AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS
PHASE III: GROUND-BASED ASTRONOMY, MATERIALS SCIENCE, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

REPORT NO. 2:

DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIALS RESEARCH, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

Joan Warnow-Blewett

Joel Genuth

Spencer R. Weart

AIP

Center for History of Physics • American Institute of Physics
One Physics Ellipse • College Park, MD 20740-3843
Tel: 301/209-3165 • Fax: 301/209-0882 • E-mail: chp@aip.org

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INTRODUCTION

The world is increasingly operating in the mode of large, temporary, multi-institutional projects. And this is particularly true for areas of the sciences where the organizational framework for research is the multi-institutional collaboration. Yet despite the fact that they have been the social framework for much research into our era's most pressing scientific issues, scholars have not given dedicated attention to these transient "institutions." Without a committed effort to understand such collaborations, current policy makers and administrators will continue to have only hearsay and their own memories to guide their management of these collaborations, and future scholars will have scanty, haphazardly-saved records from which to examine the science of our times.

The Center for History of Physics of the American Institute of Physics (AIP)—in keeping with its mission to preserve and make known the history of physics and allied sciences—is now completing a systematic examination of the process of multi-institutional collaborative research. The ultimate goal of the study is to make it possible for scholars, policy-makers, and others to understand the important practice of large-scale research collaborations. In order to locate and preserve the documentation, we need to know about the process of collaborative research and how the records are generated and used. Hence, the AIP Study of Multi-Institutional Collaborations is a broad preliminary survey, the first of its kind, into the functioning of research collaborations. We restrict ourselves to collaborations that have included three or more institutions. Our study is designed to identify patterns 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. We have structured the long-term study in three stages. Phase I, which focused on collaborative research in high-energy physics, was completed in 1992;[1] Phase II, which addressed collaborative research in space science and geophysics, was completed in 1995;[2] and

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[1] See *AIP Study of Multi-Institutional Collaborations. Phase I: 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. The reports are available upon request from the AIP Center; *Report No. 1* is also available on the AIP Center's Web page (http://www.aip.org/history/).

[2] See *AIP Study of Multi-Institutional Collaborations. Phase II: Space Science & Geophysics.* College Park: American Institute of Physics, 1995. *Report No. 1: Summary of Project Activities and Findings/Project Recommendations*, by Joan Warnow-Blewett, Anthony J. Capitos, Joel Genuth, and Spencer R. Weart. *Report No. 2: Documenting Collaborations in Space Science and Geophysics*, by Joan Warnow-Blewett, Anthony J. Capitos, Joel Genuth, and

Phase III's study of four new disciplinary areas and a category we named computer-mediated collaborations is completed with this report. Yet to come is a final report, "AIP Study of Multi-Institutional Collaborations: Comparisons and Conclusions." It will focus on comparative studies of all the fields studied under the long-term project as well as the broad questions of documentation policy and practice.

The disciplinary areas covered during Phase III were ground-based astronomy, materials science, heavy-ion physics, and medical physics. For these areas, we selected 21 collaborations to serve as our case studies; an additional three collaborations were selected for our computer-mediated category. In our choice of projects for this third, and final, phase of the long-term study, our approach was to make a conscious effort to look toward the future. For the most part, this meant that we would not require that our case studies consisted of collaborations that had published some research findings. This effort also inspired the inclusion of the computer-mediated category of collaborations in which new techniques of computer science and technology provide a core aspect of the research; these new strategies offer glimpses into the design of future scientific collaborations. Altogether 78 interviews with scientists who could serve as "informants" were conducted; interview transcripts were analyzed for historical and archival information. The work of sociologists was integrated into our historical and archival efforts; in particular, the sociological team analyzed all project interviews and produced a typology for multi-institutional collaborations. Finally, the project staff conducted numerous site visits to Federal science agency and the National Archives and Records Administration to discuss archival issues and records policies.

This report is divided into four sections. Section One is a short description of the selected projects. The second section is a historical report, which examines various organizational dimensions and functions of multi-institutional collaborations and their evolution in recent decades. Section Three is the archival analysis and appraisal guidelines to assist archivists and others who have responsibilities for selecting records for long-term preservation or destruction. The fourth section consists of the AIP Study's sociological analysis of the fields covered in Phase III. Two appendices provide acronyms and report on project activities.

These reports are designed to help responsible parties develop appropriate goals and set priorities to save the records of greatest historical value. While the historical and sociological findings provide an understanding of how multi-institutional collaborations function, the archival analysis—and, especially, the appraisal guidelines—point to the few sets of records that provide core documentation. These tools should make more effective the design and implementation of realistic and useful plans and the selection of the records that will be needed by scholars, policy-makers, and others.

Spencer R. Weart with contributions by Frederik Nebeker, Lynne Zucker, and Michael Darby. The reports are available upon request from the AIP Center; *Report No. 1* is also available on the AIP Center's Web page (http://www.aip.org/history/).

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SECTION ONE: SELECTED CASE STUDIES

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Listed below are summary descriptions of the 23 multi-institutional collaborations we selected for study. We have divided them into six categories: ground-based astronomy observatory builders, ground-based astronomy users of observatories, materials science, heavy-ion and nuclear physics, medical physics, and computer-mediated collaborations.

GROUND-BASED ASTRONOMY—OBSERVATORY BUILDERS

Astrophysical Research Consortium (ARC)

A collaboration of the University of Chicago, University of Washington, Washington State University, Princeton University, and New Mexico State University to build an optical telescope approaching national-observatory capabilities at 1/4 to 1/3 the cost. Subsequently, the collaboration added Johns Hopkins University and the Institute for Advanced Study to develop a digital sky survey project that did not include New Mexico State or Washington State. The observatory is at Apache Point, New Mexico; the observatory director is at the University of Chicago; the consortium is legally incorporated in the state of Washington. Universities contributed their own funds to cover most of the costs of the telescope, but the National Science Foundation (NSF) funded site development and contributed a mirror whose design and construction it was independently supporting. The Sloan Foundation pays for half the costs of the sky survey, whose formal title is the Sloan Digital Sky Survey (SDSS). The optical telescope was in operation and SDSS was in construction at time of interviewing.

AIP Focus: Both design and construction of 3.5 m telescope and the design of SDSS

Start and End Dates: ARC incorporated in 1984; still exists.

Team Definition: Dual definitions: By institution for observing time on the 3.5 m telescope; and by role (site development, instrument building, observatory construction, etc) for design and construction of both the 3.5 m telescope and the SDSS.

Berkeley-Illinois-Maryland Array (BIMA)

A consortium of the University of California at Berkeley, the University of Illinois at Urbana-Champaign, and the University of Maryland at College Park to build and operate a hard-wired array of antennae that will together function as the world's highest-resolution radio telescope at millimeter wavelengths. The array is at Hat Creek, where Berkeley has long maintained radio-astronomy facilities, but is operated remotely from the three member organizations. Work began in 1985. Six antennae are in operation, three more are planned, and another three are hoped for. 60-65 scientists (including graduate students) and engineers participate at any time. Funding is from the universities themselves and NSF.

AIP Focus: Design and construction of the array.

Start and End Dates: Consortium founded 1987; still in operation.

Team Definition: Each institution had a principal design and construction role.

Hobby-Eberly Telescope (HET)

A collaboration of the University of Texas at Austin, Pennsylvania State University, and Stanford University in the United States and the Universities of Munich and Göttingen in Germany to build an optical telescope and scientific instruments. The telescope will have limited tracking ability but will yield eight-meter class observing power for an order-of-magnitude less cost than a comparable telescope with full tracking abilities. Interested researchers at member organizations number about 50. The funding all comes from the member organizations. The telescope was under construction at the University of Texas' McDonald Observatory at time of interviewing.

AIP Focus: Design and construction of telescope; scientific instruments were not well developed at time of interviewing.

Start and End Dates: The telescope design was conceived in 1981; Penn State and Texas began informally collaborating in 1985; and the collaboration was formalized in 1992. The collaboration is still in operation.

Team Definition: By institution for observing time; multi-institutional teams are designing and developing scientific instruments.

Keck Observatory

A collaboration of the California Institute of Technology and the University of California system (with Berkeley and Santa Cruz being the dominant campuses and Lawrence-Berkeley Laboratory being a major participant) and secondarily the University of Hawaii and NASA to build and operate two 10 meter telescopes in Hawaii. Project management done by the California Association for Research in Astronomy, which was created for the purpose of building the observatories; science management came from both LBL and Santa Cruz. The construction has been principally funded through gifts from the Keck Foundation to Caltech; operations are principally funded by the University of California. Over $90 million has been spent. One telescope has been in use for astronomy since 1993; the second recently took first light.

AIP Focus: Principally the telescope and secondarily its scientific instruments.

Start and End Dates: Ideas for a large telescope began circulating among University of California astronomers in late 1970s, and Caltech joined discussions around 1984. Collaboration is still operating.

Team Definition: Observing time allocated on institutional basis. Multi-institutional groups designed and built scientific instruments.

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

Sagittarius-A

A collaboration of MIT Haystack, the University of California at Berkeley (Hat Creek Observatory), the California Institute of Technology (Owens Valley Observatory), the National Radio Observatory, the National Radio Astronomy Observatory, and the Harvard-Smithsonian Center for Astrophysics, to observe an intense radio source through VLBI at 3.5 mm wavelength. The collaboration has no physical location; it used the antennae at Owens Valley, Kitt Peak, and Haystack. 11 scientists participated. The collaboration itself was not explicitly funded, but the member organizations had funding from NSF or NASA. The collaboration has disbanded but can reconstitute itself.

AIP Focus: Observations of Sagittarius A.

Start and End Dates: Data taken and processed in 1994; presumably proposals submitted in 1993. Some participants may still be individually working on the data, but the collaboration has effectively disbanded.

Team Definition: The groups that made each participating observatory work.

Three Millimeter Very Long Baseline Interferometry (3 MM VLBI)

An effort of the California Institute of Technology (Owens Valley Radio Observatory), the University of California at Berkeley (Hat Creek Radio Observatory), MIT (Haystack Observatory), the Harvard-Smithsonian Center for Astrophysics, the University of Massachusetts, and Onsala (Sweden) Space Observatory to demonstrate the feasibility of VLBI at order-of-magnitude lower wavelengths than previously used. The collaboration has around 20 participants and no physical location. The collaboration itself was not explicitly funded, but American participants and organizations individually had funding from NSF, NASA, and the California Space Institute. The collaboration has disbanded but can reconstitute itself.

AIP Focus: The first successful observations at a wavelength of 3.4 mm (reported in *Nature*, 1983).

Start and End Date: All data were taken in 1981. Proposals were presumably drafted in 1980. Once the data were processed, the collaboration effectively disbanded.

Team Definition: The groups that tried to make each participating observatory work.

Very Long Baseline Interferometry Consortium (VLBI)

A consortium of MIT (Haystack), Harvard (Harvard-Smithsonian Observatory), the California Institute of Technology (Owens Valley Radio Observatory), the University of California Berkeley (Hat Creek Radio Observatory), and the University of Iowa with the National Radio Astronomy Observatory, the Max Planck Institute for Radio Astronomy, and the Onsala (Sweden) Space Observatory as “associated members” to regularize use of these observatories for very long baseline interferometry at *centimeter* wavelengths. As many as 80 scientists attended open meetings for consortium members and external users. The consortium has had a long-standing treasurer, but the positions of chairman and secretary/scheduler have rotated. NSF and collaboration members provided the (very modest) funds the collaboration needed.

AIP Focus: The consortium and not the individual observations made under its auspices.

Start and End Dates: Discussions in 1974 led to forming the consortium in 1975. The consortium disbanded over time as the stations of the Very Long Baseline Array came on line, beginning in 1989.

Team Definition: The staffs of the participating observatories.

III. *MATERIALS SCIENCE*

Center on Polymer Interface and Macromolecular Assembly (CPIMA)

A collaboration of Stanford, IBM-Almaden, and the University of California at Davis to support and coordinate research on polymer interfaces and macromolecular assemblies. The collaboration has no physical location beyond an office at Stanford. Roughly 20 faculty-level scientists and 40-45 postdocs and graduate students participate. Funded by NSF as a Materials Research Science and Engineering Center under the Division of Materials Research. Collaboration is still operating.

AIP Focus: The collaboration as a whole.

Start and End Date: Formally established in 1994 with funding for five years renewable for another five.

Team Definition: By research area with three "Interdisciplinary Research Groups" with multi-institutional memberships.

Hybrid Organic/Inorganic Semiconductors (HOIS)

A collaboration of Princeton, the University of Southern California, Hughes Laboratories, IBM, and the University of Colorado to study the semiconducting properties of various composites and the potential for using composites in manufacturing. The collaboration has no physical location. Princeton provided financial administration. Around 20 individual participants. Funded by ARPA under the Advanced Materials Processing Program. Collaboration has disbanded.

AIP Focus: The collaboration as a whole.

Start and End Dates: Approximately 1992-1996.

Team Definition: By scientific interest with Princeton, USC, and Hughes initially concentrating on crystalline organics and IBM and Colorado on polymers.

Smart Materials Consortium (SMC)

A collaboration of Martin Marietta Baltimore, Lockheed Palo Alto (now Lockheed-Martin), AVX (a ceramics manufacturer in Myrtle Beach, SC), Martin Marietta Astronautics Denver, the Naval Research Laboratory, BDM (an engineering and consulting firm outside Washington, DC), and the University of Maryland, Johns Hopkins, the University of Virginia, and Clemson to develop a better vibration-canceling device. The project was managed from Martin Marietta Baltimore, which no longer exists as a result of Lockheed's purchase of Martin Marietta. 30 plus people worked on the project at any given time. Funded by ARPA under a new "agreements authority" granted to DOD in 1993 legislation, with cost-sharing from the corporate participants and modest grants from state governments to the universities. The collaboration has disbanded.

AIP Focus: The collaboration's management and the main industrial participants.

Start and End Dates: Funding began in 1992; ended in 1997.

Team Definition: By institution and position in the process of fabricating a new device from novel materials.

NSF Science and Technology Center for Superconductivity (STCS)

A collaboration of the University of Illinois at Urbana-Champaign, Northwestern, the University of Chicago, and Argonne National Laboratory to support and coordinate their research into high-temperature superconductivity. The collaboration has no physical location beyond an administrative office at the University of Illinois. Roughly 40 faculty-level scientists and 60 postdocs and graduate students participate. Funded by NSF from its Office of Science and Technology Infrastructure. The collaboration was in operation at time of interviewing.

AIP Focus: The collaboration's overall management; little attention was given to particular lines of research.

Start and End Dates: Formal beginning in 1989; NSF funding was secure through 1999.

Team Definition: By research specialty; teams were multi-institutional.

Advanced Light Source Beamline Collaboration (ALS)

A collaboration of IBM-Almaden, the University of Wisconsin, Tulane, the University of Tennessee, Lawrence-Berkeley Laboratory, and Lawrence Livermore National Laboratory to build a beamline and end stations for materials science and surface physics at the Advanced Light Source at LBL. The leaders of the Wisconsin and Tulane contingents began their involvement at IBM-Yorktown and the National Institutes for Standards and Technology, respectively. IBM-Almaden later brought in San Jose State and Uppsala University (Sweden). All data are taken at LBL. Around 15 scientists work with the beamline at any given time. Each participating organization raises its own funds; IBM funds itself. The collaboration consists of three multi-institutional teams—IBM-San Jose-Uppsala, Tulane-Tennessee, and Wisconsin-LLNL—which each instrumented its own "end station" for the beamline.

AIP Focus: The beamline and two of the end stations, not the accelerator itself.

Start Date: Proposals drafted in 1990; collaboration was still operating at time of interviewing.

Team Definition: The groups that built individual "end stations" for detecting the outcomes from beam-target interactions.

Crystal Structure of CTA AND CTP

A collaboration of the State University of New York at Stony Brook, Brookhaven National Laboratory, and the DuPont Company to determine the structure of a group of curious crystals with potentially useful properties. The crystals were synthesized at DuPont and experimented with at both Stony Brook and Brookhaven (using both the National Synchrotron Light Source and the High-Flux Beam Reactor). 10-15 individuals participated. The only dedicated funding was from DuPont to Stony Brook to hire a postdoc to be responsible for obtaining data using Brookhaven's facilities. The collaboration has disbanded.

AIP Focus: The measurements made to determine the structure and explain the properties of the crystals; not the beamlines used and not the initial synthesis of the crystals.

Start and End Date: Collaborative work began in 1993. Major paper published in 1995, which concluded the collaborative work.

Team Definition: By institution and skill/specialty.

DuPont-Northwestern-Dow Collaborative Access Team (DND-CAT)

A collaboration of the named organizations to build and use a general-purpose beamline and multiple end stations at Argonne's Advanced Photon Source. The collaboration has an office at Argonne, where all data will be taken, though some significant end-station instrumentation is being built at the home organizations. Around 7-8 million will be spent on construction and 1 million a year on operations. Each participating organization contributes a set share of the funds. A CAT staff of six scientists and engineers, whose salaries are paid out of project funds, is building the beamline for some 20 obviously interested users and a larger pool of potentially interested scientists who are employed at the participating organizations. Beamline was still under construction when interviews were conducted.

AIP Focus: Overall organization and development of beamline; less stress on end station instrumentation.

Start and End Date: Formal agreement to collaborate was signed in 1991; collaboration still operating.

Team Definition: By scientific specialty for development of end-station instrumentation; by institution for allocation of beamtime.

Positron Consortium and Participating Research Team (PC)

The collaboration was initially a consortium of Brandeis University, the City University of New York City College, Bell Laboratories, Brookhaven National Laboratory, and Norwich University (England). It later became a Participating Research Team (PRT) with less City College involvement and the addition of Bielefeld University (Germany). Its purpose was to build and use a positron beamline and end stations using Brookhaven's high-flux beam reactor (HFBR) to create an intense source of positrons. As a consortium, the collaboration operated under a single grant from NSF with indirect support from DOE and Bell Laboratories through the time that its people dedicated to the consortium; as a PRT, each institution in the collaboration was responsible for its own funding. All data are taken at Brookhaven. 12-15 people participated at any given time. Collaboration was still operating at time of interviewing.

AIP Focus: Development of communal beamline and the positron microscope developed by Brandeis for use with the beamline.

Start and End Dates: Consortium began work in 1984. Shutdown of HFBR in 1996 has suspended the collaboration's work.

Team Definition: Variable. More by scientific interest in the consortium; more by development and control of end-station instrumentation in the PRT.

IV. *NUCLEAR AND HEAVY-ION PHYSICS*

BNL 814 and 877

A collaboration of Brookhaven National Laboratory, the State University of New York at Stony Brook, McGill University, the University of Pittsburgh, the University of Sao Paulo, and Wayne State University (and other organizations that have come and gone) to build and use a detector for the study of particles created in collisions of various ions. The collaboration takes data at the Alternate Gradient Synchrotron at Brookhaven. 40-50 participants. Collaboration's detector construction funded by DOE through a central account at Brookhaven; operations, travel, and other expenses funded through participating institutions. The collaboration is still in operation.

AIP Focus: The entire string of experiments.

Start and End Date: First proposal circa 1986; collaboration still operating.

Definition of Team: Participating institutions assigned responsibility for detector components.

BNL 878 and 896

A collaboration with a nucleus of Lawrence Berkeley Laboratory, the University of California at Berkeley, the University of California at Los Angeles, Brookhaven National Laboratory, Johns Hopkins, Goddard Space Flight Center, the University of Michigan, and Yale. The collaboration has performed a series of experiments using Brookhaven's heavy-ion beam to investigate matter built up from strange quarks. 878 was preceded by 858, which had fewer members. Also participating in 878, but not 896, were Columbia, the University of Tokyo, and Waseda University (Japan). Also participating in 896 but not 878 were Carnegie Mellon, the University of Catania (Italy), CERN, McGill, Ohio State, Rice, the University of Texas at Austin, and Wayne State. About 75 participants in 896. 878 has finished taking data but analysis is ongoing; 896 is still running.

AIP Focus: The last two experiments in the string.

Start and End Date: Funding began in 1988; the collaboration is still in operation.

Team Definition: Participating institutions took responsibility for individual detector components.

V. *MEDICAL PHYSICS*

Angiography Diagnostics

A collaboration of Stanford University High-Energy Physics Laboratory, Stanford University Medical School (and affiliated hospitals), Stanford Linear Accelerator Center Synchrotron Radiation Laboratory (SSRL), Lawrence Berkeley Laboratory (LBL), Brookhaven National Laboratory (BNL), and the State University of New York at Stony Brook Medical School to develop a non-invasive technique for imaging coronary arteries. Approximately 15 participants at any time. Funding from the Kaiser Foundation, NIH, and DOE. The collaboration initially took data at SSRL but moved operations to Brookhaven.

