determining the dose-response relations for particular cancers induced by radiation, over wide dose ranges. Paradoxically, it appears that in most cases there is more to be learned about cancer risks associated with low doses of radiation by studying populations with high and intermediate levels of exposure than by studying populations exposed only to low-dose radiation, even when the latter populations are very large.

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Federal Funding in Materials Research

James G. Ling and Mary Ann Hand

The relative merit of granting federal research funds to institutions rather than individual investigators has been a subject of controversy for some time. The recently formed National Commission on Research has included alternative funding mechanisms as one of the issues to be studied. This article summarizes the findings of a Mitre Corporation study performed between 1976 and 1978 on the Materials Research Laboratory (MRL) Program for the National Science Foundation (NSF). The study compared technical publications and other products of 16 MRL's, which had been funded with institutional grants, against similar material from individually funded research projects at 15 other universities (non-MRL's). Two universities funded with institutional grants by the Department of Energy (DOE) for materials research and two funded by the National Aeronautics and Space Administration (NASA) were also included in the study. In addition, the study compared total administrative costs (government plus university) per grant dollar for institutionally funded projects and those funded individually.

The primary objective of the study was to compare the effectiveness of institutional funding for MRL's with that of project funding for materials research. Emphasis was placed on the principal results and impacts of the MRL program since its inception in 1961, with particular focus on the period after NSF assumed sponsorship in 1972. Five investigators were involved in the study full-time for about 18 months.

Background of the MRL Program

The MRL program had its origin in the Interdisciplinary Laboratory (IDL) Program established in 1960 by the Advanced Research Projects Agency (ARPA) of the Department of Defense. The ARPA action was taken in response to a concern within the government that major hardware research and development programs were being impeded by the failure of materials technology to keep pace with needs.

Forty-five universities submitted proposals to establish IDL's, and 12 were selected. The funding arrangements with these 12 universities were designed to encourage stability and long-term university commitments. One key feature allowed the universities to make capital investments for IDL buildings and to be paid back over a 10-year period by ARPA through "building use" charges. A second key feature was that initial contracts covered a 4-year period. At the end of each year, contracts were renewed for an additional year, maintaining 4-year forward funding. This "block" or institutional funding approach, allowed the laboratories thus established to allocate funds internally to research projects rather than requiring them to request funds from ARPA on a project-by-project basis.

In July 1972, the IDL program was transferred from ARPA to NSF and renamed the MRL program. The term "block funding" was also changed to "core funding," highlighting the fact that other NSF funds, in the form of project grants, were available to support individual research efforts at the institutions. By 1976, NSF had added four new MRL's, and its funding for the MRL program in fiscal year (FY) 1976 was $14.6 million.

Two other federal agencies, the Atomic Energy Commission (AEC) and NASA, also established IDL's in the 1960's. The two IDL's originally sponsored by the former are now sponsored by DOE, and NASA continues to sponsor two of the three that it originally established.

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0036-8075/80/0912-1203$01.25/0

Summary. The performance of the 20 materials research laboratories (MRL's) at universities funded with institutional grants by the National Science Foundation, Department of Energy, and National Aeronautics and Space Administration is evaluated in comparison with 15 other universities (non-MRL's) receiving individually funded projects for materials research. Performance is measured by peer review and citation frequency analysis of publications, subjective evaluation of research achievements and researcher reputation by a panel of experts, review of equipment purchases and utilization, and analysis of administrative costs. The study concludes that there are no significant differences between the MRL's and non-MRL's with respect to innovation, interdisciplinarity, utilization of specialized equipment, concentration of funding, rate of turnover, duration of research areas, and level of effort per research paper. The MRL's have a greater number of major achievements and attract researchers with higher reputations. The MRL's tend to emphasize experimental work, and in about 70 percent of the materials research areas sponsored by the National Science Foundation there is no overlap between the two groups. Institutional grants involve much less total (federal plus university) administrative cost per grant dollar than project grants.

The Performing Sector

MRL group. The MRL's included in the present study were laboratories within 16 universities, each with its own administration headed by a director. The core (institutional) grants from NSF to each of these laboratories for 1977 ranged from $200,000 to $1,950,000. The cumulative core funds from inception of the laboratories through 1977 ranged from $0.74 million to $35.8 million each (Table 1).

These 15 universities form a mix that reflects the heterogeneous composition of project-funded institutions in general (Table 2). Five have materials science centers, which function somewhat like the MRL's and IDL's.

