 500 physicists were divided into some 20 teams fiercely competing with each other to come up with breakthroughs based on their analyses of the huge amounts of data generated by the collaboration's multi-purpose detector.

[38] The National Academy of Sciences/National Research Council conducted a thorough study of what scientific data should be saved for long-term scientific purposes. See *Preserving Scientific Data on our Physical Universe: A New Strategy for Archiving the Nation's Scientific Information Resources*. Washington, D.C.: National Academy Press, 1995.

[39]The federal funding agencies we are familiar with often impose requirements on researchers to save scientific data, usually at data centers maintained for specific disciplines. The issue of saving scientific data for issues of legal liability may be needed in other scientific disciplines, such as the life sciences; we have no reason to think this should be a concern in the physical sciences.

- In field (observational) sciences—where scientists do not control their experiments and where objects change over time—the data are valuable for long-term scientific purposes.

C. *Electronic Mail*

The first use of e-mail in our selected experiments was in 1982; many say usage became common between 1983 and 1985. By now, e-mail is ubiquitous. The result has been the creation of much more documentation. The question is: will scientists print out (or otherwise save) significant e-mail documents? There is some evidence that scientists in leadership positions in collaborations are keeping substantial quantities of their e-mail. Archivists should continue to encourage this practice on the part of scientists.

D. *Other Electronic Records*

Just about everything today is created as an electronic record and, we believe, less and less of the documentation will be available in printed format over time. This is the case for professional correspondence, personal scientific notebooks, and institutional records—including records of multi-institutional collaborations. Archivists are actively seeking ways to retain and establish access to electronic records. This is a widespread problem affecting non-scientific as well as scientific documentation. The AIP Center for History of Physics hopes to benefit from the solutions provided by others in our future work to document modern physics and allied fields.

IV. *OTHER FINDINGS OF ARCHIVAL INTEREST*

A. *Circumstances Affecting Records Creation*

Of all the disciplines studied, we found that collaborations in particle and nuclear physics generate the most documentation. In this field, just about everything individuals and teams do for an experiment is subject to review or use by others in the collaboration. In every other discipline we studied, individuals and teams have more autonomy. Consequently, collaborations in particle and nuclear physics are burdened with creating a rich collective record, while collaborations in other fields are less burdened.

We found that particular circumstances pressed for the creation of valuable documentation:

- Size (especially in terms of numbers of institutions) and geographical dispersal of institutions tended to foster records of intra-collaboration communications on technical progress.

- The emergence of fax and e-mail, with correspondingly less reliance on the telephone, resulted in additional documentation of collaborations.

- Collaborations made up of multi-disciplinary components or that required extensive communication with engineers found it necessary to write out more of their ideas than they would otherwise.

- Collaborations that had what physicists call “interesting results” tended to create more documentation of potential value to future scholars, e.g., by stimulating more written arguments over analysis and by producing more publications.

B. *Trends in Multi-Institutional Collaborations*

Collaborations have changed—even over the decade since the AIP Study started. It is more than just the impact of the Web. Many factors have changed the nature of collaborations. There is, for example, increasing scrutiny by the funding agencies and regulations imposed on the grantees and the laboratories; these, in turn, have increased the accountability collaborations have to allow for and the levels of reporting they are required to make. The general trend is for multi-institutional collaborations to become larger, more formal, and more international. In the field of particle physics, the trend is toward very, very large collaborations.

We close with one more striking change: collaborations in one field may take on characteristics of those in another field. The point was made clear to us at the last meeting of the AIP Study's Working Group (referred to earlier). The subject was the role of the builders and the users of detectors/instruments in the fields of particle physics and ground-based astronomy. A decade or more ago, most particle detectors were built and used by the same, single collaboration and most telescopes were built by a collaboration (and then maintained by the facility) for other scientists to use. The current situations are quite different because of the increasing sophistication of the instruments/detectors and the need for more sophisticated processing of much larger amounts of data. New multi-purpose detectors in particle physics have practical lifetimes that may equal those of the accelerators. This means the detectors are used by more than one collaboration and that maintenance has shifted to new permanent, technical staff at the accelerator facility. Thus, detectors are moving toward the model of astronomy in terms of builders and users of instrumentation. Meanwhile, in the case of ground-based astronomy, the instruments—the equivalent of particle detectors—are increasing in cost faster than the telescopes; the huge increases in costs for instruments and data processing have inspired ground-based astronomers to begin looking into management practices in particle physics collaborations.

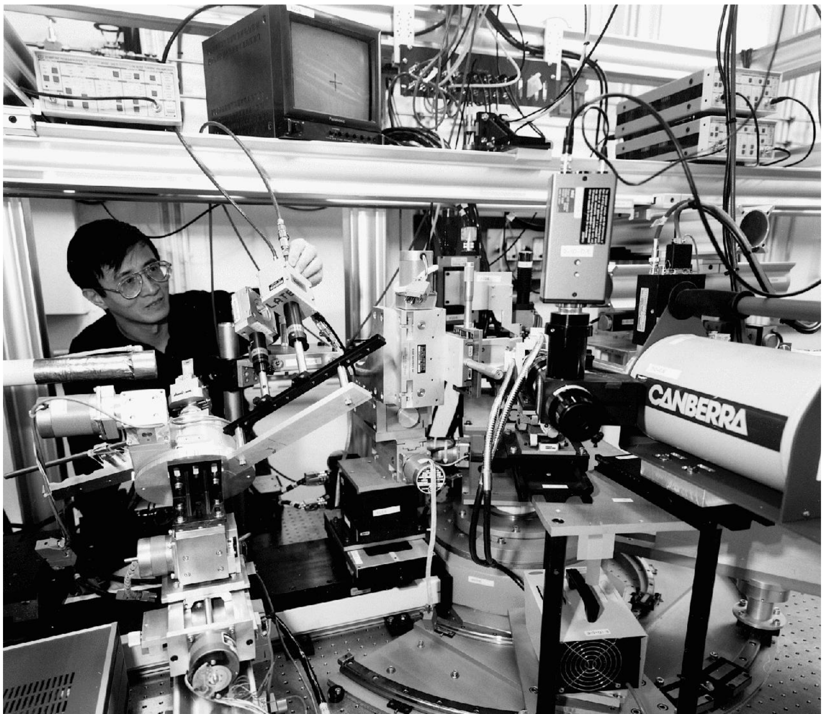
Archival appraisal of records will have to evolve to meet the challenges of changes in the technologies used by researchers as well as changes in the functions and organizational structures of the collaborations themselves.

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART B: APPRAISAL OF RECORDS CREATED

SECTION ONE:	TYPOLOGY OF MULTI-INSTITUTIONAL COLLABORATIONS
SECTION TWO:	FUNCTIONAL ANALYSIS OF RECORDS CREATION
SECTION THREE:	APPRAISAL GUIDELINES

An overview of beamline 2-ID-E on the Advanced Photon Source experiment hall floor at Argonne National Laboratory. This is one of eight beamlines managed by the Synchrotron Radiation Instrumentation Collaborative Access Team. Photo courtesy of Argonne National Laboratory.



The interior of the Advanced Photon Source experiment hall, as seen from the visitors' gallery. Visible is the fully instrumented insertion-device beamline for sector 1-ID, managed by the Synchrotron Radiation Instrumentation Collaborative Access Team. Photo courtesy of Argonne National Laboratory.

APPRAISAL OF RECORDS CREATED

In the AIP Study, our extensive fieldwork is followed by the other phase of macroappraisal projects: analytical studies to develop documentation aids for archivists, records officers, and others responsible for the records of multi-institutional collaborations. In this part of our report, we offer aids to records appraisal through three approaches:

• **A Typology of Multi-Institutional Collaborations.** Based on sociological analysis of project interviews, this section offers a classification scheme or typology for the organization and management of collaborations—the aspect of collaborations that is most closely connected to the generation and accumulation of records. The essay offers a different perspective on the characteristics of collaborations and is useful in providing guidelines to locating documentation.

• **Functional Analysis of Records Creation.** Readers will find brief analyses of the key functions of multi-institutional collaborations along with the categories of records created through these activities.

• **Appraisal Guidelines.** The guidelines combine and update those included in reports on previous phases of the AIP Study. The scope is records created by multi-institutional groups that participate in collaborative research projects. Also, for the fields of geophysics and space science, we have included records of groups that set national and international policy. It is in this section that we elucidate our finding that a modest core set of records provides adequate documentation of most collaborations. These core records are identified for each area studied by the AIP, as are the additional records needed for especially significant collaborations.

Those responsible for records should recognize the value of these analytical essays. They are reality-based, derived as they are directly from our extensive fieldwork with participants of collaborations, and the period under study is almost current. As a matter of fact, we can characterize our macroappraisal work as a historical-sociological study of organizational trends of multi-institutional collaboration and their archival implications.

AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART B

SECTION ONE: TYPOLOGY OF MULTI-INSTITUTIONAL COLLABORATIONS

Joel Genuth

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TYPOLOGY OF MULTI-INSTITUTIONAL COLLABORATIONS

I. *INTRODUCTION*

Archivists and records managers who seek to document multi-institutional collaborations will need to find their potentially valuable documentation without undertaking the kind of extensive research that AIP has performed. Sociological analysis,[40] by calling attention to those features that are powerful indicators for the character and accumulation of documentation, has the potential to provide guidelines to locating documentation. The sociological consultants for Phase III of the AIP Study, Ivan Chompalov and Wesley Shrum, attempted a systematic coding of the interviews and subjected the data to statistical analyses. They and project historian Joel Genuth received a grant from the National Science Foundation to revise and expand this data set to cover all three phases of the AIP Study. Under the new grant, we have recoded the information collected in Phase III, coded information on the collaborations studied in Phases I and II, and revised the conceptual framework for the coded information.[41]

Here we present a classification scheme or typology for the organization and management of collaborations—the aspect of collaborations that is most closely connected to the generation and accumulation of records.[42] A wealth of features can be used to characterize organizational arrangements, including scientific establishments, even though they generally have a less pyramidal and formalized organizational structure than government offices, corporations, and many other human groupings that sociologists tend to study. Our challenge was to limit the information we extracted from the interviews conducted during the AIP Study. Even focusing on macro-sociological, synchronic aspects yielded too many variables for performing cluster analysis.[43] We found, however, that our variables were sufficiently interrelated to justify reducing them to four factors:

- Formalization (which combines presence of written contracts, presence of an administrative leader, division of administrative and scientific authority, self-evaluation of the project, and

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[40]In the aggregate, the three phases of the AIP Study present an extraordinary opportunity for sociological analysis. Against the backdrop of a scholarly literature that consists primarily of tightly focused histories and ethnographies, a comparative perspective is badly needed. A data set of over 50 collaborations spanning six specialties in physical research opens the possibility for generating inductive hypotheses and statistically significant relationships that can serve as starting points for comparative analysis.

[41]A book manuscript is in preparation with chapters on the formation of collaborations, their size, their organization and management, the interdependencies of their parts, and their outcomes.

[42]The basis for the typology is "cluster analysis"—a statistical technique that groups objects on the basis of how closely they resemble each other across a range of variables. We performed cluster analysis on the organization-and-management variables for the 46 collaborations for which we had complete information. There is no mathematically acceptable way to include in cluster analysis those cases for which we had partial information.

[43]Excluded from systematic purview are such topics as the evolution of organizational forms over time, cultural processes that occur within interorganizational boundaries, and the impact of changes in the political and social environment on the organizational structure and management of collaborations.

outside formal evaluation);

- Hierarchy (which combines levels of authority, system of rules and regulations, style of decision-making, and degree to which leadership subgroups made decisions);
- Presence of scientific leadership; and
- Style of division of labor.[44]

The result of applying cluster analysis across the four factors is that collaborations can be reasonably divided into four organizational types. By establishing which category a collaboration belongs to, reasonable predictions can be made about the character and dispersal of a collaboration's records. With one notable exception, organizational types are *not field specific*—meaning that the particular disciplinary specialty of a collaboration (e.g., materials science or geophysics) is not a clue to its organizational type. The exception is particle physics. One of the clusters is comprised mostly of particle physics collaborations and most of the particle physics collaborations in our sample fell into this cluster.

The first organizational type is comprised of collaborations with a high degree of formalization, high degree of hierarchy, high scientific leadership, and specialized division of labor. We designate this type "highly structured." The second and third types differ from the first in that they are comprised of collaborations that are either less formal or less hierarchical than the highly structured. They are distinguished from each other by their needs for scientific leadership and by their method of dividing labor. The second type never has a designated scientific leader and usually has a specialized division of labor; the third type usually has a designated scientific leader and always has an unspecialized division of labor. We designate them "semi-structured with no scientific leader" (type two) and "semi-structured unspecialized" (type three). The collaborations in the fourth type register the lowest amounts of formalization and hierarchy, while still possessing scientific leadership and a specialized division of labor. We designate them "low-structured."

II. *HIGHLY STRUCTURED COLLABORATIONS*

The ***highly structured type*** of collaboration is characterized by the classical Weberian features of a bureaucratic form of organization: hierarchy of authority, written rules and regulations, formalized responsibilities, specialized division of labor. Although there are variations among the highly structured collaborations we studied, several manifestations of this organizational pattern are common: extensive external evaluation, committees upon committees with various designations and functions, officially appointed project managers, clear lines of authority (administrative and scientific), and a well-defined hierarchy of authority. Such a set of characteristics originates with the need to make sure that no participating organization's interests inappropriately dominates the collaboration. It well serves multi-organizational collaborations when participating scientists can sharply distinguish the collaboration's "engineering" from its "science" and can pursue the science autonomously from each other and from the engineers—provided that the engineering is well done and competently documented.

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[44]Together these factors comprise much of what sociologists understand as "bureaucracy" in the classic sense articulated by Max Weber at the turn of the 20th century. However, because "bureaucracy" has become an epithet in popular American discourse, we will shun its use here.

A pertinent example of this type of collaboration involved several universities (with secondary participation by a government agency) in the construction of an astronomical observatory. Astronomers at several affiliated campuses responded to encroaching light pollution at their observatories by entertaining novel telescope and observatory concepts that would vault them into the vanguard of optical observing power. They calculated that a telescope with a much larger primary mirror than they had ever constructed, if placed at an optimal site and accompanied by state-of-the-art detecting instruments, could yield as much as 100 times the observing power they currently enjoyed. Two groupings obtained seed money to flesh out their ideas, and the one that received an endorsement from the interested astronomers called for a telescope that would be unprecedented in the size of its mirror and the complexity of its operating mechanisms.

The technical challenge of the mirror plus the overall size and sophistication of the observatory promised to make the project extraordinarily expensive. Even dedicated fund-raising efforts and excellent luck only brought the instigating campuses within two-thirds of the calculated cost for the observatory. The only plausible partners were the instigating campuses' chief competitors. One became a full partner on the strength of its good fortunes in fund-raising. Another became a junior partner by donating a site for the observatory.

The quantities of money involved and the history of competition between the partners induced the university administrators to formalize explicitly their arrangements in order to guarantee that neither imposed its interests on the other. They created a corporation whose sole purpose was to design, build, and operate the observatory. The documents of incorporation specified the partners' fiscal responsibilities and payment schedule, which isolated the observatory from internal developments that could undercut support for the observatory in any of the participating organizations. The documents set forth a hierarchical authority structure for the collaboration and specified the general responsibilities of each part of the structure so as to give the organizations equal authority or to render organizational affiliation irrelevant. The Board of Directors, comprised of three representatives from each full partner so as to insure equality, was the ultimate authority and actively exercised its authority. It met every two months, which forced the other parts of the organization to report frequently on their progress, organized external panels of experts to review developments at what it considered strategic points, and required its approval be obtained for any significant budgetary shifts within the collaboration. The corporation's staff was responsible for the things that any optical astronomer, regardless of further scientific or technical specialization, needed from the observatory: the telescope (including the mirror and the pointing and tracking mechanics), observatory buildings, and the infrastructure to operate the telescope and a suite of scientific instruments. The head of the corporation's staff was an engineer with the title of project manager. He was, in the view of the participating scientists, the unambiguous decision-maker over all issues faced by his staff. A Science Steering Committee (SSC), comprised of astronomers from the participating universities, was responsible for producing a set of scientific instruments and for advising the Board of Directors and the corporation staff about engineering options that could affect the observatory's scientific capabilities. The SSC made its internal deliberations consensual on the assumption that in debating the value of various scientific instruments it would not encounter issues that required an exercise of authority to resolve. But the SSC was the authoritative conduit of messages from astronomers to the project manager and the Board:

> They [SSC members] write up the issue, they write up the decision that we've all agreed to and they present it to the Board of Directors. So that's consensual within the Science Steering Committee, but if you're not in the Science Steering Committee you don't have any say in it at all. So if you're an astronomer at [a particular campus] and you wanted something, you can talk to Science Steering Committee members, but you don't have any formal say in the issue at all. Only the Science Steering Committee decides which instrument they're going to build; how much money are we going to give that PI for building it; are we going to refurbish the instrument with a better detector, whatever.

These arrangements successfully eliminated the interests of the individual organizations from observatory policies and eliminated administrative ambiguity from the collaboration. Individual participants disagreed strenuously over the substance of observatory design and construction, and their arguments may well have been inflamed by personality conflicts, but there was little if any doubt about the proper procedures for reaching decisions or the quality of the decision-makers' intentions. A partisan in the conflicts, who believed the wrong side won more often than not, when asked about the quality of the organization, said:

> Yeah, I thought it was a very well organized project, both within [the corporation] from the project manager down through the engineers, and with the responsibilities of the Science Steering Committee...[A]nything having to do with money formally went to the Board of Directors for approval. It was clear and unambiguous what the lines of authority were on really every issue, and I think it worked fine. And the collaboration, generally speaking, did not pay much attention to rivalries among the partners. There was a contract that stipulated where the money came from; there was nothing to talk about once the contract was signed.

III. *SEMI-STRUCTURED COLLABORATIONS WITHOUT A SCIENTIFIC LEADER*

The ***semi-structured no scientific leader*** type is similar to the highly structured type in terms of having formally organized, highly differentiated structures. The reasons for the formalization and differentiation are much the same as in the highly structured type: participants whose common history is either competitive or nonexistent needed to insure that nobody's private interests were stamped on the collaboration, especially when the collaboration controlled a lot of money; and collaborations that wish to separate "science" from "engineering" needed to insure that the appropriate people stay focused on each. Unlike the highly structured collaborations, these collaborations did not designate a single scientific leader to represent scientists' interests or to decide scientific issues. The strong sense of hierarchy present in the observatory-building collaboration we described—in which some scientists were more important than others, the important scientists felt they were outranked by project management, and the Board of Directors actively monitored developments and adjudicated disputes—did not carry over with the formalization and the division of labor. In this form of the semi-structured collaboration, collaboration administrators tended to solicit the input of research scientists into the collaboration's affairs, to place scientists in charge of developing the collaboration's instrumentation, and to work on the collaboration's external relations and benignly neglect internal politics.

A good illustration of this kind of collaboration is one that built a synchrotron-radiation beamline for various kinds of materials, chemical, physical, engineering, and biological research. The instigating organizations varied in their abilities to capitalize the collaboration, varied in their needs to produce proprietary and published results, and lacked a history of collaborating on this level. Consequently, the organizations spelled out their rights and responsibilities in a legally binding agreement that was just short of formal incorporation:

> ...the kind of thing one would create for a joint venture with two companies, where you set up a, it's almost like a separate little incorporated outfit. It's not incorporated. It's very close to being a free-standing organization with every aspect—intellectual property rights, all the financial parts, the duties and responsibilities of the board, the director, all of the details of how you get out of this agreement, what you owe... It's a very thorough document.

As with the highly structured collaboration, the legal agreement stipulated the time and quantities of payments the member organizations would make to fund the collaboration, which insulated the collaboration from internal developments in its member organizations, and set up a hierarchical authority structure for the collaboration. As with the highly structured collaboration, the ultimate authority was a Board of Directors, comprised of representatives of the member organizations, to insure that the collaboration did not become an extension of the interests of any single member organization. As the highly structured collaboration entrusted design construction and operation of the telescope and observatory infrastructure to a professional project manager and staff, so this semi-structured collaboration entrusted the design, construction, and operation of the bulk of the beamline to a professional group with the sole responsibility of serving the collaboration. And as the highly structured collaboration commissioned scientists at its member organizations to design and build instruments to be used in conjunction with the telescope, so the semi-structured relied on scientists at member organizations to design and construct "end station" instrumentation to be used in conjunction with the beamline.

These organizational formalities made for a well-understood system of responsibilities and reporting. However, that system did not operate in nearly as hierarchical a fashion as the highly-structured collaboration's; the relationships among Board, staff, and scientists at member organizations were quite different. From the outset, the semi-structured collaboration was to serve a multi-disciplinary set of scientists—many of whom had not previously used synchrotron radiation in their experiments—with a beamline whose components stretched the state-of-the-art but were not novel in their design. Instead of a single Science Steering Committee to decide on instrumentation and to channel the views of technically experienced scientists to the staff and Board, the semi-structured collaboration had working groups for each of the major scientific disciplines that would be using the beamline, and many of the prospective users were as much or more in need of learning about synchrotron radiation from the staff as they were in need of making their expectations known.. Instead of a scientist with pride-of-authorship in the innovative design of the instrumentation's central component looking over the shoulder of a project manager with an autocratic style, the semi-structured collaboration Board designated as its staff director a scientist experienced in developing synchrotron beamlines for academic materials research, and charged him with developing a beamline that could simultaneously serve a wide variety of scientific disciplines. Instead of scientists constantly seeking to convince the project manager to provide them with the observatory of their dreams and an activist Board making sure the disputes were properly aired, the semi-structured collaboration's success hinged on collegiality between the collaboration's full-time staff and the scientists at member organizations. So long as the scientists at member organizations found the collaboration staff responsive and forthcoming, and so long as the staff could meet the technical burdens they assumed within the limits imposed by the collaboration's budget, the Board was passive instead of activist. The staff proposed an annual budget and the Board members no longer even needed to gather to consider it. "We often do the meetings by video conferencing now instead of flying back and forth to each other's institutions."

IV. *SEMI-STRUCTURED COLLABORATIONS WITH UNSPECIALIZED DIVISIONS OF LABOR*

The ***semi-structured unspecialized*** type is the complement of type two. Where type two was similar to the highly structured type in its formalization and differentiation but distinct in its more collegial management, type three was similar to the highly structured in its hierarchical management but distinct in having less formalization and differentiation. The most obvious difference between the two types of semi-structured collaborations is the presence of scientific leadership. In type two it is unimportant; in type three it is important. When a collaboration's teams are carrying out similar tasks instead of filling specialized roles, intellectual authority is needed to set standards for the teams' work.

A collaboration that creates a global data set by processing, reducing, and combining data from similarly instrumented earth-observing satellites well represents this type of collaboration. Such a global data set had long been desirable to would-be modelers of the climate, but seemed impossible to produce until a multi-national band of computer scientists and computer-savvy geophysicists convinced themselves that they could deal with the large quantities of low-quality data that extant satellites were producing. International agencies, eager to sponsor a project that would not require the design and construction of new hardware, supported a string of workshops that yielded concrete plans for sampling and calibrating data, applying an algorithm for obtaining the desired information, and then passing the processed data to a central data archive that would interact with researchers to make sure the data sets were in fact usable and used. On the strength of these plans, the agencies formally endorsed the project.

The international band of instigators assumed they could manage the project themselves and rely on their shared scientific motivations and standards to guarantee the quality of the work each would perform. During one of the planning workshops preceding the formal start, the scientists drew up a view graph for how the project would work:

> What was interesting was that at that stage we didn't imagine a central processing center; we imagined distributing processing. Everybody would get a copy of the code and apply it locally and ship the results to some central location.

Complete informality, however, was out of the question. The international agency's program manager and advisory committee had to be satisfied with the project's organization, and the scientists were obliged to obtain mutual commitments from their national governments, since the international agency did not control the satellites or have its own funds to support research. Under these circumstances, the scientists could limit the intrusion of formalization they did not initially want, but could not organize a project without at least a token accommodation of the norms of international, diplomatic agreements.

> [The project] didn't quite go all the way formally. For example, I don't believe the United States has ever formally committed to this program... [Rather] agencies instead of governments have simply said, "We'll step up to this." Projects depend on people in that agency being willing to fight the internal battles to make it happen. [The project] exists because [an American funding agency's] program manager is willing to spend money on it; and we've cajoled and convinced other people in other countries to spend money.

Indeed, major participating scientists did not even attend the meeting at which the representatives of national governments made their pledges to the project.

It did not take long for the scientists to realize that self-management through mutual trust had its drawbacks, because their needs could not be satisfied without the exercise of authority. The scientists' principal need was to agree on a single algorithm for sampling the data and deriving the desired parameters from the data. Before the formal start of the project, they realized they had no intellectual consensus for the algorithm: "the last decision we made at [the last planning workshop] was that we didn't know how to analyze the data. In other words, we had all the scientists there fighting and yelling and screaming and disagreeing, and the bottom line was that there wasn't any clear choice [among their algorithms]." The route towards consensus made them realize that they lacked the organizational structure the project would need to succeed. Ideally, the scientists advocating algorithms were to take the same data sets, use their algorithms to derive the same parameters from the data sets, and reconvene to decide whose approach worked best. The problem was that the advocates of various approaches to a project algorithm were not all equally capable of handling data sets that were large enough in size to be a fair test of what the algorithm faced.

> Some people would only do this much, some people would do more and so on. So we had to define tasks all the way up from "you do exactly one image" to "you do them all." It required some design work so that each task was nested within a larger one.

It can be impossible to get everybody to do the same thing when not everybody has the same resources (assuming one cannot condone lowering the community's standards to fit the member with the fewest resources). This project and the other collaborations in this category were distinctive in their lack of a specialized division of labor. Each team was to do the same thing to its data—first in the attempt to arrive at a consensus for the algorithm and then for the ongoing processing of the data streams from the satellites. If scientists with pride of authorship in their algorithms were going to vary in their ability to subject them to competitive tests by processing the same data, *a fortiori*, how was the project to impose a uniformly high standard on the teams that were going to sample, calibrate, and process the data that the project assigned to them? A team could not do much to advance its own interests, the collaboration's interests, or the scientific community's interests by lavishing specialized craftsmanship on a task that was valuable insofar as others did it in just the same way. Thus the collaboration could not much rely on either the narrowly or broadly defined interests of its members to insure the teams would perform to their best capabilities.

A more formal agreement, like the highly structured collaborations had and the semi-structured without a scientific leader had, might have committed participants to making specified contributions or set up a collaboration budget and management that the teams would try to please in order to acquire funding. But the opportunity for creating such formalization had passed and left the somewhat bitter truth:

> ...in this kind of environment where things aren't really that formal, you don't have much control. So if a team is either not doing the job it said it would do on the schedule it agreed to do it on, you can't do anything because you're not paying the bills.

In the absence of formalization as a viable source of project discipline, the project opted to centralize its operations in a member organization that could then be responsible for enforcing scientific standards.

> The data is such a mess—with the instruments misbehaving and calibrations fluctuating and everything else—that it really required a central place where you look at all of it together to try to figure out what the hell it's doing.

The question of which organization should be the central place was academic. Among the national agencies interested in supporting the project, only the American agency was prepared to support a global processing center; and among the American organizations showing interest in participating in data processing, only one had the resources to be a global processor of data.

The project continued to function without an administrative leader; its various managerial duties were performed by different scientists from the nations and agencies whose satellites provided raw data. However, the principal scientist at the global processing center became the *de facto* scientific leader. Leadership and decision-making authority over developing the algorithm to derive geophysical parameters devolved to him, because once the unprocessed data were sent to the global processing center for inter-calibration and quality checks, it made logistical sense to do the scientific processing at the global center rather than redistribute the corrected raw data sets for analysis only to recollect them. Among scientists whose ideas about analyzing the data differed from the scientific leader's, the leader's authority did not sit well. To one such scientist, the intercomparison of algorithms the leader pushed "was ineffective. It didn't result in a consensus algorithm; it just resulted in saying that all these algorithms are equally mediocre. So [the leader] said, 'Well, mine is as good as anybody's, so I'm going to use mine.'" Such resentments did not cripple the project. All recognized that the scientific leader, using the ideas of others, kept improving the algorithm and re-analyzing the earlier data, and the global center made corrected raw data available for others to use in developing their own ideas for deriving geophysical parameters.

Collaborations with unspecialized divisions of labor operate successfully with less formalization than highly structured collaborations, but they require as much hierarchy as highly structured collaborations. In collaborations with unspecialized divisions of labor, the participating organizations lack the sense of competition-among-equals or independence-of-purpose that lead to the drafting of formal agreements that precluded any organization from being dominant. But because the teams all perform similar tasks, these collaborations require a central scientific decision-maker to set standards for suitable contributions and to wield authority to correct contributions that do not meet standards.

V. *LOW-STRUCTURED COLLABORATIONS*

The ***low-structured*** type of collaboration is, as the label suggests, the absence of the classic features associated with Weberian bureaucracy. The membership of this type is dominated by particle physics collaborations. Among all the specialties in physical research we covered, particle physics alone has a distinct style of collaboration. Occasionally, particle physics collaborations fall outside the main category for particle physics. And occasionally collaborations in other specialties most closely resemble a typical particle physics collaboration. But it seems justified to speak of "particle physics exceptionalism."

Particle physics collaborations are exceptional in their combination of two characteristics. First, the participants find that their collaborations are highly egalitarian. Compared to what we heard from collaborators in other disciplines, particle physics collaborators describe decision-making as participatory and consensual, define their organizational structure through verbally shared understandings rather than formal contracts, and institute fewer levels of internal authority. At the same time, in contrast to collaborations that did not publish scientific findings collectively, the scope of particle physics collaborations encompasses nearly all the activities needed to produce scientific knowledge, including those activities most sensitive to building a scientific career: the collaborations always collectivize the data streams from the individual detector components built by the participating organizations, they frequently track who within the collaboration is addressing particular topics with the data, and they routinely regulate external communication of results to the scientific community.

Particle physics collaborations minimize the powers that collaboration-managers can exercise in order to make their members comfortable with the large breadth of activities that the collaboration as a whole regulates. In all other research specialties we examined, participants in collaborations were more autonomous than particle physicists in the generation and dissemination of scientific results; and the participants (more or less happily) allowed collaboration managers to exercise discretionary powers to secure what the collaboration as a whole needed. Collaborations court disaster if their breadth of activities is narrow and their decision-making is participatory, or if their breadth is broad and their decision-making is hierarchical. In the former case, they risk becoming bogged down as participants argue over matters they do not need to be discussing or risk becoming ineffective as participants take too little responsibility for collective functions. In the latter case, they risk alienating participants by failing to take into account interests or considerations that members consider vital.

The prevalence of high-breadth, egalitarian collaborations in particle physics is due to the dispersal of particle physicists among many universities, the specialty's centralized institutional politics, and competitive pressures. Because particle physicists in the United States and Europe are dispersed among many universities and because they crave integrated, multi-component detectors, they need to be in high-breadth collaborations in order to conduct publishable research. Because collaborations must submit proposals to central authorities for access to an accelerator, participants are behooved to commit to an organizational structure that convinces the accelerator laboratory's administration that they are properly organized to produce what they promise. With respect for internal structure thus secured before any commitment of resources to the collaboration is made, collaboration administrators have not required formalized powers to maintain order and could afford to grant broad rights of participation to all members of the collaboration, from graduate students to senior faculty. Such Athenian-style democracy has produced publications rather than cacophony because competition for discoveries and for career-advancing recognition limit the collective tolerance for intra-collaboration dissent.

The organizational and management features of "particle physics exceptionalism" are well illustrated by an experiment at Fermilab that smashed a beam into a fixed target and searched for particular particles and their decay chains in order to measure whether a particular process occurred as theoretically predicted. The collaboration succeeded with little formalization. The collaborating organizations did not pool funds, so they did not need formal rules to insure that no member received an unfair share of the benefits of collaborating. Rather, each major American organization had its own contract with DOE or NSF, and foreign governments supported the participation of their groups.[45] No administrative or engineering leader for the collaboration was needed because of a well-understood division of labor that left the participants implicitly trusting each other because most were recapitulating or building on the past successes that were the foundation for their scientific reputations.

> [One component] was clearly [a foreign group's] since it was their invention. The drift chamber system I had built for [an earlier experiment], and the design of the channel was the same as we used for that experiment. So I was naturally responsible. The high resolution proportional chambers had been [another organization's] responsibility for [the earlier experiment] so it was natural for [the leader of that group] to take that over.

[45]The collaboration did depend on the ability of Soviet participants to travel to the United States. By not pursuing a formal agreement, the collaboration effectively gambled that neither government would prove an obstacle. At times, it appeared the collaboration might lose the gamble, but each time participants were able to secure their governments' cooperation.

The newest member of the collaboration took responsibility for the only desired component for which there was no experienced team.

The experiment did have a designated scientific leader, whose title was spokesperson, but it had no hierarchy of scientists. Once Fermilab approved the collaboration's proposal for beamtime, the spokesperson's duties were a mixture of scientific coordination, which was intellectually strenuous since he had to become well versed in the technical needs and characteristics of each component, and administrative routines (e.g. making sure the collaboration covered all the data-taking shifts). However, whenever the collaboration met as a whole to discuss how to operate the detector, how to combine data streams, and how to perform analyses, all titles disappeared:

> One thing we did well was argue. It was small enough. This was an extended family and you could scream at anybody you wanted to, and you did from time to time. There were some people who weren't screamers and that was fine. In fact, that was probably better. We did not have the kind of authoritarian thing where people felt intimidated from saying what they really thought. In a group meeting, you could pretty much let your hair down and holler at anybody you wanted.

Not even the most vituperative of Cold War rhetoric put a damper on uninhibited, egalitarian discussions of the experiment between American and Soviet physicists:

> It was entertaining to watch in fact. The Russians first came shortly after Reagan's speech in which he declared the Soviet Union the evil empire. They were understandably circumspect and a bit clannish in general... We'd finally sit down around the table and start to discuss physics and that evaporated. On a given day, one set of groups would gang up on the others, and on the next issue everyone would change sides, they would split. It was the usual physics free for all, as in all collaborations.

VI. *CONCLUSION*

By ascertaining several features of a collaboration—whether there is a board of directors, a single scientific leader, an engineering or administrative leader, external evaluations, a decision-making hierarchy, a specialized division of labor—archivists may be able to determine quickly a collaboration's organizational type. They can then predict the likely character and location of a collaboration's documentation.

- Highly structured collaborations generate voluminous records that accumulate at the apex of their hierarchies. Senior administrators in participating institutions have the formal agreements under which the collaborations operate. Boards of directors, in order to set a collaboration budget, require reports from the collaborations' teams and from the external advisory panels they commission. Their engineering leaders, in order to set specifications for the design and construction of instrumentation, need the participating scientists to describe and justify the goals that the collaborations' instrumentation should meet. Their engineering leaders, in order to serve the ongoing operating needs of collaboration members who use instrumentation, require technical documentation for instrumentation from contractors and for instrumentation contributed by scientists. Their scientific leaders must collect and distribute the information the participating scientists need in order to contribute sound advice to the engineering leader and to contribute instrumentation that interfaces smoothly with the main body of the collaboration's instrumentation.

- Semi-structured collaborations without scientific leaders also create voluminous records, but only the records needed for legal and fiscal administration are likely to accumulate in designated locations. Like the highly structured collaborations, senior administrators in the participating institutions have the formal agreements under which the collaborations operate. And like the highly structured, their boards of directors require information on which to determine the collaboration's budget. However, because these collaborations serve a heterogeneous set of independent participating scientists (which is why they do not have a designated scientific leader), there is far less of a uniform hierarchical structure to intra-collaboration discussions of technical feasibility and scientific needs. The engineering leaders can be quite autonomous from participating scientists when they know their goal is to provide flexible instrumentation that proves serviceable for many different potential scientific users. Scientific teams in these collaborations often build instrumentation only for their own use and thus do not provide the engineering leader with the technical documentation that other users would need. Participating scientists, because of their diverse interests, are more prone to assess a collaboration's development in team meetings of like-minded specialists than in collaboration-wide meetings. The result of such features is that core records accumulate with representatives to the boards of directors and their supervisors, but the detailed records that should be retained when a collaboration is especially significant are highly dispersed.

- The semi-structured collaborations with unspecialized divisions of labor are less prone to create records that high-level administrators of the participating institutions would collect in order to document the institutions' responsibilities and rights. However, these collaborations do have a hierarchy that leads to the accumulation of records with their scientific or administrative leaders. To insure that the contributions of the teams in these collaborations are meeting collaboration-wide standards, the teams must pass documentation to the leaders for evaluation or meet with the leaders for collective assessments of everyone's efforts. When leaders draft manuscripts for publication, they circulate the manuscripts to the participants and collect suggested revisions. These practices concentrate intellectually and technically significant records with the leaders.

- The low-structured collaborations are easiest to document. Because they usually exist to tap the capabilities of a major facility controlled by a permanent institution, they must pass records documenting their internal organization and plans to the permanent institution in the course of obtaining permission to use the facility. Because these collaborations are highly participatory and egalitarian, the participants must document their individual efforts in order to enable each other to learn what they need to know to participate meaningfully. Often a collaboration leader takes responsibility for this documentation.

We hope this categorization of collaborations can help archivists and others with responsibility for records to find the documentation they should consider retaining to meet the needs of institutional administrators and future historians. Although these categories do not convey prescriptive implications for which institutions should save what records, they do indicate the sorts of records collaborations generate and where these records accumulate.

- Core records[46] of highly structured collaborations and semi-structured collaborations without a scientific leader are with the institutions' representatives to the collaborations' boards of directors or with the supervisors of the representatives.

- Core records for semi-structured collaborations with a scientific leader and an unspecialized division of labor do not always exist and are not considered important to participants.

- Core records for low-structured collaborations are best sought at the institutions whose facilities such collaborations have used.

- Detailed records worth saving only for especially significant collaborations accumulate with the engineering leader of highly structured collaborations.