AIP Focus: Development and use of beamline and detectors for angiography.

Start and End Dates: Work began in 1979 and is ongoing.

Team Definition: By functional specialization and institutional affiliation—beamline development (SSRL and BNL), detector development (LBL), data processing and analysis (Stanford Physics with medical input), clinical diagnosis (Stanford Medical School and the hospitals).

National Digital Mammography Development Group (NDMDG)

A collaboration of the Sunnybrook Medical Center (a hospital affiliated with the University of Toronto Medical School), General Electric, the University of Chicago, the University of North Carolina Hospital, Thomas Jefferson University (medical school and affiliated hospital), and Massachusetts General Hospital to develop and test two systems for digital mammography against each other and against analog mammography. Sunnybrook subcontracts for design and manufacturing of its system to Fischer Electronics, which effectively functions as another collaboration member. Collaboration has no central place to take data, but Sunnybrook provides coordination services. About 30 participants, excluding technicians that assist in the manufacture of hardware. National Cancer Institute funds collaboration with some in-kind contributions from General Electric. Project involves hardware development, image processing, clinical trials, and teletransmission.

AIP Focus: Development of instrumentation, image-processing, and computer-aided diagnosis.

Start and End Date: A 1991 workshop stimulated submission of proposals; collaboration was still operating at time of interviews.

Team Definition: By institution and role—hardware development, software development, clinical evaluation.

Radiology Diagnostic Oncology Group (RDOG)

A series of collaborations with overlapping memberships to assess the efficacy of various radiological techniques and modalities for diagnosing cancers of various organs. Harvard Medical School and the American College of Radiology (ACR) have respectively done the statistical analyses and data processing for all RDOGs; the collaboration has no physical location but ACR is the headquarters for administration and records. RDOG principal investigators come from the radiology departments of various medical centers. About 25-30 intellectually engaged people in each RDOG study and perhaps an equal number performing specialized tasks. Funding from the National Cancer Institute.

AIP Focus: RDOGs 1, which was devoted to prostate and lung cancers, and 2, which was devoted to pancreas and colon cancers.

Start and End Dates: RDOG 1 began in 1986; RDOG 5 in progress at time of interviewing.

Team Definition: By institution.

VI. *COMPUTER-MEDIATED COLLABORATIONS*

Center for Research in Parallel Computation (CRPC)

A collaboration of Rice, the California Institute of Technology, the University of Tennessee at Knoxville, the University of Texas at Austin, Argonne National Laboratory, Los Alamos National Laboratory, and the Northeast Parallel Architectures Center at Syracuse University to develop ways of making parallel computing as easy as supercomputing. The Center's director and administrative headquarters are at Rice. Around 50 faculty-level participants and perhaps 200 overall at any one time. Core of funding from NSF's Office of Science and Technology Infrastructure; additional funding from a host of agencies that support the Center-relevant work of individual Center members. Collaboration began operating in 1989 and is ongoing.

AIP Focus: CRPC's overall structure; little attention to individual lines of research.

Start and End Date: Formally established in 1989; collaboration still in operation.

Team Definition: By research area with six multi-institutional groupings of participants.

Grand Challenge Cosmology Consortium (GC3)

A collaboration of Princeton, MIT, the University of California at Santa Cruz, the University of Illinois and the National Center for Supercomputer Applications (NCSA), the Pittsburgh Supercomputing Center (PSC), and the University of Indiana to develop and use computation techniques for simulating cosmological processes. About 35 participants. Funding from NSF through the High Performance Computation and Communications Program, but ARPA has contributed money to both NSF and NASA programs for high-performance computing.

AIP Focus: Entire collaboration.

Start and End Dates: Funding began in 1993; collaboration was in operation at time of interviewing.

Team Definition: Institutional as determined by the PIs' scientific interests.

Upper Atmosphere Research Collaboratory (UARC)

A collaboration of the University of Michigan, the Stanford Research Institute, Lockheed Palo Alto (now Lockheed-Martin), the University of Maryland, and the Danish Meteorological Institute to develop software that enables scientists to use remote instruments at the Sonderstrom facility in Greenland, coordinate their use of the remote instruments, and to merge individual data sets. Funding from NSF's computer science and atmospheric science directorates. About 30 people participate actively in the creation or use of the software.

AIP Focus: UARC as a whole. UARC is one of several projects that serve as "test beds" for a "national collaboratory;" we did not investigate the other projects in this program.

Start and End Dates: Funding for UARC began in 1992; still in operation at time of interviewing.

Team Definition: By institution responsible for each instrument in Greenland plus additional University of Michigan teams for software and social science.

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SECTION TWO: HISTORICAL ANALYSIS

Joel Genuth

SECTION TWO: HISTORICAL ANALYSIS

I. *INTRODUCTION*

In Phase III of the AIP Study of Multi-Institutional Collaborations, we conducted 78 structured interviews on 23 selected cases from five areas of physical research: ground-based astronomy, materials science, heavy-ion physics, medical physics, and "computer-mediated collaborations"—a term we invented to cover collaborations that develop or exploit computation capabilities for physical research. This interview program provided a different basis for historical analysis than did the interview programs in Phases I and II, where we intensively examined collaborations in one or two disciplines. To cover five areas without greatly extending the length and cost of Phase III, we accepted the challenge of reaching reliable conclusions with a less intensive collection of data than we had undertaken in the previous two phases.[3] The total number of interviews conducted was reduced, the number of collaborations investigated was increased, and thus the number of interviews conducted per case was severely reduced. Furthermore, we increased the number of close-ended questions in the question set to elicit larger numbers of readily coded responses for sociological analysis and consequently reduced the number of open-ended questions that elicit responses for qualitative analysis. Even with these limitations, it still proved possible to construct narrative accounts for the individual selected cases, to identify patterns in those accounts for most of the five areas of research,[4] and to provide the basis for archival implications from the accounts.

II. *GROUND-BASED ASTRONOMY: OBSERVATORY BUILDERS*

Only universities were charter members of all of these collaborations, in most cases, and only universities have been full institutional members. In only one of our cases (ARC) did the collaboration invent a less-than-full-member category 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 (HET), but securing government funding was not a pre-requisite to formalizing a collaboration and initiating work.

Our sample did not include any collaborations that included 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.

A. *Project Formation*

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

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[3] See Report No. 1, Section One, Part I for a description of the goals and methodology for this phase of the long-term study.

[4] The exception is medical physics where we only had three collaborations in our sample and had difficulty eliciting cooperation from participants in our selected cases.

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 estimated construction costs 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 (Keck). 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 (ARC).[5] 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 (HET). Another built a smaller-than-national observatory that covered a frequency range for which there was no dedicated national observatory (BIMA).

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 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 try 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 (ARC). In another case, deans and department chairmen who were frustrated with a local history of argument and uncertainty over how to

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[5] 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.

recapitalize astronomy threw their weight behind collaborating with other universities that had well-articulated plans for a new observatory (BIMA). 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 (HET).

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.)

B. *Organization and Management*

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 (ARC); in the rest, representation reflected the relative sizes of the members' contributions. The Boards met at least twice a year and as often as six times a year.[6]

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 became more inclusive 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.

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[6] I am including conference calls in this tally. In one case (ARC), the Board met face-to-face only once a year; in no instances did a collaboration operate without any face-to-face Board meetings.

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 services from 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 (Keck and HET) 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 to be let, 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 in which scientists were building a technologically novel component that was organic to the observatory's systems engineering (Keck). 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 (ARC), 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 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 (BIMA) went beyond the moderately professional 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. And 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.[7] Graduate students and postdocs were heavily relied on to perform labor that could have been done by construction workers.

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 efficiency and maintaining their individual institutions' prerogatives and traditions. None of the collaborations we studied went so far towards centralization 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 an active decision-making body.[8]

C. *Activities of Teams*

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 (Keck, HET, and ARC) 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 (BIMA) centralized consideration of observing proposals. Scientists

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[7] 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.

[8] This finding would certainly have been different had our sample included collaborations involving AURA-managed observatories. AURA appoints a "project director" with the power to make decisions when engineering and scientific interests 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 that contribute financially to the project resolve intra-project disputes.

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 a highly or moderately professionalized collaboration, the scientists from member institutions participating in the collaboration's Science Steering/Advisory Committee had only an advisory role in the development and construction of the observatory, but the Committee was still 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,[9] their engineering interfaces with each other were trivial or non-existent, 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.

D. *Internationalism*

All of these collaborations 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 (HET) and Taiwanese (BIMA) 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 (ARC). 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.

E. *Data Analysis*

Use of all of these observatories has been determined by judgement of proposals submitted by scientists from member institutions. Thus none of the collaborations actively managed the topics

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

addressed through the use of its facilities. However, the Board itself of the self-managed collaboration has considered instigating large observing projects that would require several scientists to coordinate their efforts.

Observatory operations have been the primary collective computational problem faced by these collaborations. One (ARC) attempted to develop the software for remote operation of the telescope. Another (Keck) relied on computerized controls to manage an observatory with more moving parts than usual.

In three of the cases, the collaborations have left data processing and analysis almost entirely in the hands of individual observers, who are expected to figure out how to process data from technical documentation provided by instrument builders and from talking to other observers. 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 data acquisition system to accommodate other software packages that observers might prefer to use on their data.

F. *Dissemination*

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. All decisions about publication and allocation of credit have been in the hands of observers.

G. *Social and Scientific Significance*

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 as well as was initially specified, 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 to astronomy of three of the observatories 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 organizational approach to managing observatory development.

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

These collaborations 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.[10]

A. *Project Formation*

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 having to rely on one another for seeing to the technicalities of getting one another's observatories to operate well enough to support interferometry; observatory directors did not want to continue worrying how their observatories' comparative productivity was being affected by the extra observing time interferometry users needed to configure an observatory for interferometry and then reconfigure it

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

for independent observing. To resolve these difficulties, the 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 (VLBI Consortium); the second involved the continued use of informal collaborations for observations that attempted to expand the wavelength regime in which interferometry was possible (Sagittarius A and 3-millimeter VLBI). 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 interested astronomers 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.)

B. *Organization and Management*

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

The formal collaboration 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 to provide the officers with a collective sense of what were the most significant and widespread obstacles to more successful and more sophisticated observations.

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.

C. *Activities of Teams*

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 formal 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 in time for the designated observing time.

Neither type of collaboration 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.

D. *Internationalism*

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 the 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.

E. *Data Analysis*

Only the informal collaborations made data analysis a collaboration activity. Processing and analysis of data from observations made through the services of the formal consortium benefitted from the fact that the consortium kept the quantity of VLBI observations in line with the capacity of the correlators to process the data. But the consortium set no standards and provided no technical support for the correlation of the data. The scientists who won observing time through the consortium were on their own for the processing and analyzing of their data.

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.

F. *Dissemination*

The formal consortium and its officers played no role in dissemination of scientific results; all decisions 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.

G. *Social and Scientific Significance*

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

These two types of collaborations, plus the Very Long Baseline Array, 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 purpose of collaboration 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 formalized collaboration withered, though it could be revived should the technically ambitious whet the appetites of many astronomers for VLBI observations at wavelengths that the VLBA cannot reach.

IV. *MATERIALS SCIENCE*

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, and we are here discussing all the materials science collaborations we researched. Consequently, this section is considerably longer than the "Uses of Accelerators" section, which now includes only two collaborations in heavy-ion physics.

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 collaborations, and were major participants in all but one. 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.

Funding arrangements varied significantly. 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.

Materials science, outside its recent use of accelerators, has traditionally been "little science." Usually individual institutions petition NSF 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.

A. *Project Formation*

All the collaborations that did not use accelerators owed their existence partly to ferment in the politics of funding agencies. A new NSF program (Science and Technology Centers, which have been run from the Office of Science and Technology Infrastructure), change within NSF's Materials Science program, and the Defense Advanced Research Project Administration's (DARPA) exercise of new legislative authority have all stimulated materials scientists to collaborate across institutions. None of these collaborations began as unsolicited proposals for collaborative ventures, and participants in only one of these cases reported that their collaborative proposal had been preceded by an unsolicited non-collaborative 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. Although materials scientists would not have created organized 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 (DND and ALS) 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 (Positron). 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 (Crystal). 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 high-energy 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 (Positron). 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 (CPIMA and HOIS), neighboring university and industrial scientists formed the nucleus of a collaboration; in one case (STCS) neighboring university and FFRDC scientists formed the nucleus; and in one case (SMC) 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 (HOIS and SMC) 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 (Positron, Crystal), consulting relationships (DND), and prior collaboration at another accelerator laboratory (ALS) 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 (DND, ALS), 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; or they submitted a proposal with fewer collaborators than seemed desirable and let the accelerator laboratory's management match them with complementary proposals.

As with most other collaborations, drafting a proposal was the central challenge to the formation of all materials science collaborations. 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 to bringing to bear 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 (SMC and HOIS) which were both DARPA-funded, included corporate laboratories with competitive economic interests, and one (Smart Materials) 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 (CPIMA, and STCS) 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 (DND), the collaborators had no difficulty in establishing conditions for taking proprietary data or using proprietary instrumentation in conjunction with the collaboration's instrumentation.[11]

B. Organization and Management

Ultimate authority for three of the four non-accelerator collaborations (CPIMA, STCS, and SMC) was vested in an inter-institutional board, which was usually called the Board of Directors. (In the fourth case [HOIS], 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 others 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.

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[11] 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.

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 has 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 (Positron). Initially, this collaboration tried to function as a unified organization, and recapitulated the roles and structures of a high-energy physics experiment.[12] A collaboration-wide proposal for funding led to a partial centralization of the funds available. The scientist who was most responsible for convincing the involved scientists to collaborate and who was overall principal investigator on the collaboration-wide proposal led discussions of collaboration affairs (though he was not referred to by participants as a spokesperson). The participants met frequently because they all wished to spend time at the accelerator laboratory and none was so distant as to make occasional trips prohibitive. They operated the beamline collectively, even though their detectors did not have to be elaborately integrated, and assumed that discussions would lead to consensus on what targets to put in the

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[12] Corporations that participate in collaborations normally insist on safeguarding their interests in ways that limit the collaboration's ability to function as a unified organization, but in this case the corporate scientists participated as individuals with their corporation disavowing any responsibility for the research program should the individuals' terminate their involvement.

beam and what detectors to use. The scientist at the laboratory oversaw development and integration of the beamline components and the installation of the individual targets and detectors. This organizational framework broke down because of both intra-collaboration disagreements and because the accelerator laboratory's management insisted on strict compliance with intrusive safety standards. The collaboration reconstituted itself to grant much more autonomy to its component members along the lines of 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 (STCS and CPIMA) 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 (STCS and CPIMA) 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 (STCS) 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 (SMC and HOIS) 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 than was the case with the NSF-funded collaborations. Both of these 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 (SMC) 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 (HOIS) 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 DARP 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 (HOIS) 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 (DND CAT), 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. (In practice, the former responsibility was more onerous than the latter because many of the scientists at the member institutions were medical and life scientists without the sophistication to question staff about how best to design a beamline.) Annual Board meetings were the principal form of oversight for assessing the staff's progress, for setting any new directions necessitated by the need to comply

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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.

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, (LBL-ALS Beamline) 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 the spokesperson recruited to design and procure this component took charge of overall beamline construction. However, these roles did not have the significance of their namesakes in high-energy physics experiments, because there were so few collective issues once the beamline was operational. Each team built its own "end station" in which to do its own experiments with its own instrumentation. An annual collaboration meeting in conjunction with the accelerator's (ALS) Users Committee meeting has been sufficient to keep the collaboration sufficiently coordinated. (A laboratory-employed scientist has 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 (Crystal). 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.[14] 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.

C. *Activities of Teams*

"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 (CPIMA, STCS, and HOIS) did directly

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[14] In many respects, this collaboration resembles astronomy collaborations performing very long baseline interferometry observations.

support the acquisition of new instrumentation by member institutions, and in the fourth, a corporation-dominated collaboration (SMC) purchase of collaboration-relevant instrumentation by a corporation was counted towards its cost-sharing obligations. The new instrumentation was invariably purchased—sometimes by a 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 that was a point of policy or due to a lack of interest in using another institution's instrumentation, given that the teams and their roles in the DARPA-supported collaborations were sharply divided along institutional lines.

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 (SMC), 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 (HOIS), 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 (STCS and CPIMA) 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 was to take data jointly with collaboration members, and collaboration administrators especially esteemed joint data-taking among members of different teams as indicative of the collaboration's efficacy in stimulating research that independent proposal-writing would not have generated. Both collaborations balanced participants' desire 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 (LBL-ALS), "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 (DND), 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 (Positron), 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 (Crystal Structure), 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 (ALS and Positron after it reorganized) 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 (ALS), 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, has 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 (DND). 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.

D. *Internationalism*

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 (SMC), 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 (CPIMA and STCS) and the accelerator-using collaborations did not operate under such strict requirements. However, none formed with institutional international participation.[15] One of the non-accelerator collaborations developed an

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

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 (ALS, Positron), foreign institutions became prominent participants only as the original institutions encountered difficulties in raising funds for the beamline or in dedicating personnel to use the beamline. 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.

E. *Data Analysis*

None of the non-accelerator materials science collaborations have needed collaboration-wide policies on the acquisition and processing of raw data, because none of them took data on a collaboration-wide basis. All data were taken by teams or smaller units of the collaboration; and the data-taking unit controlled the data. The intellectual property agreements worked out in the course of forming collaborations that included corporate competitors were the basis for sharing or not sharing data within these collaborations. In general, these agreements obliged participants to share data about the characteristics of the materials and the performance of the components they were experimenting with, but not to share data about the processes by which they were making the materials and components. In the collaborations without corporate competitors (CPIMA and STCS), data sharing was generally encouraged and the work of individual participants frequently overlapped in ways that made them interdependent. However, the interdependent researchers were left to their own devices for making arrangements to share data and to analyze them jointly.

Practices were more varied among the accelerator-using collaborations. In the self-managed beamline-building collaborations (LBL-ALS and Positron after reorganization), teams were unambiguously in charge of acquisition, processing, and analysis of data through their individual end stations. Data sharing within the collaboration was not uncommon, but not required; no provisions were made for sharing data outside the collaboration. In the lone instance of a collaboration (Positron) in which it was normal to hold collaboration-wide discussions of data acquisition and analysis, the members had collaboration-threatening conflicts over the appropriate division between individual initiative and collective responsibility for obtaining scientific results. It reorganized itself to make clear that teams that controlled individual end stations were empowered to take and analyze data.

The formally managed beamline-building collaboration (DND) relied on scientists at member institutions to define (and in some instances to satisfy) their detection and software needs; however, the professional staff was responsible for providing the infrastructure to make the detectors and software work with the accelerator and the rest of the beamline instrumentation. When instrumentation developers worked with collaboration funds, they were obliged to insure that others in the collaboration could operate the instrumentation and read out the data; if working with independent funding, instrumentation developers were not so obliged. The member institutions determined what data were taken, with corporate members entitled to keep their data proprietary if they paid for the cost of the beamtime. Rules over long-term ownership of data were still under discussion at the time of our study. The accelerator laboratory and its federal patron (DOE) would like data that are not designated “proprietary” at the time of acquisition to become public property after a designated period.

The collaboration pursuing integrated studies of materials (Crystal) took data on multiple beamlines and also had chemical data on the composition of the materials. All data streams funneled into the postdoc hired to develop the experiments that the chemists’ corporation could not perform in-house. Though everyone in the collaboration was entitled to all the data, the postdoc took responsibility for processing all the data streams (using the infrastructure in place at each beamline). And the postdoc took on the major analytic task of imagining a single model that would account for all of the data.

F. *Dissemination*

Almost none of these collaborations maintained ongoing collaboration-wide policies for the reliability of results, when to present results at conferences or publish them in journals, where to present or publish results, 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).

G. *Social and Scientific Significance*

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 (Crystal) 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 been externally stable. Only one has dropped an institutional member (Positron), and that was because of the retirement of the institution’s leading scientist. Only two have added organizations; one (CPIMA) because a founding administrator took a new job at a different institution, and one (Positron) because it needed more funds and labor than its current members were capable of generating.

Internally, however, the accelerator-using collaborations have been far more likely to be stable and long-lasting than the non-accelerator collaborations, which tended to be either stable and short or dynamic and long-lasting. 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 [Crystal]; it only lasted 18 months and only produced one publication.) In all cases, the collaboration’s 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. The collaboration’s internal organization thus revolved around obtaining and maintaining the instrumentation. Once the participants decided how best to organize themselves for these tasks, only failure or problems could inspire organizational ferment.

