Data on U.S. Materials Research Laboratories: Prototypes of Interdisciplinarity in Universities

Rustum Roy and Tonia K. Devon

This article reports basic data on the nation's materials research laboratories collected in a survey conducted by the Materials Education Council in collaboration with the Materials Research Society. Thirty-eight separate, formally interdisciplinary laboratories are included.

Historical Review

Advocacy for creating interdisciplinary aggregations of university faculty to collaborate on research in the field of materials was initiated in the late 1950s by industrial research directors such as W.O. Baker of Bell Laboratories and C.G. Suits of General Electric. They perceived that the great industrial research laboratories had demonstrated the necessity for interdisciplinary team research. Industrial/engineering problem-solving had begun to reveal and promote natural interdisciplinary development in the knowledge of materials. Between 1960 and 1962, the Department of Defense (DOD) through its Advanced Research Projects Agency (ARPA) awarded 12 step-funded block grants to set up research centers under the Interdisciplinary Materials Research Laboratories (IDMRL) program. The Department of Energy (DOE) soon countered with three others before 1964, and NASA entered the list with three smaller ones. During the same period a few other universities set up MRLs without grants or contracts, based on their perception of the optimum university structure for conducting such materials research.

Comprehensive data on the status of this significant national experiment in reforming the general pattern of university research was obtained some 12 years later in the first National Academy of Sciences evaluation of the field of materials, the COSMAT report.[1] The report tabulated the numbers of faculty, students, papers published, dollars of support, subfields emphasized, etc., for nearly 30 U.S. laboratories (see Vol. III, p. 7-117).

Two striking discoveries emerged. The first was the enormous range (a factor of 10) in "productivity" of research (number of papers, papers/dollars, papers/faculty members) and teaching (number of graduate degrees, degrees/dollars, degrees/faculty members) (see p. 189ff). The second was the resistance of the university structure to interdisciplinarity. Many faculty faced an ill-defined and low-prestige reward structure in comparison to their discipline-based efforts. A survey of industrial leaders showed that, regarding "interdisciplinarity" and "interaction with industry," the performance of most university MRLs was very modest. As if to reinforce this, when the ARPA laboratories were transferred to the National Science Foundation (NSF) in 1972, the acronym *ID*-MRL was altered by dropping the ID (interdisciplinary) prefix, de-emphasizing this goal.

> ***Editor's Note:*** The opinions expressed in this article are those of the authors and not the Materials Research Society.

Table I: University Materials Research Units.

- California Institute of Technology (11)
- Carnegie Mellon University (26)
- Clarkson University (3)
- Cornell University (29)
- Dartmouth College (6)
- Lehigh University (8)
- Massachusetts Institute of Technology (Center for Materials Science & Engineering) (23)
- Massachusetts Institute of Technology (Industrial Composites) (22)
- New York State College of Ceramics at Alfred University (21)
- North Carolina State University (10)
- North Carolina State University (Analytical Instrumentation Facility) (28)
- North Carolina State University (Materials Research Center) (32)
- Northwestern University (9)
- Pennsylvania State University (Materials Research Lab) (38)
- Purdue University/University of Notre Dame (31)
- Rutgers (Center for Ceramic Research) (20)
- Syracuse University (30)
- Texas A&M University (15)
- University of Alabama (34)
- University of Arizona (14)
- University of California, Berkeley (26)
- University of California, Los Angeles (19)
- University of Chicago (24)
- University of Connecticut (37)
- University of Florida (7)
- University of Illinois at Urbana-Champaign (17)
- University of Kentucky (1)
- University of Massachusetts (2)
- University of Massachusetts (12)
- University of Missouri-Rolla (16)
- University of Pittsburgh (35)
- University of Tennessee (27)
- University of Texas at Austin (13)
- University of Texas at San Antonio (4)
- University of Wisconsin-Madison (5)
- University of Wisconsin at Milwaukee (18)
- Vanderbilt University (Center for Materials Tribology) (33)
- Vanderbilt University (Center for Space Processing of Engineering Materials) (36)