- Detailed records are dispersed in semi-structured collaborations without a scientific leader.

- Detailed records accumulate with the scientific leader of semi-structured collaborations with an unspecialized division of labor.

- The scientific leader of low-structured collaborations often keeps the collaboration's collective records.

[46]Core records are the small set that should be saved for all collaborations. See Part B, Section Three of this report.

AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART B

SECTION TWO: FUNCTIONAL ANALYSIS OF RECORDS CREATION

Joan Warnow-Blewett

with the help of Anthony Capitos

FUNCTIONAL ANALYSIS OF RECORDS CREATION[47]

The key functions of all scientific activities can be summarized as establishing research priorities, administration of research (including development of instrumentation), the research and development itself, and dissemination.[48] We list the key functions of multi-institutional collaborations below[49] and illustrate the process of functional analysis by providing a brief analysis of the functions along with the categories of records created through these activities. Our illustrations have been drawn from the three fields we studied in most detail—geophysics, particle and nuclear physics,[50] and space science. Details on these categories of records are provided in the next section of this report, *Appraisal Guidelines*.

I. *ESTABLISHING RESEARCH PRIORITIES*

A. *National/Multi-National Discipline Priorities*

Geophysics

Establishing broad research priorities in geophysics and oceanography, as in space science, is done on a discipline level. When global phenomena seem important, priorities are worked out not only in national but in multi-national disciplinary organizations. This function of establishing research priorities is carried out in many different arenas. In the United States, the National Academy of Sciences' advisory boards, such as the Ocean Studies Board, the Polar Research Board, and the Board on Atmospheric Science, are sites for the scientific community to voice their opinions concerning broad program ideas. On an international scale, organizations like the International Council of Scientific Unions (ICSU) and the World Meteorological Organization (WMO), along with programs like the International Geophysical Year, have helped to set goals in the fields of geophysics and oceanography. In ICSU, priorities for broad areas to pursue typically rise up through one or more of the international unions for scientific disciplines (e.g., the International Union of Geodesy and Geophysics), its interdisciplinary bodies (e.g., the Scientific Committee on Oceanic Research), or its joint programs (e.g., the World Climate Research Programme). Through

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[47] As project archivist during our Phase II study of space science and geophysics, Anthony Capitos made important contributions to a previous version of this report.

[48] The functional analysis can be elaborated for specific disciplines. For example, a particular characteristic of multi-institutional collaborations in particle physics is that they carry out functions on two levels. First, each individual group fulfills the functions required by its own institution, including raising funds for the experiment and, frequently, training of graduate students. Second, the collaboration as a whole is a mini-institution with an internal organizational structure headed by one, or perhaps two, spokespersons, together with group leaders from each institutional member; and, increasingly, by a more elaborate structure to oversee the various functions of the experiment—including those required by the accelerator facility, from the initial proposal for beamtime to completion of the experiment.

[49] The categories of functions have been based upon Joan K. Hass, Helen Willa Samuels, and Barbara Trippel Simmons, *Appraising the Records of Modern Science and Technology: A Guide* (Cambridge, Mass.: Massachusetts Institute of Technology, 1985).

[50] The AIP Study examined the field of high-energy physics during its first phase and the field of heavy-ion physics in its third phase; both fields are included in the discipline of particle physics. We have also been told that our findings conform to patterns in nuclear physics collaborations.

interaction with these groups and institutions, the scientific community promotes ideas for large multi-institutional collaborations.
Documentation: National Academy of Sciences' Ocean Studies Board, Polar Research Board, and Board on Atmospheric Science; International Council for Scientific Unions (its unions, interdisciplinary bodies, and joint programs), and the World Meteorological Organization.

Particle and Nuclear Physics
The main body to shape national planning in the U.S. is HEPAP (High Energy Physics Advisory Panel). Commissioned by the Department of Energy, its panels and subpanels are composed of prominent leaders of the high-energy physics community.

Another major influence on national policy are the decadal surveys of the National Academy of Sciences' Board on Physics and Astronomy. These reports—on particle physics and other disciplines—focus on documenting the accomplishments of a field of physics during the previous decade and analyzing the requirements for continued progress.
Documentation: Department of Energy, High Energy Physics Advisory Panel; National Academy of Sciences' Board on Physics and Astronomy.

Space Science
The Space Studies Board of the National Academy of Sciences (NAS) is charged with the responsibility of suggesting broad areas of research in which NASA should focus its efforts. This Board, with its sub-committees, is comprised of distinguished members of the space science community. It has been both a brake on flight center plans that seem too grandiose and an alternative route through which scientists from outside the flight centers can campaign for projects.

This advisory structure does not seem to exist for the European Space Agency as formally as it does for NASA in the United States, although the European Space Science Foundation's European Space Science Committee hopes to fill the role of recommending broad areas of research for ESA in the manner of the NAS Space Studies Board. Advice and reviews on specific projects are considered by the ESA Space Science Advisory Committee's working groups.
Documentation: National Academy of Sciences' Space Studies Board; European Space Science Foundation's Space Science Committee; ESA Space Science Advisory Committee.

B. *Individual Project Research Priorities*

Geophysics
The more specific hypothesizing and defining of priorities takes place as programs or projects are focused and shaped by the scientific community. In the cases we studied, we found two different approaches by research scientists: obtaining funding for formal workshops (usually employed by

"technique-aggregating" projects) and informal gatherings (usually employed by "technique-importing" projects).[51]

In the formal workshop approach, instigators for projects obtain support from funding agencies to hold workshops for interested research scientists which define the scope and methodology of the project, select members of an Executive Committee and an institutional base to serve as the project's Science Management Office, along with a principal investigator (PI) to administer it, and initiate a set of proposals for submission to a funding agency.

For the international projects we studied, ICSU and WMO have been particularly influential in setting up workshops and symposia, which typically generate a number of workshop panels. If project proposals receive the blessing of ICSU and WMO, workshop panel members and other interested scientists submit proposals to their national funding agencies. ICSU's members—the national academies—are apt to pressure funding agencies to provide support.

In the less formal approach, the process of establishing priorities for specific projects can be initiated wherever key research scientists get together. Meetings of the American Geophysical Union or review panels of funding agencies are examples. Some, but not all, consortia need funding to set themselves up and prepare proposals. In the technique-importing projects we studied, funding agency personnel played an important role in defining the terms of consortia formation and, in some cases, later project research activities.

Whether the approach is formal or informal, scientists involved in the instigation of geophysics and oceanography projects should take care in documenting these initial meetings and workshops. Documentation: Minutes and other records of workshops and initial meetings of consortia, proposals to funding agencies, correspondence of program managers at funding agencies, professional papers of scientists.

Particle and Nuclear Physics
New multi-institutional collaborations in particle and nuclear physics are initiated for a variety of reasons. However, the opening of a new accelerator facility and the discovery of new detection techniques or strategies are the most prominent stimuli to the formation of new collaborations. Planning for new experiments is typically initiated by a small core of individuals from several institutions who seek opportunities for their creativity, their passion for leadership, or their need to build a record of professional accomplishment. The core group develops proposals and seeks additional institutions to flesh out the collaboration. Once in place, a collaboration may extend its lifetime by proposing future experiments that modify the original in meaningful ways, thereby generating a "string" of experiments. In other cases, an idea for a brand new experiment will emerge from one or more members of an existing experiment; this often results in the joining up of some institutional members and the dropping off of others. So the cycle continues. In most

[51]Technique-importing projects import, for academic research, established techniques from industrial research or other scientific fields. Technique-aggregating projects aggregate geophysical techniques to study, for example, a global phenomenon. These geophysics projects are described in more detail in Part A, Section One: Historical-Sociological Findings, II.A., in this report.

cases, the originators of the future experiments become the group leaders for their institutions and one of the originators becomes the collaboration's initial spokesperson.
Documentation: Correspondence of spokespersons and group leaders, professional files of individuals, Physics Advisory Committee records, and laboratory directors' files.

Space Science

In space science the plans for a project or mission are well-defined prior to the selection of the scientific staff. Until recently, ideas for specific projects or missions were typically generated by scientists and engineers at NASA's flight centers. Currently, at NASA Headquarters there are levels of working groups, from the discipline scientists' working groups up to the NASA Advisory Council, which help structure and define the scope of projects to be promoted. These committees are comprised of members of the space science community, including space scientists located at NASA's flight centers. It is through this structure that NASA's discipline scientists are able to campaign for support for particular projects. As ideas for new projects are passed up through this advisory structure, they are better defined and ideas for particular instruments to be included are identified.

NASA Headquarters may ask a flight center to do a pre-phase A study under the direction of a lead engineer to judge the feasibility of the proposed project. If the outcome is positive and funding is secured, NASA asks the center to do a full-fledged Phase A study for the instrument payload and asks a center or subcontractor to do a Phase B study for the spacecraft.
Documentation: NASA Headquarters discipline scientists and program managers, NASA flight center project managers, and lead engineers who oversaw Phase A studies (not all of whom became project managers).

Once a project is defined and funding obtained, the NASA Headquarters discipline scientist usually becomes program scientist and a Headquarters engineer is appointed program manager. Together with the project manager at the flight center, they prepare an Announcement of Opportunity (AO) to be issued by the Associate Administrator for Space Science. This AO defines what types of instruments are requested for the NASA mission and what technical restraints these instruments must operate within. Individual teams propose their instrument ideas to NASA Headquarters. Following a standard peer review of the scientific merits of the proposals and an engineering assessment of their feasibility, the Associate Administrator for Space Science makes the final decision concerning which instruments will be included on a project's payload.
Documentation: NASA Headquarters discipline scientists and program managers, the NASA Associate Administrator for Space Science, and flight center project managers.

For projects of the European Space Agency, ideas are proposed through the agency's astronomy or solar system working groups which, in turn, report to ESA's Space Science Advisory Committee. The recommendations of this advisory committee are sent to ESA's Science Programme Committee, which makes the final decision concerning which projects ESA should pursue. The Science Programme Committee issues AOs for instruments for successful projects.
Documentation: ESA working groups, ESA Space Science Advisory Committee, and the ESA Programme Committee.

II. *ADMINISTRATION OF R & D*

A. *Support/Funding*

Geophysics

In the geophysics cases we studied, domestic funding was provided by various agencies (and often more than one). The process involves submission of proposals to discipline program managers at funding agencies, peer and panel reviews at the program level and—for larger projects—review at the highest policy level, such as the National Science Board of the NSF. To be more specific, technique-aggregating projects submit a package of proposals to one or more funding agencies where a set of individual proposals (and, thereby, principal investigators) are selected. For the most part the technique-importing projects we studied were supported by block grants from funding agencies to the consortia which, in turn, selected proposals for using the imported techniques; however, in two of these cases, would-be individual users had to submit proposals for approval by the funding agency. Finally, we note that consortia are funded, in part, by institutional members.

<u>Documentation</u>: Consortia standing committees and subcommittees, program managers and proposal files at funding agencies, and professional files of principal investigators. Additional documentation, at higher levels not dealt with by our study, will be found in the records of university administrators, records of the Office of Management and Budget, and records of the U.S. Congress.

Particle and Nuclear Physics

The collaboration as a whole submits a proposal to an accelerator laboratory. The proposal is an official request for allocation of accelerator beamtime and includes plans and goals of the experiment. Proposals are reviewed, often extensively, by the laboratory's Physics Advisory Committee (PAC) which then makes its recommendations to the laboratory.

<u>Documentation</u>: Physics Advisory Committee records, proposals to laboratories for experiments, and Memoranda of Understanding and other contracts between laboratories and collaborations.

The funding for experiments is typically acquired through proposals from each institutional group in the collaboration to one of two funding agencies for the discipline, the National Science Foundation (NSF) or the Department of Energy (DOE). This procedure gives university departments the ability to manage the activities of their faculty members in accordance with the needs of their graduate students and the demands on their laboratory and shop facilities. The exception to this pattern is that major funding for the largest detector experiments is often provided by the agency to the accelerator laboratory rather than to individual institutional teams. A separate office may be set up at the laboratories for these experiments. This procedure strengthens the ability of the accelerator laboratories to monitor the expenditures and activities needed to create such detectors.

<u>Documentation</u>: Proposals submitted to DOE and NSF, proposal files of principal investigators, other proposals and reports, and laboratory directors' files.

Space Science

NASA space science projects that are sufficiently large or are part of large programs are funded through dedicated line-items of the NASA budget and face annual reviews from the Congress and the Office of Management and Budget. Smaller space science projects fall into the Explorer

program, an annually approved budget line item that does not specify a particular project, and leaves the decision as to which project to fund with NASA's Associate Administrator for Space Science. Since NASA is both the funding agency and the planning agency, these processes occur concurrently. The most detailed budget records concerning the funding decision-making process would be located at NASA Headquarters with the program manager responsible for the individual project.
Documentation: NASA Headquarters program managers, NASA Associate Administrator for Space Science. Additional documentation, not dealt with by our study, will be found in the records of university administrators, records of the Office of Management and Budget, and records of the U.S. Congress.

The European Space Agency's budget is approved in five-year intervals, thus removing the concern of yearly appropriations for a project. This funding is used for the construction of the spacecraft itself. The individual instruments for an ESA project are funded by the appropriate government agency of the country whose scientist is chosen to provide the instrument, not ESA itself.
Documentation: Funding agencies of participating countries, professional papers of principal investigators (PIs), and with informational copies commonly sent to the relevant project manager at ESA's flight center, the European Space Research and Technology Centre (ESTEC).

If a European experiment is included on a NASA project, the European country pays for the construction of the instrument, much as for an ESA project. This process also works in reverse for American investigators included on European projects. No money is exchanged between countries during these international projects; therefore, the records concerning the funding of an international project will be in multiple locations.
Documentation: (For NASA instruments) NASA Headquarters discipline scientists, (for European instruments) funding agencies of participating countries, professional papers of principal investigators. If the instruments are part of a NASA mission, there would be funding records with the Headquarters program manager responsible for the project; for ESA missions, these documents would be with the project manager at ESTEC.

B. *Staffing*

Geophysics

Staffing of geophysics and oceanography projects is most visible in records of workshops and consortia and the subsequent funding process. Workshops and consortia select committees and science administrators; proposals, as a minimum, identify principal investigators and, often, prospective team members. Decisions to fund proposals are made at various levels of funding agencies or by committees of consortia. Additional information on staffing of projects would be in the records of chief administrators, staff scientists, and papers of principal investigators.
Documentation: Workshop and consortia records, Science Working Groups and consortia committees, funding agencies, chief administrators, and professional files of principal investigators.

Particle and Nuclear Physics

Prior to the submission of the proposal to the laboratory for beamtime, institutional membership on a collaboration is determined by the original core group of principal investigators (PIs). In the course of reviewing proposals, the PAC or laboratory director may pressure the proponents of similar proposals to resubmit a unified proposal (the so-called "shotgun marriage") or may insist that the proponents of a proposal find additional collaborators in order to have enough resources to carry out all the proposed work.
Documentation: Correspondence of spokespersons and group leaders, Physics Advisory Committee records, and laboratory directors' files.

Decisions regarding which individuals (physicists, postdocs, graduate students, etc.) should staff the experiment are made by each institutional group leader.
Documentation: Correspondence of spokespersons and group leaders, professional files of individuals, and Physics Advisory Committee records.

Space Science
Experiment (instrument) teams are formed to respond to individual AOs from NASA Headquarters; at their core are stable groups of scientists developing instruments with grant support. The co-investigators are selected by the principal investigator for the additional designing skills, scientific background, or the prestige that they can bring to the experiment team.
Documentation: Professional records of principal investigators.

C. *Organization and Management*

Geophysics
In technique-importing projects there would normally be a consortium responsible for appointing standing committees (or one with subcommittees responsible for separate aspects of the project). These advise or direct project executives. A consortium in these projects proceeds in one of two ways: (1) it creates an arena in which institutions can participate as equals even when one among them is made responsible for administration, or (2) it creates a new independent, freestanding entity in which the involved institutions can vest responsibilities that they do not want any extant member institution to dominate. The technique-importing projects need to operate far longer—in order to apply the technique to many objects of curiosity—than the technique-aggregating projects. They therefore adopt a more secure institutional base and more formal chain of command. Project executives include an Executive Committee and a chief administrator. Another key position at some project headquarters is that of staff scientist.
Documentation: Consortia headquarters records, records of federal funding agencies, and professional files of principal investigators.

Technique-aggregating projects unite multiple, independent principal investigators who form a Science Working Group (SWG) that, in turn, selects members for an Executive Committee. In these projects, there would typically be a modest Science Management Office run from an institution and under the direction of one of the principal investigators with grant funds to spend on coordinating logistics for the principal investigators.

Technique-aggregating projects, as compared with technique-importing projects, usually have a more *ad hoc*, informal institutional base in order to maximize self-governance. The SWGs for these projects are critical in managing what is intrinsically collective to the design of the projects, such as the allocation of space and the track of oceanographic research vessels, the distribution of core samples, a common data processing algorithm for combining data streams from several individual instruments, and protocols for comparing data sets obtained by deploying several techniques at the same site. That is usually the limit of power allotted to a project's Science Working Group, although—for example—the Executive Committee of the working group might be called on at times to add a judgement of project relevance to the proposals to funding agencies. The rest is left to the discretion of individual principal investigators.

The Science Management Office (SMO), under the direction of its principal investigator, is responsible for the logistics of technique-aggregating projects. The office provides technical infrastructure and gets people and their equipment to the site where they can take their data. While this is challenging in all cases, it is particularly so for ship-based oceanographic projects as compared to land- and space-based geophysics projects. SMOs are also responsible for creating centralized data management systems to facilitate exchanges of data streams and to maintain project-wide data bases. They also organize post-field-work workshops for intra-project exchanges of preliminary findings, which—among other things—often inspire joint data analyses efforts.
Documentation: Science Management Office's principal investigator files including records of the Science Working Group and its Executive Committee.

Particle and Nuclear Physics
While the outline of the experimental plan is covered in the proposal of the whole collaboration to the accelerator laboratory, numerous decisions on details follow its approval. One major category, assignments of responsibility for development of detector components, may involve written agreements between institutional groups and with the accelerator laboratory. Later details, modification of plans, work schedules, etc. would be made by or reported to the collaboration as a whole. Progress reports are submitted to the laboratory and funding agencies.
Documentation: Physics Advisory Committee records, MOUs and other contracts between laboratories and collaborations, intra-collaboration mailings, and, in some cases, Accelerator or Research Division files.

Space Science
The Science Working Group (SWG), which is comprised of the principal investigators involved with a project and chaired by the project scientist, establishes the details of the scientific strategy for a particular project. These groups have been especially important in establishing the scientific priorities for planetary encounters and for astronomical satellites with relatively low orbits and thus short operating potential.
Documentation: NASA flight center project scientist.

The engineering of the entire spacecraft falls under the responsibility of the project manager. The project manager has the final word on all budgetary and technical problems once the project is under development, except for appeals to the program scientist.
Documentation: NASA flight center project manager.

Although NASA prefers a particular method for starting space science projects with predefined roles and responsibilities, not all projects are started through traditional channels and international projects require flexibility in the participating agencies. For these reasons, the scope of responsibility for the project manager, the Science Working Group, and the experiment teams has to be refined as each project is initiated. In particular situations, the project manager may have little involvement in the overall project design or the Science Working Group may have little voice in changes in engineering options.
Documentation: NASA flight center project manager and project scientist.

III. *RESEARCH AND DEVELOPMENT*

A. *Instrumentation*

Geophysics

Research and development of instrumentation for academic geophysics mostly takes place in geophysical research institutes, which maintain engineering staffs to service the facilities they provide their research staffs. University departments of geophysics or geology usually do not have the research and development laboratories and machine shops to support design and construction of instrumentation. However, the body of instrumentation available for academic geophysical research is supplemented by the efforts of commercial interests (e.g., oil exploration companies) and governmental functions (e.g. detection of nuclear weapons tests) to develop instrumentation that university geophysicists may parasitically use or adapt for their purposes.
Documentation: Records of consortium Executive Committees as well as other standing committees (and subcommittees where they exist). Records of project Science Working Groups, administrators of the Science Management Offices, and other principal investigators.

Particle and Nuclear Physics

Between approval and dissemination of research results, there are three major stages in experiments in particle and nuclear physics: (1) the design, construction, and testing of the detector's components, (2) assembly, integration, and testing of the detector and data collection at the laboratory, and (3) data analysis. Collaborations assign responsibility for design and construction of detector components, including software to process the signals put out by the components, to institutional members. The responsible physicists usually design and build their components in the laboratories and machine shops of their home institutions with only occasional subcontracts for materials or devices they can neither buy from a supplier nor make themselves; software is always written in-house. When a collaboration anticipates that components for an experiment will be tricky to integrate, the collaboration actively coordinates the substantive development of the components; when integration appears straightforward, the collaboration as a whole tends to limit its interest to the performance, schedule, and cost of developing components.

Documentation: Papers of group leaders, intra-collaboration mailings, technical records of collaborations, (including experiment [or "running"] logbooks, computer programs and software) Ph.D. theses, and, in some cases, subcontracting records.

Space Science

The function of designing and constructing instruments takes place at the experiment (instrument) team level. It is the principal investigators and members of their team who are responsible for

carrying out this function. Project management is less concerned with the design of the instrument than its electronic requirements and integration with the spacecraft. The principal investigators have the option of building the instrument at their respective facilities or contracting out the construction of particular instruments or portions of instruments. It is important to note that the development of most instruments used on NASA projects was funded earlier by NASA basic research grants administered by discipline scientists.
Documentation: Principal investigator professional records, NASA Headquarters discipline scientists.

The integration of the instruments into the spacecraft falls under the responsibility of the project manager. Most projects have an interface control document, which defines the way the experiments will be interfaced with the spacecraft. In some NASA projects the project managers have appointed instrument managers to deal with the principal investigators on instrument-spacecraft interfaces. In European projects, a project manager may appoint a "payload specialist" to serve a similar function.
Documentation: NASA flight center project managers and instrument managers; ESTEC project managers and payload specialists.

B. *Gathering and Analyzing Data*

Geophysics

While preliminary plans for gathering and analyzing data are spelled out in proposals, the more detailed plans are developed by individual principal investigators and consortium administrators of technique-importing projects and by Science Working Groups (made up of all principal investigators) and Science Management Office administrators of technique-aggregating projects. Virtually all principal investigator teams keep logbooks on the data-gathering techniques they employ (instruments, locations, and so forth) that provide the metadata necessary for data analysis. The data gathered by the cases studied by the AIP included electronic data, cores (of ice, of sediment) and water samples.
Documentation: Consortium administrators, including staff scientists; Science Management Office (Science Working Groups and administrators); professional files of principal investigators; and databanks.

Particle and Nuclear Physics

A collaboration collects data during "runs"—periods when the accelerator laboratory operates the accelerator for the collaboration's benefit. Data are taken around the clock, and everyone in the collaboration is responsible for taking shifts to keep track of the performance of beam and detector. Advances in electronic circuitry and computer software have steadily increased collaborations' abilities to filter out signals they are not interested in, and to collect larger sets of signals they are interested in. Sophisticated data analyses are performed "off line" after the data are collected. Often graduate students and postdocs have worked on data analyses at the accelerator laboratory, where they enjoyed the stimulation of each other's efforts and the benefits of more powerful mainframe computers (before the power of PCS rendered mainframes obsolescent). Data analysis is carried out increasingly at the home institutions.
Documentation: Intra-collaboration mailings, technical records of collaborations—including experiment [or "running"] logbooks, other logbooks, raw data tapes and data summary tapes,

computer programs and software, and other scientific data—and Ph.D. theses.

Space Science

Until recently, the function of gathering and analyzing data has been the domain of the individual experiment teams. Instruments were built and data were processed with no one being able to make use of the data without the cooperation of original investigators; data streams were combined at the discretion of the principal investigators. Pressure from other scientists wanting to access data or use instruments has encouraged a trend towards more user-oriented projects, which impose standardized data processing that enables outside users as well as the original investigators to extract reliable results.
Documentation: Professional records of the principal investigators.

IV. *COMMUNICATING AND DISSEMINATING RESULTS*

Geophysics

In most cases, collaborations in geophysics and oceanography require that each team produce an article to be published with the others as a set—often as a special issue of a science journal. However, collaborations do not control the content or author lists of publications. Instead, it is the principal investigator of each experiment who is in control of the team's data and publications. Members of other teams must obtain permission of the principal investigator to use the data; in such cases, it is traditional that the principal investigator be asked to review the draft publication and be listed as an author. If a member of their own team prepares an article for publication, it is customary for the principal investigator to review the article and be listed as an author. The inclusion of other members of the team as authors varies from case to case. Arrangements for making oral presentations are typically even more informal, although principal investigators would usually be aware of their team members' plans.
Documentation: Chief administrators at consortia and Science Management Offices, professional papers of principal investigators and other team members, and press releases and other public affairs materials.

Particle and Nuclear Physics

Communication of research results becomes increasingly formal over time. The initial presentation of research results may well be an oral report given at the accelerator laboratory to test reactions to the findings. Subsequently, collaboration members will select individuals to make presentations at various professional meetings or topical conferences; usually some kind of balance is struck between giving the young professionals the chance to show themselves (especially at regional or national meetings) and having the senior physicists make the more visible presentations at international conferences. Submission of articles to refereed journals is often a drawn out process with drafts reviewed by each member of the collaboration. Through all of this there will be informal, sometimes crucial interchanges between individuals on the collaboration and outside colleagues.
Documentation: Intra-collaboration mailings, correspondence between spokespersons and group leaders, professional files of individuals, papers prepared for publication or for talks, and—for access to a full range of publications—High Energy Physics databases maintained at the Stanford Linear Accelerator Center.

Space Science

In space science, the communication and dissemination of results is not controlled by the entire project, but by individual principal investigators for their own teams. While in some teams topics are assigned, in most cases the principal investigator is aware of the work being done by team members and there are no real requirements about who within the team specifically takes the lead in drafting on what topic. In space science, part of the "rules of the road" is that it is the responsibility of each principal investigator to negotiate wider use of the team's data and arrangements for listing authors on publications that result. These issues may be discussed by the project's Science Working Group.
Documentation: Professional records of principal investigators, NASA flight center project scientist.

At the completion of the project, NASA requires the principal investigators to process their data for placement in the National Space Science Data Center for use by others. In recent years the quality of the metadata that make the data accessible to others has greatly improved, so that—for most users and most applications—it is no longer necessary for outsiders to contact the principal investigator in order to fully understand the creation of the data and any peculiarities they might have. Exceptions are in cases where unusual or subtle details are needed from the data, such as in high-energy astrophysics, where it is important that users contact the principal investigators who understand the instruments and, therefore, the data.
Documentation: Records of the National Space Science Data Center, records of experiment principal investigators.

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART B

SECTION THREE: APPRAISAL GUIDELINES

Joan Warnow-Blewett

with the help of Anthony Capitos and Lynn Maloney

APPRAISAL GUIDELINES

I. *INTRODUCTION*[52]

During the long-term AIP Study of Multi-Institutional Collaborations, project staff examined the disciplinary areas of geophysics (including oceanography), ground-based astronomy, materials science, medical physics, particle and nuclear physics, space science, and one category we named computer-mediated collaborations. This section, Appraisal Guidelines, is organized along the same lines. It is based on a number of sources: (1) the archival assessment of over 450 interviews conducted on nearly 60 collaborations selected as our case studies; (2) the patterns uncovered through the historical and, in part, the sociological analysis of these interviews; (3) numerous site visits to federal scientific agencies and to the National Archives and Records Administration; (4) countless site visits to archival repositories; and (5) the AIP Center's general knowledge of archival institutions in various settings. We suggest that these appraisal guidelines be read in conjunction with the Typology, Functional Analysis, and Project Recommendations sections of this report.

The purpose of our appraisal guidelines is to assist archivists and others with responsibilities for selecting records for long-term preservation. Appraisal guidelines are not fixed rules; they are informed recommendations that require interpretation by those who select records. The guidelines are based on a decade of field work by the project staff of the AIP Study of Multi-Institutional Collaborations. Overall, we have endeavored to take into account future needs of scientists and administrators in science policy and management, as well as historians and sociologists of science.

We remind our readers that appraisal guidelines require unending revision. As the process of collaborative research changes (and we have seen such changes in collaborations since the 1970s), the kinds of evidence needed will be altered. Equally important, the formats of the evidence will change. Most of the records described in these guidelines are paper files, but there is a marked shift towards electronic records. Many records (such as correspondence, logbooks, and a variety of other files) are widely created in electronic formats; archivists are experimenting with ways to retain these records in electronic format for future use by historians and others.[53] In recent years, Web pages—covering project staff, progress reports, and much other material on individual collaborations—have become particularly visible. We need to watch new technologies and try new solutions for securing adequate documentation.

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[52]Lynn Maloney and Anthony Capitos (who both held the position of project archivist) made substantial contributions to previous AIP Study's Appraisal Guidelines—for high-energy physics (Phase I) and for space science and geophysics (Phase II), respectively.

[53]The retention of e-mail and other electronic records is an issue which many archivists are currently grappling with. See, for example, Philip C. Bantin, "Developing a Strategy for Managing Electronic Records—The Findings of the Indiana University Electronic Records Project," *American Archivist* 61 (Fall 1998), pp. 328-364. Note also that the May/June 2000 issue of *Archival Outlook* included a report (p. 18), "NARA Agreement with NSF Gives Impetus to Electronic Archives R&D." In it, the Archivist of the United States, John Carlin, announced that "we are on the verge of a major technological breakthrough for the preservation of computer-generated records."

These guidelines address records created by multi-institutional groups that participate in collaborative research projects. Also, for the fields of geophysics and space science, we have included records of groups that set national and international policy. Outside the scope of these guidelines are the records created by other activities at the government laboratories, universities, and other institutions involved, and by other activities of individual scientists. We recommend different appraisal guidelines for these materials.[54]

In our appraisal guidelines we aim to identify for long-term preservation only a small fraction of the records created by multi-institutional collaborations. The AIP Center for History of Physics has long been aware that archival preservation is too costly to save records indiscriminately.

Finally, these guidelines reflect two of the purposes of the AIP Study: (1) to identify a small set of core records that should be permanently preserved for all collaborations in a given disciplinary field, and (2) to distinguish the wider array of documentation that should be preserved for selected experiments—those that are of major scientific significance and, if possible, some that are of special value because they can serve as typical or representative of a period or category of experiment—and that, therefore, will be of high interest to future historians, sociologists, and other users. Hereafter, these selected experiments will be referred to as "significant." Action mechanisms for identifying these experiments are included in our Project Recommendations.

II. *GENERAL APPRAISAL GUIDELINES*

A number of categories of records are common to many or all of the collaborative research projects in the fields studied by the AIP project. These categories include proposal files of federal funding agencies, audio-visual materials, Ph.D. theses, subcontracting records, electronic scientific data, Web site records, other institutional records, and papers of individual scientists.

A. *Proposal Files of Federal Funding Agencies*

Federal funding agencies are responsible for supporting virtually all collaborative research in the disciplinary areas studied by the AIP Study. Essential, core documentation can be found in proposal files. The award "jackets" (as the National Science Foundation calls them) include proposals with budget requests, peer and panel reviews, any significant correspondence concerning a project, and progress and final narrative and fiscal reports. In addition, we found that some program managers at funding agencies played an important role in defining the terms of consortium formation and, in some cases, later project research activities.

Federal funding agencies should save proposal files for all successful proposals as well as the records for the (relatively few) unsuccessful proposals that stimulate significant debates or controversies. In addition, correspondence of program managers actively involved with project research activities should be preserved. These records should eventually be transferred to the National Archives.

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[54]See Haas, Joan K., Helen Willa Samuels, and Barbara Trippel Simmons, *Appraising the Records of Modern Science and Technology: A Guide*. (Cambridge, Mass.: Massachusetts Institute of Technology, 1985), and, also, Joan N. Warnow with Allan Needell, Spencer Weart, and Jane Wolff, *A Study of Preservation of Documents at Department of Energy Laboratories*. (New York: American Institute of Physics, 1982).

B. *Audio-Visual Materials*

Photographs and, in some cases, videotape recordings help capture the various stages of multi-institutional collaborations; we believe most archival and records management programs will want to preserve a selection of these materials to illustrate collaborations, whether they be significant or representative. The selection might include scenes of people building detector components, collaboration members with instrumentation or during meetings, and a variety of other activities. The AIP Center for History of Physics will be pleased to make copies of a few especially informative images for its Emilio Segrè Visual Archives.

C. *Ph.D. Theses*

We make note that Ph.D. theses provide valuable documentation on instrument development and software design and analysis in disciplines where graduate students are assigned much of this work. This is the case in particle physics, but also in pre-collaboration grants in geophysics and space science. The work of graduate students is documented in some detail in Ph.D. theses. All theses are available from University Microfilms, Inc. and university libraries or archives typically preserve Ph.D. theses submitted to their university. To make theses for a given experiment/project more accessible, the PIs (principal investigators) should compile a listing with the following information on each thesis: author, title, advisor, degree, degree date, and institution.

D. *Subcontracting Records*

When appraising records of significant collaborations, archivists should be on the lookout for subcontracts involving substantial or innovative research and development. While it is the case that the collaborations selected for the AIP Study only occasionally subcontracted at this level, we have been told that more recent collaborations tend to involve subcontracts to industry for substantial research and development. In such cases, the laboratory or university which has the responsibility for monitoring the subcontractor would have a set of files and technical reports. Where substantial or innovative research and development is subcontracted to industrial and other institutions, an adequate record of policy, administrative, and technical activities should be preserved.

E. *Electronic Scientific Data*

The AIP Study did not make special efforts to appraise electronic scientific data records, especially when we learned through meetings of our Working Groups that they were not useful for research purposes by historians and other scholars. Nevertheless, we are aware that these data are important for long-term scientific purposes in several of our fields—in particular geophysics, medical physics, and space sciences.[55] In other fields, where data are not useful for long-term purposes, we recommend that data records should *not* be kept permanently except in limited

[55] For those disciplines where electronic data are of permanent value, the data should be provided by the original users with adequate metadata to make them of value to secondary users. The preparation and retention of data should follow the recommendations of the National Research Council's report, *Preserving Scientific Information on our Physical Universe: A New Strategy for Archiving Our Nation's Scientific Information Resource. Report of the Steering Committee for the Study on the Long-Term Retention of Selected Scientific and Technical Records of the Federal Government* (Washington, DC: National Research Council, 1995).

quantities for exhibit purposes or under special circumstances; we elaborate on these records in our section on particle and nuclear physics, III.F.3.d., below.

F. *Collaboration Web Site Records*

Multi-institutional collaborations are increasingly making use of Web sites as an effective means of communicating with their members. Records placed on publicly accessible parts of collaboration Web sites typically contain lists of participants, summaries of the experiment's strategy, and summaries of the design of its instruments. Interviewees have also spoken of initial and final designs of instruments (or detector components and the detector's overall design) as being on the Web along with electronic-media discussions that went into producing the final designs. Some sections of collaboration Web sites may be accessible only to collaboration members. Early action will be needed to secure a permanent record of selected portions of a collaboration's Web site; we suggest that Web site administrators seek the input of archivists to accomplish this. For important details, see Part A, Section Two: Archival Findings, III.A.

G. *Other Electronic Records*

Collaborations that are considering the transfer of their records to electronic format should be advised that the electronic records management community recommends magnetic storage over optical storage for long-term retention purposes. One of the collaborations among our case studies was committed to putting its records on a compact disk. The intentions were laudable—i.e., to increase the quantity and accessibility of information being delivered to the funding agency. Unfortunately, CDS are not archival; they will be unreadable within a few years unless there is a concerted effort on the part of the funding agency to migrate the data to new technologies.

H. *Collaboration Records of Participating Institutions*

Proposals, narrative and financial reports, and summaries of each of the collaboration's groups/teams should be kept for significant experiments in the archives of the participating universities and national facilities (i.e., DOE National Laboratories, NSF National Observatories, etc.). They provide a clearer picture of significant collaborations from the perspective of individual institutions. In addition, some proposal files at the home institutions will include valuable documents not held elsewhere.

Many universities have grants and contract offices that retain contracts, including proposals and budgets, negotiations, interim reports, and changes in contracts; these records for significant collaborations should be transferred to university archives. At the national facility level, staff who constitute a group/team on a collaboration submit formal requests for funding along with details on staff, equipment, past progress, proposed plans, etc.; these records, along with year-end budget reports, should be preserved in the laboratory archives. Finally—in cases where the National Laboratories receive direct support from the DOE to cover costs of major detectors for a significant multi-institutional collaboration—detailed narrative and financial reports should be preserved at the laboratory along with correspondence and records of any site visits by the funding agency. In these cases, the centralization of management required by the large budgets involved gives the DOE National Laboratory greater responsibility and authority than the individual groups in the collaboration.

I. *Papers of Individual Scientists*

To document significant collaborations (as well as careers of distinguished scientists), archivists and records officers should place the highest value on the papers of PIs and other leaders of multi-institutional collaborations. Papers of these scientific leaders are prime locations for documentation of a number of topics, including details of staffing, plans for data gathering and analysis, and use of the data by collaboration members. The papers will typically contain proposals, personal notebooks, and correspondence with other collaboration leaders and with funding agencies. In cases where the scientific leader was also an instigator of the collaboration, the files may provide especially unique documentation of the initial thinking and early plans of the project. When individual scientists have been leaders of significant collaborations or have regularly played a leading role in important research, the records of their participation should be saved (whether or not the full range of papers documenting their careers merits archival preservation).

III. *FIELDS STUDIED BY AIP*

A. ***Geophysics and Oceanography***

The scope of these guidelines is records created by multi-institutional groups who set national and international policy and groups who participate in collaborative research projects in geophysics and oceanography.