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 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 (HOIS and SMC). These collaborations were internally stable, because even when participants felt dissatisfaction, the difficulty of reopening negotiations over the intellectual property agreement seemed prohibitive. However, they also either went out of business at the end of their initial funding, rather than try to recast the intellectual property agreement to take into account the shifts in interests among individual scientists and their institutions; or they have not needed to be revived because of a merger among the collaboration’s corporate members. The NSF-funded collaborations (CPIMA and STCS) presumed that the extant framework for research would not most efficiently 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 their findings and their organization could together 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 more than one competing corporation was 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 (SMC) that the corporations dominated; in another, university participants felt that the corporate scientists were too circumscribed out of fear of releasing proprietary information (HOIS); 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 individually a post-collaboration research direction. 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. All are credited with deepening researchers' appreciation of the difficulties in mastering the relations among the structure, properties, synthesis, and use of new materials.

V. *HEAVY-ION AND NUCLEAR PHYSICS*

There are only two collaborations in this category (BNL 877 and BNL 896). However, these collaborations fit readily into the patterns we found in our earlier in-depth study of high-energy physics. We are therefore confident that our findings are reliable.

The collaborations were comprised predominately of universities, but national laboratories (including both federal government laboratories and Federally Funded Research and Development Centers) also participated. Both collaborations had dedicated funds from a single major source to build large quantities of instrumentation; the participating institutions only had to cover the costs of travel and the salaries of postdocs and graduate students. Both directed the heavy-ion beam of a synchrotron on a metal target to generate interactions that were detected by instrumentation arrayed behind the target.

A. *Project Formation*

As was the case in high-energy physics, the construction of a new accelerator has spurred researchers into a reconsideration of their interests and social relations. Both collaborations formed to do fixed-target, heavy-ion experiments at Brookhaven in anticipation of the completion of the Relativistic Heavy Ion Collider. Though both included fragments of prior collaborations in their new collaborations, both created novel working relationships among the participants.

The goal of these collaborations was to build and use elaborate, multi-component detectors that the participants would collectively use to characterize accelerator-induced interactions. Collaboration was needed to spread the costs and to include all the expertise needed to build and use the components. The fundamental act that united these collaborations in the eyes of their participants was the drafting of a proposal (whether for funding or space and time at the accelerator laboratory). Once the proposal was accepted by the accelerator laboratory and a memorandum of understanding between the laboratory and the collaboration finalized, these collaborations considered themselves formal entities.

The instigators of these collaborations were prone to use friendships and word-of-mouth within their sub-communities and the accelerator laboratories to find the scientists they needed to draft a plausible proposal. To build and operate a multi-component detector collectively required that the collaborators begin with high confidence that they could sustain close working relations.

Only as their ambitions expanded beyond what could be supported with the people whom the instigators could personally contact did the instigators resort to less direct recruiting strategies. In one instance, the collaboration came to include both nuclear and high-energy physicists with distinctly different scientific interests.

B. *Organization and Management*

These collaborations, both of which built sizable, multi-component detectors for their collective and exclusive use, adopted similar organizational structures.[16] Each divided labor for building detector components along institutional lines. Each drew from a dedicated source of centralized funds held on its behalf by the accelerator laboratory. Each used its memorandum of understanding with the laboratory to codify intra-collaboration agreements to spend most of the funds through member institutions for the design and construction of individual detector components. Each had a member responsible for tracking the development of the components and dealing with the systems engineering problems that the component builders created for each other. Each had a "spokesperson," who was the scientific leader, to represent the collaboration to the accelerator laboratory and the outside world generally and to lead intra-collaboration discussions. Each held collaboration-wide meetings three to four times a year to discuss major issues of research strategy and to review results; and between the meetings each used conference calls and e-mail among senior scientists from each institution to discuss progress, money, and responsibilities. Each assumed that discussions would result in consensus with the spokesperson making decisions only as a last resort.

This framework worked better for one of the collaborations (BNL 878/896) than the other (BNL 814/877). The latter was larger than envisioned by its instigators because the accelerator laboratory had recommended the instigators increase the goals, cost, and size of the collaboration. As a result, both nuclear and high-energy physicists were working with the same instrumentation. Unfortunately, the scientific interests of the two fields required that the instrumentation be operated differently. To avoid forcing the spokesperson to make a decision that would have favored one faction over another, the collaboration opted for the efficiency-reducing compromise of changing operating parameters in the middle of each data-run.

C. *Activities of Teams*

"Team" in these collaborations usually referred to the institutional member(s) responsible for a particular component or, less frequently, for a particular line of data analysis. Teams in these collaborations were constrained by the systems engineering of the overall detector and the research strategy set by the collaboration as a whole. Each team had to design its component to fit into the geometry of the overall detector and to perform at a level that fit the capabilities of the other components. Yet the technical challenge represented by each component varied widely—some advanced the state of the art while others were conventional; some were uniquely designed for an experiment while others were designed for this general style of experimentation. Most components were built in the laboratories and shops of the participating institutions, but occasionally contracts were let to acquire a large, commonly needed component (e.g., a

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[16] These collaborations, which were performing heavy-ion physics experiments, resemble high-energy physics collaborations performing fixed-target experiments. Though we did not investigate the collaborations planning colliding-beam, heavy-ion experiments, presumably they are similar to collaborations that perform colliding-beam, high-energy experiments.

magnet).[17] Regardless of where the component was built, teams always provided the software for reading out and processing the raw data from their components. As with hardware, teams' software had to conform to collaboration-wide, system-level standards, because the collaborations operated on the assumption that data analyses would employ multiple data streams.

D. *Internationalism*

Non-American institutions were integral to these collaborations. They were needed for their manpower and they provided instrumentation that was in one instance unique and in other instances more easily obtained by having the non-American group do the work. No administrative or cultural burdens resulted from the international participation. The non-American institutions used their own funds to pay their employees and support their laboratories and machine shops. However, the collaboration was free to use its central funds to purchase the materials and off-the-shelf items that the non-American institutions needed to build their components.

E. *Data Analysis*

All data streams from every detector component were deemed the collaboration's collective property. Participants considered intimate familiarity with the detector a pre-requisite to competent data analyses and thus made no provisions for enabling outsiders to work with the data. Both collaborations sought to maximize individuals' freedom in the selection of topics to analyze and methods of analysis. However, both recognized that an entirely *laissez-faire* system was potentially dangerous. One collaboration (BNL 814/877) sought to track the research plans of graduate students in order to differentiate their dissertation topics, but its efforts proved unwieldy. As a result, occasionally graduate students claimed to have made the same measurement, and the collaboration had to judge the merits of the different analytic techniques in order to produce an official collaboration-wide measurement. The other collaboration (BNL 878/896) eschewed monitoring who was analyzing which topics, but limited methodological individualism by defining sequential "stages" of analysis (from general- to special-purpose) and writing "interface documents" to mediate between the stages. Individuals were free to exercise choice within any analysis stage, so long as their programs fit with the interface documents.

F. *Dissemination*

Both of these collaborations made publication a collective effort. Drafts of papers were circulated among the scientists who participated in the research, and manuscripts were not sent to a journal for consideration until all had indicated their approval. Both these collaborations were concerned with providing career-enhancing exposure to junior members, and they used collaboration management of dissemination to insure equity in opportunities for exposure.

G. *Social and Scientific Significance*

Both performed a series of experiments, with the accelerator laboratory periodically requiring the collaborations to re-propose for beamtime. A central core of personnel and institutions were at

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[17] We did not obtain good information on how much design work such contractors performed.

the heart of the collaborations, but other groups joined and left depending on the collaborations' needs and the other groups' prospects and interests. In this way, both collaborations resembled high-energy physics collaborations performing "strings" of experiments. However, one of these collaborations (BNL 814/877) was more tightly "strung" than the other (BNL 878/896). Both its membership and its detector were more stable than the other, which grew dramatically in size in order to enlarge and reconstruct its detector.

Success for these collaborations was usually less a matter of meeting deadlines and budgets and more a matter of producing scientific publications. Though neither has (yet) produced an individual result or discovery of widely recognized importance, participants were satisfied with the productivity of the collaborations and the opportunities they afforded for graduate students.

VI. *MEDICAL PHYSICS*

The three collaborations in this category included as institutional members medical schools and their affiliated hospitals[18] (with researchers 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 with statisticians and professional societies. 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.[19] Two of the collaborations (RDOG and NDMDG) were oriented towards diagnosis of cancers; both were funded principally by the National Cancer Institute with modest cost-sharing from corporate participants. The third (Angiography Diagnostics) was cardiology-oriented and had support from a philanthropic foundation, DOE, and the National Institutes of Health (NIH).

A. *Project Formation*

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 (Angiography Diagnostics) 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 (RDOG) that

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

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

originated because policy makers were uncomfortable with the paucity of information for assessing diagnostic modalities. In between was one (NDMDG) in which a funding agency's desire to satisfy an interest group dovetailed with research efforts that were already underway in bio-physical circles.

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 (Angiography Diagnostics). 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 (RDOG) 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 of the people they worked with contributed to the plausibility of their studies. The collaboration (NDMDG) 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 (Angiography) 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 (RDOG) 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 (NDMDG) 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 proposals from single investigators 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.

B. *Organization and Management*

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 (RDOG) 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 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 lead radiologist 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 (NDMDG). 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 (Angiography) 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, it had to reach a collective assessment on how best to collect data, it had to schedule beam time on a national laboratory’s accelerator, and it had to 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 expectation, and institutional affiliations. However, in none of these collaborations were scientific orientations an issue. Financial expectations were only an issue in the collaboration (RDOG) 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 to the practitioners of other specialties—troubled participants in the self-managed collaboration (Angiography) but did not threaten the collaboration’s existence. Only the institutional affiliation problem was an issue in more than one collaboration (Angiography and NDMDG), 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 (NDMDG) and its funding agency had to address how much a corporate participant should share in the costs of its involvement.)

C. *Activities of Team*

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 (NDMDG) where the teams worked in near total autonomy and another (Angiography) 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 while in the latter the physicists worked in university departments and national laboratories. 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.

D. *Internationalism*

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.

E. *Data Analysis*

Medical physics collaborations, unlike all others AIP has studied, had human subjects and were obliged to archive data on patients *and* to keep those data confidential.

Intra-collaboration data practices followed directly from the management and origins of the collaborations. In the collaboration that had its management externally imposed and was formed to assess diagnostic techniques (RDOG), information was carefully compartmentalized.

Individual members of teams took data in deliberate ignorance of what other team members were finding, the teams sent their data to the collaboration's administrative unit (which digitized the data and performed basic quality checks), and the administrative unit sent the processed data to the statistical group for analysis. The teams never had access to all the data streams until the statistical 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. In the collaboration that was barely managed and was formed to develop novel diagnostic systems (NDMDG), the teams shared data as they saw fit; participating corporations were entitled to keep proprietary any information they feared could help competitors, but in practice the engineering of the systems the corporations were designing was sufficiently different that none of the participants felt the corporations ever withheld anything of value to the collaborators. In the self-managed collaboration (Angiography), the teams shared all data, which sometimes led to difficulties, not because anyone felt data should be proprietary, but because practitioners of one specialty occasionally resented having their work questioned by practitioners of another specialty.

The character and intensity of computation demands were noteworthy only in the barely managed and self-managed collaborations (NDMDG and Angiography). In both, the teams had to custom-write algorithms for analyzing or processing data; in one (NDMDG) the collaborations also investigated new electronic forms of acquiring and transmitting medical data.

F. *Dissemination*

The barely managed collaboration (NDMDG) 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 (Angiography), 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 (RDOG), 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.

G. *Social and Scientific Significance*

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.

Internally, these collaborations have all been organizationally stable. However, one of the system-developing collaborations (NDMDG) 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 have the potential to alter the environment for 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 (RDOG). 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. *COMPUTER MEDIATED COLLABORATIONS*

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 proposals for projects 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" have influenced physical scientists in the traditional areas covered by AIP. Our work is a first attempt to use the concepts and categories we have already developed in the AIP Study to characterize these collaborations.

Most of the participants in the collaborations we studied 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.

A. *Project Formation*

Two of these projects (GC3 and CRPC) 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 (UARC) originated in shifts in 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 (GC3, CRPC) 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 (CRPC) resulted from the merger of two competing proposals. The other (GC3) had its proposal fall slightly short in the competition for funds twice, and finally succeeded when one of its member 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[20] 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.

B. *Organization and Management*

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 (GC3) avoided the problem by increasing the autonomy of participants and decreasing the role of collaboration leader, another (CRPC) eliminated the problem by reducing the number of participants and interests in the collaboration, and the third (UARC) lived with the problem and the toll it took on the collaboration's morale and future viability.

The collaboration that avoided the problem (GC3) 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 to using the collaboration for collaborative research 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 (CRPC) 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

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[20] 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.

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 (UARC) 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 moved to make his institution the focal point for software development, to the dismay of the computer scientists and physical scientists at the institution that managed the scientific instruments. 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 sometimes 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.

C. *Activities of Teams*

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.

D. *Internationalism*

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.

E. *Data Analysis*

Only one of these collaborations collected data in the conventional sense. (The other two produced simulations and software only.)

F. *Dissemination*

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.

G. *Social and Scientific Significance*

It has become a truism that we live in the "Information Age," and future historians will no doubt debate when 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 the importance of 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 developing 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.

REPORT NO. 2: DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIALS SCIENCE, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

SECTION THREE: ARCHIVAL ANALYSIS AND APPRAISAL GUIDELINES

Joan Warnow-Blewett

SECTION THREE: ARCHIVAL ANALYSIS AND APPRAISAL GUIDELINES

For the AIP Project Recommendations on general steps that institutions should take to improve their documentation of large collaborations, see Report No. 1, Section Two: "Project Recommendations."

I. *INTRODUCTION*[21]

During Phase III of the AIP Study of Multi-Institutional Collaborations, we examined four new disciplinary areas (ground-based astronomy, materials science, heavy-ion physics, and medical physics)[22] and one category we named computer-mediated collaborations. Our report on archival analysis and appraisal guidelines is organized along the same lines. It is based on a number of sources: (1) the archival assessment of 78 interviews conducted on the 23 selected 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) site visits to archival repositories, especially during previous phases of the AIP Study; and (5) the AIP Center's general knowledge of archival institutions in various settings. We suggest that these archival analyses and appraisal guidelines be read in conjunction with the AIP Study's Project Recommendations to be found in Report No. 1 of this publication.

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 two years of field work—by the project staff of the AIP Study of Multi-Institutional Collaborations—devoted to the subject areas covered during Phase III. Readers familiar with the appraisal guidelines in our reports for Phases I and II will recognize that the guidelines issued here lack the functional analysis of key activities of collaborations—a challenge we will take on for our forthcoming final report covering the entire, long-term study. 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.

Appraisal guidelines require unending revision. As the process of collaborative research changes (and we have seen such changes 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

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[21] Project historian Joel Genuth has been helpful in developing these archival findings and appraisal guidelines.

[22] During prior stages of the long-term study, the AIP project staff surveyed collaborative research in high-energy physics (Phase I) and space science and geophysics (Phase II).

format for future use by historians and others.[23] In recent years, Web pages—covering project staff, progress reports, and much other material on individual collaborations—have become particularly visible; access to some of the valuable information requires passwords. We need to watch the new technologies and try new solutions for securing adequate documentation.

The scope of these guidelines is records created by multi-institutional groups that participate in collaborative research projects. We have not included records of groups that set national and international policy. Also outside the scope of these guidelines are the records created by activities at the government laboratories, universities, and institutions involved, and by other activities of individual scientists. We recommend different appraisal guidelines for these materials.[24]

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 highly significant collaborations.

II. *GROUND-BASED ASTRONOMY: OBSERVATORY BUILDERS*

A. *Archival Analysis*

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 or 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).

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[23] 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.

[24] 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).

Documenting the building of national observatories presents another kind of problem.[25] Here the difficulty has to do with the records responsibilities of the National Science Foundation (NSF)—the agency that supports the building and maintenance of the national observatories in the U.S. 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 hold onto a lot of documentation, 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.

Despite these important differences, we have 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 cope with the trade-offs between scientific capabilities and engineering and financial burdens. In the telescope-building 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.

B. *Appraisal Guidelines*

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

We do not have the usual small set of core records for observatory-building collaborations. Instead, we have categorized each and all of these collaborations as significant and recommend that more extensive documentation should be permanently saved.

2. *Records to be Saved for Significant Collaborations*

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 for future use by scientists/administrators and historians.

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[25] 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.

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. Location: In the possession of NSF 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.

d. *Board of Directors Minutes of Meetings*

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.

e. *Records of Project Manager*

Various types of records, e.g., progress reports, 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.

f. *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 project manager or secretary-treasurer.

g. *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 project manager or secretary-treasurer.

h. *Records of Science Project Team*

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.

i. *Contracts and Associated Records*

Observatory-building collaborations, like those involved in building other large facilities, contract out the construction of components and/or 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.

j. *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 the collaboration's Web site.

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

A. *Archival Analysis*

If it is difficult to document the building of observatories, it seems virtually impossible to document collaborations of observatory users[26]—at least radio telescope users. The reason is straightforward. They leave a scanty paper trail (except for observational data)—because they require little or no dedicated funding and only minimal organizational structures—and they

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[26] Our 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.

neither design nor build the instrumentation they use. 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 collaborations will be useful for future research. As we learned, the data streams from each of the participating observatories first had 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 for anyone to accomplish if they had not been involved with the data acquisition.

B. *Appraisal Guidelines*

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

a. *Proposal Files of Radio Observatories*

Each VLBI collaboration petitions for time on all the observatories it wishes to use for its interferometry work and each observatory evaluates 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: Proposal files of radio observatories.

b. *Proposal Files of National Optical Observatories*

These would be typical jackets for successful proposals—in this case, to obtain time on the optical telescope. They should include proposals, referee reports, progress and final reports. We are naturally focused on proposal jackets for collaborative research projects. Likely location: Proposal files of national optical observatories.

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 likely to be 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 the 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.

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.

IV. MATERIALS SCIENCE

A. *Archival Analysis*

Our historical analysis of collaborations in materials science makes distinctions between those that make use of accelerator 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 judged proposals from researchers employed by member institutions; all three cases lacked a physical location beyond their offices at the fiscally accountable university. For university-managed collaborations in materials science, responsibility for records must rest with the university where those offices are (or were) located.

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 out of 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 always, 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 practice 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 characteristics 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, while we found that the collaborations rented space for offices at the synchrotron laboratories, these offices are freestanding and impermanent; they 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.

B. *Appraisal Guidelines*

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 MRSECs and STCs judge proposals from researchers employed by member institutions, the NSF jackets lack funding details (e.g. individual proposals) of the research of MRSEC and STC collaborations. Overall, future users will find documentation of the initial plans and ambitions of the centers, how they had to modify plans to suit NSF, and community reactions to the center's plans and accomplishments.

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.
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. 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 Executive Board (or Governing Board, Program Committee, or Technical Representatives Committee)*

Archivists should look to preserve the records of the highest-level group of researchers active 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 home pages 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.

f. *Collaboration Records on Compact Disk*

One of the collaborations among our case studies was committed to putting its records on a compact disk to be delivered to its funding agency. This is a novelty for us, but one we can imagine becoming more widespread. The purpose of the CD is to increase the quantity and accessibility of information being delivered to the funding agency. The disk will include the collaboration's final reports along with (non-proprietary) electronic scientific data illustrated with test procedures, videos of tested manufacturing techniques, conference papers, and reports of meetings. Likely location: In the possession of the relevant program officer at the funding agency.

V. *HEAVY-ION AND NUCLEAR PHYSICS*

A. *Archival Analysis*

We are confident of our findings in this category even though we have only two case studies (four were transferred from Uses of Accelerators—our former category—to Materials Science). Our earlier in-depth study of high-energy physics experiments at national accelerator laboratories[27] provided substantial understanding of experiments in the related fields of nuclear and heavy-ion experiments at these laboratories. We find the familiar roles of laboratory PACs (Physics Advisory Committees) governing access to particle accelerator beamtime, the MOUs (Memoranda of Understanding) detailing institutional commitments, spokespersons providing liaison between the collaborations and the laboratory as well as the outside world, and collaboration-wide meetings. In our case studies we also find management structures 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 physics collaborations that archivists should be on the lookout for. Finally, we

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[27] See *AIP Study of Multi-Institutional Collaborations. Phase I: 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. All of the reports are available upon request from the AIP Center; *Report No. 1* also available on the AIP Center's Web page (http://www.aip.org/history/).

are, not surprisingly, in the world of Web sites that include rich documentation available to all, but with non-public areas accessible only to those with proper passwords and no guarantee of permanence. Information on collaboration Web sites will be included in our forthcoming report covering the long-term AIP Study.