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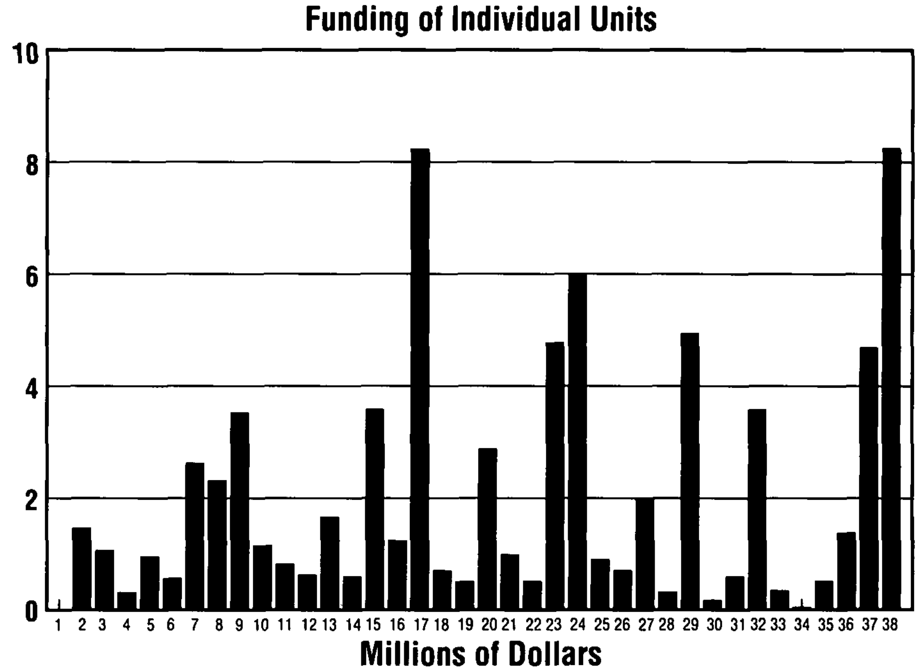

Figure 1. Funding levels for each of the 38 units in the survey.

In 1980 NSF hired the Mitre Corporation to assess the performance of MRLs. This study,[2] unfortunately, focused largely on the NSF-funded laboratories and on a limited set of questions.

Substantial changes have occurred in the field of materials research. Polymers and ceramics have successively moved to displace alkali halides and metals as the focus of the cutting edge in materials research. Semiconductors and electronic materials have grown to a dominant position, largely in industry and largely in the electrical engineering and applied physics communities. The dominant position of the U.S. in materials research (relative to other countries) has also been sharply diminished. Targeted basic science is at long last becoming much more acceptable in academia. Indeed, during the 1980s "university-industry coupling" became as fashionable as it had been looked down upon mainly because it was alleged to be a source of funds. Yet, as we pointed out elsewhere,[3] unrealistic expectations from such arrangements are likely to be counterproductive. State governments have entered as major funders of targeted materials centers. The Materials Research Society came into existence in 1973 and has proved to be a potent force for inducing interdisciplinary interaction. Despite these major changes and several recent agency studies[4] on materials research areas or goals, there is no set of comprehensive data on the activities and performance of *all* the nation's MRLs. The National Research Council's recent four-year multimillion dollar study does not even provide a list of such interdisciplinary units, let alone any evaluation of this major U.S. effort in creating and sustaining interdisciplinary research units within the existing university structure.

From the viewpoint of engineering and science policy, several basic questions need to be addressed. The following are the most significant:

1. What is the evidence that universities, given the (huge) incentive of $40-50 million per year, have successfully institutionalized interdisciplinary research on campus?

2. What structures and strategies within universities have led to the most effective MRLs?

3. Is there evidence that the special advantage of block funding, which saves enormous amounts of time and money in writing proposals, has produced any better or more research than if the money had been given by traditional routes in disciplines? (Mitre Corporation's detailed study answered this question in the negative, maintaining that block and nonblock performance was roughly equal, despite the advantage to the former.)

The second iteration of the National Academy's study of the materials field, started in 1986, had not obtained any such data by 1988. At that time the Materials Research Society and the Materials Education Council volunteered to obtain a minimal set of basic data on this component of the nation's materials research effort for the "MS&E Study." This article is a result of that effort.

Our goal was to obtain rudimentary data on the number, size, scope, disciplinary composition, and topical emphasis of most *formally designated* interdisciplinary materials centers* at universities. It was necessary, of course, to put certain boundary conditions on which ones to include. There are nearly 100 materials science and engineering *departments* (degree granting units) in the United States, and all have substantial research efforts. Similarly, at least as many physics and electrical engineering departments have active materials research programs within departmental boundaries. All such efforts would fall under "materials research," but they are institutionalized as single-department efforts.