Non-NSF block-funded group. The two DOE core-funded materials laboratories were included in this study. One is at the University of Illinois; the other, at Lawrence Berkeley Laboratory (LBL). Both laboratories have large, well-established materials research programs housed in central facilities and stress interdisciplinary collaboration in research. The program at LBL includes chemistry, physics, metallurgy, ceramics, and nuclear engineering; that at Illinois encompasses ceramics, metallurgy, physics, chemistry, and chemical engineering.

The two NASA institutions with core-funded materials programs were also included in this study. Both were among the universities originally selected to be IDL's. The materials research program at Rensselaer Polytechnic Institute was started in 1960; that at the University of Washington, in 1963. Both are much smaller in terms of core funds received than the MRL's supported by NSF. The objectives of the materials research programs at these universities are related to NASA's mission and differ substantially from those of the NSF-funded MRL's and the DOE-funded IDL's.

The distribution of MRL members by discipline shows that physics departments have been involved most heavily in MRL research, followed by materials and chemistry departments. This distribution has held since July 1972.

Since taking over the MRL program, NSF has encouraged the MRL's to concentrate their research efforts into specific areas. The MRL's generally choose the areas they wish to emphasize. However, NSF has occasionally expressed a preference.

NSF project-funded group (non-MRL's). To compare project-funded and institutionally funded research, the study team used as a control a group of universities that do not receive federal institutional funding for materials research. From FY 1970 through 1975, 164 universities that did not have MRL's or IDL's received NSF project grants for materials research. The study team selected the 15 institutions receiving the largest amount of NSF project funds over this 6-year period. Together they accounted for 40 percent of project funds granted in FY 1975 by NSF's Division of Materials Research (DMR) to individual academic researchers outside the MRL's and IDL's. The primary concentration of DMR funds at these institutions was in the physics and materials departments.

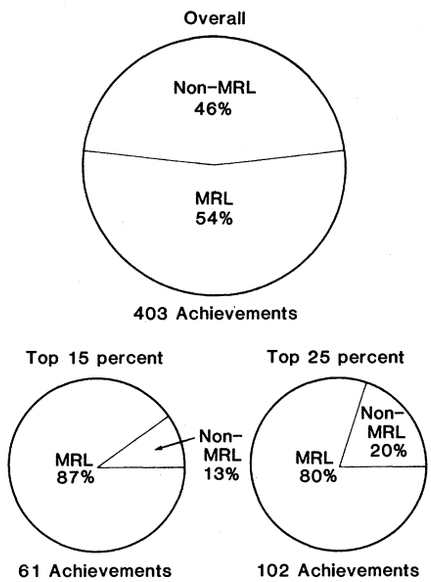

Fig. 1. Results of evaluation of major achievements (NSF-sponsored research activities only).

Research Capability

The capability of universities to perform research was measured in terms of researchers and equipment. To see whether the MRL's had attracted researchers with higher reputations than the non-MRL's, the study team compiled a list of 229 full professors who had joined or left seven MRL and ten non-MRL universities between 1966 and 1976. The departments of interest were those engaged to a significant extent in materials research. The professors' reputations were evaluated on the basis of two criteria: subjective judgments by a panel of 19 experts and the number of awards received for scientific research. All statistical tests were performed with a type 1 error (alpha) tolerance of .10. The results of this comparison show that the universities with MRL's attracted researchers with a higher average reputation than did the non-MRL schools with or without materials centers.

Availability of equipment was compared by analyzing equipment inventories provided by 11 MRL's and 8 non-MRL's. These inventories identified the purchase price and date of purchase of all equipment. Equipment that cost less than $3000 was excluded. The comparison showed that equipment expenditures for MRL central facilities were not significantly different from those of materials science centers at non-MRL's. It also showed that materials research equipment holdings of universities with MRL's (including equipment outside central facilities) were more extensive than those of non-MRL universities without materials science centers. The average cost per item of equipment in MRL central facilities and at the non-MRL materials science centers was also higher than at other non-MRL's.

In related analyses, the study team determined that about 70 percent of the materials research areas sponsored by NSF

at the institutions surveyed showed no overlap between MRL's and project-funded institutions. Also, it was found that there were no statistically significant differences between MRL's and non-MRL's in concentration of funding, annual rate of turnover in research areas, duration of research areas, and continuity of staffing.