B. *Appraisal Guidelines*

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

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

The heavy-ion physics research collaborations we studied were conducted at the DOE's Brookhaven National Laboratory. The proposals at NSF or DOE overlap with 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 how funding the collaboration would affect the national research programs in heavy-ion and nuclear physics. Location: In possession of the relevant program officer at NSF's Physics Directorate or at DOE's Office of Energy Research.

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

These 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. Locations: In the records of the PACs at DOE National Laboratories.

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

a. *Records of Spokespersons*

As in high-energy physics, 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) 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,

(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 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 BNL National Laboratory staff. Likely location: In staff records at 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. *Collaboration Web site Records*

Records placed on publicly accessible parts of the collaboration Web sites typically contain lists of participants, summaries of the experiment's strategy, and summaries of the design of its detector components. Interviewees have also spoken of initial and final designs of components and the detector's overall design as being on the Web along with electronic-media discussions that went into producing the final designs. On some Web sites, a link to "collaboration business," can only be followed by those with a login identification and a password; because of the greater detail and intimacy of collaboration discussions, archivists should make every effort to capture the records in such password-access sections.

VI. *MEDICAL PHYSICS*

A. *Archival Analysis*

It is virtually impossible for us to assess with any certainty the archival situation in the area of medical physics. The reasons are several. Most important is the fact that 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,[28] or in dealing with the key funding agency—the National Institutes of Health (or its constituent parts such as the National Cancer Institute).[29] Also, 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. Consequently, our appraisal guidelines and

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[28] The AIP Member Society most relevant to medical physics is the American Association of Physicists in Medicine which joined the AIP in 1973. The AAPM's fairly recent affiliation (and 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.

[29] 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.

Project Recommendations to funding agencies and research institutions (see Report No. 1) in the field are—for the most part—merely suggestive.

B. *Appraisal Guidelines*

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 private foundations.

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-reference those of would-be collaborators, the proposals are 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 for a collaboration. Likely location: At the appropriate NIH or subsidiary institute research program.

c. *Records of Synchrotron Light Source Advisory Committees*

To obtain space at the accelerator, collaborations have to submit a research proposal to convince the Facility Advisory Committee of the scientific value of its 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 discussion 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 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 such cases, 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.

VII. *COMPUTER-MEDIATED COLLABORATIONS*

A. *Archival Analysis*

In this 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 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.[30] Although never a formalized program of its own at NSF or DOE, projects that could 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.

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[30] 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.

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 (KAI) program under development at NSF. Collaboratory-style projects will also fall within the KAI 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.[31]

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 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 generated a plethora of records—far more than can be saved, even for significant projects. At least until the design of these discussion chat rooms is better understood, the records generated also 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.

B. *Appraisal Guidelines*

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 chat rooms 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).

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[31] 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.

REPORT NO. 2: DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIALS SCIENCE, HEAVY-ION AND NUCLEAR PHYSICS, MEDICAL PHYSICS, AND COMPUTER-MEDIATED COLLABORATIONS

SECTION FOUR: SOCIOLOGICAL ANALYSIS

Ivan Chompalov

Wesley Shrum

SECTION FOUR: SOCIOLOGICAL ANALYSIS

I. *INTRODUCTION*

One of the most significant developments in twentieth-century science is the proliferation of projects that require the resources and expertise of multiple teams of researchers. Indeed, the growth of Big Science is not simply an increase in the quantity of research, measured by exponential growth of the number of scientists and of the number of their publications (Price 1963), but an increase in collaborations involving a number of institutions. Such interorganizational efforts are found in all areas of science that require significant resources and complex instrumentation. Whatever the objective—to produce experiments in particle accelerator centers, build instruments or telescopes, or coordinate several laboratories—the co-presence of scientists, engineers, project managers, technicians, graduate students, and staff from multiple organizations constitutes a novel development in the social organization of science. Following the tradition from the first two phases of the AIP Study of Multi-Institutional Collaborations, we term these formations “multi-institutional collaborations.”[32]

We have focused on two questions that confront scholars of multi-institutional collaborations:
(1) What types of collaborations are there?
(2) How, if at all, are these types related to important outcomes?

Significant variation among collaborations is recognized. Its mere demonstration is no longer as important as the question of whether there are identifiable patterns of social organization.[33] Our goal is to characterize multiple types in a systematic fashion—that is, can a robust classification scheme be developed? Accordingly, the first problem is to determine the general dimensions that characterize multi-institutional collaborations in science, to operationalize these dimensions, and examine the extent to which they allow us to distinguish empirical clusters to form a classification. But such a classification scheme is of limited value in the abstract. It becomes significant insofar as the types defined are related to important sociological outcomes. The second problem is to identify and develop indicators of these outcomes and to determine whether they bear any relationship to the groups identified in the classification.

In Phase III of the AIP Study we tried to address the question of developing a typology for multi-institutional collaborations in science and technology by examining 23 recent collaborations in five general areas (ground-based astronomy, materials science, medical physics, heavy-ion and nuclear physics, and computer-centered research). Face-to-face interviews were conducted with 78 scientists. The instrument was a structured questionnaire, including both fixed and open-ended items. The coded information was then aggregated across collaborations, so that the collaboration became the unit of analysis.

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[32] For operational purposes, a multi-institutional collaboration is defined as a research project involving three or more organizations. The analysis and conclusions of Phase III are based only on the study of multi-institutional collaborations in the U.S.

[33] Jane Maienschein, with reference to the biological sciences, proposed a threefold classification of collaborations based on the reasons for collaborating: to promote an efficient division of labor, to enhance credibility, and to build community (1993).

In the first part of this report, we specify five outcome dimensions previously identified as important to the operation of scientific collaborations. In the second part we discuss the seven structural dimensions that emerged from earlier phases of the AIP Study and were incorporated directly into the design of the questionnaire for Phase III. In the "Results" section we first present a summary of the findings concerning bivariate relationships, which is then followed by an analysis that develops a variety of classification schemes and examines their relationships with outcome dimensions. The results indicate that a classification based on *technological practice* is superior to other structural dimensions in its ability to predict perceived success, trust, stress, conflict, and documentary routines.

II. *OUTCOMES OF MULTI-INSTITUTIONAL COLLABORATIONS*

Contemporary scholars have distinguished trust, stress, documentary practice, conflict, and perceived success as critical dimensions in knowledge production.[34]

The role of trust in interorganizational relations has been well documented (Alter and Hage 1993; Ring and Van de Ven 1994; Browning et al. 1995; Gulati 1995; Kramer and Tyler 1995). It is not an exaggeration to claim that trust is required for all systems of knowledge production and especially when scientific institutions and individual researchers have to coordinate their efforts toward a common goal, as is typically the case for multi-institutional collaborations. The recognition of "trustworthy persons" is a necessary component in building research networks (Shapin 1995) . In multi-institutional collaborations, it is not merely the identification of trusted associates at the outset but the continual reliance on mutually agreed objectives, practices, technical alterations, and project deadlines that makes trust such an important factor for the duration of a project.[35]

Scientists engaged in multi-institutional collaborations are often exposed to high levels of stress for a variety of reasons: complex technological demands, unclear or changing social

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[34] These five dimensions appear to be important to scientific activity regardless of the level at which social and intellectual change is examined, i.e. the work group, the organization, the specialty, or the discipline. Thus, in spite of the scarcity of comparative studies of multi-institutional collaborations, it seems likely that they are important here as well.

[35] We decided to focus on trust as a result of the social organization and practices of collaborations, although in other circumstances it can be studied as a prerequisite of successful interorganizational arrangements (e.g. Browning et al., 1995). The degree of trust both towards other researchers and towards the project management was generally high, but at certain times there were doubts as to the reliability of some collaborators. Often this happened when new people joined the collaboration. Misgivings about their trustworthiness usually had a temporary character: "I think broadening the collaboration for this experiment led to some distrust, which I believe has been almost wholly alleviated at this particular point, but it's certainly what's caused the problems early on. They just didn't trust each other's results, basically." (Interview with a heavy-ion physicist). **NB**: Interviews were on condition of anonymity. A copy of this paper with full identification of interviewees is available to qualified scholars at the American Institute of Physics' Niels Bohr Library.

arrangements, the need to coordinate geographically dispersed groups, the clash of interests, ambiguity in the distribution of authority, and the pressure to perform according to the expectations of funding agencies, as well as time constraints. The last factor is especially important, since time is a critical resource in working together (Zabusky 1995). In many cases the degree of stress induced by schedules and deadlines is higher than in routine academic settings.[36] This is mainly due to pressure from funding agencies and participating institutions to perform within tight budgets and under time constraints.

Documentary practice—the generation and use of records—is essential for the work organization of multi-institutional collaborations. Beyond that, the role of historical accounts has long been recognized—as has the fact that the reconstruction of such accounts depends heavily on the preservation of written documents. The ultimate intent of the AIP Study is to assist archivists and others in identifying and locating the kinds of records most valuable in documenting the organizational structures and functions of multi-institutional collaborations. Data on two variables that measure documentary practices of collaborations—dispersion of core records and quality of records—were analyzed to help meet this archival goal. Project historians and archivists identified the core records (i.e., the small set of records that should be saved for all collaborations of a given scientific discipline); they also identified the likely locations of the core records for each of the collaborations selected for study. Project sociologists included these data in their database. We posit that the extent to which core records are dispersed is an indicator of project decentralization as well as of the degree of difficulty involved in reconstructing accounts of the collaboration (Warnow-Blewett 1997).

All social formations that involve ongoing use of resources, even those that involve only prestige, have the potential for conflict. Conflict is an inherent element of organizations because the bases of conflict such as functional differentiation between subunits, heterogeneity of the staff, styles of supervision, form of power, the reward system, and so on, are part of the organizational system (Hall 1977). As organizations *sui generis* multi-institutional collaborations are not devoid of disagreements, contentions, and conflict. From a sociological point of view, conflicts are especially interesting because they provide insight into the dynamics of social cohesion in the collaboration, as well as what this might be due to.

Of course, success or “performance” is the most valued outcome of science, the criterion in terms of which projects are evaluated. Various measures of success have been used, including the number of publications, citations, and patents (Pelz and Andrews 1966; Irvine and Martin 1985). These are usually considered as “objective indicators” that reflect productivity. Without

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[36] One of our informants discussed the stress from time pressure in his collaborative project: “Well, compared to an academic department I’d say it’s night and day. This was a project; this was an industrial situation, if you will, where there were real schedules. And you might fail to meet them, but it was completely unambiguous what they were, and if you failed to meet them, you’d better have a good reason for it or you’d get chewed out. Academia doesn’t work that way at all. Academia is much more democratic, touchy-feely, ‘yeah, we think we want to do that; let’s think about it; we’ll get back to you when we’ve got it worked out’.”(Interview with a ground-based astronomer.)

recapitulating the debates about the problems with these measures, we feel that even if there were an independent, aperspectival standpoint from which success could be determined, perceptions of success are crucial because they influence the reputations of collaborators and their likelihood of acquiring further resources. Multi-institutional collaborations may be defined as successful or unsuccessful in terms of many dimensions—the extent to which they accomplish objectives, are completed on time or within budget, produce results that are used by others within and outside the field, and so forth. Yet there is often a general sense in which projects (especially those that require substantial commitments of resources and personnel) are evaluated positively or negatively by the scientists who work on them. It is in this sense that we speak of the "success" of a collaboration.[37]

III. *STRUCTURAL DIMENSIONS OF MULTI-INSTITUTIONAL COLLABORATIONS*

The AIP Study of high-energy physics, space science, and geophysics enabled us to identify seven primary dimensions that were important in multi-institutional collaborations.[38] All of the interviews from the first phases had been previously assessed and categorized in terms of major topics or themes.[39] These major themes, along with other factors identified in the historical analysis, led to the recognition of general and specific properties of collaborations. We identified seven major structural dimensions of multi-institutional collaborations: project formation, magnitude, interdependence, communication, bureaucracy, participation, and technological practice. These dimensions and some of their constituents may be summarized briefly.

(1) Project formation and composition. Collaborations have a variety of origins. In some, one sector is dominant, both in origin and constitution. Others encompass academic, governmental, and private sectors. The role of pre-existing relationships among researchers varies, as well as supervision, and funding agency involvement.

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[37] It is often not only the scientific achievement of the project, but precisely the fact that it came as a result of a fruitful common effort that was emphasized by individual participants when they elaborated on the success of a collaboration: "I would say this has been very, outstandingly successful. In terms of scientific results, relationships between people, building new relationships, being successful at a complex facility—super." (Interview with a materials science researcher.)

[38] These dimensions are all familiar from the literature on complex organizations. We initially identified ninety characteristics or subdimensions, and subsequently narrowed these down to approximately fifty. The subdimensions were then classified in terms of seven major dimensions. Of course, some factors we identified as subdimensions could well be considered independent dimensions in other circumstances. In each case we sought to provide one or more indicators of each subdimension.

[39] Joel Genuth was primarily responsible.

(2) Magnitude. Some collaborations are larger than others, in terms of the number of organizations, teams, individual participants, graduate students, and subcontracts. Costs for personnel and instruments differ a great deal, as does the length of the project.

(3) Interdependence. Data-sharing, the analysis of joint data, and the autonomy of organizational teams with respect to instrumentation distinguish collaborations in terms of the interdependence of their constituent social formations.

(4) Communication. Relations with the public are sometimes managed by a designated public relations officer. Results may or may not be popularized and restrictions may be placed on publications. Internal to the project itself, a communications center is sometimes utilized, and projects may depend more or less on formal communication modes.

(5) Bureaucracy. The degree of bureaucracy is a fundamental aspect of organizational structure and has been conceptualized in a wide variety of ways. Phases I and II showed that collaborations could be distinguished according to the presence of a lead center, designated scientific and administrative leaders, and the division of authority between them. In Phase III, we also included the presence of written contracts and coordination of schedules as well as the presence of outside formal evaluation in assessing the degree of formalization. We also found that projects vary in terms of levels of authority, style of decision-making, and presence of advisory committees.

(6) Participation. Graduate students are involved more in some collaborations than others. Principal scientists may be more or less interested in and devoted to a project. International involvement is sometimes crucial for a project but in others it is not present at all.

(7) Technological practice. Multi-institutional collaborations vary in the ways they acquire and use instrumentation. Characteristics of acquisition and use allow us to distinguish a broad array of factors that may be designated the “technological practice” of the collaboration. Some collaborations design and build their own equipment, some advance the state-of-the-art in instrumentation, and some modify their instruments during the course of the project.

Technological practice is not merely instrumentation but includes the management of topics and the checking of results.

IV. *RESULTS*

We first describe the characteristic features of our sample in terms of seven structural dimensions. Table 1 presents three measures for each structural dimension, indicating how those were distributed in the sample of 23 multi-institutional collaborations (See Table 1 in Appendix S-3).

A. *Findings from Bivariate Analysis*

Sixteen breakdown variables were selected in order to reduce meaningfully the number of cross tabulations (since we had 96 unmodified variables). The breakdown variables were chosen to reflect the importance with respect to comparisons of certain measures in each group of general dimensions. The final set of breakdown variables included disciplinary field, sectoral composition, size (number of participants), number of organizations, number of teams, length from formulation of the original idea to funding, length from funding to first publication of results, international participation, levels of authority, designated scientific leader, designated administrative/engineering leader, communications center, style of decision- making, division of authority, disagreements between teams, and disagreements between researchers and project management. All these variables were recoded as categorical, except field of research, which was left in its original form (nonorderable discrete). Only associations significant at $p<0.05$ are reported. The most important results from cross tabular analysis may be summarized briefly.

1. Surprisingly, in the Phase III sample, field of research was not related to many variables at the bivariate level, and—more importantly—it was not significantly associated with the organizational indicators. Therefore, certain organizational features of collaborations persist regardless of the broad specialty area. Nevertheless, there were several relationships where field mattered (See Figure 1 in Appendix S-4). For example, field affects instigating sector. Ground-based astronomy and medical physics are more likely than heavy-ion physics and especially materials science to have been instigated only by the university sector. Sectoral composition reflects the same pattern. Field of research is also significantly related to scrutiny from outside authorities. Medical physics was the only field in which most collaborations received scrutiny from Congressional committees or White House offices—two thirds of these projects were scrutinized. This seems natural, since there is a great social and political interest in research on medical diagnostics and treatment. The only other field to receive some attention from the same authorities was ground-based astronomy.

2. The magnitude of multi-institutional collaborations was, as anticipated, positively related at the bivariate level to their formal organization and management. Thus, size (number of participants) and the existence of external Advisory Committee are positively associated (See Figure 2 in Appendix S-4).

Large (83.3%) and medium (75%) collaborations are more likely to have such a committee than small collaborations (11.1%). This finding is within reasonable expectations, since normally we would expect greater oversight for bigger projects, where more people are involved. Size of the project is also significantly related to presence of administrative leader. The direction of the association is in accordance with previous findings in the organizational literature—that larger organizations tend to be more centralized and formalized. For our sample, large (100%) and medium (87.5%) collaborations are more likely to have a designated administrative leader than small collaborations (33.3%). Furthermore, larger collaborations are more prone to have a division between intellectual and administrative authority. Collaborations with a large number of participants have division of authority in 83.3% of the cases, those with a medium number of participants in 75%, and those with a small number of participants in 22.2%. Finally, duration is usually related to greater formalization. For example, we found a significant covariation between levels of authority and length from the formulation of the original idea to funding (See Figure 3 in Appendix S-4).

Collaborative projects with a shorter period to funding are more likely to have fewer levels of authority than a typical academic department as compared to longer projects. More specifically, 90% of the short collaborations have fewer levels of authority than an university department, which is more than twice as much as collaborations where time to funding was one year and a half or longer.

3. A number of structural characteristics of multi-institutional scientific collaborations were related to two important outcomes of these collaborations—conflict (disagreements) and trust. The general conclusion is that greater magnitude and greater formalization lead to more problems and less trust. For example, Figure 4 in Appendix S-4 shows that style of decision-making has a significant impact on problematic results due to time pressure (although, strictly speaking, this is not a causal relationship). This relationship is in the predicted direction—that more "hierarchical" collaborations would tend more often to have problematic results caused by time pressure. Thus, 83.3% of the hierarchically run projects had problematic results due to time pressure as compared to only 10% of collaborations where decisions were taken more consensually than hierarchically and to none of the consensually-run projects. Next, length from funding to first publication of results from the collaboration is significantly related to conflict between teams (See Figure 5 in Appendix S-4). Longer collaborations (with regard to first publication) tend to have more disagreements between teams. Two thirds of collaborative projects for which it took two years or more to first publication of results had conflicts between teams as compared to just 18.2% of projects where publication of results occurred within a year and a half or less after funding. Division of authority significantly contributed to conflict between researchers and the project management (See Figure 6 in Appendix S-4). Multi-institutional collaborations in which there was a division between intellectual and administrative authority had conflict between scientists and the project management in 38.5% of the cases vs. none of the projects where there was no such division.

Overall, the degree of trust was fairly high. However, there was some covariation with the organization and magnitude variables. Style of decision-making is associated with trust (Figure 4 in Appendix S-4). In all collaborative projects with a consensual style of decision-making, the degree of trust towards other researchers was high; by contrast, trust was high in only one-third of collaborations with a hierarchical manner of decision-making. Size and trust towards the project management are negatively related (See Figure 7 in Appendix S-4). In over three-quarters of the small collaborations the degree of trust towards the management was high, as compared to all medium projects, and only one-third of the large collaborations. Finally, hierarchy (levels of authority) is also negatively associated with trust (See Figure 8 in Appendix S-4). Collaborations with fewer levels of authority than a typical academic science department are characterized by high degree of trust towards project management in 92.9% of the cases in contrast to only 44.4% of multi-institutional collaborations with the same hierarchical structure as an university department.

B. *Technological Practice as a Basis for Classifying Collaborations*

Our principal analytical question is whether collaborations may be classified into types based on structural dimensions that are related to important outcome variables. Cluster analysis proved to be a useful tool for categorization[40], while analysis of variance is appropriate for determining the relationship between types of collaboration and outcome dimensions.