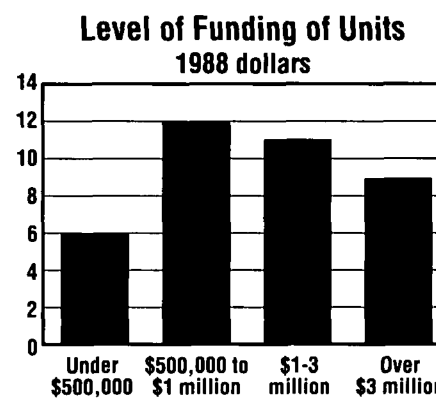

Figure 2. Funding levels vary greatly for the 38 materials research units considered in this survey. Six units funded above $4 million account for 48% of the total funding represented by the survey data.

These distinctions were clearly made at the first national (policy) Colloquy on Materials.[5] The Directorate of Materials Research in NSF, for example, designates only 25% of its budget to the categories of metallurgy, ceramics and polymers. Our limitation was to centers which *formally* crossed departmental boundaries.

We also wished to concentrate on centers which had some track record, i.e., had been in business long enough to be evalu-

*Interdisciplinary = interdepartmental on campus. It requires that the structure formally cut across departments and involve faculty from several such departments. See Reference 6 for a detailed categorization of academic materials teaching and research structures.

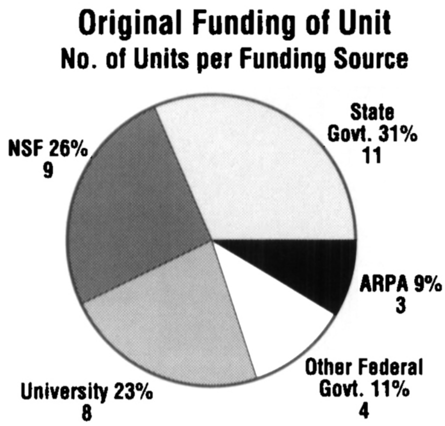

Figure 3. Where original funding came from for 35 of the materials research units in the survey.

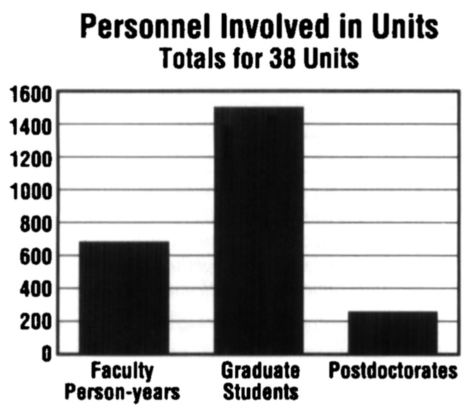

Figure 4. Personnel involved in the 38 materials research units in the survey.

ated meaningfully. Policy formation is greatly misled when promises in the rhetoric used to start a program are considered as though these goals had been realized. After the NSF's Engineering Research Centers (ERCs) were started, many policy commentators not only mistakenly spoke of them as though they were the first attempts at interdisciplinary work but also as though their *goals* had become reality. They neglected the 25-year history of the NSF's own MRLs, from which much could have been learned to help guide the ERCs.

This study will provide a starting point for examining interdisciplinary research in the United States in the broadest framework by providing aggregated data on the first major federal effort in funding interdisciplinary materials research.

Study Parameters

This study, started May 1988, was limited to *formally organized, interdisciplinary units* with a separate budget line within the university. It excluded materials research within departments of physics, electrical engineering, materials science and engineering, chemistry, etc. Some 100 questionnaires were sent to major U.S. research universities. In response we obtained data on 38 units.

We found that university materials research units more than 2-3 years old are distributed among at least 33 university campuses in 38 separate units (see Table I). Vanderbilt, the University of Massachusetts, North Carolina State University, and Massachusetts Institute of Technology all have more than one unit per campus. Materials research units are located across the United States, but there is a noticeable concentration in the Eastern states, with a total of 15, followed by Southern states (including Texas) with 12. Of the 38 units, 24 concentrate on metals, 24 on ceramics and composites, 20 on electronic materials, 19 on polymers, and 9 on "other" areas.