1. ***Policy and Planning Records***

a. *Records of the National Academy of Sciences' Ocean Studies Board, Polar Research Board, and Board on Atmospheric Science*

In the United States, the National Academy of Sciences' advisory boards like the Ocean Studies Board, the Polar Research Board, and the Board on Atmospheric Science are sites for the scientific community to voice their opinions concerning broad program ideas. The impact of reports issued by these boards in geophysics and oceanography is particularly strong when relevant proposals are being considered by funding agencies. In addition, the National Academy of Sciences—like its counterparts in other countries—is a member of the ICSU (International Council of Scientific Unions); accordingly, the Academy usually influences the international programs that emerge through workshops instigated by ICSU.

The National Academy of Sciences should continue to save records of its Ocean Studies Board, Polar Research Board, and Board on Atmospheric Science as part of the Academy Archives. The records should include minutes, background papers, reports, and correspondence. Location: National Academy of Sciences.

b. *Records of the International Council for Scientific Unions and Records of the World Meteorological Organization*

ICSU plays a major role in establishing broad research goals in all areas of the sciences. In ICSU, ideas for research programs typically rise up through one or more of its international unions for scientific disciplines, its interdisciplinary bodies, or its joint programs. In the projects we selected for study, ICSU joined with the WMO (World Meteorological Organization, a United Nations specialized agency) to provide support for organizing symposia on likely areas for research projects. When symposia generate promising plans, the instigators petition ICSU and WMO, who jointly decide whether or not to create a program office. From this office a program manager will appoint symposium leaders to a steering committee. The program manager and steering committee together search for a scientist to be "seconded" to the WMO for the purpose of heading an international SMO (which may or may not be physically located at the WMO).

ICSU should continue to save, as part of the ICSU Archives, records documenting support for symposia, workshop panels, and subsequent program administration meetings held with WMO. At WMO, the records of the Director of the World Climate Research Programme should be preserved and eventually transferred to the WMO Archives; these records should include minutes and reports of the steering committee and project workshops, and correspondence with—and other records of—the international SMO. Locations: ICSU and World Climate Research Programme, respectively.

2. ***Core Records to be Saved for All Collaborations***

We list core records here for consistency of reporting. However, in the field of geophysics, all large collaborative projects are considered significant. The reader should bear in mind that most geophysics research has been—and continues to be—carried out without multi-institutional cooperation. Because there have been relatively few large, multi-institutional collaborations during our period of study (i.e., projects that began operations between the late 1960s and the late 1980s), we have felt no need to offer guidelines for identifying the most significant collaborations. Instead, we recommend that additional records (see 3, below) should be saved for all large collaborations over and above the core records described here.

Proposal Files of Federal Funding Agencies

In the geophysics cases we studied, technique-aggregating projects submitted a package of proposals to one or more funding agencies where a set of individual proposals (and, thereby, PIs) were selected. For the most part, the technique-importing projects we studied were supported by block grants from funding agencies to the consortia which, in turn, selected proposals for using the imported techniques; however, in two of these cases, would-be individual users had to submit proposals for approval by the funding agency. The proposal process for larger projects in geophysics involved review at the highest policy level, such as the National Science Board of the National Science Foundation. Funding agencies that supported geophysics and oceanographic projects included in our study were the National Science Foundation, National Oceanic and Atmospheric Administration, United States Geological Survey, and the National Aeronautics and Space Administration. For details, see General Appraisal Guidelines, II.A, above. Locations: Relevant funding agencies.

3. ***Additional Records to be Saved for All Large Collaborations***

a. *Consortium Headquarters Records*

In consortia, it is the standing committees (and subcommittees where they exist) that tackle the most important issues such as determining the designs and specifications for instrumentation, staying abreast of industrial data-acquisition techniques, reviewing plans for deploying instrumentation, and—in most cases—determining the research done with the technique.

There is an Executive Committee for each consortium. Its importance at the inception of projects, during which project boundaries and ground rules are debated, is consistently high; during later periods of projects, the role of the Executive Committee has varied. The administrative head of each technique-importing project is a geophysicist called chief scientist, director, president, etc. Their importance in terms of administrative and intellectual power has varied. One consistent responsibility of the administrative head has been to develop formal rules for formatting data, curating samples, and publishing both preliminary, descriptive findings and a volume of refined, analytic findings. A "staff scientist" works with each scientific party to insure that rules are followed, to serve as liaison between the scientific party and both the assisting project engineers and the chief administrator at project headquarters, and to facilitate communication and distribution of samples following data acquisition. For consortia that establish a project headquarters, the headquarters may be a new freestanding entity or an office at an instigator's home institution.

Historically valuable records of consortia headquarters should be preserved. These records would include files of the standing committees (and subcommittees), the Executive Committee, and administrative head of the consortium (chief scientist, director, president, etc.), and staff scientists. Where a consortium headquarters is attached to an academic institution, the most appropriate repository for its records would be the academic archives of the institution with which it is affiliated. Funding agencies should facilitate these arrangements through the contracts for consortia made with these institutions. If these arrangements fail, the records of the consortium should be offered as a gift to the Archivist of the United States and the National Archives and Records Administration. We expect documentation for the largest or most controversial projects will also be found in the records of the academic institution's administrative and contracts and grants offices. Where consortia headquarters are at new, freestanding institutions created for the project, the records should be offered as a gift to the Archivist of the United States and the National Archives and Records Administration.[56] Again, the funding agencies should facilitate these arrangements. Locations: In the records of the relevant Consortium Headquarters.

b. *Science Management Offices*

An SMO, under the administrator (who is one of the PIs) is responsible for the logistics of technique-aggregating projects in geophysics and oceanography. Other responsibilities include data management systems and post-field-work workshops. A Science Working Group (SWG), made up of all the PIs, and its Executive Committee manage what is intrinsically collective to the design of the project.

Records of the administrator of the SMO and of the project's SWG (and its Executive Committee), including minutes of meetings and reports, should be preserved. In all cases, the most appropriate repository for these records would be the archives of the institution with which the SMO is affiliated. Funding agencies should facilitate these arrangements through the contracts for SMOs made with these institutions. Locations: In the records of the relevant Science Management Office.

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[56]The National Archives has indicated its willingness to consider such acquisitions on a case by case basis.

c. *Scientific Data*

Most of the data are electronic in format and observational in character; these are both raw and processed. Their usefulness for long-term scientific purposes is unquestioned.

B. ***Ground-based Astronomy—Observatory Builders***[57]

Like particle accelerators, observatories are major—and very expensive—research facilities. Few are built in any one decade and each is essentially unique. Consequently, we take the position that each telescope-building collaboration should be categorized as significant with substantial documentation permanently preserved.

1. ***Core Records to be Saved for All Collaborations***

We list core records here for consistency of reporting. However, in the field of ground-based astronomy observatory builders, all projects are considered significant. Additional records (see 2, below) should be saved for all collaborations over and above the core records described here.

a. *NSF Grant Award Jackets*

In any case where NSF funded some fraction of an observatory's design and/or construction, its proposal jacket provides valuable documentation; e.g., referee reports give a sense of the community's response to the plans. For details, see General Appraisal Guidelines, II.A., above. Location: In the possession of NSF Division of Astronomy program officers.

b. *NSF Cooperative Agreement Jackets for Research Facilities*

It is important to distinguish between NSF grants for research projects and NSF cooperative agreements for facilities—its national observatories in this case. Grants provide funds for best effort and contracts specify deliverables with awards and punishments; contracts now have largely been replaced by the more flexible cooperative agreements. NSF research facilities are operated by contractors in a fashion similar to DOE National Laboratories. The cooperative agreement jackets for research facilities contain somewhat different documentation from grant award jackets. Both types of files include proposals, referee reports, minutes of panel meetings, and progress and final reports; in addition, cooperative agreement jackets for research facilities include NSF site visit reports, correspondence with contractors, and—in many cases—reports of the contractor's visiting committees. On the negative side, since NSF research facilities function as funding conduits for research, the NSF jackets lack funding details (e.g. individual proposals) of the research use of the facility. Locations: In the possession of NSF's Division of Astronomy program officers.

c. *Documents of Incorporation (sometimes called MOUs)*

Documents the formal governing structure and the obligations and rights of collaboration members. Likely locations: In possession of the collaboration's secretary-treasurer as well as the institutional records of member institutions.

2. ***Additional Records to be Saved for All Collaborations***

a. *Board of Directors' Minutes of Meetings*

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[57]It should be remembered that the AIP project's case studies of telescope-building collaborations did not include any collaborations involving national telescopes.

These files typically include associated briefing books and may include reports of any internal science advisory committees and/or any external panels commissioned to review designs of major observatory components. These minutes and associated records document the major strategic decisions faced by the collaboration during the design and construction of the telescope and its sub-systems. Likely locations: In possession of the secretary-treasurer and the project manager.

b. *Records of Project Manager*
Project managers' files consist of various types of records—e.g., progress reports—that document the details of observatory construction and shake-down and intra-collaboration discussions of the balance among scientific, engineering, and fiscal considerations. The records may include minutes of any Science Advisory/Science Steering Committee as well as reports of any external panels commissioned by the Board of Directors. Likely location: In possession of the project manager.

c. *Records of Science Advisory/Science Steering Committees*
These are committees of scientists from the member institutions that document ongoing assessments of telescope development as well as discussions regarding enlarging scientific capabilities vs. assuming engineering and financial burdens. Their main responsibility is telescope instrumentation and the records are particularly valuable in documenting this development. Likely locations: Among the records of the Board of Directors and/or in possession of the project manager or secretary-treasurer.

d. *Records of Design Review Panels*
These are external panels commissioned by the Board of Directors to review designs of the telescope and its sub-systems. Likely locations: Among the records of the Board of Directors and/or in possession of the project manager or secretary-treasurer.

e. *Records of Science Project Teams*
In cases, such as the Keck Observatory, where the collaboration needed to develop a telescope component (i.e., a mirror) that was both novel and innovative, the responsibility lies with a project scientist, who heads a group that might be labeled the Science Project Team. In these cases, the sub-system of the telescope would be so innovative that it could not be built under a standard contract; the records provide unique documentation. Likely location: In the records of the project scientist.

f. *Contracts and Associated Records*
Observatory-building collaborations, like those involved in building other large facilities, contract out the construction of components/telescope sub-systems—typically at the behest of the project manager. If the contracts involve design and development in addition to construction, the records should be permanently preserved. Likely location: Records of the project manager.

g. *Technical Reports (sometimes called Memoranda Series or Technical Memoranda)*
Series of technical reports/memoranda for providing collaboration members, or future telescope operators and users, with information needed to understand the designs, the reasoning behind the designs, and other technicalities of the telescope; at times these are more informal with in-house

knowledge of problems and how to work around them and with tricks-of-the-trade in designing and performing observations. Likely locations: Available in a number of locations, including the files of the project manager and the secretary-treasurer; often found on a collaboration's Web site.

C. *Ground-based Astronomy—Observatory Users*[58]

1. *Core Records to be Saved for All Collaborations*

a. *Proposal Files of Radio Observatories*

Each VLBI (Very Long Base Interferometry) collaboration petitions for time on all the observatories it wishes to use for its interferometry work and each observatory evaluates—through its TAC (Time Allocation Committee)—the proposal it receives. Though less formal than proposals for money, the proposals for time still document the initial goals and strategies of the observers, the quantity of resources mobilized for the observations, and any expected problems in making the observations. Most important for documentation of VLBI collaborations are the proposals of scientists who are first authors of collaboration publications. Likely locations: In TAC records of relevant radio observatories.

b. *Proposal Files of NSF National Observatories*

These would be typical jackets for successful proposals—in this case, to obtain time on the telescope. The proposals are reviewed by observatory Time Allocation Committees (TACs). They should include proposals, referee reports, progress and final reports. We are naturally focused on proposal jackets for collaborative research projects. Likely location: In TAC records at the relevant NSF National Observatory.

c. *Records of Observatory Consortium Chairpersons*

A formal VLBI collaboration requires the organizational structure of a consortium of radio observatories. Consortium chairpersons are responsible for learning the desires of VLBI researchers and arguing their case to observatory directors; their records should thus yield valuable insights into the standing of interferometry within radio astronomy and the practitioners' efforts to obtain improvements in the state-of-the-art. Scientists in this position are usually on academic faculties or observatory staffs. Likely location: Among the professional papers of consortium chairs.

2. *Records to be Saved for Significant Collaborations*

a. *Papers of First Authors of VLBI Collaborations*

The first author of a collaboration's first publication obtained scientific results from the correlated data and secured the collaboration's consent to submit the results for publication. The scientist's records thus uniquely document intra-collaboration assessments of the quality and significance of the observations. The first author may also be responsible for coordinating the observatories' collection of data and the moderator of the collaboration-wide e-mail discussions of observing tactics and logistics. First authors are on the faculty of academic institutions or observatory staff. Likely location: In the professional papers of first authors.

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[58]Bear in mind that the AIP project did not study any collaborations conducting sky surveys or using optical telescopes.

b. *Records of Observatory Consortium Secretaries*

These records include the proposals to do VLBI observations on a consortium's time, referees' responses to the proposals, and materials related to the details of scheduling the most and best observations into the available time of the member observatories. The files provide important documentation of science policy and planning of the consortium of radio observatories. Consortium secretaries are on academic faculties or observatory staffs. Likely location: In the professional papers of consortium secretaries.

D. ***Materials Science***

1. ***Core Records to be Saved for All Collaborations***

a. *NSF Cooperative Agreement Jackets for Centers*

It is important to distinguish between grants for NSF research projects and cooperative agreements for NSF centers—Science and Technology Centers (STCs) and, in this case, Materials Research Science and Engineering Centers (MRSECs). Grants provide funds for best effort and contracts specify deliverables with awards and punishments; contracts now have largely been replaced by the more flexible cooperative agreements. Among other things, cooperative agreements allow NSF to get involved in administration and become partners with its centers. Jackets for NSF center cooperative agreements contain somewhat different documentation. In addition to proposals, referee reports, minutes of panel meetings, and progress and final reports, the jackets include NSF site visit reports, and (we recommend that they include) valuable preproposals. On the negative side, since most, if not all MRSECs and STCs make the final decisions on which researchers at member institutions get funded, the NSF jackets lack funding details (e.g. individual proposals) of the research of MRSEC and STC collaborations. Overall, future historians and other users will find documentation of the initial plans and ambitions of a center, how the center had to modify its plans to suit NSF, and community reactions to the center's plans and accomplishments. For further details, see General Appraisal Guidelines, II.A., above. Locations: Records of MRSECS are in possession of NSF's Division of Materials Science; records of STCs are in NSF's Office of Science and Technology Infrastructure.

b. *DARPA (Defense Advanced Research Projects Administration) Proposal Files*

Proposals, referee reports, MOUs/Intellectual Property Agreements, and progress and final reports. The proposals document the plans and ambitions of the collaborations and the level of information the participants were willing to share about their individual capabilities prior to the negotiation of an intellectual property agreement. The MOUs/Intellectual Property Agreements document the terms on which the corporations could jointly participate and could individually share information with the participating universities; successful negotiation of the MOUs was a prerequisite to the start of funding from DARPA. Files should also contain projected schedules of deliverables and reimbursements that provide the basis for intra-collaboration milestones. For details, see General Appraisal Guidelines, II.A., above. Location: In the possession of the relevant DARPA program officer.

c. *NSF Grant Award Jackets*

In most materials science collaborations using facilities at national laboratories, each institutional member raises its own funds, with corporate members using internal funds and academic institutions going to NSF. In at least some cases, member institutions apply jointly to NSF.

Award jackets include proposals documenting the plans and ambitions of the collaboration, referee reports, minutes of panel meetings, and progress and final reports. For details, see General Appraisal Guidelines, II.A., above. Location: In possession of NSF's Division of Materials Science program officer.

d. *Proposals to Corporate Management*

Corporate researchers proposing to build and share a beamline at a DOE National Laboratory have to convince their corporate management to underwrite a share of the construction costs. These records are the functional equivalent of a proposal, albeit less formal than what university scientists submit to a federal funding agency. Likely locations: In the records of individual researchers or—where they exist—in the archives of the corporation.

e. *Records of Executive (Program) Committees of MRSECs and STCs*

In both the MRSECs and STCs, scientists or groups of scientists desiring funding have to submit an annual proposal (which, among other things, is supposed to justify the interdisciplinary and multi-institutional aspects of their work that make them acceptable for this sort of funding). A collection of such proposals comes to the Executive (Program) Committee for evaluation. That evaluation sets the scientific agenda. The records of this review process (proposals, reviews, and award decisions, etc.) would provide a definitive record of the scientific evolution of the MRSEC or STC project as well as insight into the management criteria imposed. A sampling, at least, of these files (every three or five years) should be preserved. Likely locations: In records of the MRSEC or STC or the academic officer it reports to (e.g., the vice-president or associate provost for research).

f. *Records of Facility Advisory Committees (FACs) at DOE National Laboratories*

The materials science collaborations using facilities at DOE National Laboratories in our case studies used two synchrotron radiation facilities and one breeder reactor facility. Use of these research facilities is governed by a Facility Advisory Committee (FAC); this is our generic term to cover several titles used by the laboratories. For example, Argonne's Advanced Photon Source (APS) has two relevant FACs: (1) the APS Program Evaluation Board, a scientific peer advisory board that evaluates proposals to form research teams to gain research access to the APS and reviews subsequent scientific performance; it formally advises laboratory management on the scientific appropriateness of proposed research and the likelihood of success and (2) the APS Management Plan Review Committee, a staff committee that reviews management plans of collaborations and advises APS management on the collaboration's readiness to sign a formal Memoranda of Understanding (MOU) and begin construction and subsequently operate beamlines at the APS. In general, FAC records include proposals, letters of intent, and conceptual design reports submitted by the collaboration to apply for space to develop a beamline and end stations. The records will not include proposals for money, since each member institution is responsible for its own funding, but researchers will find MOUs between the collaboration and the DOE facility covering obligations of the collaboration and the facility to each other. The files may also provide justification for FAC actions and recommendations. Interviewees indicate that these are the best, perhaps the only, collective statements of collaboration goals and strategies. The records of the FAC for the breeder reactor are also important for the impact of safety concerns and regulations. Location: At the relevant research facility at the DOE National Laboratories.

g. *Memoranda of Understanding between Member Institutions*

Sometimes referred to as joint agreements, these legal documents lay out the powers of the collaboration's Board of Governors, the obligations of the member organizations, and their privileges to use the finished beamline. They include terms on which staff scientists will work with the corporations on proprietary research. Likely locations: In the records of the Facility Advisory Committee for the relevant DOE National Laboratory facility and in the archival records of collaboration member institutions.

2. ***Records to Be Saved for Significant Collaborations***

a. *Records of the Executive Board (or Governing Board, Program Committee, or Technical Representatives Committee)*

Archivists should look to preserve the records of the highest-level group of active researchers in the particular collaboration; this committee typically serves as the primary body that deliberates on the collaboration's internal organization and research directions. Records should include minutes of meetings, notes on conference calls and other discussions, and reports prepared for the project manager, etc. Likely location: In the records of the collaboration project manager or spokesperson/staff director.

b. *Records of External Advisory Committees*

Most materials science collaborations (not using national facilities) have external advisory committees that assess their strengths and weaknesses with the eyes of friendly critics. These committees usually consist of prominent scientists from non-member institutions, such as executives of corporations and national laboratories. The records document the collaboration's relations with non-academic sectors and the prospects of its research contributing directly to manufacturing or the programs of government agencies. Likely location: In the possession of the collaboration project manager.

c. *Records of Annual Meetings of the Collaboration*

In at least some instances, materials science collaborations hold formal annual meetings (those using national laboratory facilities tend to be far less formal). In one of the AIP's case studies, annual meetings included representatives of corporations that were not part of the collaboration, who were present both to learn and advise, and representatives of the funding agency (DARPA in this case) who used the meetings as a basis for a review of the collaboration. Records of annual meetings should include briefing materials and annual reports produced by collaboration members; they may also include reviews prepared by funding agency staff on the basis of the meetings. Likely locations: In the files of the collaboration project manager and the funding agency program officer.

d. *Records of Spokespersons/Staff Directors*

Collaborations using facilities at DOE National Laboratories all had a person responsible for providing liaison between the collaboration and the laboratory. This scientist was the communications center—the person to whom everyone provided information and requested results. The records should include written and e-mail correspondence, any collaboration-wide mailings, and records of the collaboration's top scientific board (sometimes labeled the Board of Governors). They should provide documentation of intra-collaboration institutional and scientific concerns. Location: In the papers of the collaboration spokesperson/staff director.

e. *Newsletters and Sector Descriptions*
Some materials science collaborations using national facilities serve as sub-facilities by making their beamlines and end stations available to a community of users at their member institutions. In our case studies, we found these collaborations making use of their Web sites to distribute newsletters (the functional equivalents of progress reports) and/or sector descriptions that provide information on the capabilities of the apparatus installed on the beamline. During the collaboration's lifetime, the Web pages are maintained electronically by its office at the DOE National Laboratory facility. Likely location: Assignment of responsibility varies; for information, contact collaboration spokesperson/staff director.

E. ***Medical Physics***
1. ***Core Records to be Saved for All Collaborations***
a. *Proposal Files of Private Foundations*
Private funding agencies have been important supporters of collaborative research in medical physics. Proposal files along with referee reports and progress reports provide core documentation. Likely location: In proposal files of the relevant private foundation.

b. *NIH Proposals Jackets*
In the NIH and its subsidiary institutes, the collaborations we studied were formed on the basis of the most successful proposals from individual applications. Even in cases where institutional applications cross-referenced those of would-be collaborators, the proposals were individually refereed within their individual research specialties. Successful proposals for each institutional study, along with referee reports, should provide evidence of the importance given to research in the collaborative framework; progress reports would document important difficulties. We hope, but do not know, that program officers at the agency make a central file of successful individual proposals; such files would constitute a most valuable record of NIH support of multi-institutional collaborations. For further details, see General Appraisal Guidelines, II.A., above. Likely location: At the appropriate NIH or subsidiary institute research program.

c. *Records of Facility Advisory Committees at DOE National Laboratories*
To obtain space at the DOE accelerator for purposes of synchrotron research, collaborations have to submit a research proposal to convince the Facility Advisory Committee of the scientific value of their work. In addition, research that includes the liabilities of exposing humans to synchrotron radiation imposes additional considerations on the laboratory directors. Location: At the synchrotron facility of the relevant DOE National Laboratory.

2. ***Records to be Saved for Significant Collaborations***
a. *Minutes of Collaboration Meetings*
In the field of medical physics, minutes of collaboration meetings range widely in formality and detail. In collaborations requiring protocols, minutes will document discussions of each study's conceptual and technical design and discussions of possible mid-course changes in each study's

design. At the other end of the spectrum, minutes may only list actions that the collaboration decides to take. When the task of minuting meetings is taken on by a scientific leader, the quality of the result will be based on personal inclinations. In some cases, minutes will be the only collectively generated records for internal consumption. Likely locations: A variety of possible locations, from the American College of Radiology and relevant medical research centers and medical schools, to synchrotron facilities at relevant DOE National Laboratories.

b. *Records of Group Leaders for Statistical Analysis*

Our case studies indicate that at least some collaborations divide labor for data acquisition (done by radiologists, surgeons, and pathologists) and data analysis (done by bio-statisticians). In the latter case, the records of the group leader for statistical analysis would document the development of bio-statistical methodology for the clinical evaluation of radiological techniques. Likely location: In the records of the group leader at the relevant medical school or medical research center.

c. *Protocols and Samples of Data Collection Forms*

When the purpose of the collaboration is to test state-of-the-art procedures in the field of medical physics, protocols and data collection forms provide critical documentation of the participants' understanding of how best to reduce the complexity of medical evaluations into statistically manageable categories. These records have usefulness for future scientific research—at least as long as the procedures are state-of-the-art. The value of their application goes beyond a specific area of medical research. For example, our case study dealt with assessing radiological techniques for diagnosing cancer in organs; these records would be equally useful for such topics as identifying the best method for quantifying blood flow. Although summaries of protocols are often appended to publications of research results, detailed protocols rather than summaries are needed to repeat or build on previous research. Location: In records of the American College of Radiology Data Management Office.

F. *Particle and Nuclear Physics*

1. *Core Records to be Saved for All Collaborations*

a. *NSF Grant Award Jackets* or *DOE Proposal Files*

The proposal files we address here are those submitted by each of the institutional groups participating in a collaboration experiment (normally as part of a larger budget request by a unit of an academic physics department or a research group at a laboratory).[59] Proposal files provide rich summary information on research goals and techniques, budgets, the agency review process, and (for accepted proposals) project progress and expenditures. The proposals at NSF or DOE overlap what the collaborations sent to the laboratory's Physics Advisory Committee, but comments collected on the proposals to the federal agencies will be oriented towards the effect of funding the collaboration on the national research programs in areas of particle and nuclear

[59]The other major category of proposals are those submitted to the funding agencies by the accelerator laboratories for major detectors and for building or upgrading accelerators. These proposal files would frequently include documentation of agency site visits. All proposals (approved or rejected) for major detectors and for new or upgraded accelerators should be preserved.

physics. Location: In possession of the relevant program officer at NSF's Physics Directorate or at DOE's Office of Energy Research.

b. *Laboratory Directors' Files*

These are a primary source of correspondence, reports, memoranda, and other records documenting laboratory policy and substantive programs in particle and nuclear physics. In most single-purpose accelerator laboratories, these files will be found in the office of the director and, for example, the director for research; in multiple-purpose laboratories, such as Brookhaven National Laboratory, they would be located primarily in the office of the associate directors responsible for particle and nuclear physics. Locations: In director's files at DOE National Laboratories and other accelerator laboratories.

c. *Proposals to and Records of Physics Advisory Committees (PACs) of National Accelerator Laboratories*

Each laboratory has an advisory committee to review proposals (written and oral) for particle and/or nuclear physics experiments at the site. Committee names vary; our generic term is Physics Advisory Committee (PAC). These records document the original plans of the original collaborators and the role of the PAC; they include the review materials generated within or commissioned by the Committee and the MOUs (Memoranda of Understanding) documenting the fiscal and other responsibilities of the accelerator laboratory and the collaboration's member institutions. Interviewees considered PACs to be the important intellectual hurdle and its reviews the most substantive, whereas reviews by federal funding agencies were considered to be a check to make sure the collaboration's plans fit adequately with the national program. PAC records are likely to include minutes of full committee meetings or private recommendations, formal proposals with budgets, letters to collaboration spokespersons on decisions, and, more recently, impact statements by laboratory staff and reports of PAC subcommittees summarizing conclusions. Most proposals submitted by collaborations constitute a request for access to the accelerator (beamtime, beam conditions, etc.) and approval of the physics and experiment plan. In the case of more recent experiments, involving the construction of large detectors, proposals will be more complex as they frequently involve direct funding to the laboratory from the DOE or NSF. In the case of successful proposals, PAC files will have contracts and other records documenting the arrangements between the laboratory and the collaboration, including each institutional group. The arrangements cover funds, responsibilities for constructing and assembling detector components, computing support, safety regulations, and so forth. Over the years, contracts have become increasingly formal; since the 1980s there are MOUs for most experiments. Meetings of PACs may be tape-recorded. Locations: In the records of the PACs at DOE National Laboratories and other accelerator laboratories.

2. ***Records to be Saved for Significant Collaborations***

a. *Records of Spokespersons*

The spokesperson serves as liaison between the collaboration, the accelerator laboratory, and the world-at-large. The records should include:

1. Correspondence of the spokesperson with laboratory administrators and collaboration group leaders and individual members

2. Intra-collaboration mailings

During the 1970s and ’80s intra-collaboration mailings became the standard procedure for virtually all experiments; responsibility for their distribution was typically assigned to the spokesperson. These mailings provide the most valuable documentation of the organizational structure and research process of multi-institutional collaborations in particle and nuclear physics. The records are compact and increasingly found as a numbered, chronological set of “memoranda.” The following are the types of records we have found:

- Organization charts and other documents showing organizational structure; in some cases, they show individuals in charge of such functions as data analysis and publications;
- Substantial management plans, often taking months to write and get approved;
- Agendas and minutes of collaboration meetings. These document the decisions that had to be made with collaboration-wide consultation. Even when the minutes are brief and written to be readily comprehended only by those in the collaboration, they should at least give future historians some ideas of what seemed important enough to discuss at collaboration meetings at particular times; and
- Technical reports for detector development, computer software, analysis, etc. These may be written reports which frequently appear as memoranda, or transparencies for oral reports given at meetings (outlines and some technical drawings). And

3. Records of any Inter-Institutional Boards (or Executive Committees). These document discussions and decisions over the major social and scientific strategies of the collaboration. Location: In the records of the spokesperson.

b. *Records of Collaboration Group Leaders*

These records, including the proposal submitted as PI (principal investigator), should be kept permanently when the collaboration group was responsible for an innovative detector component or technique. Location: In papers of collaboration group leaders.

c. *Records of Project Managers and Project Engineers*

These collaboration positions—familiar to us from our studies of other disciplines, e.g., space science—seem to be emerging in particle physics collaborations. For significant projects, these records should be reviewed for technical notes, detector logbooks, and other categories of unique documentation. The positions we found were held by Brookhaven National Laboratory staff. Likely location: In staff records at DOE National Laboratories and other accelerator laboratories.

d. *Intra-Collaboration Technical Committee Records*

We found one of these committees consisting of senior collaboration members with a taste for hardware issues; we believe such committees may be widespread. Likely location: In the records of the group leader who chaired the Committee.

e. *Accelerator/Research Division Files on Experiments*

Accelerator laboratories have a department or division responsible for maintaining beamlines of accelerators and the overall experimental areas, as well as supplying technical and other services to experimenters. Records of these divisions are the key laboratory files documenting experiments after their approval. They typically include copies of proposals, exchanges between the laboratory and the experimental collaboration and between various offices at the laboratory, and some engineering drawings. In some laboratories, correspondence with experimental collaborations after approval continues to be kept in the PAC files. Likely locations: In relevant department/division of DOE and other accelerator laboratories.

3. *AIP Project Guidelines on Selected Technical Records*

a. *Experiment (or "Running") Logbooks*

These are the logbooks maintained by the full collaboration that track the overall functioning of the detector and provide the best chronology of data-gathering. Among the various types, the experiment logbooks are of greatest value. They may require the cooperation of a member of the collaboration to decipher handwriting or "translate" shop talk; we recommend a tape-recorded interview by a knowledgeable historian or archivist whenever possible. We welcome the fact that some experiment logbooks—or portions of them—are being computerized. Experiment logbooks should be preserved at the accelerator laboratories. Location: For information on location, contact the spokesperson of the collaboration.

b. *Other Logbooks*

Collaborations tend to generate a variety of other logbooks, the most common being the detector component logbooks (kept by institutional groups responsible for individual components of the detector). In addition, there may be logbooks for construction and testing, data analysis, and patent logbooks—kept by institutional groups, other subgroups, or individuals. Logbooks (other than experiment "running" logbooks) should be appraised according to the particular significance of various aspects of the experiment, e.g., logbooks on specific components of the detector that were particularly novel; analysis logbooks, where this activity was a special feature of historical interest; or patent logbooks that may have been created because of patent implications. Appraisals should be conducted by a knowledgeable archivist or historian in conjunction with a physicist familiar with the experiment. Since most of these logbooks document work on the institutional group or individual level, those (or sections of them) of archival value should be preserved at the group's institutional archives. Location: For information on location, contact the spokesperson of the collaboration.

c. *Blueprints and Specifications*

Engineering drawings of detectors and their components—and the more recent CAD/CAMs (Computer Aided Designs/Computer Aided Mechanicals)—are maintained at the laboratories at least in microform, if not also in the original, accompanied by a database providing a variety of access points. Specifications provide information on quality of materials and tolerances required. The system is in place to save these records and the microfilm format is space efficient. In cases where laboratories keep originals, we recommend saving original blueprints and specifications only for the most significant experiments; if it is economical to locate and destroy the balance of the originals, a good deal of storage space will be opened up. Likely locations: In the accelerator or research department of DOE National Laboratories and other accelerator laboratories; if not, contact the spokesperson of the collaboration.

d. *Electronic and Other Scientific Data*

N.B.: The following scientific data records should *not* be kept permanently except in limited quantities for exhibit purposes or under special circumstances.

1. *Raw Data Tapes and Data Summary Tapes (DSTs)*

All, except the earliest, of the experiments in particle and nuclear physics that AIP studied generated data in electronic format. Raw data tapes are *not* useful to individuals outside the collaboration, including particle and/or nuclear physicists. DSTs, on the other hand, may be of some use to particle and nuclear physicists outside the collaboration for a limited period of time; their use probably requires accessibility to collaboration members as well as documented software. DSTs should be retained for perhaps ten years to insure their availability to physicists who may want to use them for research purposes. Permanent preservation of raw data tapes and DSTs should be limited to an extremely small sample for exhibit purposes; the most appropriate repositories would be the accelerator laboratories or a science museum. Location: For information on location, contact the spokesperson of the collaboration.

2. *Computer Programs and Software*

A number of accelerator facilities and experimental groups maintain computer programs and software. These "libraries" are frequently drawn on by particle or nuclear physics collaborations who then must further develop programs and software to meet their specific needs for data gathering and analysis. Future historians will be interested in documentation of the computer programs for the trigger systems on the detector and for data analysis. The full working program is *not* needed, only documentation sufficient to know how the software was laid out, its logic, and who did what to it. A copy of the computer program listing, often kept on microfiche, captures this information and should be preserved. In addition, software should be retained for those few raw data tapes and DSTs that are selected for preservation. The most appropriate repository is the accelerator laboratory. Location: For information on location, contact the spokesperson of the collaboration.

3. *Other Scientific Data*

Bubble chamber experiments ceased in most labs by the late 1970s, but at Fermi National Accelerator Laboratory the last was in 1989. They produced data records in the form of films that showed tracks of particles and their interactions. These films are extremely bulky. Prior to the mid-'70s, spark chambers produced still photos with particle tracks; they now produce data on magnetic tapes (covered above). Emulsion experiments continue, producing data in the form of particle tracks in emulsion stacks that are studied with special microscopes; the stacks require special storage conditions. These data should be kept in very limited quantity even for the most significant experiments to illustrate discoveries of new particles. They have some usefulness for exhibit and educational purposes; CERN, for example, has bubble chamber film exhibited on a scanning table in one of its museums. Accelerator laboratories or museums are the most appropriate repositories. Likely locations: In the relevant DOE National Laboratory or other accelerator laboratory; if not, contact the spokesperson of the collaboration.

e. *Databases of Special Value*

Since 1974, two international databases have been maintained on SPIRES for the particle physics community: the *Experiments* database by the Particle Data Group at the Lawrence Berkeley Laboratory (LBL) and the *HEP Publications Database* by the Stanford Linear Accelerator Center (SLAC) and the Deutsches Elektronen-Synchrotron (DESY) laboratory in Germany. The *Experiments* database includes reports on all experiments approved by the laboratories. The information includes the laboratory and experiment number, approval year, and names of collaboration members and their institution (with the spokesperson asterisked); unfortunately, as membership information is updated, the historical data are wiped out. The *HEP Publications Database* is a vast bibliographic record covering preprints, conference talks, theses, refereed physics articles (many with links to laboratory experiment numbers), instrumentation articles, etc.—all with citations. The list of authors and their affiliations is complete. Locations: At DESY, LBL, and SLAC.

We recommend improvements because of the great value of these databases for historical and sociological purposes. It would be useful if a historical data set of the *Experiments* database were initiated. We hope, too, that work on the part of the laboratories will continue to enrich the *HEP Publications Database* by linking physics articles with experiments numbers; if possible, we suggest this effort be extended to instrumentation articles.

G. ***Space Science***

The scope of these guidelines is records created by multi-institutional groups that set national and international policy for space science or that participate in collaborative research projects.

Because the trend in space science collaborations during the period of the AIP Study (missions launched from the early 1970s to about 1990) was toward larger, longer, and fewer projects, we recommend that full documentation be saved for all large space science collaborations.[60]

1. ***Policy and Planning Records***

a. *Records of the National Academy of Sciences' Space Studies Board*[61]

The Space Studies Board of the National Academy of Sciences is charged with the mission to advise NASA on which areas of science it should focus its efforts upon. Through disciplinary subcommittees, like the astronomy and solar physics committees, scientific communities are able to identify the areas of research best suited to their goals. For larger NASA projects, the Board forms special *ad hoc* committees to better define the science of the mission. Although NASA is not statutorily required to heed the Space Studies Board, Congressional attention to the Board's findings make its "blessings" essential to forming NASA projects.

The National Academy of Sciences should continue to save, as part of the Academy Archives, Space Studies Board minutes, reports, and correspondence; subcommittee minutes and reports; and working papers of *ad hoc* committees. Location: National Academy of Sciences.

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[60]If the current trend at NASA—to support smaller, cheaper, and more frequent projects—continues into the future, this recommendation will require adjustment.

[61]Formerly the National Academy of Sciences' Space Science Board.

b. *Records of the European Science Foundation's European Space Science Committee*
This European Space Science Committee (ESSC) occasionally plays a similar role for ESA as that of the NAS Space Studies Board for NASA.

The minutes, reports, correspondence, and working papers of the European Science Foundation's ESSC should be preserved as part of the ESF archives. Location: ESF.

c. *Minutes and Other Records of Working Groups of NASA Headquarters*
At the NASA Office of Space Science there are several important working groups. First are the working groups, created for each discipline scientist; at this level scientists of the relevant disciplines seek to focus the needs of the profession into actual projects. Similar working groups exist up through the NASA hierarchy to its Advisory Council, which guides the NASA Administrator in making the final selection of projects and missions. It is through this structure that representatives of the space science community help NASA define and promote specific projects, including their payload of instruments.