Cluster analysis was performed for each of the seven major structural dimensions described above. Each analysis produced groups of collaborations based on different distinguishing criteria. The solutions utilized from two factors for interdependence to five factors for magnitude and participation. In addition, we developed two clustering solutions that cut across these seven structural dimensions.[41]

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[40] Cluster analysis refers to a variety of statistical procedures used to create classifications (Aldenderfer and Blashfield 1984). Unlike discriminant analysis or K-means analysis, which require the *a priori* definition of groups, cluster analysis is specifically designed to identify the groupings (clusters) discernable in a particular data set without prior knowledge of types. Clustering involves reorganizing a set of observations into groups of entities based on the estimation of similarity by statistical measures (coefficients). Similarity coefficients may be divided into four groups: distance coefficients, association coefficients, correlation coefficients, and probabilistic similarity coefficients (Sneath and Sokal 1973, pp. 119-120). We employed a standardized distance measure based on squared Euclidean distance. Since our data contain variables at various levels of measurement, we rule out the use of association coefficients (the simple matching coefficient, Jaccard's coefficient) that measure similarity between observations on binary variables. The same holds true for the probabilistic similarity coefficients. Correlation coefficients are also inappropriate since they do not satisfy at least one of the conditions of being a metric. Distance measures, however, meet the criteria of a metric and are applicable to mixed type data. Standardization was applied by setting variable means to zero and standard deviations to one to offset the effect of relative size of variables—a transformation routinely applied by researchers (Aldenderfer and Blashfield, 1984: 26). Clusters were derived using the well-known Ward's method. The number of clusters and cluster membership was determined by the cluster membership table (showing which case belongs to which cluster for a specified number of clusters) and by the dendrogram (a visual display of the stages in a hierarchical clustering solution). Clusters may be derived in several ways. The most common methods are agglomerative, hierarchical, sequential and nonoverlapping (Sneath and Sokal 1973). We began with two methods of aggregating groups—average linkage between groups and Ward's method. The former uses the average distances between pairs of observations in two different clusters to combine these clusters. Since it avoids the extremes of both nearest neighbor and furthest neighbor techniques, it is often the preferred method of linkage. Ward's method, on the other hand, is intuitively appealing since it is designed to minimize the within-cluster variance, with the aim of distinguishing internally homogeneous and externally heterogeneous groups. Results presented here use Ward's linkage algorithm since comparisons showed that it generated almost exactly the same solution as average linkage between groups but tended to be more robust with respect to the effect of idiosyncratic cases.

[41] The seven-variable solution utilized one variable from each of the structural dimensions, selecting those variables that most clearly distinguished clusters (types) in each of the previous analyses. The four-variable clustering was based on our desire to see if a simple solution could be developed based on dimensions that seemed important from prior historical analysis.

Which clustering solution is best? Clearly, different solutions may be preferred for different purposes. In light of the fact that the present state of our knowledge on collaborations in science does not allow us to make a decision based on prior research or on theoretical grounds, we concluded that this issue could and should be resolved empirically.

Table 2 in Appendix S-3 shows that clustering based on technological practice is superior to other structural dimensions in providing a classification that relates to outcomes. Each of the nine dimensions along the rows of the table was used to define discrete groups of collaborations. These discrete groups, or "types," were used as independent factors in an analysis of variance for five sets of dependent variables. Clusterings by magnitude and bureaucratic organization—as well as the seven- and four-variable solutions—are related to reported conflict and documentation. However, <u>only the clustering based on technological practice is related to each of the five outcome indicators</u>.[42] The other solutions are at best related to two outcomes, while clustering by project formation, participation, interdependence, and communication are unrelated to any outcome.[43] We conclude that technological practice is the most promising dimension for framing a classification of multi-institutional collaborations and devote the remainder of the paper to its elaboration.

Figure 9 in Appendix S-4 provides a dendrogram, or graphic representation, of the clustering by technological practice. This device facilitates a judgment about the number of clusters that best characterizes multi-institutional collaborations. There is no statistical means of determining a "correct" number of clusters. However, if we select the rescaled distance nine as a cut-off point for the final solution there are four well-defined groups of collaborations. With a three-cluster solution, the distances at which clusters combine are quite large (that is, relative dissimilarity between the clusters being combined). A five-cluster solution is also a possibility, but then one cluster (at the bottom of the dendrogram) has a substantially different elevation than the other four. Increasing the threshold value by just one unit results in a four-cluster solution, which yields interpretable clusters of roughly equal sizes. Table 3 in Appendix S-3 provides the names of collaborations in each cluster, complementing the findings from examining the dendrogram. Four clusters (types) were identified: managerial, decentralized, noninstrumental, and routine. A description of the distinguishing characteristics of these types is provided in the next section, entitled Discussion.

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[42] The specific outcome indicators are given in Appendix S-2. The technological practice indicators and factors are given in Appendix S-1. Average cluster values for each cluster (type) are given in Table 4a in Appendix S-3 (for factors) and Table 4b in Appendix S-3 (for indicators).

[43] This does not mean, of course, that none of the individual variables that comprise the structural dimensions are related to outcomes. Table 2 (Appendix S-3) was generated by running each typology (classification) against all variables. The same specific indicators are not necessarily related to structural classifications. An 'X' in a cell shows that at least one indicator of a given type is related to the structural dimension.

The dendrogram shows that with one exception[44] the clusters (types) do not exhibit field-specific differentiation. The main divisions are otherwise unrelated to the scientific areas that provided the basis for our sample. Collaborations in ground-based astronomy are found in every type except the routine type.

The mean differences in technological characteristics of the four types of projects are shown in Table 4a in Appendix S-3 for the factors used in cluster analysis. Judging by the dispersion, clusters one (managerial) and four (routine) are the least homogeneous among the four, with the largest standard deviations on most variables. Table 4b (Appendix S-3) presents means and standard deviations for the nine variables that were used to construct these factors. In the discussion we return to these tables in order to examine each collaborative type in more detail.

Descriptive statistics showing differences between clusters (types) on the five outcome dimensions are presented in Table 5 (Appendix S-3), while Table 6 (Appendix S-3) shows the results of an analysis of variance with each type of collaboration representing a separate group. The models for perceived success, trust, conflict, stress, and documentary practice are statistically significant at the 0.05 level, indicating that one or more contrasts between means is significant.

Projects from the decentralized type are rated as more successful than other technological types. The omnibus test provides support for the hypothesis that the sample means came from populations with significantly different means.[45] The strength of this relationship is measured by η^2 (eta squared). Thus, 41% of the variation in rated success is explained by the typology—a rather strong relationship by normal standards in the social sciences.[46]

For trust towards other researchers the primary differences are between the first type (managerial) and each of the other three types. Types two (decentralized), three (noninstrumental), and four

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[44] Four out of the five routine projects are engaged in materials science research.

[45] The F ratio is significant at $p<0.05$, indicating that technological practice affects the perception of successfulness of the multi-institutional collaboration. The modification of the Tukey HSD test for groups of unequal sizes shows which individual means differ significantly from one another. Two contrasts are significant at $p<0.05$—between types two (decentralized) and one (managerial) and between types two (decentralized) and four (routine). In both cases decentralized collaborations are judged to be more successful.

[46] Collaborations of the decentralized type were characterized by high technological instrumentation (a composite variable combining designing of own equipment, building own equipment, and subcontracting); low technological management (technological difficulties—whether the instrument turned out differently than originally proposed and management of topics for analysis); and high degree of checking of results within the collaboration.

(routine) exhibit uniformly high levels of trust towards colleagues.[47] The analysis of variance confirms that significantly lower levels of trust are perceived in collaborations from the managerial type. The value of eta squared indicates that 59% of the variation in trust towards other researchers in the collaboration can be explained by the clustering.

Table 5 (Appendix S-3) indicates similar differences for conflict and stress. The greatest conflict between teams (perceptions of serious disagreements) was reported for collaborations of type one (managerial), and the lowest in type four (routine). Forty percent of the variation in conflict between teams is explained by the simple ANOVA model.[48] The degree of stress caused by deadlines is, on average, higher in multi-institutional collaborations from the managerial technological type as compared to projects from the routine type.[49]

Differences in documentary practice are especially large between types one (managerial) and two (decentralized), with greater dispersion of records in the latter. The overall test for the difference between multiple means is significant, with 39% of the variance in the dispersion of records explained by the classification.[50] In the following section, we provide a more detailed examination of each of the four groups that have been identified through cluster analysis and shown to have an impact on significant outcome dimensions.

V. *DISCUSSION*

(1) The most distinctive feature of the seven multi-institutional collaborations that constitute the first type was the combination of management of data analysis and planned development of instrumentation. We propose to designate these collaborations as managerial, not to imply high levels of bureaucracy, but because there are relatively high levels of control over instrumentation and data analysis.[51] Collaborations of this type included the Astrophysical Research Consortium,

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[47] The Tukey HSD multiple contrasts test revealed significant pairwise differences between the first cluster and all the others.

[48] The multiple comparisons test for unequal group sizes provides evidence that the only statistically significant contrast is between multi-institutional collaborations from type one (managerial) and those from type four (routine).

[49] The *omnibus* analysis of variance test shows that not all the group means are equal in the population. For the relationship between the technological practice and stress induced by deadlines, 36% of the variation in stress is explained by cluster membership. The modified Tukey multiple comparisons procedure revealed one significant pairwise contrast between types one (managerial) and four (routine).

[50] Only one pairwise contrast is significant at $p<0.05$, showing that type two (decentralized) collaborations records are significantly more dispersed than collaborations records from type one (managerial).

[51] We provide labels for each of the four clusters (types) based on the their distinctive characteristics using the typology (classification) itself. For ease of interpretation in the discussion of specific clusters (types), we employ a comparison of the average values on the

the Science and Technology Center for Superconductivity, the Keck Telescope, the Positron Diffraction and Microscopy Project, BNL E-814 and E-877, BNL E-878 and E-896, and Sagittarius A.

The managerial group is the only type in which most of the collaborations actively managed the topics to be analyzed by individual members (row 7, column one in Table 4b in Appendix S-3). Topical management does not imply imposition of research themes on the participants, but rather the coordination of data analysis by the collaboration team. For example, the observation of the Galactic Center Sagittarius A at 3 mm. frequencies had to be done at four observatories according to a maser time standard. Some, but not all of these projects exhibited overlap of topics. For instance, the relativistic heavy-ion experiments at Brookhaven, known as E-814 and E-877, had several graduate students working with electromagnetic interactions. Although they were measuring slightly different things, some items—like a total cross-section—needed to be compared.[52]

The technological configuration associated with type one, centered on management of data analysis, is associated with lower levels of trust between project teams and relatively high levels of stress and disagreements (See Table 5 in Appendix S-3). These collaborations are also perceived as less successful than all but the routine type. Apparently, the relatively standardized, planned development of instruments is not associated with lack of conflict. Rather, attempts to maintain high levels of control may themselves generate difficulties. Managerial multi-institutional collaborations are, in this respect, the opposite of those in type two (decentralized), which have the lowest levels of management of data analysis and the highest perceived success.

(2) The most significant difference is the one that sets type two apart from the other types. In none of these projects was there central management of data analysis. Topics for analysis were controlled by independent teams. For this reason, we term type two decentralized. This type consists of Dupont-Northwestern University-Dow Collaborative Access Team (DND-CAT), the Angiography Diagnostics Project, the VLBI Network, the Hobby-Eberly Telescope, and the BIMA Array. The characteristics of decentralized collaborations are in some respects quite similar to those of the managerial type in terms of a focus on technological instrumentation and cross-checking of results among teams.

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original measures (See Table 4b in Appendix S-3) rather than the constructed indices (See Table 4a in Appendix S-3). For example, in Table 4b (Appendix S-3), a value of 1 in the first column of the first row indicates that each of the seven collaborations in the first cluster (type) put a great deal of effort into the design of equipment for dedicated use.

[52] Checking the accuracy of each other's results was rather the rule than the exception in managerial collaborations since there was little segmentation in topics for data analysis. Thus, the graduate students working in overlapping areas within experiment 814 at BNL sometimes discovered disagreements in the measurement of cross-sections that needed checking. Typically this had something to do with the calibration of a detector or was due to people using different codes. However, results checking was even more common in types two (decentralized) and three (noninstrumental).

An exemplary case is the BIMA Array. This collaboration built an array of six short radio wavelength antennas for astronomical observations, using a decentralized group of project teams. In answer to the question of whether the collaboration managed topics to be analyzed by its individual members, a participant replied, “No, no. We do it in the usual [academic] way. The faculty individuals have their special science interests, and the students that work for them work with them depending on the style of the individual faculty.” (Interview with a BIMA scientist)

One difference between managerial and decentralized collaborations is reflected in their documentary practices. The dispersion of core records is much greater in the latter. This state of affairs is a result of their characteristic of team control. Decentralized collaborations tend not to exert control over data analysis, while managerial collaborations exercise a great deal.

Management of data analysis and lack of changes in the instrumentation seems to have contributed to the greater centralization of records in the managerial type. It is worth emphasizing here that decentralized collaborations view themselves as extremely successful, perhaps because they are patterned on the traditional, academic organization of science.

(3) Five multi-institutional collaborations were included in the third technological type: the Grand Challenge Cosmology Consortium, the 3 mm VLBI Collaboration, the Radiology Diagnostic Oncology Group (RDOG), the Crystal Structure of CTA and CTP Project, and the Upper Atmospheric Research Collaboratory (UARC). We designate this type noninstrumental because its primary distinction is that these collaborations neither design nor build their own equipment, nor do they subcontract the construction of such equipment. All of them performed sophisticated experiments or observations by making use of already existing facilities. Thus, for example, the project on Crystal Structure brought together materials scientists, solid state chemists, and solid state physicists from Dupont, BNL, and SUNY-Stony Brook. These researchers sought to determine the structure of the high temperature form of CTA and CTP from which the nonlinear optical material crystallizes, using an already existing beamline at the National Synchrotron Light Source in Brookhaven.

(4) What distinguishes collaborations that belong to the last type is relatively low innovation and high coordination of results. Typically, high coordination of results is the product of the division of labor within a collaboration—separate research teams tackling specific topics that have to be integrated. Like the noninstrumental type, these projects had relatively large overlaps in the topics addressed.[53] But unlike the noninstrumental type, teams in routine collaborations never checked the accuracy of each other’s results. For example, there were three separate teams in the Advanced Light Source Beamline Collaboration, each responsible for an end station. Checking

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[53] Overlap of topics for data analysis was a common phenomenon in collaborative arrangements of the routine type and was viewed as a natural state of affairs, beneficial for participants as well as the project as a whole. A pertinent illustration is provided by a member of the Center for Polymer Interfaces and Macromolecular Assembly (CPIMA), who elaborated: “We have actually taken advantage of overlap in a sense that, if there is some common material that is being examined by multiple techniques, that [overlap] can lead to a very important synergy.” (Interview with a participant in CPIMA.)

and coordination occurred within the individual research teams, but not between them. Another distinctive feature of these routine projects was that, while several designed and built instruments, they were less likely than other types to push the state-of-the-art in their respective scientific fields and there was not much time pressure. The membership of the routine group of collaborations includes the Advanced Light Source Beamline Collaboration, the Center for Polymer Interfaces and Macromolecular Assembly (CPIMA), Materials Partnership for Hybrid Organic/Inorganic Semiconductors (HOIS), the National Digital Mammography Development Group (NDMDG), and the Smart Materials Consortium.

The nature of the relationships between the technological practices of collaboration and the dependent measures is complex, and the emerging patterns are not always intuitive.

Nevertheless, at least one fairly clear-cut contrast in terms of collaboration outcomes appears to be the division between managerial and routine projects. Neither of these types define themselves as particularly successful compared to the other types.[54] Where they differ is in such interpersonal relations as trust, stress, and conflict. <u>Managerial collaborations have a lower degree of trust toward other researchers, higher levels of reported stress, and more serious disagreements between teams, while informants from routine collaborations report higher trust toward their colleagues, lower degree of stress due to time pressure, and relatively few disagreements.</u>

Although technological management is associated with higher conflict, our data do not allow us to determine whether management practices generated these conflicts, or were implemented to reduce them. A closer examination shows that technological management in and of itself may or may not be positively associated with conflict and stress within the collaboration. Thus, the collaborations that comprise the decentralized type are not highly managed, yet exhibit higher levels of stress and conflict than routine collaborative projects. It seems that this is due to the combination of lack of management and frequent modification to the instrumentation.

Managerial collaborations, which also experienced high degrees of conflict and stress induced by deadlines, did not have any changes in instrumentation, but like decentralized projects, engaged in results checking. Thus, regular checking of the accuracy of each other’s results could be the common denominator of high levels of conflict and stress.

VI. *CONCLUSION*

Through cluster analysis we have identified four types of multi-institutional collaborations: managerial, decentralized, noninstrumental, and routine. The more general findings from Phase III may be summarized in four points.

<u>First</u>, expanding the scientific areas of study from the initial focus to a variety of other fields demonstrates the utility of specifying seven major structural dimensions: project formation,

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[54] Recall that the most successful projects belong to the decentralized type, which is also characterized by comparatively high degree of stress and between-team conflicts. Thus, it looks like success in multi-institutional collaborations comes “at a price.”

magnitude, bureaucratic organization, interdependence, communication, participation, and technological practice. These features can be studied using a variety of indicators based on open and closed-ended questions with principal scientists and project leaders as informants. It is always desirable to interview as many individuals as possible, but for most measures there was a high level of agreement on basic features of each project.

Second, for most of the typologies we developed, collaborations did not fall into clear types by disciplinary field. Therefore, the structural dimensions are not only more useful theoretically, but are necessary to understand the empirical variability of collaborations.

Third, of the seven structural dimensions examined here, only technological practice relates to a range of outcome variables. We employed a broad definition of "technological practice" that does not focus exclusively on hardware, but incorporates the diverse ways that instrumentation and data analysis tasks are organized, characteristics of the management of topics, and technical change as well as the uses of equipment. The principle finding is that from technological practice we generated a typology that correlates with stress, trust, conflict, documentary practice, and perceived success.

Finally, it is worth emphasizing that the *comparative* study of multi-institutional collaborations in science and technology has been neglected. In spite of their significance in the past half century, and the likelihood that they will grow in number and importance in the future, sociologists of science have focused on the single laboratory. While such laboratory studies are critical to our understanding of the dynamics of knowledge production, an expanded scope is necessary to capture the structure and process of contemporary science owing to emergent forms of social organization. We conclude that the important aspects of these forms, varied as they are, can be systematically described in terms of their major structural dimensions and studied comparatively. Results show that a classification based on a broad conception of technological practice outperforms others in its ability to predict the full range of sociological outcomes of multi-institutional collaborations.

SOCIOLOGICAL ANALYSIS

SOCIOLOGICAL ANALYSIS: APPENDIX S-1
TECHNOLOGICAL PRACTICE DIMENSIONS

Indicators were produced by factor analysis of the original set of variables, recoding for consistency in sign were necessary. All variables were coded as dichotomous (1=Yes; 0=No). The questionnaire items that generated the original data are as follows.

Factor One

(1) Did the collaboration put a lot of effort into designing any equipment for its dedicated use?
Designing own equipment

(2) Did the collaboration but a lot of effort into building any equipment for its dedicated use?
Building own equipment

(3) Were there subcontracts with outsiders to obtain the instrument?
Subcontracts with outsiders

Factor Two

(4) Did the (instrument, equipment, detector, procedure) represent a major advance in the state of the art? State-of-the-art

(5) Did time pressure cause problematic results?
Time pressure

(6) In data analysis, were there overlaps in topics addressed by collaborators?
Recoded to reverse values as “topical segmentation.”

Factor Three

(7) Did the collaboration manage the topics which were to be analyzed by its individual members?
Recoded to reverse values as “team control.”

(8) Did the instrument turn out differently than originally proposed?
Instrument change

Factor Four

(9) Overall, did teams check the accuracy of each others’ results?
Results checking

SOCIOLOGICAL ANALYSIS: APPENDIX S-2
OUTCOME VARIABLES

1. Success—an index composed of two original variables:

How successful do you think this project was as compared to your other scientific work?
4. Very successful 1. Not successful at all

How successful do other people think it was? 4. Very successful 1. Not successful at all

2. Trust—measured by two original indicators:
What was the degree of trust compared with your experiences in an academic department?

(a) Towards researchers on other teams 3. High 2. Medium 1. Low

(b) Towards the project management. 3. High 2. Medium 1. Low

3. Conflict—measured by four original indicators:

In every collaboration there are some disagreements and problems.