Findings

Funding Levels

Total funding for the 38 units from all sources stood at $75,716,000 for fiscal year 1988. The Eastern United States led with 45% of the funding, followed by the Midwest with 28%, the Southern states with 23%, and the Western states accounting for the remaining 3%.

Funding varies greatly, most units receiving between $500,000 and $3 million per year (see Figures 1 and 2). However, six units are funded above the $4 million level, and together they account for 48% of the total funding represented by the survey data. Those units are housed at the University of Chicago, Cornell, University of Illinois at Urbana-Champaign, Penn State, MIT, and the University of Connecticut.

Since World War II, the federal government and industry have provided essentially all the funding for such materials research. Since the mid-1980s we must add the states to those sponsors. Although states have sporadically sponsored science and technology research in the past, there was an extraordinary surge of such activity in the 1980s. For the units in the survey, the average percentage of funding from state governments was 16.4%, and state governments were responsible for the startup of an impressive 11 of 35 units in our sample. State governments should also be given credit for their innovative programs, begun with much less fanfare than those in many federal agencies and avoiding the enormous wasting of resources on the proposal and review processes by most federal agencies. The states are responding in new ways to the hope that money invested in *applied* science can have a high rate of social return.

NSF and the universities themselves account for the origin of 26 and 23% of the units, respectively. ARPA is well-known as the original funder for research for strategic purposes, but, due to increase in total units over the past decade, the laboratories ARPA started are now only a quarter of the total. Other federal government agencies have provided original funding for 11% of the sample (Figure 3).

The federal government contributes the most funding to university materials research units, an average of 42.2% in 1988. This amount is very small in terms of overall federal support for materials R&D. Currently, the federal government provides $1.5 billion annually to the materials R&D endeavor. Forty-nine million dollars of that—or 3%—reaches the collective budgets of materials research units in our sample. In comparison, the NIST's Institute for Materials Science and Engineering receives $30 million per year, plus money from other federal agencies.[6] Bearing in mind the comparatively minor amount of funding that goes to the universities, one acquires a perspective on the inappropriateness of looking to the universities to "revitalize the economy" and fix the foreign trade balance.

Education and Personnel

A large portion of the traditional, ongoing mission of the universities is to train the national workforce. In addition to their incremental contributions to the frontiers of knowledge, a major outcome of materials research units is education of new scientists and engineers. The laboratories are crucial in training the talent pool that can continue the pursuit of quality materials R&D. In this regard the materials units in the survey incorporate a large number of graduate students and contribute to the financial support of approximately 1,500 graduate students per year. The total number of students being trained is no doubt somewhat larger. One institution claims that while 8 graduate students are financed, another 12 are working in the laboratory.

Although other authors have placed the ratio of postdoctoral personnel to graduate students in MRLs at approximately 1 to 4, our survey shows a ratio in 1988 of 1 to 6 (see Figure 4). Perhaps, the brain-drain from the laboratories into industry and

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government[7] has increased lately.

The 38 materials science units used 650 faculty person-years in 1987. This is rather amazing since the Academy's MS&E Study estimates a total of 1,000 faculty members in materials departments in the U.S. Together, faculty in the units were drawn from 17 fields. This is encouraging in light of the need perceived among an increasingly wide range of professionals for materials science and engineering education and research to evolve more rapidly toward interdisciplinarity. A noteworthy 22 units each combine within themselves faculty from 4-5 fields (Figure 5). This figure appears to parallel the nearly fivefold increase during the last 20 years in academic departments in the United States that have adopted the title "Materials Science and/or Engineering."

The skewed nature of professional background of those trained in materials science—fully 70% in academic departments specialize in metallurgy—is not reflected in the research of the units surveyed. As Figure 6 reveals, 24 of the units do work on metals but the research fields are fairly evenly distributed. Ceramics and composites are a close second, and polymer and electronic materials a close third. This is a hopeful sign that some disciplinary barriers are being overcome in such laboratories, and multidisciplinarity, perhaps even interdisciplinarity, is on the rise.