The records (correspondence, minutes, recommendations, etc.) of NASA discipline scientists and their working groups should be scheduled for permanent retention by NASA Headquarters and eventually transferred to the National Archives. This recommendation also holds for NASA administrators and their working groups further up in the NASA hierarchy. These working groups and the administrators they report to are: subcommittees of the Space Science Advisory Committee for each NASA division, Space Science Advisory Committee for the Associate Administrator for Space Science, and the Advisory Council for the NASA Administrator. This documentation should also include the Office of Space Science's strategic planning records. Location: NASA Headquarters.

d. *Records of the European Space Agency's Working Groups and Committees*
In a similar fashion to NASA, ESA has levels of working groups and committees. ESA's Astronomy Working Group and its Solar System Working Group reflect the interests of their scientific communities in proposing projects. Their reports and proposals are passed upward to ESA's Space Science Advisory Committee. The SSAC, on the basis of these recommendations and taking into consideration scientific, programmatic, and financial elements, makes the final choice among competing projects. The SSAC recommendation, although not legally binding, is usually accepted by the ESA executive and is included in its own proposal to the ESA Science Programme Committee, which is the final decision-making body for the scientific program.

The records, including minutes, reports, and correspondence, of these ESA working groups and committees should be saved permanently in the ESA Historical Archives in Florence. Location: ESA.

2. ***Core Records to be Kept for Each Project or Mission***[62]

We list core records here for consistency of reporting. However, in the field of space science, all large projects are considered significant. Additional records (see 4, below) should be saved for all large collaborations over and above the core records described here.

a. *Records of NASA Headquarters' Discipline Scientists as Study Scientists and Program Scientists*

As programs are developed, a discipline scientist is asked to become the "study scientist" for a project and later, when funding is secured, the program scientist. The program scientist is the audience for the Phase A work of a NASA flight center investigating the feasibility of a proposed NASA project. In addition, this scientist develops Announcements of Opportunity that stimulate instrument proposals for particular projects. In general, the program scientist represents the scientific aspects of the mission to NASA Headquarters; responsibilities include representing the scientific community in the development of projects and acting as a conduit for bringing the problems of the project scientist (at the NASA flight center) to higher authorities if the project scientist fears the integrity of the project's scientific goals could be compromised.

Files of discipline scientists documenting their role as study scientist and program scientist should be scheduled as permanent and eventually transferred to the National Archives. They would include correspondence, Announcements of Opportunity, documents concerning the selection of PIs, and project planning and development records. Location: In the files of the relevant NASA Headquarters' Discipline Scientist.

b. *Records of NASA Headquarters' Program Managers*

The program manager is the NASA Headquarters representative to a project. Program managers are held accountable for a project's budgetary impact on the rest of the projects within their programs. Therefore, they must prepare budgetary justifications and review the progress of the project for Headquarters. If major changes are desired in the budget or scope of the project, the program manager is the person responsible for making the decisions.

The program manager's files should include project planning documents, project review documents, program development reports, correspondence, minutes of project or program meetings, budgetary records, schedule records, and program progress reports. They should be scheduled as permanent and eventually transferred to the National Archives. Location: In the files of the relevant NASA Headquarters' Program Manager.

3. ***Other Core Records of Space Science***

Grant Proposal Files of NASA Headquarters' Discipline Scientists

Most of the space science instrument teams we studied used versions of instruments that had been developed by others and modified by the individual teams—under prior NASA grants—for the harsh realities of research in space. These NASA research grants are funded and administered through NASA Headquarters' discipline scientists. These proposal files provide the most effective, efficient documentation of instrument development for NASA space projects; they

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[62]In ESA projects, counterparts of NASA's program managers and program scientists would generate records at ESA Headquarters.

should include all successful proposals as well as records for the (relatively few) unsuccessful proposals that stimulate significant debates or controversies, correspondence, and—for successful proposals—progress and final narrative and fiscal reports. They should be scheduled for permanent retention and eventual transfer to the National Archives. Location: In the files of the relevant NASA Headquarters' Discipline Scientist.

4. ***Additional Records to be Kept for All Large Projects or Missions***[63]

a. *NASA Flight Centers' Project Managers*

The project manager is the principal authority in matters relating to the project's engineering. Reporting to the program manager at Headquarters, the project manager is in charge of the budget for the project as well as being the principal contact for the sub-contractors needed to construct the spacecraft and for the scientists building instruments. The project manager's records are probably the most complete set of records of a project's technical and fiscal sides, from inception to launch. When the project moves into its operational phase, these records are sometimes broken up; while some are kept by the project manager for reference on future projects, most are sent to the operations manager (who handles day-to-day management after launch), who chooses the files judged most useful and sends the others to records storage.

For large NASA projects, records of the project manager should be scheduled by NASA flight centers for permanent retention and offered to the relevant Branch Archives of the National Archives. The records should include project approval documents, budgetary records, reports and presentations relating to design reviews, reports of test results, progress reports, correspondence with contractors, spacecraft status reports, and—at least in some cases—minutes of the SWG meetings. If records were transferred to the operations manager, they should be returned to the project manager's records when the project is complete. Location: In the relevant NASA Flight Center.

b. *NASA Flight Centers' Project Scientists*

The project scientist advises the project manager on the scientific aspects of the project and is also a PI (principal investigator) on the project with responsibility for developing one of the payload experiments (instruments). The scientist chairs the SWG (Science Working Group) which is the forum for the PIs to discuss the scientific problems and plans for the mission. After the spacecraft is launched, PIs can submit proposals to the project scientist to receive further funding for analysis of the data.

For large NASA projects, the records of the project scientist should be scheduled as permanent by NASA flight centers and offered eventually to the relevant Branch Archives of the National Archives. The records should include SWG minutes and recommendations, correspondence with PIs, logbooks and other records about the use and operation of the instruments, and proposals for further analysis of the data from user/investigators. Location: In the relevant NASA Flight Center.

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[63]In ESA projects, project managers and project scientists at ESA's flight center, ESTEC (the European Space Research and Technology Centre), generate records similar to their counterparts in the U.S.

c. *NASA Flight Centers: Science Working Groups*

The SWG is comprised of the project scientist and the PIs involved on a project, each of whom is responsible for an experiment (instrument) of the payload. This group is the main forum for the investigators to discuss the scientific issues involved in a project. The project scientist, who is also a PI, acts as the chair and represents any scientific concerns of the group to the project manager or to other NASA officials. These concerns could include developing spacecraft trajectories, solving instrument interference, deciding the scientific topics to be addressed, and establishing priorities for the use of the instruments during flight.

The minutes and reports of this group and any correspondence between the project scientist and the PIs will give the best insight into the collective science aspect of the project. These records are kept as part of the project scientist's materials (copies of the minutes may or may not be kept by the project manager). In scheduling and transferring the project scientist's material for large NASA projects, SWG records should get high priority. It is important to note that the project manager's responsibilities cease at launch, while the project scientist's continue. Location: In the relevant NASA Flight Center.

d. Records of Principal Investigators (PIs)

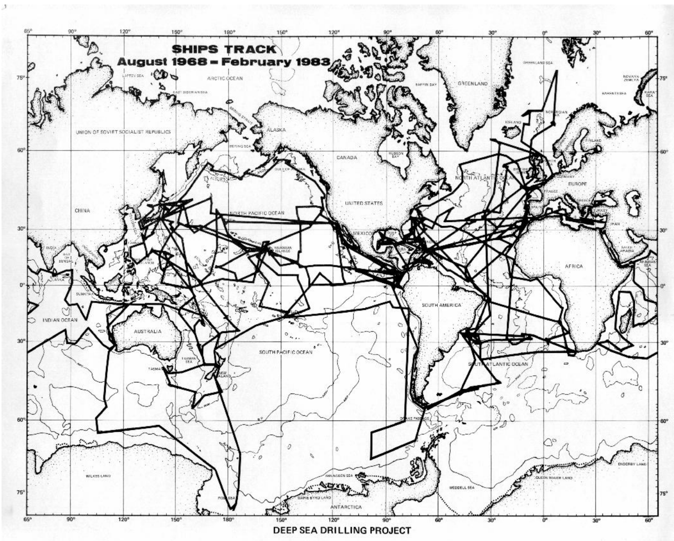
Records of PIs should be saved, particularly in cases where the PI's team was responsible for an innovative instrument or technique. The records should include the proposal submitted as PI. Location: In papers of project PIs.

e. *Space Science Experimental Data*

The data—both raw and processed—are electronic in format and usually observational in character. Their usefulness for long-term scientific purposes is unquestioned.

H. ***Computer-Mediated Collaborations***

It seems inappropriate to specify records to document this category of our AIP Study. We can generalize that funding agencies should preserve grant and cooperative agreement award files as core records. We can also recommend that data generated by chatrooms should only be saved for significant collaborations and that, even in these cases, a selection of the data be made based on a key aspect of the research program (in the case of UARC, the selection might be based, in part, on periods of the campaigns designed for tests of remote access to the instrumentation).



DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

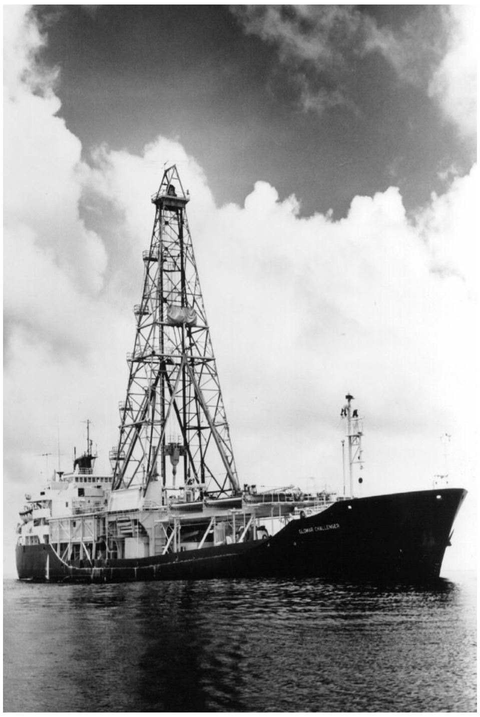
PART C: CURRENT ARCHIVAL PRACTICES AND PROJECT RECOMMENDATIONS

SECTION ONE: CURRENT ARCHIVAL PRACTICES

SECTION TWO: PROJECT RECOMMENDATIONS

Left: The general track of expeditions of the D/V Glomar Challenger (the research vessel for the Deep Sea Drilling Project) during the period August 11, 1968 until February 23, 1983. The ship had just departed from Papeete, Tahiti. Photo courtesy of Scripps Institution of Oceanography (SIO) Archives, University of California, San Diego (UCSD).

Above: Glomar Challenger at sea. Photo courtesy of SIO Archives, UCSD.



Above: Rig floor Operations, Glomar Challenger. Photo courtesy of the SIO Archives, UCSD.

CURRENT ARCHIVAL PRACTICES AND PROJECT RECOMMENDATIONS

In Parts A and B of this report, we covered the initial phases of the documentation strategy research employed by the AIP Study: the findings of our field research and our analyses of the data collected through that research.

In Part C we introduce another stage of documentation strategy research—a stage that is particularly suited to a discipline history center like the AIP Center—in which we address policy and programmatic issues. The purposes of this stage are two-fold: (1) to pinpoint records of long-term value that are at risk under current procedures and (2) to develop recommendations for policies and procedures to safeguard records that will be needed by research administrators, historians, and other scholars. For the AIP, this stage is critical. We conduct the first stages to learn how to document an area. With that knowledge in hand, we assess the ability of archival and record-keeping programs to secure the important records; then we issue formal, policy recommendations to institutions that have control over the records.

When we compare the scope of the records needed to document collaborations against our assessment of current archival policies and practices, the urgency of our project recommendations is abundantly clear.

AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART C

SECTION ONE: CURRENT ARCHIVAL PRACTICES

Joan Warnow-Blewett

R. Joseph Anderson

CURRENT ARCHIVAL PRACTICES

I. *INTRODUCTION*[64]

Once we understand enough about multi-institutional collaborations to know the kinds of records that should be saved and the likely locations of those records, we have come halfway to being able to document them. The remainder of the task is coping with institutional archival policies and practices that inhibit the documentation of collaborations.

Archival policies and practices differ widely in the U.S. The differences can be seen most clearly in terms of the sectors of our society in which the institutions operate. We have organized this section of our report accordingly.

The AIP's knowledge of archival programs has accumulated since its history program was initiated in the early 1960s. Those early experiences—trying to save one scientist's papers at one repository—bear little resemblance to our present goal of documenting multi-institutional collaborations. Now we might need to save the records of one collaboration at several repositories—repositories that probably would be in different sectors (academic, government and/or government-contract, and, perhaps, corporate institutions).

In the spring and summer of 1997, the AIP History Center conducted surveys of archives at leading research universities and at corporations with strong R&D programs to assess their ability and willingness to identify and preserve the records of historically important multi-institutional collaborations and the papers of key collaboration members. We also wished to improve our overall knowledge of these archives; our prior knowledge had been based on a variety of sources, including interviews with archivists, published sources, site visits, correspondence regarding preservation of papers, and other contacts. Our contacts with corporations had been far less frequent than with universities.

The AIP also needed to broaden its understanding of the ways federal science agencies operate—in particular, how well their records management programs protected their historically valuable records. After years of site visits and interim reports on records programs at these agencies (and at the National Archives, the repository for agency records), the AIP assembled the first-ever meeting of science agency records officers and representatives of the National Archives and Records Administration (NARA) in 1999. The meeting achieved its goal of updating and clarifying our knowledge of current programs at the agencies and at NARA.

II. *ACADEMIC ARCHIVES*

A. *General Findings*

On the academic side there is an emerging tradition (at least in English-speaking countries—and with the usual unfortunate exceptions) of documenting full careers of outstanding faculty. The early efforts of the AIP Center for History of Physics to document modern physics focused on

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[64] Former project archivist Anthony Capitos contributed to a precursor of this section, see *Report Two, The AIP Study of Multi-Institutional Collaborations, Phase II: Space Science and Geophysics*. College Park: American Institute of Physics, 1995.

cooperation with repositories in academia—the site of the most important physics research, especially during the pre-World War II period. By 1980 we could state with some confidence that the professional papers of physicists with distinguished careers would qualify for acceptance by many, if not most, academic repositories following well-established procedures.

But, by the mid-80s, we realized that we could not afford to be too optimistic. Academic archives programs appeared to be suffering from reduced resources. Further, with the onset of the AIP Study of Multi-Institutional Collaborations, a new and basic question remained: would academic archivists be receptive to the idea of documenting outstanding multi-institutional collaborations? Our discussions with academic archivists indicated a wide interest in the archival issues involved. At the same time, most of them stated that budgetary and space constraints made action difficult. Accordingly, while academic archivists recognized the role a faculty member might have as a collaboration spokesperson or principal investigator, most told us that they would hesitate to commit their limited resources to technical files or even to the records of group or team leaders (unless, perhaps, they played this role on a number of collaborations). These discussions and the AIP's previous experience with academic archives led us to believe that we would have the greatest success where the aims of documenting significant collaborations overlap with an academic archives' aims of documenting significant careers.

During the years of the AIP Study, we have found that the overwhelming responsibility for documenting multi-institutional collaborations in the fields we covered will fall on the shoulders of the academic and government sectors. Across the board, most of the scientists playing leading roles in our selected collaborations were employed by academia. In addition, we found important offices affiliated with academic institutions set up to administer geophysics collaborations and we are asking—in our project recommendations—that academic archives extend their policies to accession these important records. Because of the major role to be played by academic archivists, we determined that we needed a clearer picture of their capability and willingness to document collaborations.

B. *AIP Survey of Academic Archives*

The repositories that we surveyed generally are at the top of the academic tree. They are located at major research institutions whose programs in the physical sciences represent the best and most prosperous of American academe, and their faculties include many of the leaders in the multi-institutional collaborations that we have studied.[65] We sent the academic survey to 42 repositories and received a total of 37 returns for a response rate of 88%.

The academic questionnaire contains 12 questions and seeks two kinds of information. First, we asked respondents to describe their program; questions included the size of the staff and the collection, whether there had been staff expansion or reduction in the past five years, expansion space for the collection, the nature of records management, and policies on electronic records and collecting personal papers of faculty and staff. Second, we asked whether they would accept

[65]We surveyed repositories at research universities that rank in the top quartile in one or more of five physics-related fields (physics, astronomy, astrophysics, oceanography, geophysics) in *Research-Doctorate Programs in the United States*. Washington, D.C.: National Academy Press, 1995

collaboration-related records of faculty who were key participants in multi-institutional collaborations and the records of the collaboration itself if it was headquartered on their campus.

As we expected, the survey showed a significant relationship between staff size and collection size. All 37 respondents reported on staff size, and the results range from one repository with one staff member to one with 45 staff. To summarize, 14 said that they had less than five staff; 14 said that they had between five and 12; and nine said that they had 15 or more staff. Collection size showed a similarly broad range; of the 32 respondents who answered this question, nine reported holdings of between 1,600 and 6,423 linear feet; nine reported holdings of between 7,500 and 15,000 linear feet; and 12 reported holdings of between 17,353 and 83,875 linear feet. More than three-quarters of the archives with 15-plus staff had collections of more than 17,353 linear feet, as compared to a little over one-third of archives with five to 12 staff, and only one-tenth of archives with less than five staff.

The next questions covered staff additions and reductions in the past five years; 41% of respondents reported additions and 39% reported reductions. Change in staff size is related to several of the other variables. Staff additions show a positive correlation to existence of a records management program and willingness to accept records of key faculty involved in multi-institutional collaborations. Most of these relationships lend themselves to common sense interpretations. For example, archives with staff reductions were over two times more likely not to have a problem with expansion space. This probably reflects a general decrease in activity; with fewer staff the archives may accession less material and thus need less expansion space. Staff additions, on the other hand, are a sign of an active program, and it follows that these archives are considerably more likely to have a records management program and are more likely to accept collaboration-related records of key faculty. There is also a correlation between staff additions and staff size; medium size programs (those with between five and 14 people) are much more likely than large or small programs to have had staff additions in the past five years.

Willingness to accept collaboration-related records from key faculty participants is related to the existence of a records management program, and there is a strong relationship between records management programs and several other important variables, including the existence of a policy on preserving faculty papers and a policy on electronic records (although it is important to note that only five archives said that they currently have an electronic records policy in place). As expected, there are very strong correlations between accepting papers of collaboration members and both preserving faculty papers generally and accessioning records of multi-institutional collaborations that had their administrative offices at the university. Thus 96% of archives which reported that they would accept collaboration-related records of key faculty participants also said that they would accept administrative records of collaborations headquartered on campus.

The findings from the academic survey are mixed, but the results seem generally positive. The range of programs is very wide in terms of staff and collection size. A little over a third of respondents reported fewer than five staff—almost certainly fewer people than needed to adequately document a major research institution—but nearly a quarter said that they had 15 or more staff, which seems large by university archives standards. At a minimum we were able to identify an archivist or similar staff member at all the institutions in our target group, and the question about staff additions/reductions during the period 1992-1997 reveal a fluctuating pattern of loss and gain rather than the sharp declines that we had heard about anecdotally during this era of government and academic downsizing. Overall, in fact, respondents reported a few more staff additions (41%) than staff reductions (39%).

More significant for our study of multi-institutional collaborations, 82% of respondents said that they would accept the collaboration-related papers of their faculty who were key participants in highly ranked collaborations, and 78% said that they would accept the administrative records of a highly significant collaboration if it was headquartered at their university. An important reality check here is that the AIP Center's International Catalog of Sources for History of Physics and Allied Sciences contains entries for the records of only three multi-institutional collaborations already in academic archives. In light of this, the strongly positive responses to these two questions should probably be interpreted as evidence of willingness to preserve records of collaborations rather than of active efforts to identify and accession them. However, the responses offer the hope that if a third party like the AIP History Center is able to rank collaborations and help identify valuable papers and records, most of the archives in this sample may be willing to provide a home for those related to their university (because of a major role by faculty or the site of an administrative office).

III. *FEDERAL AGENCIES*

A. General Findings

Each federal agency is required by law to have a set of records schedules that determines how long records will be retained and when records of long-term value are to be transferred to the National Archives and Records Administration (NARA). These schedules must be approved both by senior management at the agency and by NARA.

It is not enough to review the records schedules from federal agencies; a review of the records management program which will implement the schedules is equally important. When discussing records programs with agency records officers, their description of the programs and the proper use of the records retention schedules may differ from the actual implementation by agency employees. Our findings show that, in general, federal agencies and their laboratories (or contract laboratories) do not document their research and development activities well.

We have learned that it is the responsibility of the agencies to see that their records schedules are maintained and properly applied. For example, agencies must update their records schedule manuals as new records series are identified (via inventorying or other means) and they must schedule new program records within a year. NARA has oversight responsibilities. It also has authority to conduct evaluations of agency records management programs; however, for reasons of efficiency, most of NARA's efforts in this area are shifting to a new initiative called a Target Assistance Program. TAP is an agency-initiated nationwide collaborative program customized to help agencies work on their records problems.

The findings that follow are based on fieldwork conducted throughout the decade-long AIP Study of Multi-Institutional Collaborations. They were reviewed in 1999 through correspondence and by a working group meeting held at the AIP in October 1999 with current agency records officers/historians and staff of the NARA Life Cycle Management Division.

B. *Specific Agencies*

1. *Department of Energy*

The AIP History Center has paid close attention to the Records Management Program of the DOE since the mid-1970s while we were designing an exhaustive study of record-keeping at DOE National Laboratories. Since then, as we shall show, the upgrading of DOE's program has been remarkable.

The new DOE R&D Records Schedule, approved in August 1998 by NARA, is by far the best schedule we have studied. Other science agencies have included sets of criteria for identifying research and development records for permanent retention. But we are particularly impressed with DOE's guidelines for procedures to rank scientific research projects as "significant," "important," and "other" and—and this is most important—to involve a committee including the science records creators and records managers in this ranking. We also want to point out the importance placed on the proper evaluation of scientific policy and planning records in the DOE records schedules. NARA should consider identifying the DOE Records Management Program's development of criteria for the appraisal of R&D records—along with procedures for ranking the importance of specific scientific research projects—as a Best Practice Award for federal agencies.

More than two years have passed since the DOE R&D Records Schedule was approved. We hope DOE will continue to make formal assessments as to the success of its implementation at both the headquarters and field levels. Beyond that, we urge DOE to reconvene on a regular basis the committee of its leading records managers to explore the need to update the schedules and procedures for securing R&D records.

2. *National Aeronautics and Space Administration*

The NASA record schedules were approved—for the most part—during 1994; since then changes have been submitted and approved when necessary to keep the manual active and correct. The schedules concerning research and development records were evaluated, not only by NASA senior management and the National Archives, but by the Federal Records Centers involved and by others affected by the changes—chiefly the flight centers. The manual of 10 schedules or chapters is arranged by function, which better reflects the workings of the agency than the previous 27 schedules arranged by subject.

Many of the NASA records schedules are written in a very general manner, in order for the manual to be applicable both to NASA Headquarters and to the flight centers. The records of mid-level Headquarters scientists are fit into other functional locations. For example, the term "program" and the term "project" are interchangeable in the schedule, even though—in NASA parlance—program scientists and program managers are Headquarters positions, and project scientists and project managers are at flight centers. On the other hand, records of the upper level management offices at Headquarters are specifically discussed and systems of records that are specific to a NASA center are also specifically described for that center.

The AIP Center gathered most of its data on NASA's records management program and practices during its study of collaborative research in space science. Accordingly, it should be noted that the findings that follow are based on fieldwork completed prior to our 1995 report.[66] Our fieldwork discussions (primarily site visits) included NASA records management staff at both NASA Headquarters and the three flight centers involved with our selected case studies, discipline scientists at Headquarters, branch scientists at the flight centers, and the National Archives appraisal archivist, along with general interviews with NASA program scientists.

We found that NASA's records management program reflects the relationship that NASA Headquarters has with its flight centers. Each of the flight centers has its own specialized interests and takes a somewhat independent stance from Headquarters. Records managers at flight centers feel entitled to interpret the records retention schedules to best fit their particular center. Although the new NASA records retention schedule is an improvement over the previous one, its reception has not been overwhelmingly positive. While one flight center's records manager accepted the adoption of the records schedule manual, another stated that it was not appropriate for his flight center. Part of the problem could stem from the fact that the new records retention schedules are written in such general terms that the flight centers have difficulty in understanding how they are to be applied.

A second problem which arises from this schedule is the assumption that NASA scientists are actually filing their records according to standard procedures. The NASA records management program assumes that central filing procedures are being used along with a uniform filing index. Our interviews with several discipline scientists and project scientists showed that records were not being handled according to these procedures.

As with scientists in most federal agencies, fear of the destruction of records combined with lack of knowledge about records management procedures has made NASA scientists keep their records in their own offices. According to one discipline scientist, concern about the retention of his records prompted him to send them to the NASA History Office; no one from the History Office has ever contacted him about these records. Another NASA scientist stated that he has kept some records from the projects he was involved with but doesn't know what will happen to them since no one—during the many years he as been with NASA—has ever been in touch with him about records management.

NASA records management has never taken a proactive approach to the selection and retention of records. According to one flight center records manager, the only records they accession are ones that people send to them voluntarily. At the start of a large project, the flight center records manager stated, they will ask the project administrators to remember records management at the end of their project. Unfortunately, this seems to be the norm for NASA flight centers, due to the lack of staff to perform more proactive duties. Records management at NASA flight centers has

[66] *The AIP Study of Multi-Institutional Collaborations, Phase II: Space Science and Geophysics*. College Park: American Institute of Physics, 1995.

mostly been a neglected area; some have a few full-time employees, some contract employees, and others only one half-time employee.[67]

During our site visits to flight centers, a search by records management staff could turn up no records for two of our case studies. We also found that records of some of the founders of a flight center had been removed to a private institution.

Only one of the NASA flight centers has a fully established archives and records management program.[68] The Jet Propulsion Laboratory (JPL) in 1989 established an archives and records management program with six full-time employees, including an archivist. Along with this program, JPL has included an oral history component to supplement the historical materials kept at their archives. This program could be the model for the rest of NASA's flight centers, and some at the National Archives are pleased with what JPL has accomplished. On the other hand, NASA Headquarters is not entirely satisfied with the situation at JPL. JPL, unlike other flight centers, operates under a NASA contract (with the California Institute of Technology). Due to this arrangement, JPL does not feel that it creates federal records other than the required deliverables and does not have to follow the NASA records management program. JPL's primary reason for disliking NASA's program is that the language of the records schedules, along with the types of records covered, do not fit well with the language and records of JPL. In addition, records in the JPL archives are only available to public researchers after they have been reviewed and cleared by the original creating office. Although JPL has established an archival program, access to these records—essential for historians—has been problematic. Under the new contract NASA and JPL signed, if JPL wishes to use Federal Records Centers, it must employ the revised NASA uniform filing index. However, according to JPL, the contract still seems unclear as to whether JPL is creating federal records or not. Currently, JPL is developing its own records retention schedule, which will not be based on the new NASA schedule.

Finally, the AIP data show that most NASA project managers do not retain many project records after a spacecraft has been launched and their position on the project has ceased (the position of project scientist, on the other hand, remains through the lifetime of the project). The records of project managers are transferred to the operations group, who have the opportunity to take what they need in order to keep the spacecraft in working order; the rest of the documentation is sent to records storage. According to our questionnaires and interviews, when project managers leave or retire from NASA, they tend to leave any remaining records in their offices for someone else to deal with.

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[67]We have learned that a number of NASA sites—Ames Research Center, Glen Research Center, Goddard Space Flight Center, Johnson Space Center, Kennedy Space Center, and Marshall Space Flight Center—now have fully established records management programs.

[68]More recently, archival or history programs have been initiated at Glen Research Center, Johnson Space Center, and Marshall Space Flight Center.

3. *National Institutes of Health*

Of all the scientific disciplines relevant to the AIP Study of Multi-Institutional Collaborations, we are least familiar with medical physics and with the lead funding agency for the field, the NIH. In fact, our direct contacts with NIH were limited to meetings with the two senior science administrators on our Working Group and a site visit we made to the NIH historian.[69] As a result, we will be addressing only one aspect of the NIH records management program—its need for a strategy to identify significant research and development records for permanent retention.

R&D records at the NIH fall into two categories: grant case files (related to external research) and intramural research records (related to research within the various institutes of the NIH). Attempts by NIH to secure these records focused, in the 1980s, on the grant case files and, in the 1990s, on the intramural research records. All efforts failed despite the involvement of the NIH directors of intramural research and other key players.

During the October 1999 meeting at AIP, the supervisor of the National Archives' Life Cycle Management Division recommended that NIH work with NARA's TAP program to develop a strategy to secure significant records in both the grant case files and the intramural research records. The NIH historian indicated that she and the NIH records officer would take the initiative.

4. *National Oceanic and Atmospheric Administration*

The records retention schedules for NOAA are in the process of being revised. To date, four chapters of the Disposition Handbook have been revised; three remain.

Chapter 1200 of the NOAA Disposition Handbook—which covers Scientific and Technical Records—was approved in 1995. This schedule includes provisions for significant project records with guidelines to help with their identification. Under its terms, project case files would include materials such as correspondence, memoranda, e-mail printouts, progress reports, working papers, etc. Prior to the closing of the project, the appropriate division chief is to use a list of criteria to help determine if the project is to be considered significant; these criteria include the awarding of a national or international prize, the work of a prominent NOAA investigator, and the fact that the project was subject to widespread media attention or received congressional scrutiny—just to name a few examples from the list. Records for projects meeting one or more of the selected criteria are to be retained permanently. This system of selecting significant project case files also covers research notebooks, project proposals, budget information, and planning files, which are to be transferred to the appropriate project case file.

Three more chapters of the Disposition Handbook need to be revised. At the moment, they fail to cover many of the records created in those programs. A contractor has been hired to revise the chapter that covers the National Ocean Service; this may be completed in 2000. The remaining chapters will follow, depending on funds.

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[69]During Phase III of the AIP Study, our contacts–for interviewing purposes–were with members of our selected collaborations employed by academic departments, medical schools, university hospitals, and other participating institutions such as the American College of Radiology.

Although the new NOAA schedule, when finished, will be a great improvement over the current schedule, it is the application of this new schedule which will determine whether the records management program will improve. Unfortunately, there continues to be a lack of managerial support for the records program resulting in a Records Management staff of one with one assistant. A major concern is not providing enough records training for all of NOAA. The modest program of training sessions (one in the DC Metro area and another in two different regions each year) is clearly not enough, given the size of NOAA.

One positive action taking place in NOAA is the organization of a BioData Working Group involving all of the program offices. The purpose of this group is to assure the long-term stewardship and archiving of NOAA's biological, chemical, and associated data. The Working Group is reviewing various options to establish a policy for archiving and managing data sets.

5. *National Science Foundation*

The NSF is currently the major U.S. funding agent for projects in geophysics, oceanography, and astronomy; it shares responsibility with the Department of Energy for supporting projects in high-energy physics. The AIP Center has long been concerned about documenting NSF's pivotal role in basic research. In recent years, AIP project staff met with a number of NSF Program Officers and other NSF administrators; we reviewed the manual for NSF records schedules with the NSF records officer in January 1999.

Overall, the Records Management Program at NSF is a modest success. The all-important records of the National Science Board are secured (although it is not clear that the disciplinary subgroups of the NSB are scheduled for permanent retention) and documentation of the review process for accepted scientific proposals is satisfactory. However, NSF's records schedules were completed in 1982 and by now it is obvious that updates and revisions are sorely needed.

In the case of updates, the records programs should take into account that NSF funds a variety of scientific research programs beyond individual research projects. We point in particular to its facilities (national observatories and laboratories) and centers (Science and Technology Centers and Materials Research Science and Engineering Centers). Research awards now take the form of cooperative agreements and contracts in addition to the traditional grants. These new types of awards determine varying responsibilities on the part of the NSF and recipients of support (as well as varying types of records). We found that pre-proposals are a critical part of the funding process in materials science. None of these new procedures or categories of records are reflected in the records schedules. We consider that this area of funding and oversight constitutes the major update that needs to be made. The gap between agency programs and records schedules underlines the need for proactive and educational records management programs.

In reviewing the records retention manual we found several important sections that need clarifications to avoid misunderstandings (e.g., how can one find the category where NSF Program Announcements are to be scheduled? and are records created by the NSF Director really not covered in the records schedules?). In fact, it seemed possible that some other important records series are not covered (such as heads of NSF Directorates and directors, executive officers, and program officers of NSF Divisions).

Finally, we point to the fact that the NSF records schedules cover only records at NSF Headquarters; NSF facilities and centers do not produce federal records. They are required only to provide NSF with deliverables, including budget and progress reports. It is clear that many valuable records will be lost unless they (or their host institution) or the National Archives takes responsibility.

6. *United States Geological Survey*[70]

We know of no plans to revise the current records retention schedules for the USGS, but revisions are definitely in order. For example, the USGS schedules state that none of its project case files are considered permanent; they are to be destroyed after thirty years. These records would include contracts, technical records, drawings and photographs, progress reports, correspondence, planning documents, etc. This disposition is supposed to be followed unless superseded by an individual division schedule. Project proposals and laboratory project notebooks fall under the same fate as the project case files with which they are associated.

In practice the divisions do specify some project records to be retained—notably seismic and other geophysical data. USGS has been fairly consistent on the retention of the geological data from its projects because of their long-term usefulness for scientific and practical purposes. These records remain in USGS custody for seventy-five years before they are transferred to the National Archives. Some at the National Archives feel that the scientists have no interest in the preservation of their records beyond the published materials and scientific data. This is compatible with AIP's experience.

The USGS records management program appears to be severely understaffed. One of the main problems facing the USGS records management program is its lack of identity within the institution. Most of the USGS scientists we interviewed did not even know of the existence of a records management program nor what happened to their records. An education program to help scientists identify important records, along with helping them understand the records management program, would be a beneficial first step in securing the important scientific documentation of this agency. Two examples of this problem: one division chief at headquarters expressed certainty that there was no records program at USGS, and one USGS branch has not transferred any records to its Federal Records Center in more than a decade.

C. *Conclusion*

AIP Study findings from our fieldwork over the years were clarified and sharpened during the discussions with science agencies and the National Archives at our 1999 meeting at AIP. All of the agency records officers—with the possible exception of DOE—are well aware that they are critically understaffed and short of funds, and that their scientists and administrators are largely unaware of their programs. The result is that they cannot meet training goals or enjoy the

[70]The AIP Study's limited exposure to the USGS included: (1) meetings with scientists in the Geologic Division whom we interviewed about selected case studies and (2) discussions with USGS Headquarters staff on the records management program. The current USGS records officer has informed us that these findings, published in 1995, are still accurate.

efficiencies of proper records-keeping—to say nothing of halting the loss of historically valuable documentation.

Two agency records officers described new efforts to tackle these problems. NASA now has an Awareness Training Program. At DOE, "education" and "awareness" are buzzwords that they try to insert at every opportunity; this approach leads, they believe, to better understanding and, eventually, better support and funding by their DOE administrators. At the same time, NARA realizes that it needs to improve its communications with agencies and to respond to agency needs with TAP and other initiatives.

IV. *CORPORATE ARCHIVES*

A. *General Findings*

Over the decades, the AIP Center has had minimal experience with corporate archives and what experience we have had has not been encouraging. We have found that few research corporations have archival programs and, where these programs exist, they have focused on administrative records and those that provide protection of their patent rights. It has been a major exception to the rule to find corporate archives that would accession the professional papers of their distinguished scientific staff. In addition, the records of many corporate archives have not been made easily accessible to historians and other external researchers.

Corporations did not play a primary role in the multi-institutional collaborations we studied. In fact, with the exceptions of materials science and medical physics, corporations were not among the member institutions of our selected case studies. There were, however, indications—at least in high-energy physics and materials science—that the presence of corporate institutional members was growing. In high-energy physics, we are aware that corporations have been full members of collaborations (in cases more recent than the period we covered). In the field of materials science, there are at least two, relatively recent catalysts that have boosted the presence of corporate members: (1) synchrotron radiation facilities are attractive to many corporate researchers, and (2) the introduction of NSF's Materials Research Scientific and Engineering Centers (MRSECs) has fostered collaborative links between academia and the corporate world. Finally, in the area of medical physics, we have just learned that the NIH expects multi-institutional collaborations to have a higher profile in its research programs in the near future; this should mean increased participation by corporations. We believe that collaborations are becoming more important in scientific research. It seems equally evident that corporations are becoming more important to collaborations.

For these reasons (and because the AIP Center is considering a future research project to understand how we might do a better job of documenting physics in industry) a survey of corporate archives was conducted.

B. *AIP Survey of Corporate Archives*

As a whole, the academic survey (II.B., above) presents a picture of varying but generally active efforts by America's leading research universities to document their programs and faculty. Predictably, the corporate survey presents a very different picture, and one that is both less optimistic and less clear. At the same time the corporate survey shows some interesting patterns.

We contacted the American companies that employed the most physicists, using a list developed by AIP's Statistical Research Center of the 37 companies that employed approximately half of all U.S. physicists in industry in 1994.[71]

Identifying appropriate staff to contact provided the first major contrast between academic and corporate archives. For the former, we already had well-established contacts with the heads of nearly all the university archives in our sample through our long-standing efforts to preserve papers, and we had records from most of them in ICOS. In addition, all but a few were listed in the Society of American Archivist's *Membership Directory*. Finding the appropriate contact person for the 37 corporations proved much more difficult. We tried a variety of sources including industrial directories and the SAA *Directory of Business Archivists,* which provided only a few names, and we then tried calling the corporate headquarters and asking for the name and address of the archivist or other similar staff member. Altogether, we were able to identify archivists, records managers, librarians, or historians for 27 of the 37 corporations on the AIP list.

The corporate questionnaire contains the same general questions as the academic instrument, although some were modified to reflect the corporate environment. The survey results substantiated our impression that most big-science corporations don't have professional archival programs, although we confirmed that a few do. We did up to three follow-ups to obtain responses and received a total of 19 returns for a total response rate of 70%. However, in reviewing the returned questionnaires, we found that about half were from records management or library programs that do not retain corporate records permanently, and two were memorabilia collections maintained by company retirees working as volunteers. After a careful review we decided that eight of the respondents have operations that appear to be real archives capable of preserving company records on an ongoing basis and, through follow-up research, we learned that three additional enterprises on our list preserve corporate records by donating them to non-corporate archives. This made a total of only 11 out of the 37 listed in the AIP report.