How serious were the disagreements:

(a) Between teams 4. Very serious 1. Not serious at all

(b) Between junior and senior members 4. Very serious 1. Not serious at all

(c)Between scientists and engineers 4. Very serious 1. Not serious at all

(d) Between researchers and project management 4. Very serious 1. Not serious at all

4. Documentary Practice—measured by two indicators:
Quality of record-keeping 3. High 2. Medium 1. Low

Dispersion of records (number of locations where core records are kept)

5. Stress—an indicator identical to the original variable

Compared with an academic science department, how would you estimate the degree of stress induced by deadlines/scheduling? 3. Higher 2. Same 1. Lower

SOCIOLOGICAL ANALYSIS: APPENDIX S-3
TABLES

Table 1: Characteristics of Multi-Institutional Collaborations
(n=23)

Variables	Means / Percentages
Project Formation and Composition	
% University-instigated	48%
Pre-existing relationships*	2.74
% Dominant sector	70%
Magnitude	
Number of participants	39.39
Number of organizations	6.13
Years from original idea to funding	2.09
Interdependence	
Degree of instrumentation autonomy*	2.48
Degree of data sharing autonomy*	2.83
Degree of autonomy in analysis*	2.61
Communication	
% Communications center	61%
% Receiving public attention	70%
% Managing external communication	44%
Bureaucracy	
% Designated scientific leader	70%
% Designated administrative leader	70%
% Fewer levels of authority than university department	61%
Participation	2.48
Degree of graduate student	2.52
participation*	35%
Degree of central interest	
% International participation	
	70%
Technological Practice	65%
% Designing own equipment	74%
% Building own equipment	
% Advance in the state of the art	

*Scaled 1=low, 3=high.

Table 2: Summary of Analysis of Variance Results					
Type of Clustering	Outcome Dimensions				
	Success	Trust	Conflict	Documentary Practice	Stress
Project Formation					
Magnitude			X		
Bureaucratic Organization			X	X	
Interdependence					
Participation					
Communication					
Technological Practice	X	X	X	X	X
7-Variable Clustering			XX	X	
4-Variable Clustering			XX		

Note: X denotes a significant ANOVA at $p<0.05$. The variables that measure the five outcome dimensions are described in Appendix S-2.

Table 3: Classification of Multi-Institutional Collaborations Based on Technological Practice

Type 1: Managerial

Case	*Field*	*Collaboration*
1	gba	Astrophysical Research Consortium
2	ms	S&T Center for Superconductivity
8	gba	Keck Telescope
9	ms	Positron Diffraction and Microscopy
13	hinp	BNL E-814 and E-877
15	gba	Sagittarius A
20	hinp	BNL E-878 and E-896

Type 2: Decentralized

Case	*Field*	*Collaboration*
3	ms	Dupont-Northwestern-Dow CAT
6	mp	Angiography Diagnostics
12	gba	VLBI Network
17	gba	Hobby-Eberly Telescope
23	gba	BIMA Array

Type 3: Noninstrumental

Case	*Field*	*Collaboration*
4	ccc	Grand Challenge Cosmology Consortium
5	gba	3mm. VLBI
7	mp	Radiology Diagnostic Oncology Group
14	ms	Crystal Structure of CTA and CTP
21	ccc	Upper Atmospheric Research Collaboratory

Type 4: Routine

Case	*Field*	*Collaboration*
10	ms	Advanced Light Source Beamline Collaboration
11	ms	Center for Polymer Interfaces and Macromolecular Assembly
16	ms	Materials Partnership for Hybrid O-I Semiconductors
19	mp	National Digital Mammography Development Group
22	ms	Smart Materials Consortium

*Field Key:
ms = Materials Science
gba = Ground-Based Astronomy
hinp = Heavy-Ion and Nuclear Physics
mp = Medical Physics
ccc = Computer Centered Collaborations

Table 4a: Technological Practice Cluster Characteristics*

	Factor 1		Factor 2		Factor 3		Factor 4	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Cluster 1	.88	.16	.55	.38	.14	.20	.86	.24
Cluster 2	.97	.07	.33	.12	.75	.25	1.00	.00
Cluster 3	.00	.00	.60	.30	.35	.22	1.00	.00
Cluster 4	.63	.38	.13	.18	.35	.34	.00	.00
Total	.64	.42	.42	.32	.38	.33	.73	.43

* See Appendix 1 for factor composition.

Table 4b: Cluster Means and Standard Deviations for Nine Technological Practice Indicators

Indicators	Clusters				
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Average
(1) Designing equipment	1.00 (.00)	1.00 (.00)	.00 (.00)	.80 (.45)	.73 (.46)
(2) Building equipment	1.00 (.00)	1.00 (.00)	.00 (.00)	.60 (.55)	.68 (.48)
(3) Subcontracting	.64 (.48)	.90 (.22)	.00 (.00)	.50 (.50)	.52 (.48)
(4) State of the art	.79 (.39)	.80 (.45)	.80 (.27)	.40 (.55)	.70 (.43)
(5) Time pressure	.57 (.53)	.20 (.27)	.40 (.55)	.00 (.00)	.32 (.45)
(6) Topic segmentation	.29 (.39)	.00 (.00)	.60 (.55)	.00 (.00)	.23 (.40)
(7) Team control	.29 (.39)	1.00 (.00)	.50 (.50)	.60 (.55)	.57 (.47)
(8) Instrument change	.00 (.00)	.50 (.50)	.20 (.45)	.10 (.22)	.18 (.36)
(9) Results checking	.86 (.24)	1.00 (.00)	1.00 (.00)	.00 (.00)	.73 (.43)

Note: Standard deviations are given in parentheses.

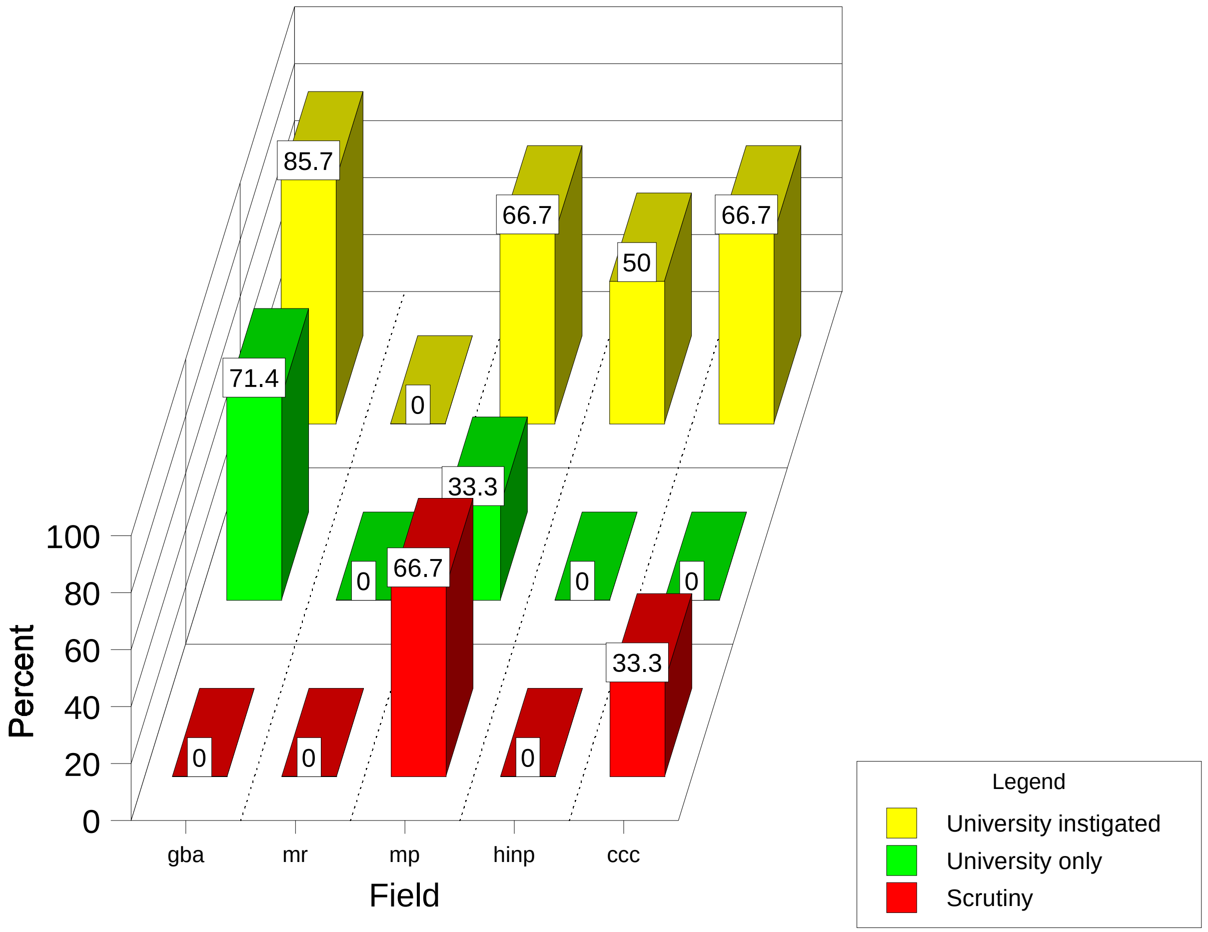
Table 5: Descriptive Statistics for Five Dependent Variables by Technological Practice Cluster Membership

Dependent Variable	Groups	N	Mean	Std. Deviation	Std. Error
SUCCESS	1.00	7	3.3929	.4756	.1798
	2.00	5	4.0000	.0000	.0000
	3.00	5	3.7500	.2500	.1118
	4.00	5	3.3000	.4472	.2000
	Total	22	3.5909	.4401	9.384E-02
TRUST TOWARD OTHERS	1.00	7	2.3571	.4756	.1798
	2.00	5	3.0000	.0000	.0000
	3.00	5	3.0000	.0000	.0000
	4.00	5	3.0000	.0000	.0000
	Total	22	2.7955	.3982	8.489E-02
CONFLICT BETWEEN TEAMS	1.00	7	2.8571	.4756	.1798
	2.00	5	2.8000	.8367	.3742
	3.00	5	2.0000	1.0000	.4472
	4.00	5	1.6000	.5477	.2449
	Total	22	2.3636	.8616	.1837
DISPERSION OF RECORDS	1.00	7	1.7143	.4880	.1844
	2.00	5	3.6000	1.5166	.6782
	3.00	5	2.4000	1.1402	.5099
	4.00	5	2.0000	.7071	.3162
	Total	22	2.3636	1.1770	.2509
STRESS	1.00	7	2.7857	.3934	.1487
	2.00	5	2.6000	.5477	.2449
	3.00	5	2.2000	.8367	.3742
	4.00	5	1.8000	.4472	.2000
	Total	22	2.3864	.6534	.1393

Table 6: Analysis of Variance Summary Table for Five Dependent Variables as Functions of Technological Practice Cluster Membership

Dependent Variable	Source	Sum of Squares	df	Mean Square	F	Sig.
SUCCESS	Between Groups	1.661	3	.554	4.140	.021
	Within Groups	2.407	18	.134		
	Total	4.068	21			
TRUST TOWARD OTHERS	Between Groups	1.972	3	.657	8.720	.001
	Within Groups	1.357	18	7.540E-02		
	Total	3.330	21			
CONFLICT BETWEEN TEAMS	Between Groups	6.234	3	2.078	3.997	.024
	Within Groups	9.357	18	.520		
	Total	15.591	21			
DISPERSI ON OF RECORDS	Between Groups	11.262	3	3.754	3.790	.029
	Within Groups	17.829	18	.990		
	Total	29.091	21			
STRESS	Between Groups	3.237	3	1.079	3.391	.041
	Within Groups	5.729	18	.318		
	Total	8.966	21			

SOCIOLOGICAL ANALYSIS: APPENDIX S-4
FIGURES



***Field Key:**

ms = Materials Science
gba = Ground-Based Astronomyhinp = Heavy-Ion and Nuclear Physics
mp = Medical Physics
ccc = Computer Centered Collaborations

Figure 1: Cross tabulation of Field by Instigating Sector, Sector, and Scrutiny from Outside Authorities

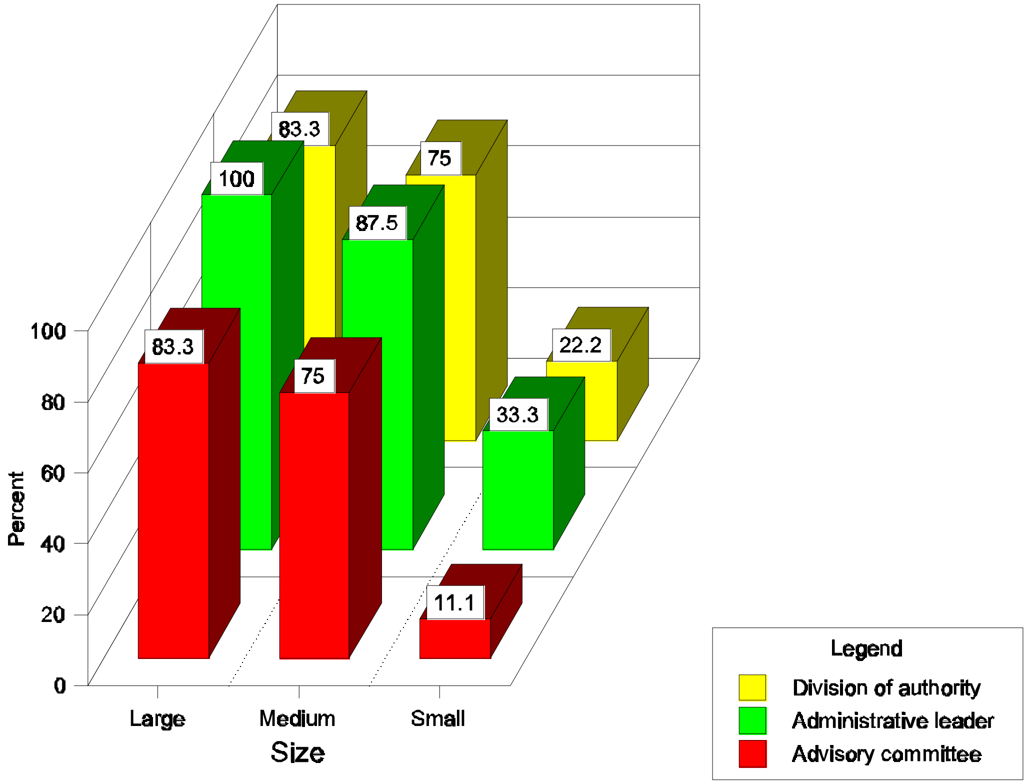


Figure 2 : Cross tabulation of Size by Advisory Committee, Administrative Leader, and Division of Authority

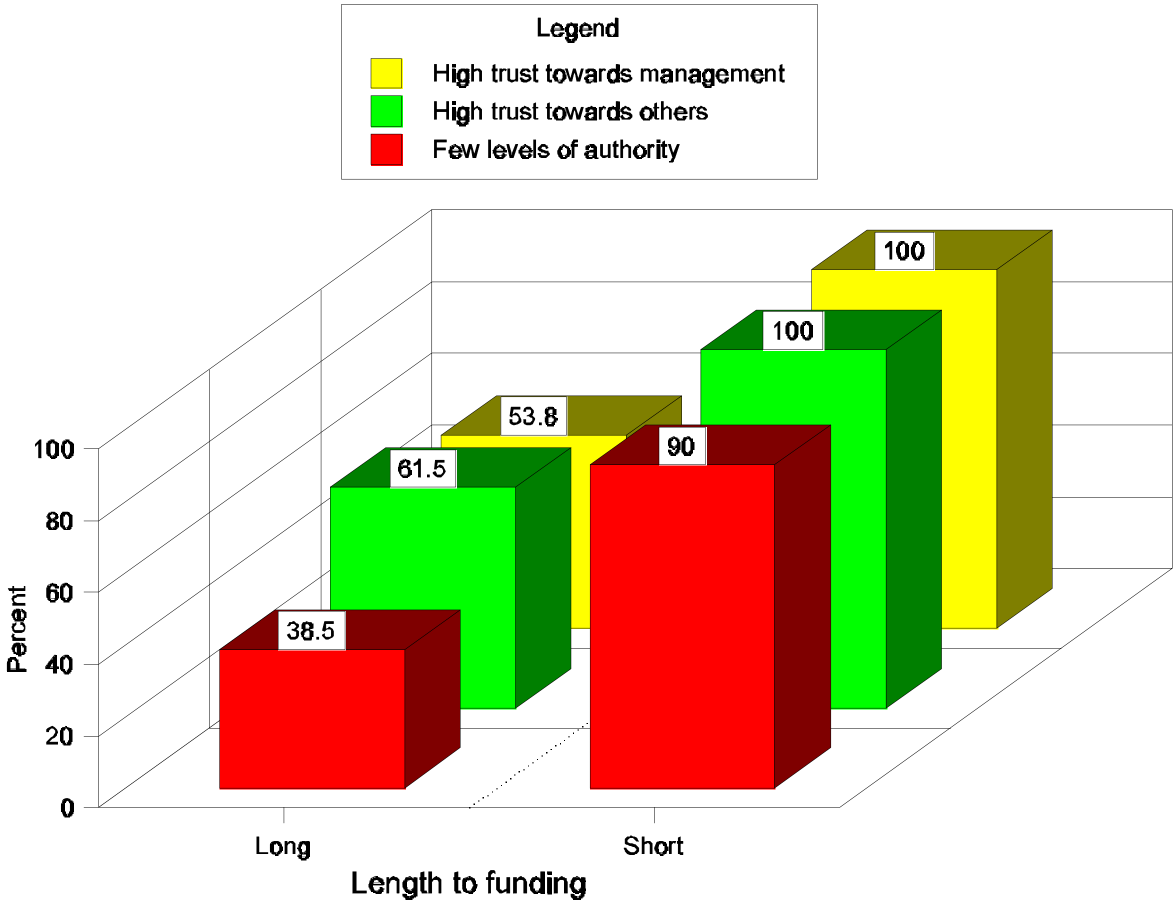


Figure 3: Cross tabulation of Length to Funding by Levels of Authority, Trust towards Other Researchers, and Trust towards the Project Management

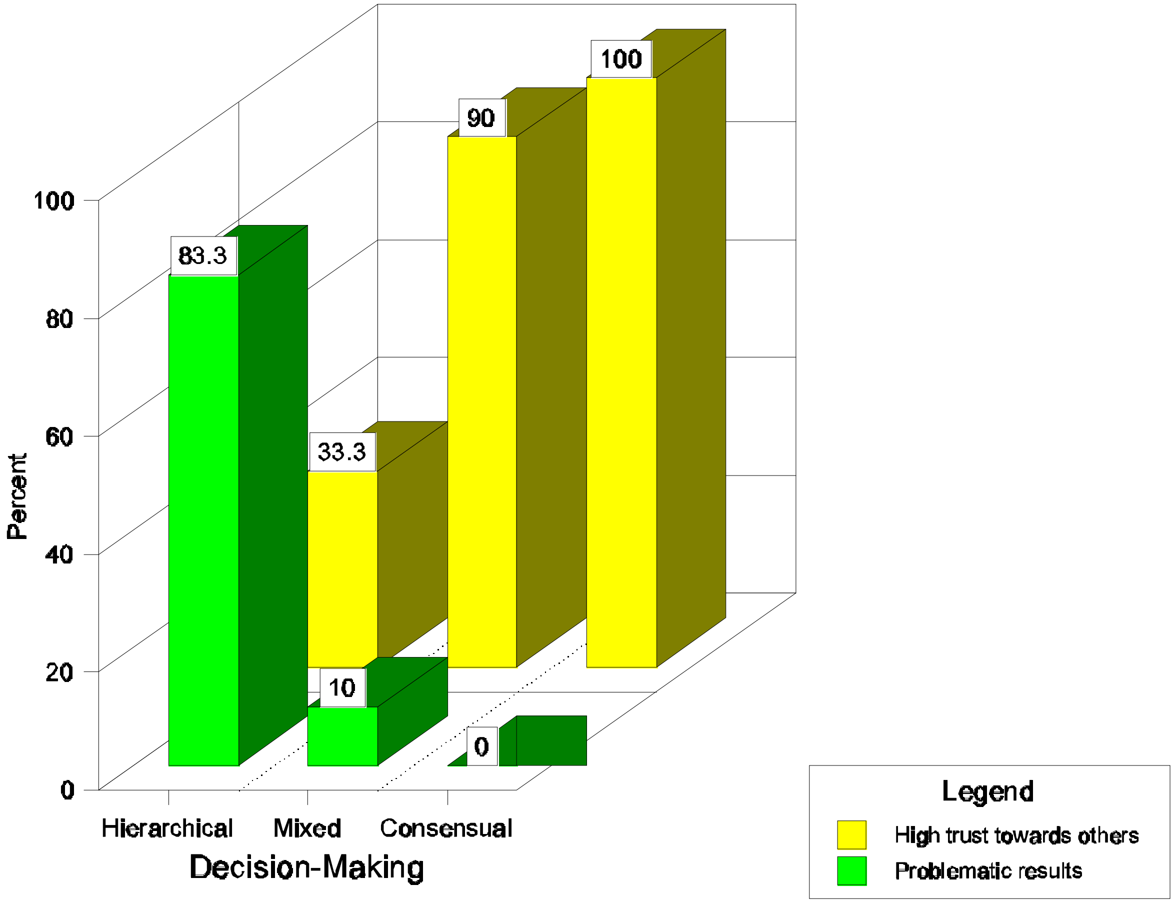


Figure 4: Cross tabulation of Decision-Making by Problematic Results and Trust towards Other Researchers