The latest national report by the Academies' Committee on Materials Science and Engineering has one major finding: In the United States the field of materials exhibits a relative lack of emphasis in synthesis and processing.[8] It is noteworthy, however, that the materials research units in our sample nevertheless already claimed in 1988 to include synthesis/processing as a research emphasis more often than any other emphasis. Our questionnaire asked respondents to check whether analysis/modeling, synthesis/processing, performance, properties, or applications were research emphases in their units. In each of the five classes (electronic materials, metals, polymers, ceramics, and composites), the two most frequently mentioned emphases were synthesis/processing and properties, followed in a cluster by analysis/modeling, performance, and applications. An exploration of the quantitative level of effort expended in each area would have been useful, but that will have to depend on a more detailed study than our survey allowed. These data may indicate that the "linguistic" takeover of "synthesis and processing" work is already under way, with many units already indicating an emphasis in a field that has been identified as one of the nation's highest priorities. If the Academy's MS&E Study report is correct in its analysis, it will be decades before the real research lack can be repaired. Most U.S. universities do not have the faculty who could teach the necessary courses in, say, sophisticated phase equilibria or crystal chemistry at levels typical in Europe.

Conclusions

Interdisciplinary MRLs have been a national experimental ground for interdisciplinarity. No detailed studies with penetrating questions are yet available on crucial policy aspects of the experiment. And the lessons to be learned from this 30-year experiment have not been exploited so far. In order to judge them by the criteria which define why they exist, one needs to gather in-depth data on the ability of such units to begin the unification of knowledge implicit in their existence, to work in interdisciplinary teams, and to transfer knowledge effectively to industry and government. The quantity and quality of research the MRLs do compared to other units should also be monitored. For the latter, a current study parallel to the Mitre study, which is now too dated to be useful, would be necessary.

On all fronts, the call for integration and interaction among fields is now heard. *Made in America*,[9] for example, recommends developing a new cadre of students and faculty who have the "ability to function effectively as members of a team" and to "operate effectively beyond the confines of a single discipline." Similarly, current NSF requests for proposals for reform in engineering education call for programs that "integrate and coordinate" as well as restructure in a comprehensive manner. The data on the record of MRLs has much to offer as a model to aid the many new efforts to establish interdisciplinary curricula and research. A critical evaluation by disinterested parties and agencies only, i.e., from industry and governmental and overseas laboratories, could be a major contribution to policy making for materials R&D in the 1990s.

Acknowledgments

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2. J.G. Ling et al., *Evaluative Study of the*

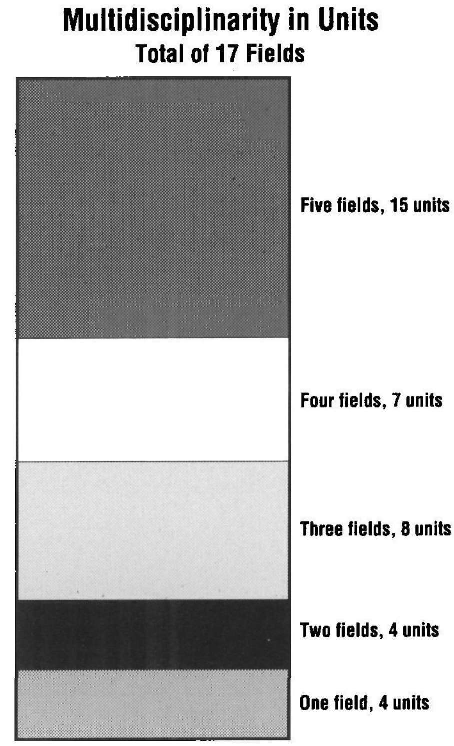

Figure 5. The majority of research units in the survey combined faculty from several fields; and 15 of the 38 units combined faculty from five fields. Together, faculty in the units came from 17 different fields.

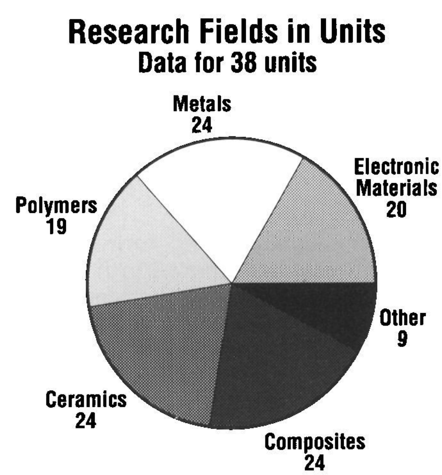

Figure 6. Number of materials research units that concentrate on specialty areas. Some of the 38 units concentrate on more than one area.