Most corporate archives are significantly smaller in terms of collection size as well in terms of staff size than their academic counterparts. Five corporations reported in-house archives staffed by less than three employees. Motorola reported a staff of four. The AT&T Bell Labs and Ford Motor Co. archives have both expanded in recent years. AT&T, which is the largest corporate archives in the U.S. and has a long-established program, doubled its staff in five years, going from 12 to 24 people (including temporary staff). Ford, which minimally supported its archives program for more than 30 years, hired a new manager in January 1997 and—in addition to the manager—now employs 14 contract archivists. IBM, which had two archives staff members at the time of the survey, has since hired a new archives manager and is also expanding its program. We also found that three major corporations place permanent records in non-profit archives: Dupont sends records to the Hagley Museum and Library, General Electric sends records to the Schenectady Museum, and 3M sends records to the Minnesota Historical Society. In summary we

[71] AIP Statistical Research Center, "The Corporations Employing the Largest Number of Ph.D. Physicists in the Private Sector, 1996." We should note that the corporate sector represents about one-third of the working physicists in the U.S.

found that eight (22%) of the 37 U.S. enterprises, who employed approximately half of all physicists in industry in 1994, had professional in-house archives and another three (8%) preserve at least some records by sending them to independent non-profit archives.

Two-thirds of the corporate archives said that they would accept the collaboration-related records of their staff who played key roles in highly ranked multi-institutional collaborations and half said that they would accept the records of highly ranked collaborations that were headquartered at their companies. However, these responses shouldn't be interpreted as evidence that the archives at top science industries, when they exist, are documenting R&D. We have visited or had lengthy phone contacts with four of the eight archives in our sample, and two of these are currently preserving records almost exclusively of business operations. And the small size of most of the archives that we identified makes it unlikely that they can go much beyond saving top administrative records.

Overall, the corporate survey reinforces the findings of a conference on business records convened by the Hagley Museum and Library and the Minnesota Historical Society in 1996—that American corporate life is not well documented and that this is as true among major science corporations as for other areas of the corporate world.[72] The results do not bode well for documenting this increasingly large sector of physics and allied sciences or of preserving industry's contributions to major multi-institutional collaborations.

C. *Subcontracts to Industry*

The AIP Study examined the importance of subcontracting to industry by multi-institutional collaborations—and the likelihood of documenting it—during its studies of high-energy physics, space science, and geophysics. Most of our findings were gathered through our regular project interviews with collaboration scientists. In addition, focused studies of specific corporations were carried out by the first project historian (who served later as a project consultant).[73]

In many of the geophysics and oceanography collaborations studied, the principal investigator of the Science Management Office was the primary intermediary between the collaboration scientists and the contractors, and the administrator's records provide the best documentation of industry involvement. In some cases, almost all contracts and correspondence with contractors have been kept in a single office, such as the Polar Ice Coring Office for the Greenland Ice Sheet Program. In some cases, such as with IRIS (Incorporated Research Institutes for Seismology), there was careful oversight by the program office of the work of contractors, and this increased the survivability of some subcontracting records. We also found that some collaborations issued a

[72] James M. O'Toole, ed., *The Records of American Business*. Chicago: Society of American Archivists, 1997.

[73] See Nebeker, Frederick, "Report on Subcontracting and the LeCroy Electronics Corporation." Report No. 4, pp. 135-142 in *AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics*. New York: American Institute of Physics, 1992. Also, "The Development of Very-Broad-Band Seismography: Quanterra and the IRIS Collaboration." Report No. 2, pp. 179-193 in *AIP Study of Multi-Institutional Collaborations, Phase II: Space Science and Geophysics*. College Park: American Institute of Physics, 1995.

newsletter that contained information about subcontracts. In space science, we found that some aspects of the relationship between scientists and industry are relatively well documented. In particular, because the selection of a contractor is in many cases a very formal process (notably in European Space Agency projects), many documents are generated by companies bidding on contracts and by project evaluators.

Other aspects are poorly documented. It is probably the case that most of the innovative engineering that takes place in industry never results in a publication, not even in the form of a thorough internal technical report or memorandum. And much of the give-and-take between collaboration and company personnel occurs in person or by e-mail, or in some other way fails to produce documents that are usually retained. Another problem concerning this documentation arises when subcontracts go to unstable companies that may go out of business before long. In oceanography, the example of the research vessel Challenger built for the Deep Sea Drilling Project illustrates how insecure the documentary record may be for work done by industry. The vessel was built by Global Marine Corporation, which, since winning the contract, underwent at least two reorganizations (one of them under Chapter 11 protection) and moved. One of our cases in space science provided another good example of this problem. It arose in the development of the fast electron experiment flown on the ISEE (International Sun-Earth Explorer) missions. The electronics of the instrument was contracted out to Matrix Research and Development, a company which has since gone out of business.

V. *OTHER FINDINGS OF INTEREST*

A. *Freestanding Institutions*

We have encountered two types of freestanding institutions during the long-term AIP Study of Multi-Institutional Collaborations: NSF National Observatories and geophysics institutes. We refer to them as freestanding because they have no affiliation with a university or other large institution and, as a result, have no natural link to a repository for their records.

The NSF National Observatories have some characteristics in common with the DOE National Laboratories. Both DOE's and NSF's facilities are internationally top-ranking institutions making major contributions to contemporary science and, although operating under contract, they can be considered to be "permanent" organizations. There are, however, two significant differences: while the DOE laboratories create federal records and have come to terms with the responsibilities of securing their records of historical value, the NSF National Observatories do not create federal records and—as younger organizations—they are just beginning to worry about coping with their old records. As already mentioned, the NSF observatories lack affiliations with archival institutions. We do not know of any that have initiated archival programs or made formal arrangements for their records to be transferred to an established repository. Until one of these choices is made, the records of these research facilities will be in danger.

The second category of freestanding institutions was made known to us during our study of research collaborations in geophysics. In two of our selected cases new, freestanding institutes were created for the sole purpose of administering the project. Because these institutes are not widely known, we describe our cases briefly here as examples of a new type of documentation problem that scientists, historians, and archivists should be more aware of.

One such institution we examined is the Joint Oceanographic Institutions (JOI). JOI is a consortium of ten American oceanographic institutions and is the prime contractor for the Ocean Drilling Program (ODP). JOI works closely with the Joint Oceanographic Institutions for Deep Earth Sampling (JOIDES), an international consortium which advises the Ocean Drilling Program on both scientific and logistical endeavors. JOI receives money from the NSF and passes it to the Ocean Drilling Program, now located at the Texas A&M University Research Foundation, to operate the program. Using JOI as prime contractor, the NSF is able to have ODP run without the legal restrictions imposed on a government agency.

JOI is thus not part of an institution which could retain its records at the conclusion of the Ocean Drilling Program. This problem is even more serious for JOIDES, where most of the scientific and policy decisions are made. Not only is there no existing repository for records of JOIDES, but it has a central office which rotates every two years to a different member institution. According to a former director, JOIDES meticulously saves and passes on its records, which includes every proposal ever submitted, minutes of all panel meetings, and audio tapes of the Planning Committee meetings. Some of these records are sent to JOI for storage, particularly workshop reports, but the rest are passed along to the next host of JOIDES. Because of the transient nature of the JOIDES office, an archival repository should be established—or arrangements made with an existing archives—for the permanent retention of these highly valuable science-policy records.

The other new, freestanding institution that our project dealt with is the Incorporated Research Institutes for Seismology (IRIS). Like JOI, IRIS is a corporation with its own headquarters and without affiliation with any academic institution. The three main programs of IRIS are the Global Seismic Network, the Program for Array Studies of the Continental Lithosphere, and the Data Management Center. Although IRIS is involved with individual experiments, its purpose is to facilitate science, not conduct it. Any proposals for experiments using its instruments have to be submitted to the NSF for funding and approval. Other than providing deliverables to the NSF and the electronic storage of scientific data, there are no mandatory record-keeping requirements imposed by the collaboration on projects supported by IRIS instruments. We know of no plans to retain records nor of a repository to place them in. According to our interview subjects, the most important records for documenting IRIS's planning and operations are the records of the committee involved with each of the three IRIS programs. These committee minutes are provided by the secretaries to the head administrator of IRIS.

B. *Policy-Making Bodies*

AIP Study staff explored record-keeping practices in the areas of policy-making bodies during our study of space science and geophysics. The three examples we offer from our findings are of interest because of the great influence these organizations have on the directions of contemporary science.

1. *National Academy of Sciences*.

The Academy plays a key role in establishing priorities for scientific research. Perhaps best known for the physical sciences are the decadal surveys of the National Academy of Sciences' Board on Physics and Astronomy. These reports—on high-energy physics and other disciplines—focus on documenting the accomplishments of physics during the previous decade and analyzing the requirements for continued progress. More particularly, during our study of space science and geophysics, we found that the influence of the Academy was often a critical factor, for example, in decisions made at NASA to support new missions and at the NSF to support new projects or even extend their program areas. The most important records at the National Academy of Sciences for documenting projects in space sciences pertain to its Space Studies Board and, in geophysics and oceanography, its Atmospheric Science Board, Ocean Studies Board, and Polar Research Board. Fortunately, the Academy has had a fully professional archives program for decades and the records of these—and other boards—are kept as part of the Academy's Archives.

2. *The International Council of Scientific Unions*.
ICSU is located in Paris. Prompted by lack of office space, it employed a consulting archivist to prepare an inventory of its records and develop an archival program. The records of ICSU consist of headquarters information including Executive Committee records, general assembly records, general committee records, yearbooks, and publications. Along with its small archives, ICSU has a document center which is comprised of its own published materials as well as publications of its disciplinary unions and committees. These records, however, do not include records of the disciplinary unions, for example, the International Union of Geodesy and Geophysics, and their committees, where the policy making is done. Their records get passed along as the Secretariats move from place to place.

3. *The World Meteorological Organization*.
The WMO also has a small archives program. During our site visit, we were primarily concerned with the records of the World Climate Research Programme (WCRP), the management office for two of our important cases. The WCRP is located at the WMO in Geneva, but is an offspring of the WMO and the ICSU. The office of WCRP's director is full of scientific and administrative correspondence, unpublished minutes of meetings, and so forth. The archivist at WMO would welcome accessioning the WCRP records (and ICSU agrees this would be appropriate), but the WCRP staff were not willing to part with what they felt are records of an independent unit.

VI. *SOME CONCLUSIONS*

There are inconsistencies and problems in archives and records management efforts at various universities, government agencies, corporations, and other research institutions. These challenges are compounded when one tries to document a collaborative research effort across institutions. Many archives and records management programs are well-intentioned but desperately underfunded and overwhelmed with work. Many research institutions—including all the national observatories and most corporate laboratories—lack archival programs altogether. Indeed, it is not at all clear that the nation's archival and records management programs are capable of doing an adequate job of documenting multi-institutional collaborations.

The problems of corporate archives are particularly difficult to resolve, as illustrated by our corporate survey. It is obvious that corporate archives and records management programs cannot survive unless they serve the parent institution, and many are just barely surviving. There is little room for preserving records of multi-institutional collaborations—a task few in the corporations would consider essential to their missions. Nevertheless, in our recommendations, we ask corporate research laboratories to meet a modest standard: those corporations that lack archival programs should initiate them and all corporations should consider documenting their role in multi-institutional collaborations to be part of their responsibilities.

Most of all, we are concerned about archival and records management programs in the academic and federal sectors, where our fieldwork shows the tasks of documenting collaborative research in the physical sciences will impose its greatest burdens. Additional resources—critical in both cases—would help resolve the problems. In our Project Recommendations we ask federal funding agencies to provide a very modest increase in overhead rates to academic institutions—an increase that would be targeted for the support of academic archives. We also ask these federal agencies to recognize that, with the exception of the Department of Energy, their own agency records programs lack the resources to meet even the legally required standards of securing adequate documentation of their programs and activities. Without professional records programs, agencies cannot meet training goals or enjoy the efficiencies of proper records-keeping—to say nothing of halting the loss of records needed for administrators and future historians.

AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

PART C

SECTION TWO: PROJECT RECOMMENDATIONS

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PROJECT RECOMMENDATIONS

All chapters of our report—whether they be findings, analyses, or assessments—lead to our project recommendations. We have provided ample evidence that changes in records programs at research institutions and federal agencies must be made to secure an adequate record of multi-institutional collaborations and their contributions to science and our society.

It may be difficult for scientists—even those who direct collaborative work—to recognize the importance of saving documentary source materials. It may seem to them that their personal recollections and those of their colleagues are sufficient. This is unfortunate from the standpoint of present needs. From the standpoint of the future it is disastrous, for even the imperfect personal recollections will die with the scientists, and later generations will never know how some of the important scientific work of our times was done.

Archivists and records managers may wonder why they must take on what might be seen as "yet another responsibility." A different perspective would be that scientific activities are simply being shared differently than in the past—fewer scientists are doing individual or small projects and more and more of them are participating in collaborative projects. We expect it will become quite natural to archivists and records managers working in the scientific arena to find that collaborative research projects have become integral to the major institutional policies, programs, and activities that they are committed to document. Nevertheless, we are well aware that archivists and records officers—particularly in academia and federal agencies, where responsibility for collaboration records is highest—are overwhelmed by workloads and inadequate budgets. Our recommendations #3.a. and #3.b. address this issue.

The project recommendations that follow are aimed at preserving only a small fraction of the records created by multi-institutional collaborations. As shown in our appraisal guidelines, records of archival value will consist of a small set of core records plus, in a few cases, a wider range of records for very significant collaborations. Our experience indicates that records of this quality will be of interest to future historians and other scholars. Multi-institutional collaborations have a diversity of characteristics that contribute to their potential interest to scholars. For example, collaborations may be not only multi-institutional but multi-disciplinary and multi-sectored as well. In addition, these multi-institutional collaborations must be seen in the context of the national and other major research facilities they use. Whether on their own or in the context of the research facilities, multi-institutional collaborations are an integral part of the "Big Science" characterized by large federally funded budgets and national and even international planning and policy making. For these reasons, multi-institutional research collaborations are of potential interest to a wide variety of scholars. Securing adequate documentation of multi-institutional research collaborations is critical for future historical studies. It is also vital for current management of technical innovation and for science policy needs of federal agencies and others who want to understand such basic issues as the effectiveness of team structures.

The following recommendations are directed to the actions needed to document collaborative research in physics and allied sciences, particularly in those fields studied by the AIP Study of Multi-Institutional Collaborations during its three phases, namely: high-energy physics (Phase I), space science and geophysics (Phase II), and ground-based astronomy (divided into observatory builders and observatory users), heavy-ion and nuclear physics, materials science, and medical physics and an area we named computer-mediated collaborations (Phase III). They are justified in more detail in the reports issued at the end of each phase of the long-term study of collaborations.[74] Many of the documents referred to are currently on paper, but our recommendations also apply to information in electronic format.

The AIP Center has encountered a wide range of complexities facing the documentation of experiments in modern physics and allied fields. On the most basic level, good records-keeping may be acknowledged by all as necessary while the experimental process is alive but, when the project is over, records can easily be neglected, forgotten, or destroyed. As a result, the most important recommendation (Recommendation #14.b.) urges a new approach to securing the documentation for future collaboration projects. We suggest that, once a project has been approved by a research laboratory (observatory, NSF center, etc.), the collaboration be required to designate a member to be responsible for its collaboration-wide records. In addition—where historical significance warrants—individuals should be named to be responsible for group- (or team-) level documentation of innovative components or techniques. This information should be incorporated into any contractual agreement with the collaboration. Use of this simple mechanism would assist archivists by assuring that records will be available for appraisal and by providing information on their location.

Multi-institutional collaborations are virtually all funded by federal science agencies and much of the research and development is carried out at agency facilities. Most of our recommendations are addressed to these agencies, as well as the National Archives and Records Administration (NARA), because successful documentation relies heavily on the effectiveness of their records management programs.

RECOMMENDATIONS

The recommendations are grouped in the following order:

Recommendations—Policies and Procedures

1. General
2. National Archives and Records Administration
3. Federal Science Agencies
4. Specific Federal Science Agencies
5. Other Institutional Settings

[74] The AIP project recommendations issued at the end of each of the three phases are available on the AIP Center's web site (http://www.aip.org/history/); sets of printed reports for each phase are available upon request to the AIP Center.

Recommendations—What to Save:[75]
1. Policy and Planning Records
2. Core Records by Scientific Discipline
3. Significant Collaborations

Recommendations—How to Save

RECOMMENDATIONS—POLICY AND PROCEDURES

CATEGORY ONE—GENERAL

Recommendation #1: Professional files of key scientific faculty/staff members should be permanently preserved by their institutional archives.

Explanation:
Virtually all of our recommendations are focused on securing records of collaborations; accordingly, we must make clear at the outset the importance of preserving papers of individual scientists.

For some decades now, it has been traditional—especially in English-speaking countries—for professional files of academic scientists to be permanently preserved in their institutional archives. Those papers most frequently sought are of individuals who have made major contributions to science or science policy on a national or international level or to their university.

There are two principal targets for this recommendation. First, university archives in all countries should have policies to permanently secure files documenting the professional careers of their distinguished scientists. Second, similar policies are sorely lacking at virtually all research laboratories and other nonacademic institutions; they should be initiated and supported by directors of laboratories, whether they be in the corporate or government sector.

CATEGORY TWO—NATIONAL ARCHIVES AND RECORDS ADMINISTRATION

Recommendation #2:

a. *The National Archives and Records Administration (NARA) should solicit increased input from subject matter experts so that it can make more informed decisions on records appraisal;*
b. *NARA should work with agencies to monitor and promote agency records management practices to insure that legal regulatory responsibilities are met, including the identification and maintenance of records of permanent value;*
c. *NARA should identify and promote best practices for records management programs that agencies should utilize, including the development of R&D records criteria. The R&D records schedule of the DOE (Department of Energy) could serve as a model for other scientific agencies;* and
d. *NARA should consider, on a case by case basis, accessioning non-federal records essential to documenting federal support of science.*

[75]The records to be saved for high-energy physics, heavy-ion physics, and nuclear physics will be found under particle and nuclear physics (Recommendations #12.f. and #13.f.).

Explanation:

2.a. ***NARA should solicit increased input from subject matter experts so that it can make more informed decisions on records appraisal.***

Although the National Archives has responsibility for the final appraisal of federal records, we are heartened that it has become increasingly aware of the importance of obtaining input from subject matter experts when appraising records of science and technology. Our particular concern is for the policy and planning records as well as the R&D records themselves. In these cases, it is urgent that the appraisal process be initiated with those who best understand the value of the documentation—the onsite records creator-scientists. Specifically, NARA should seek out subject matter specialists for the review of R&D records schedules of scientific agencies; it should also encourage records officers at science agencies to include subject matter specialists in the assessment of the importance of particular research projects; other opportunities for including subject matter specialists should be pursued.

2.b. ***NARA should work with agencies to monitor and promote agency records management practices to insure that legal regulatory responsibilities are met, including the identification and maintenance of records of permanent value.***

NARA holds to its traditional position of discouraging the placement of professional archivists at external agencies. In its experience, the placement of an agency archivist equates directly to the assembly of an institutional archives rather than conformance to the legal requirement to transfer federal records to the National Archives. For this reason, when these recommendations discuss federal records we refer to "records advocates" (i.e., someone who can argue on behalf of the historical value of records) rather than "archivists."

Accountability should be the cornerstone of a records management program. While we propose some ways to improve existing agency records schedules (see, e.g., our Recommendation #2.c., below), the most serious problems we see are the failures to implement records programs by the agencies themselves. All too often, those responsible for records programs are ill-informed about their own institution and its science and technology, and passive about gathering records and about suggesting to NARA the additions or adjustments to their records schedules needed to protect valuable records series. Typically, scientists, administrators, and other staff at the agencies are uninformed about record-keeping programs. Consequently, it is critical that NARA work with agencies to monitor and promote agency records management practices. They should see to it that the responsibility for records management has been clearly assigned and defined and that staff are appropriately trained and experienced.

Records officers must be grounded in records management principles and should be expected to serve as "records advocates." Competencies for records advocates would include skills in dealing with non-current records and archival, historical, or records management training and experience. The National Archives has seen that records advocates have been effective at such scientific settings as some of the accelerator laboratories of the Department of Energy; these have offered the National Archives a far better selection of records. The selection is better because a proactive program is in place to review records at the place where they are created—consulting those who created them—for the purpose of providing adequate documentation of the entire facility. The records advocates we have worked with most closely have been professional archivists, but trained historians or records managers skilled in dealing with noncurrent records could work equally well as part of a records management team. Records advocates should be expected to be knowledgeable about the scientific institution and the research programs it carries out. They should argue for the historical value of records in the context of agency records schedules and help NARA understand the unique records creation process at each of the science agencies. For all these reasons, we recommend that records advocates (e.g., trained archivists, historians, or records managers skilled in noncurrent records) should be made part of the records management programs—both at agency headquarters and at the key facilities and laboratories.

2.c. ***NARA should identify and promote Best Practices for records management programs that agencies should utilize, including the development of R&D records criteria. The R&D records schedule of the DOE (Department of Energy) could serve as a model for other scientific agencies.***

As part of a program to monitor records management practices at federal science agencies, NARA should consider conducting a survey of science agencies about their basic records management practices to determine the kinds of infrastructure now in place. This—along with our suggestions for implementation and for training and use of "records advocates" in Recommendation #2.b., above—should help NARA identify Best Practices for agency records management programs. A set of Best Practices is sorely needed and should be widely promulgated through the World Wide Web, other publication vehicles, and discussions at sessions of professional meetings of records managers.

For science agencies, it is critical that NARA develop Best Practices for developing criteria for the appraisal of R&D records, including procedures for ranking the importance of specific scientific research projects. After NARA rescinded the part of its General Records Schedule covering research and development records, it became necessary for each science agency to schedule these records according to the unique practices of their individual agencies. A number of federal science agencies have already done so. Among these, DOE (Department of Energy), NASA (National Aeronautics and Space Administration), NIST (National Institute of Standards and Technology), and NOAA (National Oceanic and Atmospheric Administration) have gone further to include sets of criteria that help their agencies identify significant R&D records. We believe all federal science agencies should include such sets of criteria in their records schedules. The schedules of the DOE, NIST, and NOAA could serve as models.

The new DOE Research and Development Records Retention Schedule, approved in August 1998 by NARA, is by far the best schedule we have studied. We are particularly impressed with its guidelines for procedures to rank scientific research projects as "significant," "important," and "other" and to involve the science records creators in this ranking. We also want to point out the importance placed on the proper evaluation of scientific policy and planning records in the DOE records schedule.

Our main purpose in this recommendation is to ask NARA to include the development of criteria for the appraisal of R&D records in its Best Practices. In addition, because National Archives appraisal archivists play a key role in developing agency records schedules, we ask NARA to urge them to encourage their assigned science agencies to have sets of criteria that provide effective procedures for identifying significant research and development records for permanent retention. This may require additional resources for the National Archives' Life Cycle Management Division.

2.d. ***NARA should consider, on a case by case basis, accessioning non-federal records essential to documenting federal support of science.***

Many important federally funded research organizations do not legally produce federal records, yet some of the records they produce provide valuable evidence of the government's support of science. Accordingly, we ask NARA to consider—on a case by case basis—serving as a repository of last resort for selected records of organizations not formally affiliated with the federal government that have no appropriate repository for their records. Prime examples are contractor institutions that oversee FFRDCs (Federally Funded Research and Development Centers) and free-standing research institutions.

See also Recommendation #6.b. to academic archives and #8 to NSF National Observatories.

CATEGORY THREE—FEDERAL SCIENCE AGENCIES

***Recommendation* #3:**

a. *Federal agencies responsible for negotiating overhead rates to universities should support a marginal increase to provide the modest additional support academic archives need to document collaborative and other federally funded research. The OMB should specifically include archives costs as allowable costs;*

b. *Federal science agencies should recognize the needs and benefits of providing adequate support for their agency records management program;*

c. *Federal science agencies should employ records advocates as part of their records management staff;*

d. *Federal science agencies' records management programs should increase educational programs within the agency in order to stress the importance and benefits of records management and the criteria for saving scientific records;*

e. *Federal science agencies should save records documenting interagency funding of collaborative research projects*;

f. *Federal science agencies whose research centers/laboratories are operated under contract should permanently secure their headquarters' records relating to the contractor organizations*;

g. *Federal science agencies should permanently secure proposals and other documentation related to major research facilities at their centers/laboratories and other sites*; and

h. *Federal science agencies should save controversial—albeit unsuccessful —collaborative research proposals in addition to successful ones.*

<u>Explanation</u>:

The two most important of these recommendations are #3.a. and #3.b. If science agencies adopted only these two recommendations, success in documenting significant scientific research in general, and multi-institutional collaborations in particular, would undergo a spectacular increase. For further information, see Part C, Section One: Current Archival Practices, II (Academic Archives) and III (Federal Agencies).

3.a. ***Federal agencies responsible for negotiating overhead rates to universities should support a marginal increase to provide the modest additional support academic archives need to document collaborative and other federally funded research. The OMB should specifically include archives costs as allowable costs.***

By now, readers of this report are aware that—in addition to the federal science agencies—it is the academic sector that must bear the burden of documenting multi-institutional collaborations. Over the decades federal science agencies have supported PIs (principal investigators) and research groups in academia far more than in any other sector. Each grant (or contract or cooperative agreement) has included overhead to support costs incurred by the university. No one seems to have considered the costs accrued by archives at these universities for preserving the records of significant scientific research made possible by federal funds.

Two stipulations of the OMB apply to the establishment of overhead rates: (1) universities will negotiate their overhead rates (known as facilities and administration [F&A] rates) from the Department of Health and Human Services (HHS) or the Department of Defense's Office of Naval Research (DOD) and (2) information on funding shall be derived from relevant data gathered by the National Science Foundation (NSF). Further, the principles for determining the appropriateness of costs that can be included in an F&A rate agreement are found in OMB Circular A-21, "Cost Principles for Educational Institutions." One of these allowable costs is library costs.

The fact that library costs are allowable by the OMB is unlikely to provide adequate coverage for costs for archives which, for one thing, may or may not be included within the library organizational structure. The relevant agencies (HHS, DOD, and NSF) should recognize the need for the support of academic archives and realize that an extremely modest increase in overhead rates (dedicated to support of the university archives) would make it possible for academic archives to secure the records that will be needed by science policy makers and administrators, by historians and other scholars, and by the public at large. The OMB should be urged by universities and the relevant agencies to add costs of archives to its list of costs that can be included appropriately in an F&A rate agreement.

3.b. ***Federal science agencies should recognize the needs and benefits of providing adequate support for their agency records management program.***

At our October 1999 meeting with current agency records officers and staff of the National Archives, AIP project staff were taken aback by the meager resources made available to in-house records management programs. We ask federal science agencies to recognize that, with the exception of the Department of Energy, their own agency records management programs lack the resources to meet even the legally required standards of securing adequate documentation of their programs and activities. Without professional records management programs, agencies cannot meet training goals or enjoy the efficiencies of proper records-keeping—to say nothing of halting the loss of records needed for administrators and future historians. With appropriate levels of support, agency records management programs can efficiently carry out the remainder of our recommendations.

3.c. ***Federal science agencies should employ records advocates as part of their records management staff.***

Each science agency should examine the effectiveness of its existing records management program and seriously consider the benefits of adding records advocates—e.g., trained archivists, historians, or records managers skilled in noncurrent records—to its staff, both at headquarters and at major laboratories, flight centers, etc. that carry out national scientific programs. Such advocates should be expected to work proactively with scientists and administrators to become knowledgeable about their organization and the science and technology it is dedicated to.

See Recommendation #2.b. for additional arguments.

3.d. ***Federal science agencies' records management programs should increase educational programs within the agency in order to stress the importance and benefits of records management and the criteria for saving scientific records.***

During our interviews with agency scientists and administrators, it became clear that many individuals creating important science policy records or scientific research records were unaware of the records-keeping program of their agency. This was the case in varying degrees at each of the agencies involved in our selected projects throughout our long-term study: DOD (Department of Defense), DOE (Department of Energy), NASA (National Aeronautics and Space Administration), NIH (National Institutes of Health), NOAA (National Oceanic and Atmospheric Administration), NSF (National Science Foundation), and USGS (United States Geological Survey). We also found that some records management staff were not as knowledgeable as they should be about their program. Education programs need to target both records creators and records managers. Records managers should be able to work with the scientists to assist them in following records retention policies to document their projects; this joint effort would greatly increase the survival of significant records. Agency records management staff should take advantage of workshops offered by the National Archives. They should, in turn, be expected to offer workshops for their agency employees, both at headquarters and in the field. One very effective means is to hold periodic workshops for secretaries and other files administrators (including those responsible for maintaining central files) so that they understand agency records schedules and are knowledgeable about identifying which records should be destroyed, which saved, and how and why.

3.e. ***Federal science agencies should save records documenting interagency funding of collaborative research projects.***

Individual federal agencies are usually the sole funder of collaborative research projects. In the instances where their funding responsibilities are shared with other agencies, the agency that takes the lead role should preserve on a permanent basis its records of interagency meetings, correspondence, agreements, and so forth.

3.f. ***Federal science agencies whose research centers/laboratories are operated under contract should permanently secure their headquarters' records relating to the contractor organizations.***

In some important instances, federal agencies (notably DOE and NSF) do not operate their research centers/sites directly but rather through contracting organizations. Some contractors are universities, corporations, or other longstanding institutions; other contractors are set up for the very purpose of operating FFRDCs (Federally Funded Research and Development Centers). Examples of the latter category are AUI (Associated Universities, Inc.), AURA (Association of Universities for Research in Astronomy, Inc.), and URA (University Research Association, Inc.). The role exercised by these contractor organizations over the research directions and policies of their centers/laboratories is considerable and, therefore, the importance of documenting their activities is clear. Records at the relevant agency headquarters would include correspondence between the agency and contractor, minutes of contractor board meetings, annual fiscal and progress reports, and copies of committee reports—with names like Users Committee and Visiting Committee—of the centers/laboratories under contract.

3.g. ***Federal science agencies should permanently secure proposals and other documentation related to major research facilities at their centers/laboratories and other sites*.**
When laboratories request support for new, large research facilities (such as accelerators, particle "factories," telescopes, reactors, and supercomputers) and for other major instrumentation, federal agencies should permanently secure the proposals (whether accepted or rejected) along with relevant correspondence. Files for successful facility proposals should also include financial and narrative progress reports, final reports, records of agency site visits, correspondence with site officials, and any other materials that provide valuable documentation.

N.B.: This recommendation pertains to proposals from centers/laboratories/observatories for building major research facilities; recommendation #3.h. pertains to proposals for experimental research projects.

3.h. ***Federal science agencies should save controversial—albeit unsuccessful—collaborative research proposals in addition to successful ones***.
Federal funding agencies are currently required to save records on successful research proposals (contracts, cooperative agreements). We recommend that—for multi-institutional research collaborations—the agencies also preserve the records for the (relatively few) unsuccessful proposals that stimulate significant debates or controversies. The files typically would include proposals, referee reports, minutes of panel meetings, and—in some cases—records of agency site visits.

N.B.: This recommendation pertains to proposals for collaborative research projects; recommendation #3.g. pertains to proposals from laboratories for building major research facilities.

CATEGORY FOUR—SPECIFIC AGENCIES

Department of Energy (DOE)

Recommendation #4*: *DOE should be commended for its new R&D records schedule; it should make certain the implementation of the schedule is fully supported.
Explanation:
The DOE and its records management staff, as well as the NARA liaison archivist, deserve congratulations on the development of its excellent, new records retention schedule for research

and development records—no modest task. We now ask DOE to provide the fiscal and moral support needed for the implementation of this important schedule.

We believe that the DOE's new R&D records schedule supports these AIP Project Recommendations as well as our Appraisal Guidelines (see Part B, Section Three). We ask that the DOE records officer contact us to discuss any discrepancies.

See also Recommendation #2.c. to NARA and #3.b. and 3.d. to Federal Agencies, above.

National Aeronautics and Space Administration (NASA)
***Recommendation #5: NASA needs to upgrade coverage and to clarify some confusing generalities in its records schedules*.**
Explanation:
NASA's recent records schedules are a great improvement. We note, however, that some generalities are confusing and, more important, some categories of records needed to document collaborative research in space science are not covered.

The NASA records schedules are written in a very general manner in order for the manual to be applicable to both NASA Headquarters and its flight centers. Only records of the upper level management offices at headquarters are specified with the mid-level headquarters scientists being fit into other functional locations. For example, the term "program" and the term "project" are interchangeable in these schedules, even though in NASA parlance program scientist and program manager are Headquarters positions, and project scientists and project managers are at flight centers.

NASA's records schedules do not provide for retention of some records deemed valuable by the AIP Study. Important examples are the records of the advisory groups of discipline scientists at NASA Headquarters (where ideas for most NASA projects are initiated) and records of the Science Working Group for projects at flight centers which provide the most important documentation of the scientific aspects of the mission.

National Science Foundation (NSF)
Recommendation #6: The NSF should include archival arrangements in the requirements for cooperative agreements to support its research facilities and its centers, as well as other management offices of collaborations.
Explanation:
These NSF-supported research facilities (e.g., National Observatories) and centers (both its Materials Research Science and Engineering Centers [MRSECs] and its Science and Technology Centers [STCs]) do not create federal records. Neither do science management/consortium headquarters offices or freestanding research institutions set up to administer NSF-funded collaborations. Special arrangements should be made to permanently secure the essential documentation of their research programs. Specifically, NSF should fully fund the archival programs at its national facilities and provide fiscal and moral support for proper maintenance of records at its centers and at the collaboration offices and freestanding research institutions it funds.

NSF Facilities. The NSF supports—through contractor organizations—some of the most important laboratories (e.g., Scripps Institution of Oceanography) and observatories (e.g., National Radio Astronomical Observatory) in the country. Because of their long-standing importance and because they lack affiliations with established archival repositories, we are especially concerned about the NSF National Observatories. To our knowledge these observatories lack strong records management programs. The NSF should provide the fiscal support for them to initiate archival programs to permanently secure at least their most important documentation.

NSF Centers. MRSECs and STCs are relatively new and rapidly growing phenomena at academic settings. NSF funds its centers for a period of years to function as multi-institutional collaborations and foster research in particular areas of materials science or science and technology. Although the centers are at academic settings, academic archivists will need to be persuaded to consider the documentation of NSF centers to be part of their responsibility. The fact that the NSF centers are impermanent institutions presents another danger to the records.

Science Management/Consortium Headquarters Offices Within Academic Settings. In NSF-funded collaborations that have no connection with any NSF center, one principal investigator applies for a grant enabling the collaboration to set up an office for administering the project. For the most part, these offices are within a department of a college or university; when this is the case, the most appropriate repository for the project's core records would be that institution's archives.

Freestanding Research Institutions. In some other cases, NSF grants to collaborations result in the setting up of freestanding institutions to administer their research programs. Records of such institutions have no appropriate repository; they are far more likely to find an adequate repository if they are maintained in orderly condition with adequate finding aids to facilitate research.

NSF should stipulate appropriate arrangements for records in its cooperative agreements/ contracts. A very small fraction of the amount awarded to the facilities, offices, and freestanding institutions would pay for the proper organization of records permitting greater efficiencies of operations as well as the archival maintenance or orderly transfer of records. Special NSF funding may not be required to secure the small set of core archival records of NSF centers.

See also Recommendations #7.b. to Academic Institutions and #8 to Nonacademic Research Laboratories, below.

CATEGORY FIVE—OTHER INSTITUTIONAL SETTINGS

Academic Institutions

***Recommendation* #7:**

a. *Professional files of collaboration principal investigators and other key academic scientists should be retained by their home institutions according to their individual careers;*

b. *Academic archives should enlarge as necessary the scope of collecting policies in order to accession non-federal records of NSF centers as well as science management offices and consortium headquarters offices within their institutions; and*

c. *Universities with strong science programs should request modest increases in their overhead rates to support their archives.*

Explanation:

7.a. ***Professional files of collaboration principal investigators and other key academic scientists should be retained by their home institutions according to their individual careers.***

The professional papers of PIs (principal investigators) are a prime location for information concerning the development of an experiment or an experiment team. A substantial fraction of the principal investigators in the collaborations we studied are employed by academia. The papers of those who have regularly led or participated in important collaborative research are well worth saving. In other cases, collaboration-related records kept by a faculty member should be accessioned (whether or not the balance of the individual's papers are), especially if the collaboration was deemed significant.

N.B.: This is a rewording of Recommendation #1, above. Our point here is to emphasize the essential role academic archives play in documenting collaborative research by preserving the papers of individual scientists who played leadership roles in the projects.

7.b. ***Academic archives should enlarge as necessary the scope of collecting policies in order to accession non-federal records of NSF centers as well as science management offices and consortium headquarters offices within their institutions***.

The NSF centers (both its Materials Research Science and Engineering Centers and its Science and Technology Centers) are funded for a period of years; although renewals are possible, they are not permanent. The NSF centers are organized to function as multi-institutional collaborations; most, if not all, make the final decisions on which researchers at member institutions get funded. We also found, in our study of geophysics, that science management offices and consortium headquarters offices last the lifetimes of the collaborative projects, which may be quite short. Most of these offices are NSF-funded and, as such, do not produce federal records.

The academic institutions within which these collaborations operate should hold themselves responsible for accessioning core records of the centers or management offices. If such arrangements are not possible, the records should be offered as a gift to the Archivist of the United States and the National Archives and Records Administration.

See also Recommendation #2.d. to NARA and #6 to NSF, above.

7.c. ***Universities with strong science programs should request modest increases in their overhead rates to support their archives.***

It has been noted more than once in our report that the academic sector must bear a major share of the burden of documenting multi-institutional collaborations. Additional support for university archives is essential to document significant collaborative and other federally funded research.

Academic archivists should bring these facts to the attention of their universities when it is time to renew contracts for overhead rates.