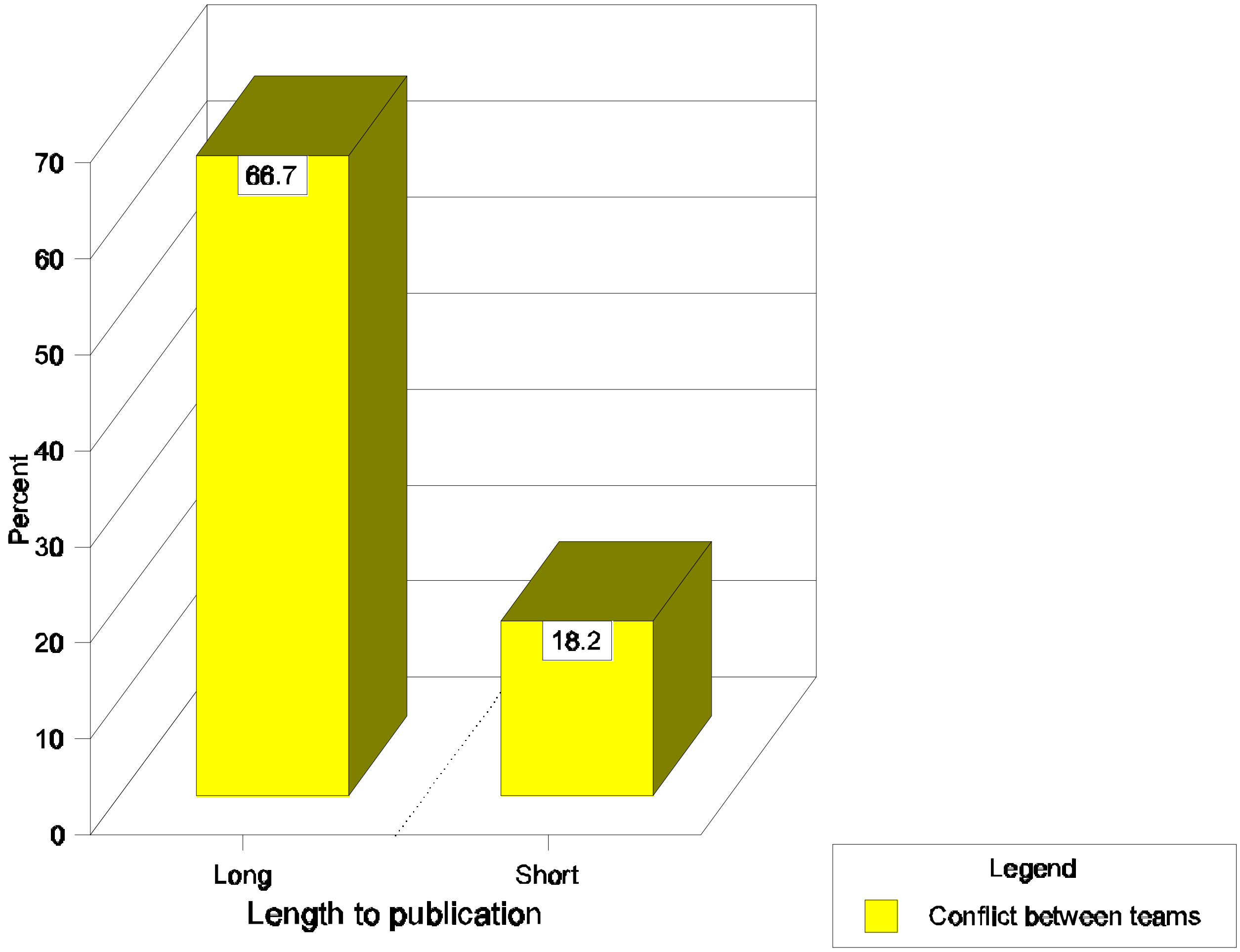


Figure 5: Cross tabulation of Length from Funding to First Publication of Results by Conflict between Teams

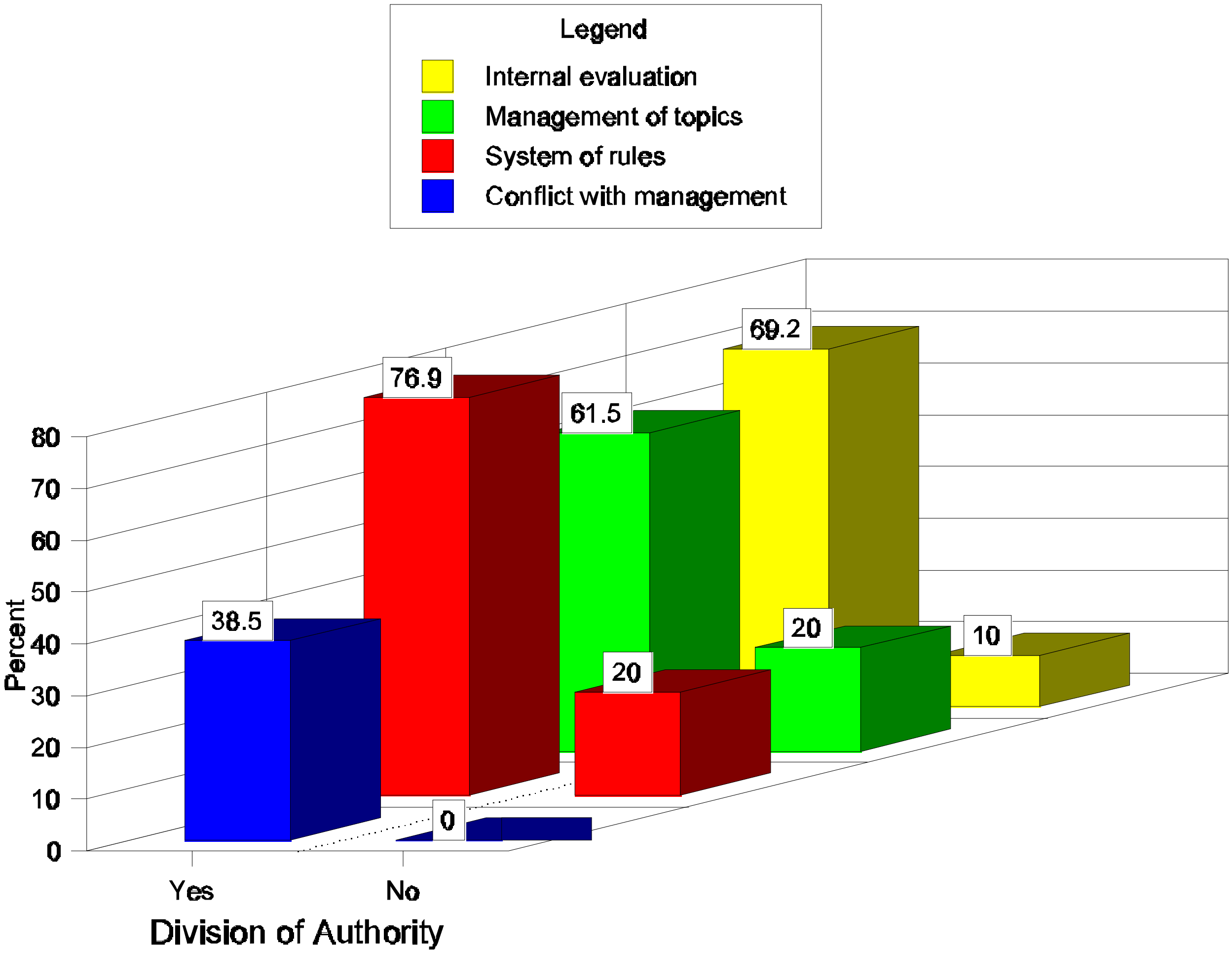


Figure 6: Cross tabulation of Division of Authority by Conflict between Researchers and the Project Management, System of Rules, Management of Topics for Analysis, and Internal Evaluation

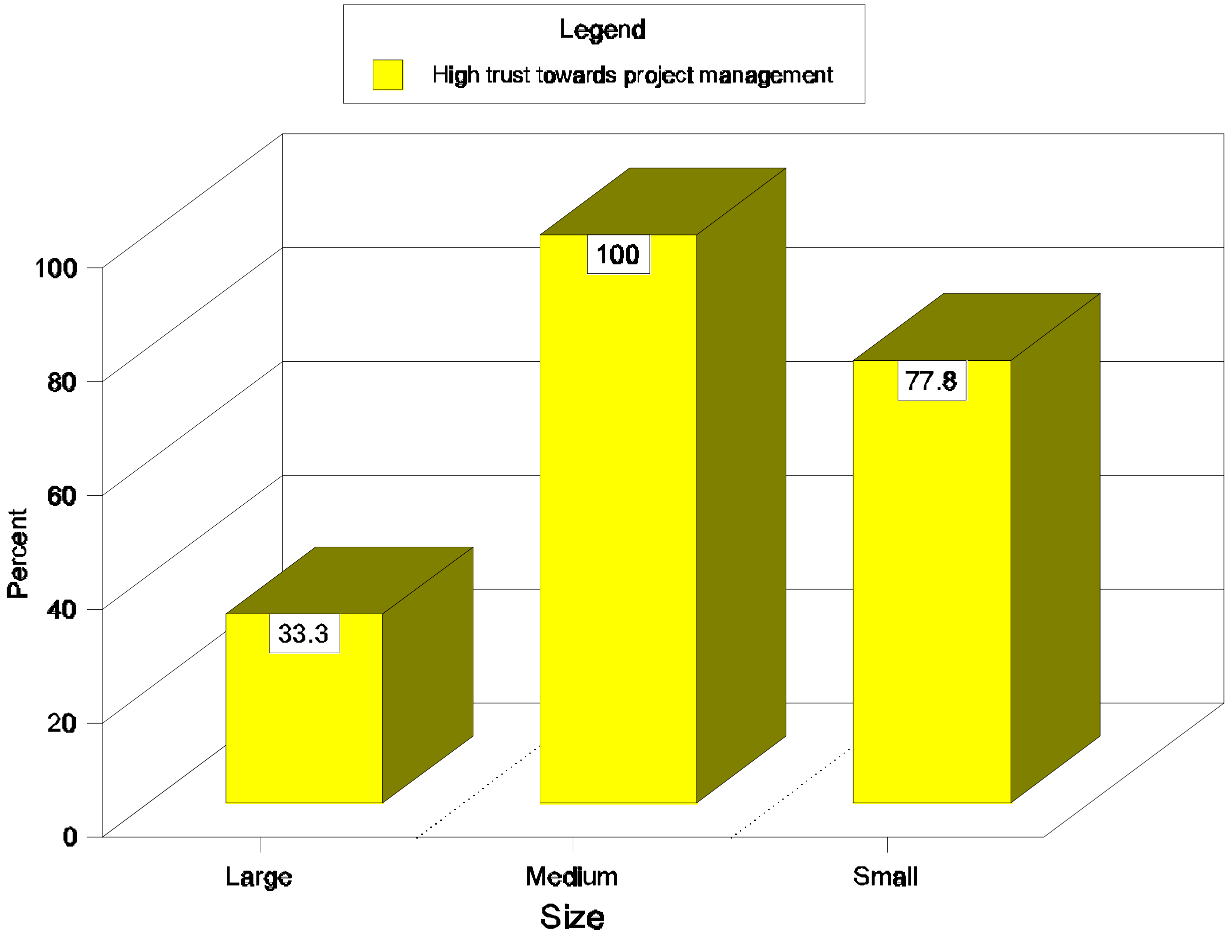


Figure 7: Cross tabulation of Size by Trust towards the Project Management

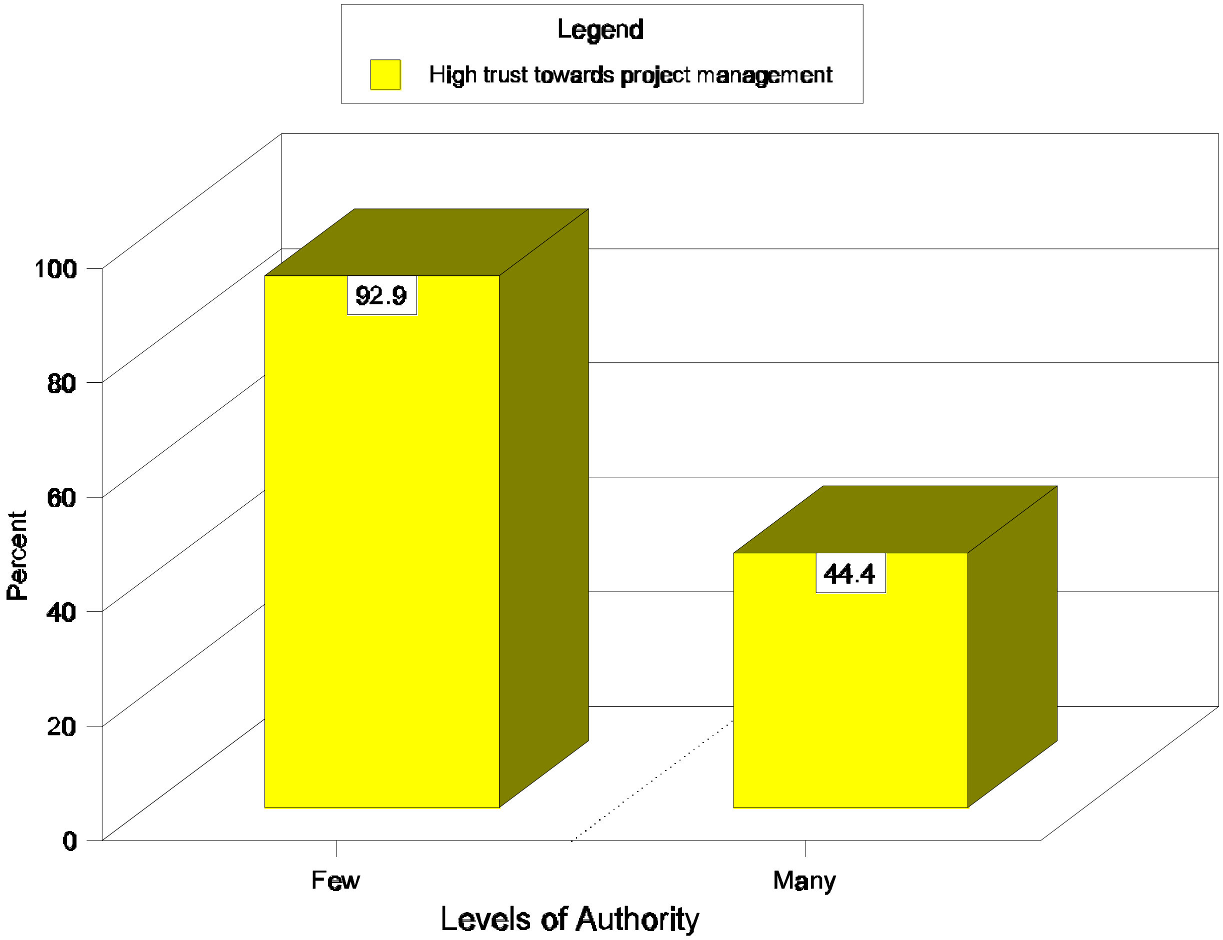


Figure 8: Cross tabulation of Levels of Authority and Trust towards the Project Management

Rescaled Cluster Distances

```
                0         5        10        15        20        25
Field   Case ID +---------+---------+---------+---------+---------+

mp          6   -+
gba        12   -+---+
ms          3   -+   +-------------------+
gba        17   -+---+                   I
gba        23   -+                       +-----------+
ms          2   -+-+                     I           I
gba        15   -+ +-------------+       I           I
hinp       13   ---+             +-------+           I
ms          9   -+---+           I                   I
hinp       20   -+   +-----------+                   +-----------+
gba         1   -+---+                               I           I
gba         8   -+                                   I           I
ms         14   -+                                   I           I
ccc        21   -+---+                               I           I
gba         5   -+   +-------------------------------+           I
ccc         4   ---+-+                                           I
mp          7   ---+                                             I
ms         10   -+-+                                             I
mp         19   -+ +---------+                                   I
ms         22   ---+         +-----------------------------------+
ms         11   ---+---------+
ms         16   ---+
```

*Field Key:

ms = Materials Science
gba = Ground-Based Astronomy
hip = Heavy-Ion and Nuclear Physics
mp = Medical Physics
ccc = Computer Centered Collaborations

Figure 9: Dendrogram for Technological Practice Clustering (Ward's Method)*

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REPORT NO 2: DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIAL SCIENCES, USES OF ACCELERATORS, AND MEDICAL PHYSICS

APPENDIX A: ACRONYMS AND GLOSSARY

APPENDIX B: REPORT ON PROJECT ACTIVITIES

REPORT NO 2: DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIAL SCIENCES, USES OF ACCELERATORS, AND MEDICAL PHYSICS

APPENDIX A: ACRONYMS AND GLOSSARY

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ACR: American College of Radiology

ALS: Advanced Light Source Beamline Collaboration, one of the AIP case study projects, which built a beamline for the Advanced Light Source accelerator at Lawrence Berkeley Laboratory.

ANOVA: Analysis of variance, a statistical technique.

APS: Advanced Photon Source, an 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

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

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).

FAC: Facility Advisory Committee, our generic term for committees, comprised of external scientists, that advise laboratories or observatories on the best use of the facilities they make available to external scientists.

GC3: Grand Challenge Cosmology Consortium, one of the AIP case study projects.

HSD: Honestly significant difference, a statistical term.

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.

KAI: Knowledge and Distributed Intelligence, a “crosscutting” NSF program to stimulate the use of recent advances in computer networking in scientific research.
LBL: Lawrence Berkeley Laboratory

MRSEC: Materials Research Science and Engineering Center, a program within NSF’s Materials Research Division.

MOU: Memorandum (or memoranda) of understanding.

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.

PAC: Physics Advisory Committees, the name accelerator laboratories usually give to the committee that advises on the allocation of beamtime.

PC: Positron Consortium and Participating Research Team, one of the AIP case study projects.

PI: Principal investigator.

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.

SDSS: Sloan Digital Sky Survey, one of the major activities of ARC.

SMC: Smart Materials Consortium, one of the AIP case study projects.

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.

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.

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.

REPORT NO. 2: DOCUMENTING COLLABORATIONS IN GROUND-BASED ASTRONOMY, MATERIAL SCIENCES, USES OF ACCELERATORS, AND MEDICAL PHYSICS

APPENDIX B: REPORT ON PROJECT ACTIVITIES

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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).[55]

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

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[55] 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 Rachel Carter, Sandra Johnson, Kiera Robinson, and Holly Russo.

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 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 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 Web site (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 Web site 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: The Final Report of the AIP Study of Multi-Institutional Collaborations—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.A. 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 to 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.

APPENDIX B: REPORT ON PROJECT ACTIVITIES

ATTACHMENTS

Attachment B-1: Papers and Sessions of Professional Meetings On the AIP Study of Multi-Institutional Collaborations

Attachment B-2: Phase III Question Set for Interview Program

PROJECT ACTIVITIES: ATTACHMENT B-1
PAPERS AND SESSIONS OF PROFESSIONAL MEETINGS ON THE AIP STUDY OF MULTI-INSTITUTIONAL COLLABORATIONS

Annual Meetings of Professional Societies

Papers given by Warnow-Blewett:

▲ 1995: Three papers on the AIP's documentation strategy (including the study of collaborations) at the annual meetings of the American Library Association, Chicago; the Department of Energy Records Managers, Albuquerque; and the Society of American Archivists, Washington, DC.

▲ 1996: A paper on the AIP Study entitled "Partnerships in Science" at the meeting of NAGARA (National Association of Government Archives and Records Administrators), Washington, DC.

▲ 1998: A paper, "The Value of Multi-Institutional Collaboration," at a plenary session of the DOE Annual Records Management Conference, Washington, DC.