Materials Research Laboratory Program, Tech. Rept. 7764, Mitre Corp., Bedford, MA, for NSF Contract OAO 7624069. See also Science 209 (1980) p. 1204-1207.

3. Rustum Roy, "University-Industry Coupling: Exaggerated Expectations," in *Forum for Applications of Research and Public Policy,* (Winter 1988) p. 32-36.

4. There have been four other internal agency studies: ARPA, August 30, 1966 and February 1971; and NSF, March 1972 and January 1974. See Notes in Reference 2.

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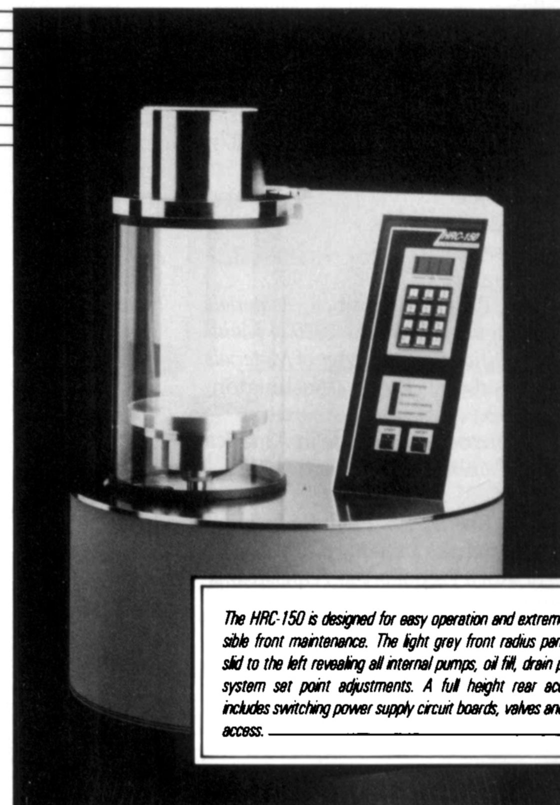

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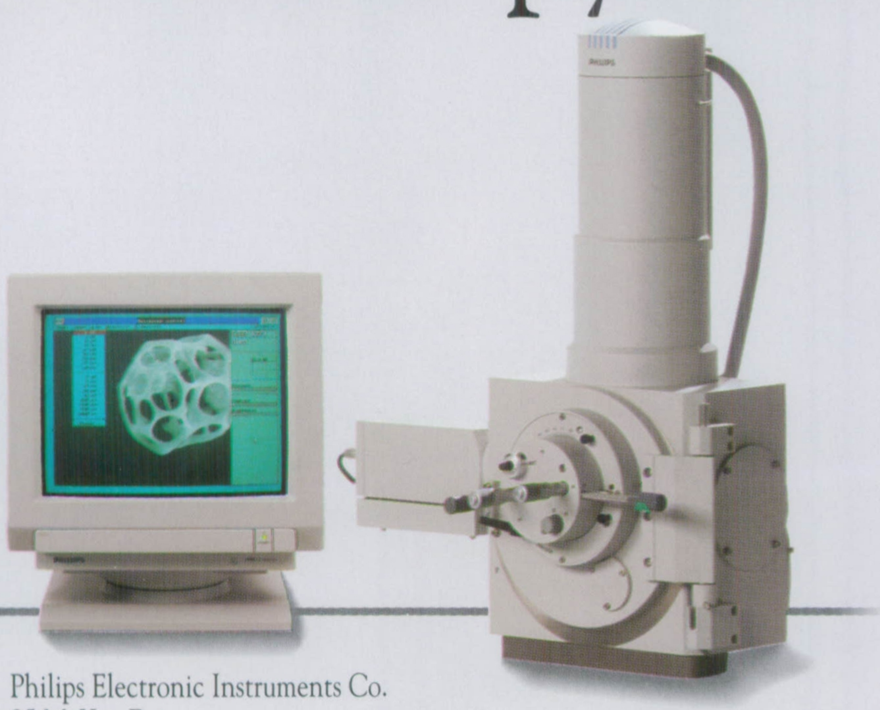

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