Universities negotiate overhead rates with specific federal agencies, but OMB guidelines must be followed. Currently library costs are allowable by the OMB but archives costs are not mentioned. Universities should urge the OMB to add costs of archives to its list of costs that can be included appropriately in an overhead rate agreement.

For details, see Recommendation #3.a. to Federal Science Agencies, above.

Nonacademic Research Laboratories

Recommendation #8: Nonacademic research laboratories (government, FFRDCs, corporate, and free-standing institutions) lacking programs to identify and permanently secure records of historical value should initiate them

Explanation:

The nonacademic laboratories in our study have included all major categories of research laboratories, primarily those in the U.S., but also some major laboratories abroad. Almost without exception, these laboratories—however important their contributions to postwar science may be—lack programs to protect their valuable records. All too many even lack records management programs (the exception here are government laboratories and FFRDCs that produce federal records and are required to have records management programs).

Our experience shows it is possible to permanently preserve an adequate record of scientific research where laboratories have records advocates (i.e. archivists, historians, or records managers trained in noncurrent records) and impossible where laboratories lack them. Records advocates are needed to work with scientists to identify and permanently secure those records of interest to future scientist-administrators, historians, and other users. From our experience it seems clear that the chief responsibility for initiating these programs lies with the individual laboratory directors. Once programs are in place, records advocates develop relationships of trust and provide an array of invaluable services to laboratory staff and management. The records they preserve provide the best means to achieve the all-important institutional memory.

For laboratories in the U.S. that create federal records (government laboratories and those of the DOE), our concern is for appropriate historical evaluation of files on site so that records that provide essential evidence of long-term value will be offered to the National Archives. In other countries, some laboratories are required to transfer permanent records to state or national repositories.

Free-Standing Institutions

Recommendation #9: Freestanding but temporary American research institutions should offer historically valuable records to an appropriate repository at the end of a project.

Explanation:

In our study of geophysics we found a few cases where, rather than setting up consortium headquarters offices in academic settings, entirely new and freestanding—but temporary—institutions were created to manage a collaborative project. Although these institutions are federally funded, their records are not federal in ownership. Selected records of these consortia should be offered to an appropriate repository such as a participating university or state historical society.

See also Recommendations #2.d. to NARA, #6 to NSF, and #8 to Nonacademic Research Laboratories, above.

National Science Foundation Facilities
Recommendation #10: The NSF National Laboratories and Observatories that lack archival programs should initiate them.

Explanation:
As already stated, these NSF facilities consist of some of the most important laboratories and observatories in the country, if not the world. There is no doubt that future historians and other scholars will need to draw on their historically valuable records.

NSF National Laboratories and Observatories lacking archival programs should initiate them. (We recommend that NSF provide the fiscal support.) They should consider maintaining their collections of records on site. Where this is not feasible, the records of archival value may be offered to a nearby university or state historical society; they may also be offered to the National Archives because they provide important evidence of federal support of science.

See also Recommendations #2.d. to NARA and #6 to NSF.

RECOMMENDATIONS—WHAT TO SAVE

CATEGORY ONE—POLICY AND PLANNING RECORDS

Recommendation #11: Records of policy and planning boards in the U.S. and elsewhere relating to multi-institutional collaborations should be saved at appropriate repositories.
Explanation:
Every scientific discipline has international and national boards (unions, committees, etc.) that set priorities for research areas and guide support for major efforts; a good number of these decisions lead to the initiation and, at times, the oversight of multi-institutional and/or multi-national collaborations. Other policy bodies operate within scientific agencies and often have more impact on specific collaboration projects. Records of these policy groups are of great value to a wide variety of scholars and scientist-administrators.

Among the disciplines covered by the AIP Study, we found policy-making bodies that have had a direct influence on collaborations in the fields of geophysics and space science. Records of policy-making bodies effecting collaborative research in these fields are listed here. For descriptions of these records, see the Appraisal Guidelines, Part B, Section Three.

POLICY AND PLANNING RECORDS

a. ***Geophysics and Oceanography***

Records of the National Academy of Sciences' Ocean Studies Board, Polar Research Board, and Board on Atmospheric Science; also, records of the International Council for Scientific Unions and records of the World Meteorological Organization.

b. ***Space Science***
Records of the National Academy of Sciences' Space Studies Board and, at NASA Headquarters, minutes and other records of various working groups from those of its discipline scientists up to its Advisory Council. In Europe, records of ESA's Space Science Advisory Committee and its working groups and its Science Programme Committee. The records of the European Space Science Committee of the European Science Foundation are also of potential value.

CATEGORY TWO—CORE RECORDS BY SCIENTIFIC DISCIPLINE

***Recommendation #*12: *A core set of records should be saved at appropriate repositories to document multi-institutional collaborations*.**

Explanation:
There is a short list of records that, taken together, provide adequate documentation of most collaborative projects in a given discipline. Core records for collaborations in the disciplinary fields studied during the long-term AIP Study are listed here. For descriptions of these records, see the Appraisal Guidelines, Part B, Section Three.

CORE RECORDS

a. ***Geophysics and Oceanography***
There have been relatively few large, multi-institutional collaborations during our period of study and these should be considered to be significant. Additional records should be saved for all large collaborations over and above the core records described here (see Recommendation #13, below).

Core records to be saved for all collaborations: proposal files of federal funding agencies.

b. ***Ground-Based Astronomy—Observatory Builders***[76]
Each observatory-building collaboration is considered to be significant: few are built in any one decade and each is essentially unique. Additional records should be saved for all collaborations over and above the core records described here (see Recommendation #13, below).

Core records for observatory-building collaborations: NSF grant award jackets and/or NSF cooperative agreement jackets for research facilities; documents of incorporation.

[76]The AIP Study's four case studies of telescope-building collaborations did not include any collaborations involving national optical or radio telescopes. As a result, our recommendations in this category are based on previous experience of the AIP Center and input from our Working Group.

c. ***Ground-Based Astronomy—Observatory Users***[77]
Core records for observatory-using collaborations: proposals and related records in Time Allocation Committee files of radio and national optical observatories and, where relevant, records of observatory consortium chairpersons.

d. ***Materials Science***
Core records for materials science collaborations: proposals to federal funding agencies and/or to corporate management; where relevant, records of Executive (Program) Committees of NSF MRSECs and STCs; Memoranda of Understanding; and—for those using DOE accelerator facilities—records of Facility Advisory Committees at DOE National Laboratories.

e. ***Medical Physics***
Core records for medical physics collaborations: proposal jackets at private foundations and/or federal funding agencies and—for those using DOE accelerator facilities—records of DOE Facility Advisory Committees.

f. ***Particle and Nuclear Physics***
Core records for particle and nuclear physics collaborations: proposal files at DOE or NSF; at accelerator laboratories—records of laboratory directors responsible for areas of particle and nuclear physics as well as records of Physics Advisory Committees documenting the process of proposals for access to beamtime on accelerators and including contracts between the laboratory and the collaboration.

g. ***Space Science***
In the field of space science, all large projects/missions are considered significant. Additional records should be saved for large projects/missions over and above the core records described here (see Recommendation #13, below).

Core records for space science collaborations: records of the relevant discipline/program scientist and program manager, along with their respective advisory groups, at NASA Headquarters. Records of their counterparts at ESA Headquarters. (Also, at NASA, core documentation for development of instruments used in space science projects/missions is provided by grant proposal files of discipline scientists.)

CATEGORY THREE—SIGNIFICANT COLLABORATIONS

Recommendation #13: Fuller documentation should be saved for significant collaborations.

Explanation:
A wider array of substantial documentation should be preserved for highly important collaborations to meet the needs of scientist/administrators as well as historians and other

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[77]The AIP Study's four case studies of telescope-using collaborations did not include any collaborations conducting sky surveys or, indeed, any collaborations of optical telescope users. Accordingly, our recommendations in this category are based solely on the previous experience of the AIP Center and input from our Working Group.

scholars. The early identification of current experiments of outstanding significance should initiate actions to secure fuller documentation for subsequent appraisal (see Recommendation #14.b., below). This documentation would include those categories of records specified in the Appraisal Guidelines prepared by the AIP Study and other records found to contain valuable evidence of the collaboration's organizational structure and research process. Records to be saved for significant collaborations in the disciplinary fields studied during the long-term AIP Study are listed here. They are described in detail in the Appraisal Guidelines, Part B, Section Three.

N.B.: We make note that, for the largest and most controversial multi-institutional collaborations, significant documentation will also be found at higher administrative levels, such as offices of presidents and provosts of universities, top administrators at agencies and laboratories, and other key policy boards. We do not address recommendations to offices at such higher levels on the assumption that their records are already secured.

RECORDS TO BE SAVED FOR SIGNIFICANT COLLABORATIONS

a. ***Geophysics and Oceanography***

Additional records to be kept for all large collaborations: records of the consortium headquarters office or the project's science management office as follows. The consortium headquarters office records, including records of standing committees, records of the consortium's administrative head, and records of consortium staff scientists. The Science Management Office records, including records of the SMO administrator and records of the Science Working Group. Also—specifically for oceanographic projects—ships' logs should be retained.

b. ***Ground-Based Astronomy—Observatory Builders***[78]

Additional records to be kept for all observatory-building collaborations: Board of Directors' minutes of meetings; records of project managers; records of Science Advisory/Science Steering Committees; records of Design Review Panels; records of Science Project Teams; contracts and associated records; and technical reports.

c. ***Ground-Based Astronomy—Observatory Users*** [79]

Additional records to be kept for significant collaborations: papers of first authors of VLBI (Very Long Baseline Interferometry) collaborations and, where relevant, records of observatory consortium secretaries.

d. ***Materials Science***

Additional records to be kept for significant collaborations: records of Executive Boards (or Governing Boards, Program Committees, or Technical Representatives Committees); records of External Advisory Committees; records of annual meetings of the collaborations; records of spokespersons/staff directors; and newsletters and sector descriptions.

e. ***Medical Physics***

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[78]See footnote 77.

[79]See footnote 78.

Additional records to be kept for significant collaborations: minutes of collaboration meetings; records of group leaders for statistical analysis; and protocols and samples of data collaboration forms.

f. ***Particle and Nuclear Physics***

Additional records to be kept for significant collaborations: records of spokespersons, including intra-collaboration mailings; records of group leaders—including, in selected cases—proposals submitted as PI (principal investigator); records of project managers and project engineers; Intra-Collaboration Technical Committee records; Accelerator or Research Division files on experiments; and selected technical records (e.g., logbooks and blueprints and specifications).

g. ***Space Science***

Additional records to be kept for all large projects/missions are: records of project managers; records of project scientists, along with the Science Working Groups; also, records of instrument managers, where the position exists (all at NASA flight centers); and—in selected cases—records of PIs of project experiments (instruments).

Additional records for space science in Europe would include records at ESTEC (ESA's flight center): records of the project managers and project scientists, along with the Science Working Groups; also, the records of payload specialists.

RECOMMENDATIONS—HOW TO SAVE

***Recommendation* #14:**

a. Scientists and others should take special care to identify past collaborations that have made significant contributions and

b. Research laboratories and other centers should set up a mechanism to secure records of future significant experiments.

<u>Explanation</u>:

14.a. ***Scientists and others should take special care to identify past collaborations that have made significant contributions***.

Future scholars, as well as science administrators and policy makers, will need considerably more documentation in order to study in more detail those multi-institutional scientific collaborations that can be considered most significant in their contributions to advances in scientific knowledge, including theory and experimental techniques.

There exist general guidelines for identifying significant research projects. The best we have found thus far are in the 1998 DOE Research and Development Records Retention Schedule.[80] Other parameters for identifying significant projects can obviously be made to meet the needs of particular research laboratories, say in the corporate sector, or by disciplines outside those covered by DOE research.

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[80]See the Department of Energy's Web site (http://www-it.hr.doe.gov/records/) for this schedule; of particular interest is the Introduction which includes a review of the guidelines and an R&D evaluation checklist. See also Recommendation #2.c. to the National Archives, above.

Our first concern must be the identification of past collaborative research projects, since the documentation becomes endangered as soon as the project has ended and scientists turn their attention to other matters. The participation of all knowledgeable parties is needed:
(1) **Individual scientists** could bring the contributions of a research project they consider to be significant to the attention of their research director, institutional archivist, etc.;
(2) **Academic departments or research laboratories** could set up an *ad hoc* history committee from time to time to identify their most significant research projects and bring them to the attention of their provost, archival program, etc.;
(3) **Policy and planning bodies**, such as DOE's High Energy Physics Advisory Panel, could compile lists of most significant research collaborations and broadcast them to their disciplines; and
(4) **History committees of AIP Member Societies** could either compile lists or survey their members for nominations and then broadcast the lists to their members.

The AIP Center for History of Physics will also contribute to the identification of recent significant research collaborations by working proactively with Boards of the National Academy of Sciences and other policy and planning bodies.

14.b. ***Research laboratories and other research centers should set up a mechanism to secure records of future significant experiments***.

The scientists and research directors—at laboratories/observatories and other research centers/sites—are best informed to identify those experiments/projects that are likely to be considered significant by future judgements. We are aware that efforts to document events from earlier decades will be frustrated by the frailties of records-keeping practices. Therefore, we urge the laboratories themselves to identify as early as possible experiments/projects of potential significance. While doing so, the research directors should bear in mind the recent emergence of subcontractors for major research and development collaborations and identify experiments/projects in which significant subcontracts should be documented—either by the laboratory, the subcontractor, or a combination of both.

Laboratories and other research centers can easily reduce the complexity of locating the additional records needed to document the more significant experiments by setting up a mechanism to identify and secure records during or prior to their creation. Once a proposal for an experiment/project is approved, the relevant administrator at the research site should require a collaboration to include in their next write-up a statement as to: (1) which individual collaboration member should be responsible for collaboration-wide records and (2) which, if any, records on the team level should be retained on a long-term basis because of scientific significance.[81] A collaboration's chief scientist knows at the outset when a particular component of the instrument

[81]Ideally, the relevant administrator would be located at a national laboratory, flight center, or other central research site where the project was conducted. In some cases—e.g., NSF centers and the Deep Sea Drilling Program—it would be the site where the project was approved for funding. Unfortunately, fields like VLBI (Very Long Baseline Interferometry) observations and medical physics lack a central site; the most relevant administrator would be the program officer at the funding agency.

or technique is revolutionary or innovative; appropriate identification and assignment of records responsibilities for these should be included. When assigning responsibility for collaboration-wide records to an individual, the chief scientist should select a collaboration member at a permanent institution; in many cases, this will be an academic institution or the research site itself. A collaboration's statement about records-keeping responsibilities should be incorporated in its MOU (Memorandum of Understanding) or other contractual agreement with the research center.

The purpose of this recommendation is to secure the records that may be needed to document significant experiments. Later, when an experiment has been identified as significant, archivists will be in an excellent position to contact the individuals assigned responsibility for the records and make arrangements to permanently preserve those of enduring value.

The laboratories and research directors should also consider employing technologies on behalf of collaborations that would assist in the capture, retention, and access to valuable evidence. For example, the research sites could offer to retain certain files, such as collaboration e-mail, Web sites, and other relevant electronic records, on their computer systems.

***Recommendation* #15: *Institutional archives should share information on their relevant holdings with each other and with AIP/RLIN*.**

Explanation:

Knowledge of institutional records and professional papers of individuals is essential to foster use by historians and other scholars. For example, papers documenting a particular experiment/project are likely to be physically located in various repositories; shared catalogs will bring them together intellectually for the user. Archivists should include sufficient facts—such as laboratory name and experiment/project number or title—to identify the collaboration documented in their collections when they prepare inventories, scope and content notes (or any other descriptions), and indexes.

One means for archivists to broadcast information on their holdings is to send descriptions of collections or records series to the AIP where they will be added to the International Catalog of Sources for History of Physics and Allied Sciences, maintained by the AIP Center for History of Physics (http://www.aip.org/history/icos.htm). In cases where the archives itself does not report its holdings to the American database RLIN-AMC (the Research Libraries Information Network-Archives and Manuscript Control) of the Research Libraries Group, the AIP can provide this service.

THE ROLE OF THE AIP CENTER

The AIP Center can play a facilitating role in a number of these recommendations. It can work with laboratories and other research institutes by: (1) providing advice to those that decide to establish or upgrade archival programs, (2) aiding in the process of identifying significant experiments, and (3) assisting laboratory advisory committees in such areas as identifying appropriate repositories for papers and records documenting significant experiments. The AIP Center will continue its work with corporate, academic, and other institutional archivists to preserve significant papers and records and to provide advice on records appraisal. In addition to its International Catalog of Sources (http://www.aip.org/history/icos.htm), the Center offers, upon request, such cataloging tools as topical indexing terms and authorized names of thousands of individuals and institutions.

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DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

APPENDICES

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

APPENDIX A: BIBLIOGRAPHY OF SELECTED READINGS

BIBLIOGRAPHY OF SELECTED READINGS

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THE AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS: FINAL REPORT

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

APPENDIX B: ACRONYMS AND GLOSSARY

ACRONYMS AND GLOSSARY

ACR: American College of Radiology.

ALS: Advanced Light Source, a synchrotron-radiation accelerator at Lawrence Berkeley Laboratory. Also our abbreviation for a collaboration (one of the AIP case study projects) that built a beamline for materials-science research at the accelerator.

AMPTE: Active Magnetospheric Particle Tracer Experiment, one of the AIP case study projects.

AO: Announcement of Opportunity, a statement from a funding agency announcing that scientists are welcome to propose experiments or projects. The AO often describes the engineering conditions that proposing scientists should meet.

APL: The Applied Physics Laboratory of Johns Hopkins University.

APS: Advanced Photon Source, a synchrotron-radiation accelerator at Argonne National Laboratory.

ARC: Astrophysical Research Consortium, one of the AIP case study projects.

AURA: Association of Universities for Research in Astronomy.

BIMA: Berkeley-Illinois-Maryland Array, one of the AIP case study projects.

BNL: Brookhaven National Laboratory.

CERN: Centre Européenne pour la Recherce Nucléaire.

CESR: Cornell Electron Storage Rings, a colliding-beam accelerator used principally for particle physics.

Chief scientist (geophysics): The administrator who oversees the day-to-day operations of a project organized as a consortium.

Co-chief scientists (geophysics): The scientists responsible for overseeing data acquisition on an oceanographic research vessel. The term is also appropriate for the leaders of *ad hoc* research teams that form to use instrumentation provided by a consortium.

COCORP: Consortium for Continental Reflection Profiling, one of the AIP case study projects.

Colliding-beam experiment (particle physics): An experiment in which two beams traveling in opposite directions are made to collide; the detector components are concentrically nested around the collision point.

Component (particle physics): An instrument (with accompanying operations and data acquisition software) that a group contributes to a collaboration's detector.

Consortium: The term customarily applied to a collaboration that expects to operate formally and for a long period of time. Consortia usually are legally incorporated.

CPIMA: Center on Polymer Interface and Macromolecular Assembly, one of the AIP case study projects.

CRPC: Center for Research in Parallel Computation, one of the AIP case study projects.

DARPA: Defense Advanced Research Projects Administration.

Detector (particle physics): A combination of components (with their accompanying operations and data acquisition software) that together enable a collaboration to characterize the events and processes occurring in a particle physics experiment.

Discipline scientist: A scientist employed by NASA Headquarters to administer a program of research and development grants for a disciplinary community and to help develop ideas for space science projects of interest to that community.

DND-CAT: DuPont-Northwestern-Dow Collaborative Access Team, one of the AIP case study projects. CAT is Argonne National Laboratory's term for a collaboration that builds a beamline to use a synchrotron radiation accelerator (see also PRT).

DOE: Department of Energy.

DSDP: Deep Sea Drilling Project, one of the AIP case study projects.

Elementary particle physics: NSF's preferred term for high-energy physics.

ESA: European Space Agency.

ESTEC: European Space Research and Technology Centre, the lone ESA space flight center.

Experiment (geophysics): *Either* the activities of a PI and team members to develop a measuring technique, use the technique to acquire data in a multi-institutional project, and analyze the data for publication; *or* the activities of a research team that uses a consortium's instrumentation to acquire and process data on which individual members hope to publish papers.

Experiment (space science): The design, construction and operation of a scientific instrument—generally consisting of sensor(s) plus electronics for signal amplification and software for instrument operation—that is flown on a spacecraft; plus processing, interpreting, and disseminating the data that are telemetered back.

Explorer: A class of NASA projects funded in series from an established line-item in the NASA budget for smaller scientific missions. Explorer projects are not directly scrutinized by Congress or the Office of Management and Budget.

Fixed-target experiment (particle physics): An experiment in which accelerated particles are smashed into a stationary target; and the detector components are linearly arrayed around the target.

FNAL: Fermi National Accelerator Laboratory.

GC3: Grand Challenge Cosmology Consortium, one of the AIP case study projects.

GISP: Greenland Ice Sheet Project, one of the AIP case study projects.

Group leader (particle physics): A scientist responsible for an institution's contribution to an experiment.

GSFC: Goddard Space Flight Center.

HEAO: High-Energy Astrophysical Observatory, a NASA program to launch satellites that studied cosmic sources of high-energy particles and radiation. The Einstein Observatory, one of the AIP case study projects, was part of the HEAO program.

HEP: High-energy physics, DOE's preferred term for elementary particle physics.

HFBR: High-flux beam reactor, a nuclear reactor operated to generate beams of neutrons for research.

HET: Hobby-Eberly Telescope, one of the AIP case study projects.

HOIS: Hybrid Organic/Inorganic Semiconductors, one of the AIP case study projects.

ICSU: International Council of Scientific Unions, a union of the national academies or other appropriate scientific institution of member nations.

Inter-disciplinary scientist (space science): A scientist who, by designation of NASA Headquarters, serves on a project's Science Working Group and performs multi-experiment data analyses, but does not contribute an experiment.

IRIS: Incorporated Research Institutes of Seismology, one of the AIP case study projects.

ISCCP: International Satellite Cloud Climatology Program, one of the AIP case study projects.

ISEE: International Sun-Earth Explorer, one of the AIP case study projects.

IUE: International Ultraviolet Explorer, one of the AIP case study projects.

JOI: Joint Oceanographic Institutes, a formally incorporated consortium of oceanographic institutions. JOI contracts with the NSF to manage the Ocean Drilling Program and subcontracts most responsibilities to the ODP project office at Texas A&M Research Foundation.

JOIDES: Joint Oceanographic Institutes for Deep Earth Sampling, an unincorporated consortium that started with four American oceanographic institutes and has expanded both domestically and internationally. JOIDES panels have set the scientific agenda for the Deep Sea Drilling Project and the Ocean Drilling Program. JOIDES's headquarters moves regularly among member institutions and currently is in Cardiff, England.

JPL: The Jet Propulsion Laboratory.

KAI: Knowledge and Distributed Intelligence, a "crosscutting" NSF program to stimulate the use of recent advances for computer networking in scientific research.

LBL: Lawrence Berkeley Laboratory.

MOU: Memorandum (or memoranda) of Understanding.

MRSEC: Materials Research Science and Engineering Center, a collaboration or single-institution research center funded through a program within NSF's Materials Research Division.

MSFC: Marshall Space Flight Center, a NASA space flight center.

NAS: National Academy of Sciences.

NASA: National Aeronautics and Space Administration.

NCSA: National Center for Supercomputer Applications, at the University of Illinois, Urbana-Champaign.

NDMDG: National Digital Mammography Development Group, one of the AIP case study projects.

NIST: National Institute of Standards and Technology.

NOAA: National Oceanic and Atmospheric Administration.

NSF: National Science Foundation.

NSLS: National Synchrotron Light Source, a synchrotron-radiation accelerator at Brookhaven National Laboratory.

NSSDC: National Space Science Data Center.

ODP: Ocean Drilling Program, the continuation, under international auspices, of the Deep Sea Drilling Project.

ONR: Office of Naval Research.

OSSA: Office of Space Science and Applications, the division of NASA that supports space science projects.

PAC: Physics or Program Advisory Committee, a committee that advises an accelerator laboratory's director on the allocation of space and beamtime for proposed experiments.

Parkfield: A rural site on the San Andreas Fault and the shorthand name for the Parkfield Earthquake Prediction Experiment, one of the AIP case study projects.

PC: Positron Consortium and Participating Research Team, one of the AIP case study projects.

PI: principal investigator, the scientist accountable for an institution's expenditure of externally contributed funds. The PI is usually the intellectual force behind the funded activity and manages the efforts of an institution's staff to carry out the activity.

PICO: Polar Ice Coring Office, an NSF contract institute to develop and deploy ice drills for scientific use. The PICO contract is currently with the University of Alaska, Fairbanks.

Program manager: An official who manages a funding agency's program of grants and contracts for research and development. In NASA, program managers are engineers and oversee the project managers at the space flight centers responsible for building the projects. In other agencies that fund science, program managers are typically scientists.

Program scientist: A scientist at NASA Headquarters who advises the program manager on scientific effects of managerial issues. The program scientist has often been the discipline scientist who helped form the project. Program scientists have influence over the selection of scientific instruments to fly on a project and represent the interests of a project's participating scientists to officials at Headquarters in the event that the participating scientists and engineers cannot resolve intra-project conflicts.

Project manager: An individual, often an engineer, who oversees a project's budget, schedule, and the interfaces among its constituent parts. In some fields, like space science, a collaboration routinely has a project manager, who is professionally autonomous from the scientists participating in the collaboration. In other fields, like particle physics, collaborations only occasionally have an individual who functions as a project manager; and when they do, the individual may not have that title and is not professionally autonomous from the scientists.

Project scientist (space science): A scientist, usually an employee of the space flight center managing the project and—in NASA—usually a PI for an experiment on the project, who advises the project manager on the engineering needs of the participating scientists. Project scientists also chair the meetings of the Science Working Group. Project scientists can appeal a project manager's decision to the program scientist. After the spacecraft is launched, project scientists control funds to support analyses of project data.

PRT: Participating Research Team, the BNL name for a collaboration that builds a beamline to use a synchrotron radiation accelerator (see also DND-CAT).

PSC: Pittsburgh Supercomputing Center.

RDOG: Radiology Diagnostic Oncology Group, one of the AIP case study projects.

RFP: Request for Proposals, a statement from a funding agency or research center to stimulate submission of proposals for the purpose of letting a contract.

SDSS: Sloan Digital Sky Survey, one of the major activities of the Astrophysical Research Consortium.

SMC: Smart Materials Consortium, one of the AIP case study projects.

SLAC: Stanford Linear Accelerator Center

SMO (geophysics): Science Management Office, the most common of the terms used for an office that takes responsibility for the logistics and other communal business for a project built around the common interests of independent PIs. One of the PIs in the project directs the SMO.

Space Flight Center: An institution, usually government-managed, for research and development into spacecraft designs and management of spacecraft construction. Space flight centers manage science projects and usually include research scientists on their staffs.

Spokesperson (particle physics): The scientist who represents a collaboration to the accelerator laboratory's administration. The term often connotes leadership and initiative in the creation of an experiment.

SSRL: Stanford Linear Accelerator Center Synchrotron Radiation Laboratory.

STC: Science and Technology Center, a type of collaboration funded by NSF's Office of Science and Technology Infrastructure to investigate topics of joint scientific and engineering interest.

STCS: NSF Science and Technology Center for Superconductivity, one of the AIP case study projects.

String (particle physics): A series of experiments performed with gradually evolving instrumentation and gradually evolving institutional and individual personnel.

Study Scientist (space science): Discipline scientists may hold the title “study scientist” during the planning stages of a mission.

SWG (space science and geophysics): Science Working Group; the group, consisting of PIs and others the PIs or funding agency consider appropriate, that sets the detailed science strategy for a project and discusses common or collective problems to the science of a project.

Team: In general, the organizational units that comprise collaborations. Collaborations frequently divide their tasks among their member institutions, which then each constitute a team. In collaborations where multi-institutional teams perform tasks, each task is usually the responsibility of a principal investigator whose institution leads the team. In geophysics, team is ambiguous. It can mean *either* the cluster of people (who can include postdocs, graduate students, engineers, technicians, and executives or employees of businesses producing scientific instrumentation) that work with a PI to perform an experiment; *or* the several researchers that together use a consortium’s instrumentation to acquire data.

3 mm VLBI: Three Millimeter Very Long Baseline Interferometry, one of the AIP case study projects.

UARC: Upper Atmosphere Research Collaboratory, one of the AIP case study projects.

UNESCO: United Nations Educational, Scientific and Cultural Organization.

USGS: United States Geological Survey.

VLBI: Used both for Very Long Baseline Interferometry, an astronomical observing technique, and for the Very Long Baseline Interferometry Consortium, one of the AIP case study projects.

WCR: Warm Core Rings, one of the AIP case study projects.

WCRP: World Climate Research Programme, an office jointly supported by WMO and ICSU for the coordination of international climatology projects.

WMO: World Meteorological Organization, a branch of UNESCO.

WOCE: World Ocean Circulation Experiment, one of the AIP case study projects.

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

APPENDIX C: PROJECT ACTIVITIES

PHASE I: HIGH-ENERGY PHYSICS

PHASE II: SPACE SCIENCE AND GEOPHYSICS

PHASE III: GROUND-BASED ASTRONOMY, MATERIALS SCIENCE, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

ATTACHMENT: *DECADE-LONG STUDY OF COLLABORATIONS COMPLETED*, BY JOAN WARNOW-BLEWETT

PROJECT ACTIVITIES

The first three of the following segments are reprinted from reports on project activities issued at the end of Phases I, II, and III of the AIP Center's long-term study of multi-institutional collaborations. (We do not include the appendixes that appeared in those reports, such as question sets used in interviews; these are available from the AIP Center.) The closing segment, covering the activities that remained at the end of the study, is reprinted from the Spring 2000 issue of the *AIP History Newsletter*.

PHASE I: HIGH-ENERGY PHYSICS

I. *INTRODUCTION: PURPOSE AND METHODOLOGY OF THE STUDY*

A. The AIP Long-Term Study of Collaborations.

Since World War II, the organizational framework for scientific research is increasingly the multi-institutional collaboration. However, this form of research has received only incidental attention from scholars. Without a dedicated effort to understand such collaborations, policy- makers and administrators will continue to have only hearsay and their own memories to guide their management; even the records necessary for efficient administration, for historical and management studies, and for posterity, will be largely scattered or destroyed.

The Center for History of Physics of the American Institute of Physics (AIP), in keeping with its mission to preserve and make known the record of modern physics, is working to redress this situation with a multi-stage investigation into areas of physics and allied sciences where multi-institutional collaborations are prominent. The long-term study began in 1989. Phase I, focused on the field of high-energy physics, is now completed; Phase II, now underway, is devoted to collaborative research in space science and geophysics; comparative studies of other fields in science and technology and questions of documentation policy and practice will be the particular foci of Phase III, to get underway in 1994.

The goal of the long-term study is to make it possible for scholars and others to understand these transient "institutions." In order to locate and preserve historical documentation, we must first get some idea of the process of collaborative research and how the records are generated and used. Hence we are making a broad preliminary survey, the first of its kind, into the functioning of research collaborations that include three or more institutions.

Our study is designed to identify patterns of collaborations, define the scope of the documentation problems, field-test possible solutions, and recommend future actions. Along the way we are building an archives of oral history interviews and other resources for scholarly use. Toward the end of the study, the AIP Center will begin to make use of its findings to promote systems to document significant collaborative research.

We focus on major research "sites." In high-energy physics, sites are accelerator facilities; in space science and geophysics, they are research vehicles (spacecraft and ocean-going vessels) or other systems for data-gathering (such as drill holes and seismic networks and arrays).

We collect three levels of descriptive data. At the most aggregated level, we prepare a census of collaborations by supplementing information that can be gleaned from databases covering the science and technology literature. The census makes possible a quantitative analysis of basic collaboration patterns and their changes over time. At an intermediate level, we conduct interviews with 150-180 selected members of collaborations chosen to cover a range of historical, sociological, and scientific parameters. Qualitative analysis of these interviews provides a foundation for generalizing about how scientists view the process of collaborative research and on where they think records of historical value repose. At the most detailed level, we conduct a few "probes," which are case studies of very significant collaborations that seem certain to be of interest to future scholars. Probes make for concrete experience in locating records, the actual preservation of priceless historical material, and historical monographs of publishable quality.

In addition, we give attention to industrial subcontracting because of the managerial problems this practice poses and the further dispersal of records it implies. We also conduct "special perspective interviews" with women and minority members of collaborations whose social roles merit study, and with others, such as program officers of funding agencies and laboratory directors, who have special information of value to our understanding of collaborative research.

Critical to the success of our study are the definition of categories for census data, the selection of collaborations for interviewing and the construction of interview question sets that are sufficiently varied to capture multiple perspectives on collaborations, yet sufficiently uniform to yield suitable results for statistical and sociological as well as historical analysis. The AIP Study of Multi-Institutional Collaborations is guided by a Working Group of distinguished scientists and science administrators, archivists, historians, and sociologists who join in designing the project's methodology and research instruments and reviewing its findings and recommendations.

Interim reports on archival, historical, and sociological findings issued at the end of each phase of the project will culminate in final reports and recommendations at the end of the long-term study. Other resources developed throughout the study, including oral history recordings and transcripts, will be available at the AIP Center's Niels Bohr Library. In addition, we would like to microfilm a few selected sets of particularly valuable documentation. Finally, working in cooperation with institutional archivists, the project will locate and see to the preservation of records, field-testing possible approaches and solutions. Indexed information on all these collections will be made widely available to scholars.

The main consultants for the project are historians Peter Galison (high-energy physics), Robert Smith (space science and geophysics), and Frederik Nebeker (former project historian, now conducting the joint AIP-IEEE study of subcontracting); archivists Roxanne Nilan (high-energy physics) and Deborah Cozort Day (geophysics); and sociologist Lynne Zucker. At the AIP, Nebeker and Joel Genuth have served as project historian and Lynn Maloney and Janet Linde as project archivist. The project is directed by Joan Warnow-Blewett with the assistance of Spencer R. Weart.

B. The Study of Collaborative Research in High-Energy Physics.

The AIP Center's two-year study of high-energy physics research focused on experiments approved between 1973 and 1984 at five of the world's major accelerator laboratories: the Brookhaven National Laboratory (BNL), the Cornell Electron Storage Ring (CESR) facility of Cornell University's Newman Laboratory, the European Center for Nuclear Research (CERN), the Fermi National Accelerator Laboratory (FNAL), and the Stanford Linear Accelerator Center (SLAC).

AIP project members obtained a broad-scale picture of changes in the structure of collaborations by using databases on high-energy physics experiments and publications at SLAC, with the assistance of SLAC staff. At a more detailed level, the project conducted close to 200 interviews on 24 selected experimental collaborations, using a structured question set covering all stages of the collaborative process. Still more detailed "probes" of three highly significant collaborations featured historical research as well as many additional interviews (a total of about 100) and work to preserve records. Specifically, Peter Galison studied the work at SLAC that led to the discovery of the psi particle; Frederik Nebeker studied the discovery of the upsilon particle at FNAL, and Joel Genuth studied the CLEO collaboration at Cornell. Meanwhile project staff surveyed the records-keeping practices of key physicists and made numerous site visits to accelerator facilities and university archives to discuss archival issues and records policies.

The project has gained substantial understanding of how to document the collaborative process in high-energy physics. The AIP Center will put this to use. During the next year or so, we will identify the most significant collaborations in high-energy physics—using a combination of citation studies, peer reviews, and other techniques. At the same time—beginning with the project's three probes—we will begin the lengthy task of working with laboratory and university archivists to locate and preserve the key records. This experience will sharpen our knowledge of the practical and policy issues that present obstacles to documentation of collaborative research. Efforts to resolve such problems will continue throughout the long-term study and, thereafter, as an ongoing activity of the AIP Center's documentation strategy.

II. *PROJECT FUNDING, STAFFING, AND INSTITUTIONAL CONTRIBUTIONS*.

A. Project Funding.

In addition to support for the project's domestic work from the Department of Energy (DOE), the National Historical Publications and Records Commission (NHPRC) at the National Archives and Records Administration, and the National Science Foundation (NSF), funding was received from the Mellon Foundation to extend the study to take international considerations into account. Mellon support made it possible for the AIP project to include collaborations using the four American sites that involve teams (also referred to as groups) from outside the United States.

A separate Mellon grant to the CERN laboratory enabled historian John Krige to carry out a coordinated, parallel study of experiments conducted at CERN. The methodology of the AIP project was fully employed in the CERN work.

B. Project Staffing.

Staffing was erratic during the first year, due to the resignations for personal reasons of the first project historian and project archivist. In each case, it took several months to locate and hire replacements, and remaining staff were loaded down with carrying out essential project tasks.

In April 1990, the second project historian (Nebeker) announced he would resign his position in September to take on the position of associate historian for the IEEE Center for the History of Electrical Engineering. This advance notice enabled the AIP project to hire another postdoctoral historian of science, Joel Genuth, whose tenure overlapped Nebeker's. With the addition of project archivist Lynn Maloney to the staff in June 1990 and the employment of Genuth, staff for the high-energy physics study was complete and stable.

There has also been a change in project consultants. Sociology consultant Thomas Gieryn left in August 1990 because of the press of other commitments; since then the task of analyzing the project's interviews and the census for sociological issues has been under the direction of Lynne Zucker of UCLA.

C. Institutional Contributions.

The AIP contributed a major portion of the time of the Center's postdoctoral historian Finn Aaserud, particularly during 1989. It continues to support the long-term project by contributing some time of the AIP Center's librarian-/archivist Bridget Sisk and its senior program coordinator Virginia French, as well as administrative and clerical costs. The AIP science writer Phillip Schewe assisted the project by reading relevant articles and writing lay-language synopses of them as background material for project staff prior to the interviews. This was very successful for our work during Phase I, particularly since Schewe is a former high-energy physicist. Finally, the project absorbed far more than Warnow-Blewett's allotted one-third time and more of Weart's time than expected.