Sessions of National and International Meetings on the AIP Study

▲ 1995 Session organized by Warnow-Blewett for the International Council on Archives (science subgroup of the Section on Academic and Research Institutes) that focused on multi-institutional collaborations. Spencer Weart presented a paper on the origins and growing significance of multi-institutional collaborations for science in recent decades. This provided an introduction to the main presentation by Tom Finholt on the Upper Atmospheric Research Collaboratory, a major testbed of the National Collaboratory. Washington, DC; session at AIP, College Park, MD.

▲ 1997 Session organized by Warnow-Blewett for the Society of American Archivists, "Where Are the Records of Multi-Institutional Collaborations?," with papers by Warnow-Blewett, Anderson, and AIP Working Group archivists Vicki Davis and Deborah Day, and with Margaret Hedstrom of the University of Michigan as chair and commentator. Chicago, IL.

▲ 1997 Session organized by Consultant Shrum for the 4S, "Multi-Institutional Collaboration," with papers by Warnow-Blewett, Genuth, and consulting sociologist Chompalov and with Woody Powell of the University of Arizona as commentator. Tucson, AZ.

▲ 1997 Session organized by Warnow-Blewett and John Krige (former AIP study consultant) for the International Congress for History and Philosophy of Science, "International Collaborations in Big Science," which included papers by Warnow-Blewett, Krige, Naomi Oreskes (AIP Working Group historian for geophysics), and Arturo Russo (former AIP study consultant). Liège, Belgium.

▲ 1998 Session organized by Genuth for the History of Science Society, "Investigations of Scientific Sprawl: Coping with the Multi-Institutional Research Project," with papers by Warnow-Blewett, Genuth, consulting sociologist Wesley Shrum, and former consulting historian John Krige and with Daniel Kevles of the California Institute of Technology as commentator. Kansas City, KS.

PROJECT ACTIVITIES: ATTACHMENT B-2

PHASE III QUESTION SET FOR INTERVIEW PROGRAM

First, some questions about your involvement and how the collaboration got started:

(1) When did you become involved with this collaboration? At what stage was the project when you got involved? What or who prompted you to become involved?

(2) Did your affiliation change during, or since, the project?

(3) Where did the idea for _____ [collaboration] come from?
[Ask a,b,c,d, and e if necessary]

(a) Did the collaboration embody someone's creative insight into experimental technique or intuition concerning physical reality?

(b) Was the project a response to a new research opportunity, like the availability of some new instrument, or to some recent discovery or theory?

(c) Did the idea for the collaboration arise or get modified through discussions among members of a National Academy panel or other advisory body?

(d) Was the collaboration a response to an internal change of the funding agency?

(e) Was there a person who was the main project instigator?
[If yes]
What was his name and title.

What was his role in the development of the collaboration.

Which sector did he come from? Did he also become the leader of the collaboration?

(4) Did anyone decline to join the project and for what reasons?

Now we'd like to ask you some short answer questions for statistical purposes. We will be returning to some of these topics later in the interview so you will be able to elaborate on them.

Let's start with the origins of the _______ [collaboration]

(5) Which sectors instigated the collaboration?
- university
- research institutes
- government labs
- government contract labs
- government agency
- corporate

(6) Was there a dominant sector in the instigation of the project?

(7) Which agency funded the collaboration?

(8) Is there a dominant funding agency for your discipline?

(9) Did the project's plans receive scrutiny from authorities outside the scientific community like Congressional committees or White House offices?

(10) Did the funding agency/agencies have to reorganize in order to manage the project?

(11) What sectors were represented in this project?
- university
- research institutes
- government labs
- government contract labs
- corporate

(12) What disciplines were represented?

(13) To what degree was the collaboration built on pre-existing working relationships between scientists or "brokered" relations among competitors? (V.36.b)

A. Pre-existing relationships:
3. To a high degree
2. To a medium degree
1. To a low degree

B. "Brokered" relations
3. To a high degree
2. To a medium degree
1. To a low degree

Now, let's talk about the magnitude of the project:

(14) How many organizations were involved during the lifetime of the project?

(a) How many subcontracts to outsiders by the project's teams or organizational members?

(15) What was the peak number of participants in collaboration?

(16) What was the number of separate teams?

(17) What was the number of graduate students working on the project?

(18) To what degree did graduate students participate in the collaboration?

3. To a high degree
2. To a medium degree
1. To a low degree

(19) What was the percentage of costs for personnel and the percentage of costs for instruments, research facilities and materials?

(20) How long did it take from the formulation of the original idea for the project to funding?

(21) How long was it from funding to first publication of findings?

Let's now turn to the structure, organization and management of the collaboration. If the answers to any of the following questions have changed in the lifetime of the collaboration, please tell us.

(22) For most of the time, was there a lead center or a host organization? [Get the name]

[If yes](a) What was its role?

(b) Was it located in a permanent organization?

(23) For most of the time, were there any contracts drawn up between the lead center and teams or among teams?

If so, with whom?

(24) What was the value of the contracts as a record of responsibilities of participating parties?

(25) For most of the time, was there a designated scientific leader?

[If yes] What was his name and title?

(26) For most of the time, was there a designated administrative/engineering leader?

(27) For most of the time, did one outrank the other?

(28) For most of the time, did the collaboration have its own external advisory committee(s)?

(29) For most of the time, was there any clear-cut division of labor within the collaboration?

[If yes] What was it?

(30) How many levels of authority were there in the collaboration?

(a) Compared with an academic science department with a chair, professors, and graduate students, would you call the levels of authority:

3. More
2. Same
1. Fewer

(31) Overall, was there a well-established system of rules and regulations about responsibilities, work and reporting?

(32) For most of the time, was there a coordination of schedules of teams within the project?

(33) For most of the time, who set the project timetable?

(34) For most of the time, how flexible was the timetable?

3. Very flexible
2. Somewhat flexible
1. Not flexible

(35) For most of the time, compared with an academic science department, how would you estimate the degree of stress induced by deadlines/scheduling?

3. Higher
2. Same
1. Lower

(36) Did time pressure cause problematic results?

[If yes] What were the problems?

(37) Did the collaboration ever formally evaluate itself?

(a) Was it ever evaluated from the outside?

[If yes] Were these evaluations systematic or ad hoc?

(b) Describe the impact on the collaboration.

(c)What type of records were produced by evaluations? By Whom? Where are they?

(38) We'd like to get your understanding about what levels, from participating scientist to funding agency, made decisions about various types of issues most of the time.

(a) First, scientific issues:

1. Funding agency
2. Host Institution (lab director)
3. External Advisory Committee
4. Administrative or Engineering Leader
5. Scientific Leader
6. Leadership Subgroups - internal
7. Collaboration as a whole

8. Individual Participating Scientists

[If response not a choice above] what was his/its name and function?

(b) Personnel issues: (below PI's)

1. Funding agency
2. Host Institution (lab director)
3. External Advisory Committee
4. Administrative or Engineering Leader
5. Scientific Leader
6. Leadership Subgroups - internal
7. Collaboration as a whole
8. Individual Participating Scientists

[If response not a choice above] what was his/its name and function?

(c) Other resource issues (time, money, etc.):

1. Funding agency
2. Host Institution (lab director)
3. External Advisory Committee
4. Administrative or Engineering Leader
5. Scientific Leader
6. Leadership Subgroups -internal
7. Collaboration as a whole
8. Individual Participating Scientists

[If response not a choice above] what was his/its name and function?

(d) Compared with an academic science department, would you characterize the manner in which decisions were made as hierarchical or consensual?

4. Strongly hierarchical
3. More hierarchical than consensual
2. More consensual than hierarchical
1. Strongly consensual

(e) Was there a division between administrative and intellectual authority?

> [If yes] describe what you mean by the administrative authority and the intellectual authority of the collaboration.

(f) What was the degree to which the leadership subgroup were making decisions as against collaboration-wide meetings?

3. High

2. Medium
1. Low

(39a) For most of the time, what was the degree of freedom of individual teams with regard to instrumentation?

3. High
2. Medium
1. Low

(39b) For most of the time, to what degree did individual teams share data?

3. High
2. Medium
1. Low

(39c) For most of the time, to what degree were teams autonomous in analyzing shared data?

3. High
2. Medium
1. Low

(39d) In other matters, for most of the time, how autonomous were [are] the units?

3. High
2. Medium
1. Low

(40) Did your project include any significant international collaboration?

Now a few questions about participation in the project:

(41) Was there any pressure from the home organization on the researchers involved in the collaboration? [tenure, promotion, salary decisions, etc.]

[If yes] (a) Was the pressure pro- or anti- “the collaboration”?
(b) Describe the pressure and what happened?

(42) Were most investigators devoted full-time or part-time to the collaboration?

(43) For most of the time, to what degree was the project a central interest of the main collaborators?

3. To a high degree
2. To a medium degree
1. To a low degree

Let’s discuss communication within the collaboration such as meetings, casual phone calls, letters, e-mail, collaboration-wide mailings, required quarterly reports.

(44) Was there a communications center?

[If yes] What was it?

[If no] With whom did you pass information to most on the project?

(45) Were the most common means of communication - formal or informal?

(a) What do you mean by ________ communication?

(46) For most of the time, how frequently did the teams communicate with the host institution or lead center?

1. Less than once a month
2. Once a month
3. Once a week
4. Several times a week
5. Daily

For most of the time, how candid was this communication?

4. Very candid
3. Comparatively candid
2. Not very candid
1. Not candid at all

(47) For most of the time, how frequently did the teams communicate with each other?

1. Less than once a month
2. Once a month
3. Once a week
4. Several times a week
5. Daily

For most of the time, how candid was this communication?

4. Very candid
3. Comparatively candid
2. Not very candid
1. Not candid at all

Now let’s talk about technology and data acquisition:

(48) Did the collaboration put a lot of effort into designing any equipment for its dedicated use?

(49) Did the collaboration put a lot of effort into building any equipment for its dedicated use?

(50) Did the __________[instrument, equipment, detector, procedure] represent a major advance in the state of the art?

[If yes] What was the technical character of the advance?

(51) Were there subcontracts with outsiders to obtain the instrument?

[If yes] What were the terms of these contracts?

(52) How much research, development, or design work did the subcontractor do?

1. Most
2. Some
3. None

(53) Did the instrument turn out differently than originally proposed?

[If yes] Did this difference have an impact on the project? What was it? [Did the change alter the project's science goals? Did it affect the designs of other instruments in the project?]

(54) Were the raw data reconstructed, measured, summarized or somehow prepared to facilitate their use in addressing scientific issues?

[If yes]

(a) Who was responsible for this task?

(b) What role did you play?

(c)Was software already available to use for this task or was it custom-written for this project?

Now let's talk about data sharing and analysis. Again, if answers have changed over time, please tell us.

(55) For most of the time, who was given initial access to the data?

(a) Did the PIs and their teams make agreements with other teams for the use of each other's data?

(b) [If yes] What was the agreement?

(56) Overall, did teams check the accuracy of others' results?

(57) For most of the time, did the collaboration manage the topics which were to be analyzed by its individual members?

[If yes] Did this lead to improvements or not?

(58) In data analysis, were there overlaps in topics addressed by collaborators from different teams?

Let's talk about writing up and communicating results of this project:

(59) For most of the time, did the collaboration manage external communication to the scientific community by its individual members?

(60) Were there any external clearances required to report the findings and methods of your project to the scientific community? [proprietary interests, national security]

[If yes] What were the rules?

Was anyone on the project restricted?

Let's now turn to the relations of the collaboration with outside agencies and users:

(61) Did the project's findings attract public or political attention?

(62) What were the collaboration's relations with the public? More specifically,

(a) Was there a public relations office or officer or was this function the main responsibility of the designated leader or host institution?

(b) Did the collaboration produce press releases? (VI.22.b)

(c) Did individual researchers popularize the collaboration?

[If yes] What was the professional and public response to that?

We are also interested in the interpersonal and professional relations during the collaboration. In every collaboration there are some disagreements and problems.

Now within the collaboration:

(63) For most of the time, how serious were the disagreements:

(a) Between teams;

4. Very serious
3. Somewhat serious

2. Not very serious
1. Not serious at all

(b) Between junior and senior members;

4. Very serious
3. Somewhat serious
2. Not very serious
1. Not serious at all

(c) Between scientists and engineers;

4. Very serious
3. Somewhat serious
2. Not very serious
1. Not serious at all

(d) Between researchers and project management.

4. Very serious
3. Somewhat serious
2. Not very serious
1. Not serious at all

(64) What issues provoked the most serious disagreements within the collaboration?

(a) Assigning priority to research topics?

(b) Allocation of credit?

(c) Evaluation and interpretation of scientific results?
[If yes] How were they resolved?

(d) Other issues?

(65) For most of the time, what was the degree of trust compared with your experiences in an academic department?

(a) Towards researchers on other teams;

3. High
2. Medium
1. Low

(b) Towards the project management.

3. High

    2. Medium
    1. Low

(66) For most of the time, to what extent did collaborators occupy distinct roles or did people work on whatever job was at hand?

3. Highly Distinct
2. Medium
1. Low

(67) How successful do you think this project was as compared to your other scientific work?

4. Very successful
3. Somewhat successful
2. Not very successful
1. Not successful at all

(68) How successful do other people think it was?

4. Very successful
3. Somewhat successful
2. Not very successful
1. Not successful at all

(69) To what degree did this project accomplish what it originally proposed to do?

3. More
2. About the same
1. Less

(70) Was the project finished on time?

3. Sooner
2. Yes
1. Later

(a) On budget?

    3. Over
    2. Yes
    1. Under

(71) Assuming the project was scientifically interesting, would you be attracted to another collaboration which was organized in a similar manner?

4. Very interested
3. Somewhat interested

2. Not very interested
1. Not at all interested

(72) To what extent are collaborations necessary for doing research in your discipline?

5. Extremely necessary
4. Necessary
3. Somewhat necessary
2. Somewhat unnecessary
1. Not necessary at all

(a) Why is that?

Next we'd like to ask some questions about the records:

(73) How did members of teams from various organizations communicate while the collaboration was in its prefunding stage (collaboration meetings, other trips, phone calls, letters, e-mail)?

(a) What was the dominant form of communication?

(b) Was anyone assigned responsibility for keeping records of the communication?

(c) Did anyone retain records of this communication?

[If yes] Who was it?

(74) What sort of documents were prepared in the course of designing and promoting the project during the prefunding stage?

(75) Were there any differences in communication during the phases of the project? (meetings, phone calls, letters, e-mail, collaboration-wide mailings)

[If yes] What were the differences?

(76) Were any communal records kept during data collection (e.g. concerning performance of equipment, quality or volume of data, etc.)

[If yes] Where are they now? Do they include reactions to the data or strictly the operations of the instruments?

(77) Where are the data maintained? Who is responsible?

(78) Were personnel issues discussed in formats (e.g. letters, memos or e-mail) that could leave any paper trail for the future?

[If yes] What formats and where might they be found?

(79) Let's estimate the volume of your records on this project.

(Do you use e-mail? If so, do you retain it? In what form?)

(80) Have you kept most of them or thrown most of them away?

(81) What do you think are the most important unpublished records of the project?

(82) What are the likely locations for these unpublished records?

Let's speak in more depth about the collaboration itself.

(83) How would you characterize the involvement of the funding agency (agencies) in project formation?

(a) Did funding agency personnel put together the proposal as a package?

(b) Did the funding agency participate in project staffing and planning?

(84) Was there competition between this project and others?

[If yes]

(a) Who were they?

(b) How did the competition affect the planning and direction of this project?

(c)Was there communication with competitors?

(85) If funding sources were multiple, how much financial support came from each source?

(a) How was a division of the funding amounts determined?

Let's return to the organization and management of the collaboration:

(86) What distinct stages did the project go through?

(87) What was the duration of each one of these stages?

(88) Was there any addition or dropping of organizations and individuals in the course of the project?

[If yes] How did it affect the functioning of the collaboration?

(89) Can you say that there was a problem of "understaffing"?

[If no] Was there a problem of “overstaffing”?

(90) What were the functions of the lead center?

(91) What were the prerogatives and role of the designated scientific leader?

(92) What were the prerogatives and role of the administrative/engineering leader?

(93) Where there conflicts between these leaders?

[If yes] What were they?

[If no] How do you account for the harmony?

(94) How was the advisory structure utilized?

a. How important was it?

b. What kind of records were created?

(95) Did the responsibilities of main actors change during the project?

(96) How did the organizational arrangements of the project evolve — more or fewer committees, greater or less bureaucratization?

(97) Can you compare the organization of this project to others you are familiar with?

(98) If you had to do it all over again, how would you organize it differently?

(99) How would you characterize the management of collaborations in your discipline?

(100) [If significant international participation]

(a) Why was significant international participation necessary? Was it mainly because of scientific expertise, or funding considerations, or politics or what?

(b) How was the division of labor decided?

(c) If there were any political or legal problems, how were they resolved?

(e) What advantages or disadvantages resulted from internationalism?

Now let’s discuss communication within the collaboration (meetings, phone calls, letters, e-mail, collaboration-wide mailings) :

(101) What information did the participants need to receive from the “communications center”?

(102) What did the “communications center” need from the participants?

(103) Did the predominate communication direction change during phases?

Now let’s talk about technology, data acquisition and data sharing:

(104) What did you need to know about other instruments in the collaboration in order to build or acquire your own?

(105) Did testing of your instrument, on its own or in conjunction with others, lead to any significant changes?

(a) If so, what was the decision-making process?

(b) What records exist that document the process?

(106) Did data-collecting strategies have to be planned in advance and coordinated among the collaborators?

(a) If so, in what forum was this done?

(b) What records were created?

(107) Did you use data collected previously by others in conjunction with the data you collected on this project?

(108) What did you need to know about other experimenters’ data on the collaboration in order to make the best use of your own, and what did the others need to know about yours?

(a) Through what channels was this information communicated?

(109) What kind of interaction with outside users of your data did you have?

(a) Did you have to do extra work to make the data you were working with useful to outsiders?

(b) How did/do outside scientists access the data?

(c) Can outside scientists obtain raw data and effectively and efficiently work with them independently of the instrument team?

(110) Were the data and facilities reused after the completion of the project?

[If yes] Was the use anticipated?

Let’s talk about writing up and communicating results of this project:

(111) Did anything about this project make it particularly difficult or easy to grant recognition to all contributors?

(a) How was the attribution of authorship determined?

Finally, we are interested in the role of collaborations in your discipline:

(112) What are the most important results in your discipline within the past decade?

(a) Which of these were accomplished through collaborations?

(113) What is your opinion of the future of such collaborations in your discipline?

(114) Who do you think has the broadest perspective on multi-institutional collaborations in your field?

(115) Is there any topic you'd like to return to?

(116) Is there anything I didn't ask that you would like to talk about?

We will analyze this interview anonymously as part of the AIP project on multi-institutional collaborations. Do we have your permission to keep the transcript in AIP archives, after the completion of the project, with your name identified, for the future use of scholars?

AIP Working Group for Documenting Multi-Institutional Collaborations in Ground-Based Astronomy, Materials Science, Heavy-Ion and Nuclear Physics, Medical Physics and Computer-Mediated Collaborations

Dr. Gabriel Aeppli
NEC Research Institute

Dr. Alan Berson
Program Manager
National Heart, Lung, and Blood Institute
National Institutes of Health

Dr. Robert L Dickman
Program Manager
Division of Astronomical Sciences
National Science Foundation

Prof. Paul A Fleury
Dean of Engineering
University of New Mexico

Prof. Phillip Geil
Department of Materials Science & Engineering
University of Illinois at Urbana-Champaign

Dr. Russell H. Huebner
Research Program Manager
Advanced Photon Source
Argonne National Laboratory

Prof. Thomas John Humanic
Department of Physics
Ohio State University

Dr. Goetz K. Oertel, President
Association of Universities for Research in Astronomy

Prof. Thomas F. Rosenbaum, Director
James Franck Institute
University of Chicago

Dr. Ulrich Strom, Program Director
Materials Research Science and Engineering Centers
National Science Foundation

Paul A. Vanden Bout, Director
National Radio Astronomical Observatory

Dr. John Watson, Deputy Director
National Heart, Lung, and Blood Institute
National Institutes of Health

Dr. Sidney Wolff, Director
National Optical Astronomy Observatories

AIP Project Consultant
Prof. Wesley Shrum
Department of Sociology
Louisiana State University

AIP Project Staff
Ms. Joan Warnow-Blewett
Project Director, AIP Study
and
Archivist Emeritus, AIP Center

Dr. Spencer R. Weart
Chair, AIP Study Working Group
and
Director, AIP Center

Dr. Joel Genuth
Project Historian, AIP Study

Dr. Ivan Chompalov
Project Sociologist, AIP Study

Mr. R. Joseph Anderson
Assistant Director, AIP Center