The Stanford Linear Accelerator Center (SLAC) too has made substantial contributions to the project by supporting the efforts of associate director William Kirk, librarian Louise Addis, and archivists Roxanne Nilan and Robin Chandler. In addition to service on the project's Working Group, Kirk and Nilan conducted pilot interviews to test the project's questions set and, joined by Chandler, conducted 14 interviews related to the project's selected experiments. Addis (also on the Working Group) provided critical leadership for the project's census work, as detailed below, and trained project staff and consultants on the use of the databases on SPIRES at SLAC.

The AIP project also coordinated its work with a history project at FNAL, funded by the National Science Foundation and directed by historians of science Lillian Hoddeson and Catherine Westfall. The AIP project shared its research results to avoid duplication of effort (such as interviewing physicists on the same experiments).

Other contributions have been made by the laboratories, especially support of the census work by the Brookhaven National Laboratory and the Fermi National Accelerator Laboratory, as mentioned later in this report.

III. *WORKING GROUP AND ADVISORY COMMITTEE*.

The study of collaborations in high-energy physics had a Working Group and a larger Advisory Committee for documenting multi-institutional collaborations in high-energy physics. The project's Advisory Committee was never intended to meet; rather, its members agreed to respond as individuals to our requests for advice. Both groups included a number of expert scientists, historians, archivists, and sociologists. However, the Working Group had a greater concentration of distinguished high-energy physicists and science administrators. The members of the Working Group for High-Energy Physics are listed in Appendix A; the Advisory Committee for High-Energy Physics is listed in Appendix B.

The project's Working Group for High-Energy Physics met twice: on 14-15 April 1989 and on 22-23 February 1991. The first meeting, near the outset of the project, was an effective tool for introducing the various groups to each others' interests and concerns. The physicists shared their knowledge of the process of collaboration from the perspective of funding agencies, laboratory administration, and laboratory users. These reports were enormously useful in shedding light on such critical points as how collaborations are formed and how they frequently extend over a string of experiments. In addition, the archivists, historians, and sociologists expressed their concerns and interests as keepers and users of the records and eventual audience for the project's findings.

The products of this meeting included revisions to the project's draft set of questions for use in its interview program, the compilation of an initial list of experiments to be included in the interview program, and the selection of the upsilon experiments—with confirmation of the two already chosen (the J and the psi discoveries)—for the more thorough "probe" studies.

The purpose of the February 1991 meeting of the Working Group was to review progress, critique preliminary findings, and set priorities for the rest of the Study of Multi-Institutional Collaborations in High-Energy Physics. All levels of project work were reviewed (the census; interviews of selected experiments; probe work; historical, sociological, and archival analysis; the parallel study underway of CERN experiments; and the study of subcontracting). In addition, the Working Group reviewed draft appraisal guidelines for records of high-energy physics experiments, plans for the project's final reports, and possible microfilming of selected files; finally, the Group discussed tactics the AIP Center might use to identify key experiments from the past as well as in the future for special preservation efforts.

IV. *CENSUS DEVELOPMENT*.

The broadest level of the study of multi-institutional collaborations in high-energy physics is the census of all high-energy physics experiments conducted for the period from 1973 through 1987 at the four American facilities and—to some extent—the CERN laboratory in Europe. This effort involved, first, defining basic data needed for the census, and second, learning how to manipulate the databases maintained on SPIRES for the high-energy physics community: the *Experiments* database by the Particle Data Group at the Lawrence Berkeley Laboratory (LBL) and the *HEP Publications* database by SLAC and the DESY laboratory in Hamburg, Germany. The *Experiments* and *HEP Publications* databases for high-energy physics, both using the SPIRES program, were made accessible to us through the SLAC Library.

For the most part, the strengths of the databases for project purposes were impressive. On the other hand, the databases had not been used previously for historical, sociological, or other "nonscientific" purposes, and certain weaknesses for project purposes were quickly apparent. These weaknesses range from the humorous and easily-solved (such as counting "et al" as a person in a collaboration) to the disappointing (e.g., the periodic updating of the members of collaborations in the *Experiments* database that removes the possibility of counting physicists on the original proposal and the identification of a collaboration's previous spokespersons).

On another level, not all laboratories were systematic in reporting which publications in the database were linked to specific experiments. This weakness was serious for a number of reasons; for example, it made it impossible to rank experiments in terms of numbers of publications and numbers of citations. For BNL, the most problematic case, project funds were used to employ as freelancer a recently retired BNL physicist, Robert Phillips, to begin to link BNL experiments to publications. This work has since been continued with BNL funding; the project is, unfortunately, not yet completed. Also, in enlarging the census to include the experiments carried out at CERN, we found another problem: the linking of experiments with CERN report numbers rather than with journal publications. Other priorities on the part of CERN staff stood in the way of a project to revise their database. On a positive note, FNAL completed a special effort working directly with Louise Addis to bring its experiment-publications identifications up-to-date. Despite limitations regarding BNL and CERN, the completion of the census has made possible a reasonable measure of the productivity of collaborations in terms of numbers of publications and their citations and provided information on the length of collaborations. The *HEP Publications* database is now more useful than ever for both scientific and nonscientific queries.

In November 1991, Louise Addis and William Kirk suggested a number of additional questions—such as the number of experiments approved for each accelerator at five laboratories and the number of experiments approved for each major detector—that could be pursued based on their solid knowledge of the databases and collaborations at SLAC. With the help of Addis, Robin Chandler developed data on these questions for analysis by Zucker. A listing of the census questions is in Appendix C.

Finally, the project manipulated the SPIRES databases to compile three lists: (1) individuals most frequently involved in collaborations, (2) individuals serving as spokespersons on three or more collaborations, and (3) institutions most frequently involved in collaborations. These data have been particularly useful—when linked to other findings from the census, interviews, and site visits—in pursuing the preservation goals of the study of high-energy physics.

V. *PROGRAM OF INTERVIEWS FOR SELECTED EXPERIMENTS CARRIED OUT AT FACILITIES IN THE UNITED STATES*.

A. Selection of Experiments.

From the outset it was clear that the project should look at a broad range of experiments in terms of both scientific and sociological factors. At the April 1989 meeting of the Working Group, a number of criteria were agreed upon. From the sociological standpoint the set of selected experiments was to cover a range in such areas as the size of the collaboration (both number of institutions and number of individuals), the starting year, the duration, the site, and the possible use of subcontracting. From the scientific standpoint each of the following was to be represented: the various detector types (including bubble chamber, hybrid emulsions, and calorimeter), a beam dump, a rare process, a “crucial test” of theory, a result contrary to current theory, a non-accelerator experiment, high transverse momentum, start-up of an instrument, start-up of an electronic facility, and a precision experiment. The Working Group nominated a number of experiments. It recommended that the project request the three DOE sites to nominate additional experiments following the criteria set up by the Working Group. Such requests were made to heads of research programs of these laboratories through site visits, telephone calls, and correspondence in May 1989.

The project staff compiled a database containing information about all 72 experiments nominated for the project’s program of interviews. For each experiment this included: title, participants, their affiliations, approval date, starting date, end date, and comments—classified as either physics comments or sociological/non-scientific comments. In July, consultants Galison and Gieryn met at the AIP with project staff to make the first cut in the list of experiments. From the original 72 nominated by the Working Group and by the representatives of SLAC, BNL, and FNAL, 27 experiments were selected, including all three CESR experiments. One of these CESR experiments was later selected for the final list in consultation with the laboratory director. Further cuts were necessary in order to limit to twenty the number of experiments for the project’s interview program. The final cuts were made during the process of investigating the current whereabouts of spokespersons for all selected experiments and subsequent discussion with advisors. See Appendix D for information on the selected experiments.

B. Selection of Individuals to be Interviewed.

The identification of individuals to be interviewed was made through discussions with the official spokespersons of the selected experiments (a first step made at the recommendation of project advisors) supplemented by conversations with other collaboration members. In all cases, the project sought to identify team leaders (typically called group leaders), women and minority members, and representatives of our various categories (postdocs, grad students, engineers, computer specialists, and technicians). A list of 179 candidates for interviews was thus compiled; a map was flagged with their locations to maximize travel efficiency.

C. Preparation of Working Files.

Working files were developed for each selected collaboration, including a list of collaboration institutions and members, lay language summary of the experiment, selected publications, and—where available—a biographical entry for interview subjects and a bibliography of published results.

D. Development of the Question Sets for Interviews.

The project proposal included a draft question set to be used for the project's program of interviews. That draft (developed by project staff with consulting historian Galison and sociologist Gieryn) was used to solicit further suggestions and modifications. At the meeting of the Working Group in April, and immediately thereafter, numerous additions and revisions were put forth by project advisors, staff, and William Aspray, Director of the IEEE Center for the History of Electrical Engineering.

In July 1989, three physics experiments (from 1974, 1975, and 1982) were selected for pilot interviews to test the question set. Project staff and consultant Gieryn conducted test interviews with six individuals during September and October. The staff (along with Gieryn, Hargens, and Roxanne Nilan) met in October at Fermilab to discuss their experiences and modify the question set accordingly. The revised question set was then tested at SLAC by project advisors Nilan and Kirk during November. Only minor adjustments have been made since, and interviewers (and interviewees) agree the question set has been highly successful in tracking the collaborative research process. A copy of the Question Set for Senior Physicists is in Appendix E.

We also completed work on several additional shorter question sets for other members of collaborations: representative physicists who are graduate or postdoctoral students; women physicists; and representative non-physicists, including electrical engineers, computer scientists, and technicians. These question sets were tested and have been in use since the early months of 1990. These question sets are also included in Appendix E.

E. Interviewing Activities on Selected Experiments.

From early January 1990 through March 1991, project staff have made 25 major field trips, in addition to nearby visits. Each of these trips involved scheduling appointments with interviewees, completion of working files (lay-language versions of key papers, etc.) and travel arrangements. In addition, appointments were made whenever possible with the archivists at each of the interviewee's institutions to discuss the project's documentation goals, the particular situation of the interviewee's files, and the current policies of the institutional archives. In addition to nine pilot interviews, 144 project interviews were conducted through August 1991 for the 19 selected collaborations using domestic sites.

Transcribing of the tape-recorded interviews, under the direction of the AIP Center's Virginia French, moved into high gear in Spring 1990. Particularly taxing was the hiring of freelance transcribers with word processors to carry the large load of work. Duplicate tapes were shipped out and duplicate diskettes returned for in-house printing. All 144 interviews have been transcribed in addition to seven of the pilot interviews.

F. Historical and Archival Analysis of Interviews.

Work was initiated in May 1990 on the historical and archival analysis of interviews for selected experiments. Project staff developed a form covering historical themes and archival issues; this form was used to index interview transcripts. A second form was prepared for an archival database to facilitate archival analysis. Both forms provide access points so that historical issues and archival issues can be tracked over time and by accelerator site. A copy of the indexing form is in Appendix F; the archival database form is in Appendix G. Thus far, 143 transcripts have been indexed. In addition, historical analysis of 134 transcripts and archival analysis of 141 transcripts were completed. An updated report on the historical analysis was distributed to the Working Group prior to its February

1991 meeting. For more details on archival work, see Section X. "Archival and Preservation Activities" below, and also Part B: "Archival Findings: Analysis and Future Actions," in this *Report No. 2*.[1]

G. Sociological Analysis of Interviews.

The program to carry out sociological analysis of interviews was stalled until the appointment in August 1990 of Lynne Zucker, a professor of sociology at UCLA, for the position as consultant, replacing Gieryn. Zucker appointed a postdoc, Margaret Phillips, and a graduate student, Anna Leon-Guerrero, who started work in October under Zucker's supervision.

Zucker and Phillips narrowed the theoretical sociological issues to be addressed and identified variables to pursue those issues and measures that can be used as surrogates for those variables. The issues pursued included the persistence of affiliations and other collaboration matters, influences on the degree of experimental innovation, the determinants of leadership, the effects of centralization of control, and sponsored mobility (especially the degree to which scientific research was carried out within an ever-narrowing network).

Zucker and Phillips also checked out the usefulness of alternative measures to supplement findings of the project interviews (such as the SPIRES databases at SLAC, citations including self-citations, and vitae) in order to identify the kinds of measures that can give the best accuracy in studying the issues. The analysis is multi-level, looking at individuals, home institutions, and relationships of institutions to the experiment and to the accelerator site. Because of their late start, the results of the sociological analysis will not be available until Spring 1993.[2]

VI. *PROBES OF THE UPSILON AND PSI DISCOVERIES AND THE CLEO COLLABORATION AT CESR*.

Project work on probes largely resembled the planning and scheduling of interviews for the selected collaborations. However, the differences are marked. First of all, the probes involved talking to a larger number of the participants. Second, probe work involved greater attention to collaboration records to determine what files should be saved, identify major gaps, and initiate steps necessary for preserving records of archival value at appropriate institutions.

A. Discovery of the Upsilon.

Our study of the upsilon discovery at Fermilab, under the direction of former project historian Frederik Nebeker, covered a string of seven experiments conducted between 1970 and 1985. Altogether, some 130 individuals and eight institutions (four of them outside the United States) were involved. Nebeker completed most of the interviewing and research work on the upsilon probe during four major field trips before he left the project in mid-September 1990; other project staff have done upsilon interviews as well. A total of 57 interviews were conducted (as well as notes of telephone discussions with four of the collaborators). These include six spokespersons, 21 other senior physicists (including nine group leaders), postdocs, graduate students, engineers, and technicians.

Whenever Nebeker (or other staff) interviewed participants, he also examined experiment records in or near their offices and prepared rough inventories. Nebeker also discussed upsilon files with archivists at Fermilab, Stony Brook, SLAC, CERN, and elsewhere to lay the groundwork for a plan to secure an adequate record of the experiments. Some steps have already been taken in conjunction with Adrienne Kolb, Fermilab archivist, to preserve

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[1]For information on historical findings, see Joel Genuth's report *Part A: Report No. 4:* "Historical Analysis on the Selected Experiments at U.S. Sites," *AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics* (New York: American Institute of Physics, 1992).

[2]See *Report No. 5: Sociological Analysis of Collaborations in High-Energy Physics, AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics* (New York: American Institute of Physics, publication expected 1993). In addition, Leon-Guerrero has passed her Ph.D. oral qualifying examination for her dissertation on the sociological analysis of high-energy physics (November 1991). She has received an NSF doctoral award for her dissertation research. The NSF panel was particularly impressed with her ability to combine qualitative and quantitative analysis of the AIP project's interviews and the SPIRES data.

certain very important materials, including detector logbooks and professional papers of two key participants, Leon Lederman and Jeff Appel.

B. Discovery of the J/Psi.

The discovery of the J at Brookhaven and of the psi at SLAC were simultaneous, and typically combined in references as the discovery of the J/psi. The AIP project originally planned for consultant historian Peter Galison to work on both the J and psi collaborations (led respectively by Sam Ting at Brookhaven and by Burton Richter at SLAC). Because of difficulties in contacting Ting, Galison's study was limited to the SLAC collaboration.

Galison interviewed nine members of the psi collaboration and reviewed their files. In addition, he worked with archivists at SLAC to develop and carry out a survey mailing to all available participants of the psi collaboration. With the help of archivists at both SLAC and Lawrence Berkeley Laboratory (the other major institution on the collaboration), a number of valuable records were located, including unpublished internal technical memoranda (e.g., on event analysis, on the interface between equipment and computers, and on the detector, storage ring, and accelerator), materials on Monte Carlo simulations, and minutes of committees and subgroups.[3]

C. CLEO Collaboration at CESR Mini-Probe.

The project added a "mini-probe" to its list by upgrading the CLEO collaboration at the CESR facility at Cornell University's Newman Laboratory from one of the 20 selected experiments. The reasons for this special attention are several: (1) Experiments are treated quite differently at CESR; only two collaborations have conducted experiments there since it began running in 1979, and one now monopolizes the facility; (2) CESR is one of the four main accelerator facilities in the U.S., but it is the only NSF-funded site; we wanted a better understanding of the differences between the NSF and DOE situations; (3) There has been little historical study of the Cornell accelerators, and we needed to conduct some background research to place the experiment in context; and (4) The project wanted to benefit from another in-depth exposure to research and preservation of archival records. The mini-probe was conducted under the direction of project historian Joel Genuth.

In contrast to the psi and upsilon probes, which are organized around the examination of scientific discoveries, Genuth examined the CLEO collaboration at CESR from an institutional perspective. For example, he looked for documents that shed light on Cornell's decision to pursue collider physics and its efforts to attract the interest of the physics community and obtain funding from the federal government. Genuth, with the assistance of Maloney, conducted 21 interviews.

The archival aspects of the CESR/CLEO probe are particularly challenging, especially the records of CESR and its Newman Laboratory at Cornell University. Since CESR is an NSF-contract facility, it does not produce federal records that fall under the domain of the National Archives and Records Administration. Warnow-Blewett and Genuth are working out an arrangement between the Newman Laboratory and the Cornell University Archives to safeguard the records; the prognosis is very promising.

The reports by the three historians on the probes of the discoveries of the psi and the upsilon and of the CLEO experiment at CESR are included in *Report No. 4: Historical Findings on Collaborations in High-Energy Physics*. Information on the records secured is in *Report No. 3: Catalog of Selected Historical Materials*.[4] In addition, articles by Genuth, Galison, and Nebeker are in preparation and will be submitted to scholarly journals.

VII. *STUDY OF SUBCONTRACTING*.

One aspect that the AIP project planned to explore from the outset is that of subcontracting to industry. The investigation of subcontracting throughout the long-term study is a joint project of the AIP Center and the IEEE

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[3]See *AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics, Report No. 3: Catalog of Selected Historical Materials* (New York: American Institute of Physics, 1992).

[4]The reports are published as parts of *AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics* (New York: American Institute of Physics, 1992).

Center for the History of Electrical Engineering; it is under the direction of Nebeker of the IEEE Center. During our study of high-energy physics, we sought—by means of project interviews and probes—to identify subcontracts the collaborations might have had with industry to carry out significant research-and-development. We did not find subcontracts with such design work or innovative engineering.

Nebeker presented this situation to the Working Group at its February 1991 meeting. There was general agreement that early contributions of industry to high-energy physics in the U.S. were done without contracts (although this is changing with the development of detectors for the Super-Conducting Super Collider). During the period of the AIP study, there were a number of areas, such as super-conducting magnets and photomultipliers, where the important research-and-development was carried out within industry without subcontracts from high-energy physics experiments.

The Working Group decided that LeCroy Electronics, a company that has for 25 years manufactured electronics exclusively for high-energy physics, should be the focus of the project's investigation of industrial research. LeCroy is important and a good example of successful interaction between industry and high-energy physics. Many of its staff are high-energy physicists and they have cultivated informal relations with the high-energy-physics community as a way to learn its needs. Nebeker made a site visit in May to LeCroy to interview key staff, review files, and discuss records-keeping practices; he prepared a written report on his findings.[5]

VIII. *PERSPECTIVE INTERVIEWS.*

The Working Group, at its April 1989 meeting, recommended that the project conduct perspective interviews, outside of the selected experiments and probes, to supply missing pieces from the overview of community leaders such as administrators at funding agencies and laboratories. Ten of these interviews have been completed (with Wallenmeyer and Hildebrand on DOE, Berley on NSF, Nishikawa and Kikuchi on KEK, McDaniel and Abashian on CESR, Ticho on university-laboratory relationships, and Neal on university administration).

In June 1989, the AIP Advisory Committee for History of Physics went further still and suggested the project interview a few women and minority physicists (in addition to those who participated in our selected experiments) who have made significant contributions to experimental high-energy physics or are articulate spokespersons for the concerns of women and minorities in the field. Five of these interviews with women in high-energy physics have been conducted; one black physicist was also interviewed, but primarily from the perspective of administration.

Altogether 15 perspective interviews have been conducted; all have been transcribed.

IX. *PARALLEL PROJECT ACTIVITIES AT CERN*.

Historian John Krige conducted the study of selected experiments carried out at the European CERN laboratory in Geneva, funded by a separate Mellon Foundation grant. The methodology of the AIP project was fully employed in the CERN work, for example in the criteria for selecting experiments and the question sets used in interviews.

Work on the study at CERN got seriously underway towards the end of 1989, after meetings with individual physicists and the CERN Archive Advisory Committee. Five experiments were chosen to meet a range of different criteria in keeping with the AIP project: (1 and 2) UA1 and UA2, renowned for the discovery of the W and Z particles (large, colliders, electronic, historical importance); (3) T-185 and T-228, the discovery of neutral currents (fixed target, bubble chamber, historical importance); (4) WA1 (large, electronic, neutrino physics, classical mid-1970s experiment, fixed target); and (5) WA9 (small, elegant, non-CERN participation, with an important Soviet contingent). For more information on these experiments, see Appendix D.

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[5]See report by Frederik Nebeker in *Part E, Report No. 4: Historical Findings on Collaborations in High-Energy Physics, AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics* (New York: American Institute of Physics, 1992).

Three lines of attack were made on these experiments. First, more than 30 interviews were conducted with individuals who participated in the collaborations, the sample deliberately chosen to include physicists, engineers, computer specialists, and some women. The bulk of these were with physicists and engineers who worked in collaborations UA1 and UA2. A perspective interview on the place of women in high-energy physics was also conducted. Although some differences were noted, Krige's findings confirm virtually all of those made on experiments at American sites.[6]

Second, major progress on preservation of records and papers has been made. With the active support of the CERN Archive Advisory Committee and of the CERN archivist, Krige took positive steps to trace important collections of papers related to the selected CERN experiments. This was successfully done for four of the five selected collaborations; it has proved difficult only for WA1, where most papers seem to have been destroyed. Ultimately it is expected that these will be transferred to the CERN Archive. It should be mentioned that Krige prepared a catalog of the collections of papers of two physicists involved in two of these experiments (UA1 and neutral currents). The first is particularly comprehensive and, once the papers have been transferred to the Archive, will serve as a valuable guide for archivists and historians to the kind of material that is generated in a large collaboration.

Another major preservation breakthrough was the decision on the part of the CERN laboratory to preserve the records of major experiments conducted at CERN. The CERN Archive Advisory Committee, inspired by the AIP project and in consultation with Krige, has solicited from its physics community suggestions for 20 experiments of historical interest; the Committee hopes to track down key collections of papers related to these experiments and, if possible, to transfer them to the CERN Archive. Finally, Krige has identified other important papers and encouraged physicists to deposit them in appropriate repositories; this work has been supported by the CERN Archive Advisory Committee.

Third, some results of Krige's work have been used in two reports: (1) A report summarizing the findings of the research done on experiments UA1 and UA2; this will be published in the *Sociology of the Sciences Yearbook* for 1992 and (2) A CERN Internal Report on the relation between CERN and its user community. Krige hopes to use some data, in cooperation with a young American graduate student, to compare the CDF (Collider Detector at Fermilab) with the UA1.

X. *ARCHIVAL AND PRESERVATION ACTIVITIES*.

The methodology was thoroughly effective in identifying the archival issues and pointing the way toward preservation. As expected, the in-depth work on the selected probes proved to be particularly valuable in issues regarding appraisal of technical documentation. Probe work was also useful in identifying specific difficulties in saving the records. We are more surprised at how valuable the historical analysis and the archival analysis of the interviews covering selected collaborations could be in combination with the census work. These analyses provided both an overall understanding and specific information on records creation and retention by the various collaboration members. The census combined well with these findings by giving us names of key institutional and individual players that we could approach for practical preservation work.

A. Basic Activities.

There are a number of ways the project has taken steps during the two-year study of high-energy physics to have an impact on the records-keeping practices of archivists and scientists. For example, from the start our interviews with scientists were conducted at their home institutions so that we could review their files and also meet with the institutional archivists to talk about project goals and their current archival programs. These meetings with scientists were, virtually without exception, the first time anyone had discussed with them the potential historical value of their papers. Based on previous experience of the AIP Center, we believe these discussions will have a positive impact on care of records. The meetings with archivists strengthened the AIP Center's cooperative ties,

[6]See John Krige's report in *Part B, Report No. 4: Historical Findings on Collaborations in High-Energy Physics, AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics* (New York: American Institute of Physics, 1992).

gave us "grass roots" information on the likelihood of saving records of multi-institutional collaborative research, and in return let us provide information and encouragement.

More specifically, the question sets used for interviews with senior physicists and other members of collaborations were designed with archival goals in mind. The question sets in Appendix C show that each step of the collaborative process was covered, from funding initiatives through publication of research results. There was considerable emphasis on organizational and social issues that impact on records, such as communication patterns, delegation of responsibilities, degree of bureaucratization, impact of computer technology, role of internationalism, and the use of subcontracting to industry. Further issues relating directly to archival matters were those of records creation, use, and reuse for scientific purposes. Here we were particularly keen to capture information about electronic records, both the use of e-mail and the scientific data on magnetic tapes and diskettes. All interview transcripts were indexed by project archivist Lynn Maloney to assure optimum consistency. Information on organizational and social issues was analyzed by project historian Joel Genuth; information specific to records was entered into an archival database for analysis by Maloney and Warnow-Blewett.

B. Survey of Spokespersons.

Midway through our data gathering period, both the interviews and the archival database indicated that, as collaborations have become larger and more bureaucratic, spokespersons have taken on more managerial responsibilities including records distribution. Our preliminary archival analysis showed that, of all collaboration members, spokespersons are likely to hold the best documentation. Because of this finding, the project decided to carry out a survey during the first half of 1991. We used the *Experiments* database at SLAC to compile a list of those people who had served as spokespersons on three or more collaborations. Separate survey procedures were developed for those living in the U.S. and those living abroad; project staff were assisted in survey development by sociologists Zucker and Phillips.

The domestic survey was based on a mailing and follow-up telephone interviews. The mailing consisted of a letter explaining the project and the kinds of questions we would cover in the interview; attachments included a summary of the historical analysis of the role of spokespersons, a list of records that the project is interested in, and a printout from the database describing the experiments for which that person was a spokesperson. The telephone follow-ups made it possible to cover virtually everyone included in the domestic survey. Thorough notes were taken and tape recordings were made in case further reference would be required.

Project staff adapted and shortened the interview into a questionnaire to be mailed to foreign spokespersons and returned. This questionnaire focused on the creation and retention of both collaboration and other professional records and was also accompanied by a letter explaining the project and a database printout describing the experiments for which the spokesperson acted. The survey was mailed in June. The response was disappointing: out of 17 surveyed, only four individuals replied.

Results of the spokesperson surveys were incorporated into the project's archival analysis. The domestic survey broadened the scope of the project's perspective in that many of the experiments examined in the survey differ in physics goals and in historical significance from the project's 19 experiments which are being studied in greater depth.

C. Appraisal Guidelines.

Warnow-Blewett drafted guidelines for the appraisal of records of high-energy-physics collaborations prior to the February 1991 meeting of the Working Group. The draft included key publications as well as manuscript sources. Each record category was marked for discussion purposes with a recommendation that it should be retained for all experiments, retained only for significant experiments, or that it need not be saved except in special circumstances. When appraising the informational value of the records, the Working Group was asked to take into consideration the future needs of scientists and those in science policy and management as well as historians of physics, technology, information processing, economics, and institutions, and sociologists of science.

Peter Galison—as Chief Consulting Historian—led the review of the draft guidelines providing insights on the records he and other historians on the project had found most valuable for the study of *especially significant* experiments: correspondence files of individuals, internal collaboration memoranda, and experiment logbooks. The Working Group discussion about appraisal led to the following priorities for retention of records for *all* experiments: (1) Physics Advisory Committees records, (2) laboratory directors' files, (3) proposals to the laboratories, (4) Memoranda of Understanding (contracts), (5) blueprints of detectors and their components, and (6) proposals, including narrative and financial progress and final reports to funding agencies. It was noted that virtually all of these core records are likely to be retained (or at least not destroyed) by the laboratories. It was also agreed that technical data (especially the raw data) had virtually no value after its use by the collaboration. After the meeting, Galison assisted in reviewing the guidelines before they were sent to the Working Group for their comments. See Part D: "Appraisal Guidelines for Records of Collaborations in High-Energy Physics" in this report.

D. Site Visits to Accelerator Laboratories.

Site visits to the five laboratories under study—to meet with top-level science administrators as well as with those in direct charge of records—have been particularly important in two phases of project work. First, near the outset of the project, when laboratory staff were generous in providing detailed tours of their facilities, including discussions with collaboration members in the midst of conducting experiments. Such tours were essential to our understanding of the process of collaborations in high-energy physics. The scheduling of these site visits were coordinated with periodic meetings of staff, consultants, and advisors. Also important were three site visits (in October 1989 and January and July 1990) to the CERN laboratory in Geneva to coordinate project work with CERN historian John Krige.

Later site visits to the laboratories shifted toward discussions of the project's preliminary findings and recommendations. Toward the end of the period, we made visits for the purpose of determining the extent to which the laboratories retain records documenting collaborative research and to obtain current information on their general records retention policies and archival programs. We were particularly concerned to share information on the project's appraisal guidelines and to encourage the retention by the laboratories of the *core* records to be saved for all experiments. Finally, a history conference at SLAC in June 1992 brought together Warnow-Blewett and archivists from DOE national laboratories, including FNAL, LBL, SLAC, and SSCL (Superconducting Super-Collider Laboratory); the gathering made it possible to review face-to-face the AIP project's findings and recommendations.

E. Archival Analysis.

The project's archival analysis covers a wide range of information regarding records. These include patterns of records creation, use, and reuse by the collaboration as well as patterns of records retention and destruction. We also report on the locations where valuable sets of records are likely to repose and on shifts in records practices on the part of collaborations; both of these can provide opportunities for preservation recommendations that appear "natural" to our records creators.

The archival analysis has been based on all aspects of our work—the census, historical analysis of interviews on selected experiments, historical probe work, sociological studies, site visits, and our archival database. Drafts and revisions have been issued since the initial year of data gathering; the final report is Part B: "Archival Findings: Analysis and Future Actions" of this *Report No. 2*.

F. Preservation Activities.

During the two-year study, the main efforts in locating papers and records of historical value focused on two targets: the papers documenting the three probes and the core records at the accelerator laboratories.

In documenting the probe experiments we have made substantial progress, although more remains to be done. In the case of documenting the upsilon series of experiments at FNAL, the papers of Leon Lederman (the main principal investigator [PI] and a spokesperson) and the papers of Jeff Appel have been secured in the FNAL Archives with the help of archivist, Adrienne Kolb. In the case of the psi discovery collaboration at SLAC, extensive searches for key records were conducted for the project by archivist Roxanne Nilan at SLAC and archivist Lori Hefner at LBL; extensive sets of documentation are now under their care at SLAC and LBL. Work to document the CLEO collaboration at the CESR facility of Cornell's Newman Laboratory is also well underway. As mentioned earlier, the main issue here is to establish a repository for these non-federal records; we have confidence that arrangements under discussion with the University's Archives and Special Collections department will prove successful. The AIP Center's general approach to documenting all three of these collaborations is to first secure the most central records (typically at the laboratory and in the hands of the spokesperson[s]) and—once we have information on the gaps in these collections—proceed to investigate additional papers or files (for example, in the possession of group leaders) that should be preserved.

The other focus of our preservation work has been on efforts to secure the core set of laboratory records for all experiments—*i.e.*, proposals, blueprints, etc. (See Part D: "Appraisal Guidelines for Records of Collaborations in High-Energy Physics" in this *Report No. 2*.) We were, first of all, relieved to learn that the laboratories also placed value on these basic files; at least, they had not been destroyed. We are aware that some valuable records on our core list, notably those of the Physics Advisory Committees, are not authorized by the National Archives for permanent retention in existing DOE records schedules. LBL Archivist Hefner is working to strengthen the National Archives schedules for DOE laboratories; we are assisting her and we hope our project recommendations will help legitimize the preservation of such valuable evidence.

The AIP Center is greatly impressed by the contributions of several laboratories in documenting high-energy physics, inspired in part by our study. Particularly noteworthy are the new efforts, both at SLAC and at CERN, to take steps to identify outstanding experiments and secure their documentation in laboratory archives.

G. *Project Recommendations.*

Based on our findings and analyses, we developed 12 project recommendations addressed to accelerator laboratories, universities, other laboratories, and, in part, to DOE and NSF Headquarters and to NARA. The purpose of the recommendations is to outline policies and actions that would greatly improve the documentation of high-energy-physics collaborations and the dissemination of information about the records.

The most important recommendation urges a new approach to securing the documentation for future experiments. We suggest that, once an experiment has been approved, the accelerator laboratory should ask the spokesperson to identify one of the collaboration members who would be responsible for collaboration-wide records. In addition—where historical significance warrants—individuals would be named to be responsible for group level documentation of innovative components or techniques. The information would become part of the laboratory's contract agreement with the collaboration. Use of this simple mechanism would assist archivists by assuring that records will be available for appraisal and by providing information on their location.[7]

XI. *DISSEMINATION OF PROJECT ACTIVITIES.*

A. *Talks and Publications During the Two-Year Study.*

Five issues of the AIP Center for History of Physics *Newsletter* (Spring 1988 and 1989, and Fall 1989, 1990, and 1991) had lead articles reporting on project activities. The Fall 1990 issue also featured a summary of preliminary findings.

Warnow-Blewett and Nebeker spoke about the project at the Annual Meeting of the Society of American Archivists (SAA) held in St. Louis, Missouri, in October 1989. Warnow-Blewett also focused on the AIP Study of Multi-Institutional Collaborations in talks at a conference convened in May 1990 by the Beckman Center for the History of Chemistry and at another conference in December 1990 convened by Georgetown University. Another paper on documenting postwar science and technology, including discussion of the project, was given by Warnow-Blewett in June 1991 in Milan, Italy, at a conference on archives for history of science and technology; a longer version of her paper will be published in the next issue of *Osiris*, a journal of the History of Science Society. Warnow-Blewett gave a paper on the project at the New York Academy of Science in February 1992 and at the 1992 Annual Meeting of the SAA in Montreal. Finally, Warnow-Blewett has been asked to give the Keynote Address on the AIP project at the Conference on the History and Archives of Science in Australia this November. Historian Genuth

[7]For the complete set of recommendations, see *AIP Study of Multi-Institutional Collaborations, Phase I: High-Energy Physics, Report No. 1: Summary of Project Activities and Findings/Project Recommendations* (New York: American Institute of Physics, 1992).

presented a paper on his historical analysis at a seminar of the Smithsonian Institution's History of Science Series. Krige, the historian of our parallel study of CERN, has given numerous talks drawing on his research.

B. Final Reports.

Four of the five final reports on the two-year study of high-energy physics collaborations were distributed for review by the project's Working Group and Advisory Committee in October 1991. After revisions and final editorial work, the reports were printed and distributed in September 1992. Research continues on the fifth report covering sociological analysis; its publication and distribution is expected in Spring 1993. The reports are: *Report No. 1: Summary of Project Activities and Findings/Project Recommendations*, report *No. 2: Documenting Collaborations in High-Energy Physics*, *Report No. 3: Catalog of Selected Historical Materials*, *Report No. 4: Historical Findings on Collaborations in High-Energy Physics*, and *Report No. 5: Sociological Analysis of Collaborations in High-Energy Physics*.

The distribution of the reports includes offices for high-energy physics at the DOE and the NSF, academic departments of physics most active in the field of high-energy physics, accelerator physics laboratories, and archival and records management programs at all of these institutions. The reports will also be available upon request from the AIP Center.

C. Forthcoming Publications.

Now that Phase I of the long-term study has been completed, reports on project activities, findings, and recommendations will be submitted to the newsletters of the Society of American Archivists, the History of Science Society, the Society for the History of Technology, the Society for the Social Studies of Science, and the Association of Records Managers and Administrators.

In addition, scholarly papers will be submitted to history of science and sociology journals. These will include papers by: Nebeker on the upsilon experiments; Genuth on the CLEO collaboration in the institutional setting of the CESR facility; Galison on the J/psi discovery; and Zucker, Phillips, and Leon Guerrero on sociological aspects of high-energy physics collaborations. In addition, based on his parallel study at CERN, Krige will publish two papers—one on experiments UA1 and UA2 (in the *Sociology of the Sciences Yearbook* for 1992) and one on the relation between CERN and its user community (to appear as a chapter in a forthcoming volume in the History of CERN series). At the end of the long-term project, an article on the study's methodology, findings, and recommendations will be submitted to *The American Archivist*.

D. Other Products.

Project records, especially interview tapes and transcripts, are preserved in the AIP Center's Niels Bohr Library for historical and other research purposes. They are likely to be used by historians and sociologists of science for many years to come. In addition, project records documenting details of our methodology and findings are preserved for those who may wish to carry out similar studies of other disciplines in the future. Finally, the project would like to microfilm selected paper files of high historical value; these microfilming plans depend upon the availability of project funds.

XII. *FUTURE EFFORTS TO DOCUMENT HIGH-ENERGY PHYSICS*.

The AIP project's future activities to document high-energy physics are detailed in Part B: "Archival Findings: Analysis and Future Actions" in this *Report No. 2*. We only mention briefly here that the project intends to continue sociological research and to hold a workshop with archivists during its Phase II study of space science and geophysics.

Because of their late start, the sociological research of consultant Lynne Zucker and her group at UCLA has been limited in a variety of ways. Fortunately, the Mellon Foundation has approved use of remaining funds for the group's further research. The general scope of the research will be threefold: (1) to extend the analysis of the project's 19 selected experiments, especially by focusing on characteristics of the laboratory sites, using quantitative approaches to the similarities and variation across experiments; (2) to examine the interviews of the AIP project's more detailed probes of highly significant experiments, comparing them with the results of the analysis of interviews on the selected experiments; and (3) to analyze the CERN experiments for which there are sufficient interviews, to determine what is similar to the American predictors and what is not. The findings of Zucker and her group will help us understand more completely high-energy physics research and the conduct of modern science.

PHASE II: SPACE SCIENCE AND GEOPHYSICS

I. *INTRODUCTION: PURPOSE AND METHODOLOGY OF THE STUDY*

Since World War II, the organizational framework for scientific research is increasingly the multi-institutional collaboration. However, this form of research has received slight attention from scholars. Without a dedicated effort to understand such collaborations, policy makers
and administrators will continue to have only hearsay and their own memories to guide their management; even the records necessary for efficient administration, for historical and management studies, and for posterity, will be largely scattered or destroyed.

The Center for History of Physics of the American Institute of Physics, in keeping with its mission to preserve and make known the record of modern physics and allied sciences, is working to redress this situation with a three-stage investigation into areas where multi-institutional collaborations are prominent. The study began in 1989. Phase I, which focused on high-energy physics was completed in 1992.[8] Phase II, which addressed collaborative research in space science and geophysics, is completed with this report. Phase III, now underway, will focus on comparative studies of other fields in science and technology and general questions of documentation policy and practice.

The goal of the study is to make it possible for scholars and others to understand these transient "institutions." In order to locate and preserve historical documentation, we must first get some idea of the process of collaborative research and how the records are generated and used. Hence, we are making a broad preliminary survey, the first of its kind, into the functioning of research collaborations since the mid-1970s that include three or more institutions. Our study is designed to identify patterns of collaborations and define the scope of the documentation problems. Along the way, we are building an archives of oral history interviews and other resources for scholarly use. The AIP Center will make use of its findings to recommend future actions and promote systems to document significant collaborative research.

We focus on major research "sites." In high-energy physics, sites are accelerator facilities; in space science and geophysics, they are research vehicles (spacecraft and ocean-going vessels) or other systems for data-gathering (such as drill holes and seismic networks and arrays). During the study of space science and geophysics, we conducted close to 200 interviews with academic and government scientists and administrators involved in 14 selected case studies. Qualitative analysis of these interviews provides a foundation for generalizing about how scientists view the process of collaborative research and on where they think records of historical value may be found. In addition, we gave attention to industrial subcontracting because of the managerial issues this practice poses and the further dispersal of records it implies. We also conducted "special perspective interviews" with persons such as program officers of funding agencies and discipline policy makers, who have special information of value to our understanding of collaborative research.

Interim reports on archival, historical, and sociological findings issued at the end of each phase will culminate in final reports and recommendations at the end of the long-term study. Other resources developed throughout the study, including oral history recordings and transcripts, will be available at the AIP Center's Niels Bohr Library.

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[8]See *AIP Study of Multi-Institutional Collaborations. Phase 1: High-Energy Physics.* New York: American Institute of Physics, 1992. *Report No. 1: Summary of Project Activities and Findings/Project Recommendations,* by Joan Warnow-Blewett and Spencer R. Weart. *Report No. 2: Documenting Collaborations in High-Energy Physics,* by Joan Warnow-Blewett, Lynn Maloney, and Roxanne Nilan. *Report No. 3: Catalog of Selected Historical Materials,* by Bridget Sisk, Lynn Maloney, and Joan Warnow-Blewett. *Report No. 4: Historical Findings on Collaborations in High-Energy Physics,* by Joel Genuth, Peter Galison, John Krige, Frederik Nebeker, and Lynn Maloney.

Working in cooperation with institutional archivists, we will also locate and assist with the preservation of records at appropriate repositories, field-testing possible approaches and solutions. Indexed information on all these collections will be made widely available to scholars.

The project is directed by Joan Warnow-Blewett with the assistance of Spencer R. Weart. Joel Genuth has served as project historian and Lynn Maloney, Janet Linde, and Anthony Capitos as project archivist. The main consultants for Phase II were historians Robert Smith (space science), Naomi Oreskes (geophysics), and Frederik Nebeker (former project historian and now conducting a joint AIP-IEEE study of contracting), archivist Deborah Cozort Day, and sociologist Lynne Zucker.

I. *PROJECT FUNDING AND STAFFING*

Support for this phase of the project was provided by the Andrew W. Mellon Foundation, National Historical Publications and Records Commission at the National Archives and Records Administration, and the National Science Foundation. Additional support from the Andrew W. Mellon Foundation made it possible for the AIP project team to conduct the parallel study of the European Space Agency and funded international travel.

Changes in project archivists along with the relocation of the AIP headquarters affected the efficiency of the project. Lynn Maloney left her position as project archivist in early February 1992. Janet Linde was chosen to be the new project archivist and began her tenure in April 1992, but resigned her position rather than relocate to College Park when the AIP headquarters moved to its present location in October 1993. In mid-March 1994, Anthony Capitos began work as project archivist.

III. *WORKING GROUP*

The study of collaborations in space science and geophysics was aided by a Working Group which included expert scientists, historians, archivists, and sociologists. The members are listed in Attachment C-1.

The Working Group for Space Science and Geophysics met at the AIP headquarters building in New York on 8-9 November 1991 and on 21-22 May 1993. As in our previous study of high-energy physics, the main purpose of the first meeting of the Working Group was to acquaint the space scientists and geophysicists with the goals and methodology of the project and to have the scientists acquaint project staff and other members of the Working Group with characteristics of their scientific disciplines. There was extensive discussion of the differences between high-energy physics and the several disciplines we were studying in space science and geophysics. Three major differences—the greater diversity, the greater complexity, and the longer "pre-history" of projects in space science and geophysics—led to the decision to select fewer case studies and not to attempt probes (in-depth studies of specific projects).

Prior to the second meeting, each member of the Working Group received substantial reports on preliminary archival and historical-sociological findings; the reports made possible less formal staff presentations and more group discussions. There was, for example, some discussion as to when and whether to compare space science and geophysics with high-energy physics. It was concluded that we should treat the space science and geophysics fields first of all on their own terms and only then draw comparisons with high-energy physics. A major portion of the second Working Group meeting was a review of staff findings for each of the selected case studies in to discuss the quality of the findings and to prioritize the list of remaining interview subjects. The group felt there were several areas in which the project should strengthen its historical-sociological findings. These included a fuller examination of the role of NASA Headquarters and its working groups in initiating the projects and setting their scope, and the intellectual or international factors in the creation and operation of collaborations. Accordingly, later interviews concentrated on individuals with administrative responsibility for collaborations. They were likely to know or have insights into the perspective of NASA Headquarters, to have contacts with international or military organizations, and to be sensitive to the presence or lack of intellectual cohesion in collaborations.

IV *CENSUS DEVELOPMENT*

The broadest level of study for Phase I of the study of multi-institutional collaborations was the creation of a census of data on projects with names of all participants and their institutional affiliations and the publications produced by the projects. Despite the expenditure of much effort, project staff were unable, in Phase II, to find existing electronic databases that could serve as the basis for a comparable census useful for historical or sociological study of either space science or geophysics.

V. *PROGRAM OF INTERVIEWS FOR SELECTED EXPERIMENTS*

A. Selection of Case Studies

Following the recommendation of the Working Group to conduct a thorough investigation prior to our final selection of case studies, Maloney (with the assistance of Genuth) made extensive efforts to assemble information and literature on over 30 projects that were candidates for our case studies. These efforts included discussions with members of the AIP Study's Working Group, administrators at the NSF, NASA, and other agencies, and principal investigators of candidate projects. Files for each candidate project were assembled. A meeting at AIP with consulting historians Robert Smith and Naomi Oreskes was held in February 1992 to review candidate projects. We were concerned, among other things, to avoid recent cases that scientists would not talk about candidly and to insure that our sample would expose us to a wide range of variables that could affect records creation. Twelve projects were selected to serve as our case studies for space science and geophysics. They cover a range of scientific disciplines, observation platforms, and institutional participants, and the same year span as those for high-energy physics (from 1973 to the near present). See Report No. 2, Part A: Space Science, Section 1: "Selected Case Studies in Space Science" and Part B: Geophysics and Oceanography, Section 1: "Selected Case Studies in Geophysics and Oceanography" for information on the selected case studies.

B. Selection of Individuals to be Interviewed

Genuth spent most of three months contacting leaders of the chosen projects through phone, e-mail, and correspondence to collect the information needed to define interview programs. In order to understand later stages of the projects (experiments, oceanographic legs, etc.), it was found necessary to include interviews on the infrastructure and records creation during the formative (pre-funding) stage. This formative stage of projects in space science and geophysics has typically been lengthy, political, multi-institutional, and often multinational.

We planned to conduct the same number of hours of interviews on our 12 case studies as we did for those in high-energy physics (over 400 hours); this translates into roughly 200 interviews. Ten of these interviews were reserved for special perspective interviews with key policy-makers in these disciplines, to give an overview of the discipline which might be missed during the case study interviews. The remaining interviews were dedicated to the 12 case studies. The study of contracting to industry involved another roughly 25 interviews. What appears to be a luxury—allowing an average of 16 interviews per case study—is a necessity for the fields of space science and geophysics. Even with this many interviews, we usually had to define some kind of sub-set of the project for detailed examination, in order to be able to cover both high-level administrative issues and working-level details. For example, our interview program on Voyager concentrated on four of ten experiments (instruments), and our program for the Deep Sea Drilling Project (and its successor, the Ocean Drilling Program) focused on two of the more than 100 legs that have been conducted.

C. Development of Question Sets for Interviews

Prior to the November 1991 meeting of the Working Group, draft interview question sets were drawn up, with the help of our consultants, and distributed. After discussions by the Working Group, the question sets were further revised to reflect the differences in terminology among the several fields and to capture the different range of practices that appear to be prevalent in space science and geophysics. These question sets were still primarily applicable to interview subjects close to activities related to instrumentation. Because a good fraction of the interviews would be with policy makers and administrators, we produced several variations on the question sets to capture the broad range of roles and specialties among our interviewees. Two question sets (one for space science and the other for geophysics and oceanography) were developed to interview principal investigators and their teams. Additional question sets were prepared for interviews with scientists and engineers at NASA Headquarters and flight centers and with other policy makers and administrators. A copy of the question set for policy makers is in Attachment C-2.

D. Interviewing Activities on Selected Projects

Between March 1992 and May 1994, we made 24 major field trips, in addition to nearby visits. Appointments were made whenever possible with the archivists at each of the interviewee's institutions to discuss the project's documentation goals, the particular situation of the interviewee's files, and the current policies of the institutional archives.

Transcribing of the tape-recorded interviews, under the direction of the AIP Center's administrative assistants, continued throughout the project.

E. Historical and Archival Analysis of Interviews

Work began on the historical and archival analysis of interviews during the fall of 1992. To index interview transcripts, we developed a form covering historical themes and archival issues. With help from a graduate student, Martha Keyes, project staff were able to index interview transcripts quickly and efficiently. Project historian Genuth was also aided by graduate students in his historical analysis of the indexed transcripts. All 192 transcripts were indexed and analyzed for their historical and archival content. A copy of the indexing form is in Attachment C-3. For further information, see Report No. 2, Part A: Space Science, Section 2: "Historical-Sociological Report" and Section 3: "Archival Findings and Analysis" and Report No. 2, Part B: Geophysics and Oceanography, Section 2: "Historical-Sociological Report" and Section 3: "Archival Findings and Analysis."

F. Sociological Analysis of Interviews

Lynne Zucker, professor of sociology at UCLA, carried out a sociological analysis of the interviews with the aid of her graduate students. For further information, see Report No. 2, Appendix A: "Sociological Analysis of Multi-Institutional Collaborations in Space Science and Geophysics."

VI. *PARALLEL STUDY OF THE EUROPEAN SPACE AGENCY*

A parallel study of the CERN laboratory in Geneva, conducted during our work on high-energy physics, proved useful; therefore we repeated this approach for space science by doing a parallel study of the European Space Agency (ESA). Two historians of science, John Krige and Arturo Russo, who are currently under contract to write a history of ESA, helped to develop strategies to study three projects: one ESA-sponsored collaboration and two collaborations jointly sponsored by ESA and NASA. One of our originally selected space science case studies, the International Ultraviolet Explorer, was expanded to include study of the European participation, while case studies were added of the Giotto project and the International Sun-Earth Explorer. Krige and Russo conducted about one-half of the interviews for Giotto and ISEE collaborations; the AIP project staff conducted the balance and analyzed all the transcripts.

VII. *STUDY OF SUBCONTRACTING*

The Center for History of Electrical Engineering of the Institute for Electrical and Electronic Engineers joined with us in supporting Frederik Nebeker to conduct a study of contracting to industry. It was decided that the Quanterra Corporation and the development of Very-Broad-Band Seismography should be the focus of the our investigation of industrial research. Nebeker prepared a general report based on the AIP Study's interviews and conducted interviews of principals at the Quanterra Corporation, a major provider of electronic components for seismological research. Nebeker's general report on contracting has been drawn on freely in various of these reports; his focused report, "The Development of Very-Broad-Band Seismography: Quanterra and the IRIS Collaboration," is in Report No. 2, Appendix B.

VIII. *PERSPECTIVE INTERVIEWS*

We conducted perspective interviews, outside of the selected case studies, to supply missing pieces from the broader viewpoints of community leaders such as administrators at funding agencies and international organizations. Altogether 11 formal perspective interviews were conducted along with informal visits to other administrators and scientists.

IX. *ARCHIVAL AND PRESERVATION ACTIVITIES*

A. Basic Activities

There are a number of steps the project has taken during the study of space science and geophysics in order to have an impact on the records-keeping practices of archivists and scientists. From the start, our interviews with scientists were conducted at their home institutions so that we could review their files and also meet with as many as possible of the institutional archivists or records officers to talk about project goals and their current archival programs. These meetings with scientists were, virtually without exception, the first time anyone had discussed with them the potential historical value of their papers. Based on previous experience of the AIP Center, we believe these discussions will have a positive impact on care of records. The meetings with those responsible for records strengthened the AIP Center's cooperative ties, gave us "grass roots" information on the likelihood of saving records of multi-institutional collaborative research, and in return let us provide information and encouragement.

More specifically, the question sets used for interviews with senior physicists and other members of the collaborations were designed with archival goals in mind. The question set in Attachment C-2 shows how each step of the collaborative process was covered, from pre-funding initiatives through publication of research results. There was considerable emphasis on organizational and social issues that impact on records, such as communication patterns, delegation of responsibilities, degree of bureaucratization, impact of computer technology, role of internationalism, and the use of subcontracting to industry. Further issues relating directly to archival matters were those of records creation, use, and reuse for scientific purposes. We were particularly keen to capture information about electronic records, especially the use of e-mail. Information specific to records was entered into a database for analysis by Anthony Capitos.

B. Archival Information Database

The Working Group advised during its first meeting that we would gather more information on the record-keeping practices of our interview subjects if we left them with a questionnaire form to fill out. Unfortunately, the questionnaire approach was far less successful than we had hoped. In addition to the fact that many subjects failed to send in their questionnaires, those that were received were inconsistent in their coverage. The return rate of these questionnaires was 47.4% (37.8% response for our space science case studies and 62% for geophysics). Although this is close to half, switching to the questionnaire format lost the personal description and in-depth answers to inquiries during interviews that the previous phase enjoyed. The interviews proved to be essential for the archival information database. Its close to 200 records include information concerning the interview subject's personal record-keeping practices as well as information about the location and types of records the collaboration produced. In summary, information in the archives database was drawn from both questionnaires and interviews. It was used to help identify trends or locate gaps in the documentation of our case studies. A copy of the archival database form is in Attachment C4.

C. Archives Site Visits

The major institutional settings we have encountered for projects in space science and geophysics have been academia, government laboratories (including space flight centers), government-contract laboratories, and corporate laboratories. Because of the complexity and variety of the institutional settings that we would encounter in this phase of the project, we decided to develop question sets for our meetings with archivists and records managers at the various institutional settings. We developed three versions: one to be used for meetings with an archivist, one for meetings with a records manager, and one for meetings at which both an archivist and a records manager of the institution are present. A copy of the questionnaire for combined archivists and records managers is in Attachment C-5.

To supplement the information from the interview subjects concerning the administration and planning of NASA space science projects and the functions of various offices, Warnow-Blewett and Capitos visited several individuals in managerial positions at NASA. These included NASA discipline scientists, division chiefs, and project scientists. Meetings were also held with records managers at both the Headquarters and flight center levels as well as with managers of the NASA History Office. Discussion concerning the new NASA Records Retention Schedule gave insight into the direction of NASA records management.

Along with these NASA meetings, Warnow-Blewett, Capitos, Genuth, and Anderson visited records managers and administrators in various agencies associated with our geophysics case studies including the NSF, National Oceanic and Atmospheric Administration, and Joint Oceanographic Institutes, Inc. These meetings were followed by visits to the National Archives' appraisal archivists to discuss the current records retention policies of the government agencies involved with our projects.

D. Archival Analysis

Our archival analysis covers a wide range of information on records. The topics include patterns of records creation, use, and reuse by the collaboration as well as patterns of records retention and destruction. We also report on the locations where valuable sets of records are likely to be found, which will provide opportunities for preservation recommendations that appear “natural” to our records creators.

The archival analysis has been based on all aspect of our work—the historical-sociological analysis of interviews; site visits; questionnaires from scientists, archivists and records managers; and our archival database. “Archival Findings and Analysis” for space science is Report No. 2, Part A: Space Science, Section 3 and for geophysics and oceanography, Report No. 2, Part B: Geophysics and Oceanography, Section 3.

E. Appraisal Guidelines

The appraisal guidelines were developed initially out of analyses of the structures and functions of the multi-institutional collaborations and policy groups. First drafts prepared by Anthony Capitos and Joan Warnow-Blewett were based on the interview transcripts; further additions and refinements were derived from Genuth’s historical-sociological findings. Site visits with records officers, scientists, and administrators provided key insights and guidance. After a review by project consultants Smith, Oreskes, and Day, the revised appraisal guidelines were distributed to the project’s Working Group for further comments and corrections. The “Appraisal Guidelines” for records of collaborations in space science are in Report No. 2, Part A: Space Science, Section 4; for geophysics and oceanography, Report No. 2, Part B: Geophysics and Oceanography, Section 4.

F. Catalog of Source Materials

Throughout the long-term study, we have aimed to preserve the valuable documentation we encountered, working in cooperation with institutional archivists. These records, along with our oral history interviews, will be cataloged for the AIP International Catalog of Sources for History of Physics and Allied Sciences and shared with RLIN-AMC, the major online archival database. Accessibility of information on resource materials will help to foster research on aspects of multi-institutional collaborations by historians, sociologists, and other scholars.

PHASE III: GROUND-BASED ASTRONOMY, MATERIALS SCIENCE, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

I. *INTRODUCTION*

Support for Phase III of the AIP Study of Multi-Institutional Collaborations came from the American Institute of Physics, the Andrew W. Mellon Foundation, the National Historical and Publications Commission (NHPRC), and the National Science Foundation (NSF). Work on Phase III was initiated in September 1994, but did not become active until the following June when our reports on Phase II were ready for Working Group review. Activity highlights include: work with consulting sociologists to draft, test, and revise the project's question set for interviews; selection of collaborations for case studies; conducting the interview program; indexing transcripts according to historical themes; historical, archival and sociological analysis of interviews; surveys of academic and corporate archives; meetings on archival policy issues with key administrators at federal science agencies and the National Archives and Records Administration (NARA); meeting of the Phase III Working Group; development of policy recommendations for the long-term study; and dissemination of project findings at national and international conferences. Two final reports were prepared: a report specifically for Phase III and another covering the entire long-term project (Phases I, II, and III).[9]

II. *THE INTERVIEW PROGRAM*

A. *Question Set*

Project staff first drafted the question set for Phase III in September 1995; it was examined with our consulting sociologists and a flow chart was used to put questions in an order that would make sense to interviewees. The question set went through major revisions in response to the test interviews and ongoing experience. Unlike the Phase I and II question sets, fully half of the Phase III questions were closed-ended to improve prospects for obtaining data for sociological analysis. In its final form, the question set includes four major sections. The first is a short open-ended introduction that covers the general background of the interview subject and the origins of the collaboration. The second section is closed-ended and fully covers the collaboration's activities; it is designed to elicit easily codable information for the sociologists. Next is a short open and closed-ended section which deals with archival issues not covered previously. The final, fourth section is open-ended; here we return to most aspects of the project, this time with more depth and description to aid the historical analysis. Restructuring of the questionnaire was completed before the start of the full interview program. The final question set is in Attachment B-2.

B. *Selection of Case Studies*

For Phase III, we proposed to study uses of accelerators outside high-energy physics, ground-based astronomy, materials science, and medical physics and clinical medicine. We reviewed relevant programs of federal funding agencies and held meetings with agency program managers to ascertain the prevalence and significance of multi-institutional collaborations in the four fields. A total of eight visits were made to four agencies including the Department of Energy (DOE), the National Science Foundation (NSF), the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense, and the National Institutes of Health (NIH) and its National Cancer Institute (NCI). The agency program managers provided numerous suggestions for specific collaborations whose leaders, in their judgments, possessed valuable perspectives on collaborative activities. We also obtained a wealth of programmatic documents outlining the activities of several research facilities that are (more or less) frequently used by multi-institutional collaborations.

In general, we determined that the interview program for Phase III should include some currently operating collaborations so that the AIP Center could gain some understanding of the types of structures collaborations might

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[9] Joan Warnow-Blewett and Spencer R. Weart served as Principal Investigator and Co-Investigator. Staff included Project Historian Joel Genuth, Project Archivist until April 1997 Anthony Capitos, sociological consultants Wesley Shrum and Ivan Chompalov, and research assistants Martha Keyes and Drew Arrowood. AIP provided substantial support staff, primarily R. Joseph Anderson, but also including Sandra Johnson, Kiera Robinson, and Rachel Carter.

take in the near future. In addition, we conducted interviews on testbeds for the National Collaboratory—not a field, but rather a new technique for multi-institutional collaborations to form around, which appears to be a major advance in conducting collaborative research. Our particular focus in this category was the Upper Atmospheric Research Collaboratory (UARC), an international venture of researchers connected via computer link-up to each other and to instruments located in Greenland. The scope of the "miscellaneous" category of collaborations was expanded to include interviews on the Center for Research on Parallel Computation and the Grand Challenge Cosmology Consortium; we later dubbed this category "computer-mediated" collaborations.

Considerable time was spent collecting information on suggested collaborations in order to winnow down the possibilities to a manageable number. Project staff checked book and journal databases and Web sites, spoke with laboratory administrators, and—most importantly —spoke with participants in the suggested projects. The purpose was to ascertain whether the projects were multi-institutional in more than name, whether the projects were recent enough to be a plausible indicator of current trends (but not so new as not to have dealt with the administrative issues that affect the creation and retention of records), and to identify the most significant participants in the research. 24 projects were selected.

We agreed with the sociologists that we should interview three or four participants per collaboration. A list of 90 interview candidates was compiled; 78 were interviewed. One collaboration, comprised principally of corporations, had to be dropped because interview candidates encountered too many difficulties obtaining permissions to speak with us. Also, our coverage of medical physics collaborations suffered because of the reluctance of physicians to make time for full-scale interviews.

III. *ARCHIVAL WORK*

A. *Archival Findings*

Throughout the first half of Phase III, interview transcripts were analyzed for archival information. The results, entered into a custom-designed database, were combined on the project level to develop archival descriptions of each of the case studies. The cases were then combined to form descriptions by discipline. This information, along with data acquired through a repository questionnaire, provided the basis for the report on archival findings for the four fields covered in Phase III.

B. *Surveys of Academic and Corporate Archives*

Project staff continued to visit archives at institutions where we conducted interviews and where the AIP History Center had little or no prior contact. During this last phase of our long-term study, we also developed two formal questionnaires (for academic and corporate archives) to probe the size, stability, and willingness of these archives to accept records of multi-institutional collaborations.

The questionnaire for academic archivists was sent to 42 academic repositories. The list was compiled from the top quarter of the National Research Council's rated list of academic departments in physics, astrophysics and astronomy, geosciences, and oceanography. 38 responses were received. The survey instrument for research corporations was designed with the help of AIP sociologist Roman Czujko (director, AIP Education and Employment Statistics Division). A listing of 37 corporations that, taken together, employ nearly half the physicists in the private sector was the basis of our target group; phone calls identified 27 archivists, records managers, librarians, or other staff to be included in our corporate survey. We received a total of 19 responses to our 15-item questionnaire. Project staff plan to draw on these surveys for an assessment of strengths and weaknesses of the archival community that will be included in the forthcoming report covering the long-term AIP Study.

C. *Archival Variables*

AIP staff developed archival variables and coding schemes on the basis of information AIP compiled for each of the collaborations examined in the course of the entire long-term study. The six variables were: geographical dispersion of collaboration teams, quality of records retained, geographical dispersion of core records, sectors involved with the project, federal status of records, and the use of the World Wide Web as a communications tool. Products of this work appear in the sociological analysis section of the Phase III final report and the archival analysis section of the forthcoming report covering all three phases of the AIP Study.

D. *Archival Policy Issues*
Since the AIP's move in 1993 to College Park, meetings of AIP Center staff with staff of the National Archives and Records Administration (NARA) have become far more frequent. At our invitation, John Carlin, Archivist of the United States, visited the AIP and discussed preservation of science documentation. Warnow-Blewett participated in Carlin's meetings on the draft strategic plan of NARA and shared AIP's information on attitudes and practices of scientific agencies.

Throughout Phase III Warnow-Blewett and Anderson met frequently with administrators at federal science agencies and NARA. The long-range purposes of the meetings were to learn how the AIP History Center can: (1) persuade science agencies to upgrade their record schedules, (2) help improve relationships between these agencies and NARA, (3) get NARA to be more active with respect to scientific records, and (4) feed information from AIP field work more effectively to science agencies and NARA. Project staff also needed to learn implications of recent NARA administrative restructuring, involve NARA administrators in the development of the AIP Study's policy recommendations, and formulate plans for an archival subgroup of the AIP project's Working Group. Toward the end of Phase III, we initiated joint AIP-NARA visits to key science agency sites to explore ways agency procedures could be improved to the benefit of securing significant documentation.

The new DOE R&D records schedule—approved by NARA in August 1998—was a major breakthrough. At the request of NARA, Warnow-Blewett, Weart, and Anderson critiqued the schedule DOE had submitted for NARA's approval. The new schedule was a thorough revision that incorporated virtually all of the recommendations of AIP's earlier study of DOE National Laboratories and its current study of collaborations; Warnow-Blewett joined a DOE committee in making final changes to its R&D Records Schedule.

IV. *HISTORICAL ANALYSIS*
The AIP Study employed its list of historical themes as a tool to index the transcripts of its oral history interviews. Using these indices, Genuth, with the help of Keyes, analyzed interviews; Genuth next prepared summaries of individual cases in each field and then combined them into summary reports of historical findings for each of the fields covered in Phase III: ground based astronomy, materials science, uses of accelerators, and medical physics. Genuth's essays provided the basis of his report to the Phase III Working Group; the essays were further revised and corrected in response to the Working Group's criticisms and suggestions. During the process of the analytical work, we saw the value of dividing the field of ground-based astronomy into the two areas of telescope builders and telescope users and of transferring a number of case studies from the uses of accelerators category to the materials science category.

Genuth also prepared a paper presenting a classification scheme for collaborations based on all three phases of the AIP study. Overall, he found five forms of collaborations: technique-integrating collaborations, platform-driven collaborations, coalition collaborations, facility-creating collaborations, and facility-commandeering collaborations. Subsequent work will constitute a section of the forthcoming report covering all three phases of the AIP Study.

V. *WORK WITH SOCIOLOGISTS*
Warnow-Blewett led project efforts to identify and develop relations with an organizational sociologist to serve as a consultant for Phase III work. Our inquiries led us to Wesley Shrum of Louisiana State University and to his graduate student, Ivan Chompalov. Most of the sociologists' work was carried out in Baton Rouge, but there were regular meetings of the whole project staff at the AIP. The overall style of our staff meetings was for Shrum and Chompalov to present suggestions based on their expertise as sociologists and for project staff at AIP to critique their suggestions based on their knowledge of project field work and/or expertise as historians.

Early on Shrum suggested the project use qualitative comparative analysis, a technique which can generate enough data for quantitative analysis from the small set of selected case studies that the AIP will be comparing qualitatively. Chompalov prepared a discussion paper on various analytical techniques. He also coded the interviews after checking for intercoder reliability with Genuth and Capitos.

The sociological team created out of the 78 interviews a "collaborations file" with 23 cases. All important analyses were performed on this file. Data analysis was mainly oriented to the goal of producing a typology for multi-institutional collaborations. With typologies of collaborations identified, we began using these typologies as independent variables in one-factor analyses of variance (ANOVA) against important dependent (outcome) variables. Finally, qualitative comparative analysis (QCA) was performed with archival variables as outcomes.

Chompalov and Shrum re-examined their early bivariate results to highlight for the Working Group their three most important findings: (1) that field of research was unrelated to the organizational features of collaborations; (2) that the magnitude of collaborations was positively related to the formality of their management; and (3) that the level of formality was positively related to conflict and inversely related to trust. They also refined and revised the paper they had submitted to *Science, Technology, And Human Values* for presentation to the Working Group.

VI. *PHASE III WORKING GROUP*

Warnow-Blewett obtained commitments from distinguished representatives of the four fields under study to serve on the Phase III Working Group. (See cover 3 of this report for a list of the Working Group.)

The Working Group met on 29 May at the AIP in College Park, Maryland (except for the medical physicists, who met at a later date). Reports on research activities and draft findings were distributed in advance. The purpose of the meeting was to evaluate the historical and sociological analyses of Phase III work. Overall, the meeting was enormously beneficial for the project staff and consultants, and we dare say the Working Group members also profited.

Genuth summarized his reports and called the Working Group's attention to their weakest points. Among the constructive criticisms the Working Group offered in response, two stand out. First, our selection of ground-based astronomy collaborations did not include any cases of collaborations involving any of the national observatories, which insist that collaborations they participate in have more unified management than the ones we studied. This fact placed the organizational choices of the collaborations we studied in a new light. Second, our Phase I analysis of high-energy physics so well matched the situation in heavy-ion physics, which we included under the heading "uses of accelerators," that we restructured our Phase III reports so that the heavy-ion physics collaborations are a unit to themselves and the other accelerator-using collaborations are included with materials science collaborations. Consulting sociologists Shrum and Chompalov reported findings of their research. The Working Group questioned the sociologists' methodology. 23 cases seemed low to them as a basis for claiming robust statistical relationships, and they questioned our reliance on using only scientific and administrative leaders as informants, given that others in the collaboration could have much different views on whether a collaboration had serious conflicts.

Two senior administrators at the National Institutes of Health (NIH) provided our Working Group expertise on medical physics. When we met with them on 1 December they confirmed our depictions of the individual case studies and provided project staff with valuable insights on the NIH and its member institutes. They also expressed their belief that multi-institutional collaborations will become more important in the area of medical physics. There were no other revisions to our reports as a result of the meeting.

VII. *DISSEMINATION*

A number of papers and sessions on the AIP Study were presented during the period of the Phase III work. Five papers were given by Warnow-Blewett at annual meetings of the American Library Association (1995), the Department of Energy (DOE) Records Managers (1995), the Society of American Archivists (1995), NAGARA (National Association of Government Archives and Records Administrators) (1996), and DOE Records Managers (1998). Three sessions on the AIP Study were organized for annual meetings: the Society of American Archivists (1997), the 4S (Society for the Social Study of Science) (1997), and the History of Science Society (1998). Two sessions were organized for international meetings: the International Council on Archives (1995) and the International Congress for History and Philosophy of Science (1997). For more details see Attachment B-1.

Once the long-term study is completed, articles will be submitted for publication in such scholarly journals as *Historical Studies in the Physical and Biological Sciences*; *Science, Technology, and Human Values*; and the *American Archivist*. To broadcast project findings to the scientific community, we will submit articles and news items to a number of magazines, such as *Physics Today* and *Science*.

Articles reporting on progress and plans of the AIP Study were prepared for four issues of the Center's semiannual *Newsletter*. A final newsletter article will summarize project findings and recommendations.

Since its spring 1994 issue, the History Center has been including the full contents of its semiannual *Newsletter* on its Website (http://www.aip.org/history); through this vehicle, information on progress and plans of the AIP Study of Collaborations, along with other news, has had wide distribution. Also available on the Website is *Report No. 1: Summary of Project Activities and Findings/Project Recommendations* for the AIP Study Phases I (High-Energy Physics) and II (Space Science & Geophysics). We will also issue the reports for Phase III and the forthcoming report covering the long-term study (*Comparisons and Conclusions*) in a similar fashion.

As with the dissemination of final reports for Phases I and II, the final report for Phase III will be distributed to directors and key administrators at the science agencies and research facilities for the disciplines covered in the particular phase of the AIP Study. Once again we will take care to include key offices and institutions of the archival community.

The AIP Study of Multi-Institutional Collaborations: Comparisons and Conclusions—as the summary compilation of the findings, appraisal guidelines—and policy recommendations of all three phases, will be considered by many readers to be the definitive report of the AIP Study. The distribution list will span the full range of scientific disciplines covered in the long-term study and will include directors and administrators of the federal and private funding agencies and scientist-administrators at academic and other research institutes, as well as national and international policy groups. A second list will focus on archivists and others responsible for records; it will range from the Archivist of the U.S. to headquarters and field site archivist-records managers at science agencies at home and abroad, archivists at major science universities, and those responsible for records of national and international academies and other policy-making bodies.

VIII. *FUTURE ACTIVITIES*

It needs be noted that an important aspect of the AIP Study will be continued. NSF approved a proposal by Genuth, Shrum, and Chompalov to integrate information from Phases I and II into the data developed for Phase III. With this support for another year's work, part of the project staff remains intact and will build on the work of the AIP Study. They will code interviews from Phases I and II in order to create a data set that truly cuts across all fields of research covered in the AIP Study. Their findings will be presented in a book aimed at both scholars in the history and sociology of contemporary science and at policy-makers and administrators in research institutions.

Other future activities are long-term efforts. We have begun to refer to projects such as this study of collaborations as "documentation strategy research projects" for the very good reason that, once the projects are completed, the AIP Center and such agencies as the National Archives will be in a position to incorporate the new-found understanding (of collaborations, in this case) into an ongoing documentation strategy. We have focused on two categories of documentation: the first includes the summary records that should be saved for all multi-institutional collaborations and the second is concerned with the greater depth of documentation that historians and other scholars will need for those few very significant collaborations.

We will build on our knowledge that leaders of the scientific community are in the best position to identify multi-institutional collaborations of high importance—in terms of the significance of their scientific findings or their impact on the direction of scientific research. Consequently, we have taken the initial steps to arrange for meetings with disciplinary committees of the National Academy of Science - National Research Council for the purpose of identifying a sample of the most significant collaborations in recent years. With this information in hand, the AIP Center will make every effort to locate the records and arrange for their preservation at appropriate repositories.

DECADE-LONG AIP STUDY OF COLLABORATIONS COMPLETED

by Joan Warnow-Blewett

Published in the *AIP History Newsletter*, volume XXXII, No. 1, Spring 2000

Article also available online at http://www.aip.org/history/spring2000/collabs.html

The AIP Study of Multi-Institutional Collaborations that was launched in 1989 comes to completion this spring. Initiated by the AIP Center because of the increasing importance of large-scale research projects and the many unknowns and complexities of documenting them, the AIP Study was the first systematic examination of the organizational structures and functions of multi-institutional collaborations. Readers of this Newsletter may recall that we covered research projects involving three or more institutions in physics and related fields: high-energy physics (Phase I), space science and geophysics (Phase II), and ground-based astronomy, heavy-ion and nuclear physics, materials science, and medical physics (Phase III). Throughout the study our field work consisted—on the one hand—of structured interviews with scientists who participated in collaborations selected to serve as our case studies, and—on the other hand—of site visits to numerous archival and records management programs. The interviews provided data on organizational patterns, records creation and use, and the likely locations of valuable documentation. The archival site visits to academia, federal science agencies, the National Archives, and elsewhere provided data on existing records policies and practices and the likelihood of collaborations being documented under current conditions. Reports were issued at the end of each phase of the study and are available from the AIP Center (with summary reports also available on our Web site at http://www.aip.org/history/pubslst.htm.)

Since our last account of the AIP Study (see the Spring 1999 issue of this Newsletter), the final reports on Phase III work have been fully revised and are now available. The reports include historical and archival findings, sociological analysis, records appraisal guidelines, and project recommendations directed to academic archives, the National Archives, federal science agencies and other institutions.

Other major efforts of the past year have been aimed at the development of final reports covering the decade-long study. We drafted comparative historical and archival findings and appraisal guidelines, developed a typology of collaborations, analyzed our surveys of practices in academic and corporate archives, held meetings, and revised project recommendations. Draft reports were critiqued through a mailing to archivists. The final report, The AIP Study of Multi-Institutional Collaborations, will be ready for distribution in late spring. The publication will consist of a summary report (highlights of findings and project recommendations) and a main report in which readers will find a rich harvest of the decade-long study.

The last assignments of project staff are to write articles for newsletters and journals that will bring the study and its findings to the attention of archivists, historians, and—perhaps, most importantly—to physicists and a broader audience of scientists. A book summarizing and discussing key conclusions is in preparation by project consultants Ivan Chompalov, Joel Genuth, and Wesley Shrum, supported by a new grant to AIP from the National Science Foundation.

Meanwhile, the AIP Center will begin to implement the knowledge gained through its study of multi-institutional collaborations. The formal effort will be on two levels. We will work with scientists (discipline by discipline) to identify a selection of significant collaborations and then try to locate the valuable records and save them at appropriate repositories. Equally important will be efforts to improve the documentation of collaborations more generally by finding opportunities to support academic archival programs and upgrade records programs at federal science agencies.

The long-term AIP Study of Multi-Institutional Collaborations has been funded by the American Institute of Physics, the Andrew W. Mellon Foundation, the National Science Foundation, the National Historical Public Records Commission, and the Department of Energy. We are most grateful for their steadfast and generous support. I served as project director, Spencer R. Weart as associate project director, and Joel Genuth as project historian. For further information, contact the Center or e-mail Joan Warnow-Blewett, jblewett@aip.org.

DOCUMENTING MULTI-INSTITUTIONAL COLLABORATIONS

APPENDIX D: WORKING GROUPS FOR AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS

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AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS
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