Comparison of Publications

A major effort was devoted to analysis of research publications, since these represent the primary research product of the universities. The study team obtained, from a selected set of 215 materials science experts, detailed reviews of 690 papers that had appeared primarily in refereed journals, and citation counts for 2299. Also, a separate citation frequency analysis was made for each paper.

The 690 papers included papers from the DOE and NASA IDL's, as well as MRL and non-MRL papers. They were chosen randomly with a proportional stratified sampling scheme. Publications were grouped into strata by total project support and by characteristics of the researcher's institution. Thus, 157 papers resulting from core funding under ARPA sponsorship in 1972 were compared against 244 papers resulting from NSF core funding in FY 1974 and FY 1975. This comparison was made to see whether research results were significantly different between the periods of ARPA and NSF sponsorship. The NSF core-funded papers were compared with 158 project-funded research papers from non-MRL's, 63 project-funded papers from the MRL's, and 50 DOE and 18 NASA core-funded papers. With these sample sizes, the probability of rejecting a true hypothesis (type 1 error) was set at .10.

The NSF's objectives set the criteria against which certain characteristics of research were measured. The major characteristics evaluated were the quality of performance (as measured by technical depth and accuracy), the degree of innovation, the impact on scientific progress, and the level of interdisciplinary collaboration. Results of the review showed that:

1) The NSF/MRL core-funded papers reflected a greater emphasis on experimental work than the papers from non-MRL's without materials science centers. This difference in orientation of research was the most clear-cut result of all the publications comparisons.

2) Although all the papers were predominantly oriented toward science, the proportion of NSF/MRL core-funded papers that were engineering-oriented was significantly higher than those from non-MRL's without materials science centers.

3) There were no significant differences among any of the populations compared with respect to overall indicators of innovation or measures of interdisciplinarity.

4) While differences were found in other attributes, such as quality of procedures, equipment use, and contribution to scientific progress, the review of the publications did not lead to a clear-cut acceptance or rejection of the hypothesis that MRL's produce better research (in terms of meeting NSF's criteria) than non-MRL's.

This last finding is not surprising, considering that almost all the papers had appeared in refereed journals. Also, each paper typically represented a small part of a total research effort, and the importance of the entire effort could not always be seen. Finally, all the institutions considered in the study were nationally prestigious, and averaging the characteristics of each group's output probably obscured any individual differences.

The comparison of citation frequency is valid as a measure of relative merit only if the data are reliable and if the citations are for merit rather than some other reason. The problem of nonmatching between a valid journal reference and the citation source encountered in this study could cause difficulty when dealing with a single article, but probably did not affect conclusions about populations. The

Table 1. Classification of MRL's by amount of NSF core funding.

MRL funding class	University	Core funds for FY 1977 ($ thousand)	Core funds from inception through FY 1977 ($ million)	Date of inception
Recently created	Penn State	275	0.79	15 May 1974
	Case Western	300	0.74	1 Sept. 1974
	Massachusetts	400	1.21	15 June 1973
	Carnegie-Mellon	400	1.23	15 June 1973
Small	Maryland	200	7.17	3 Oct. 1961
	North Carolina	300	7.93	2 Oct. 1961
Midrange	Harvard	575	10.2	20 June 1961
	Chicago	630	11.6	20 June 1961
	Purdue	850	11.5	5 Oct. 1961
Large	Stanford	1,200	17.6	20 June 1961
	Brown	1,200	19.5	20 June 1961
	Northwestern	1,250	21.0	20 June 1960
Very large	MIT	1,865	26.5	20 June 1961
	Pennsylvania	1,950	30.1	22 June 1960
	Cornell	1,950	35.8	20 June 1960
MRL's with multiple core support (NSF and DOE)	Illinois	1,270 NSF	23.2 ARPA/NSF	1 June 1962

Table 2. Materials research characteristics of the non-MRL's.

University	Materials department or program	Materials science center or institute	Interdisciplinary institutes*
Utah	Yes		
Florida	Yes	Yes	Yes
Lehigh	Yes	Yes	Yes
California (Los Angeles)	Yes		
Rutgers			
California (San Diego)			Yes
Ohio State			
Pittsburgh	Yes		
Wisconsin (Madison)	Yes	Yes	
California (Santa Barbara)			Yes
Connecticut		Yes	Yes
Michigan	Yes		Yes
Oregon (Eugene)			Yes
Yale			
Washington (St. Louis)	Yes	Yes	

*Not exclusive to materials research.

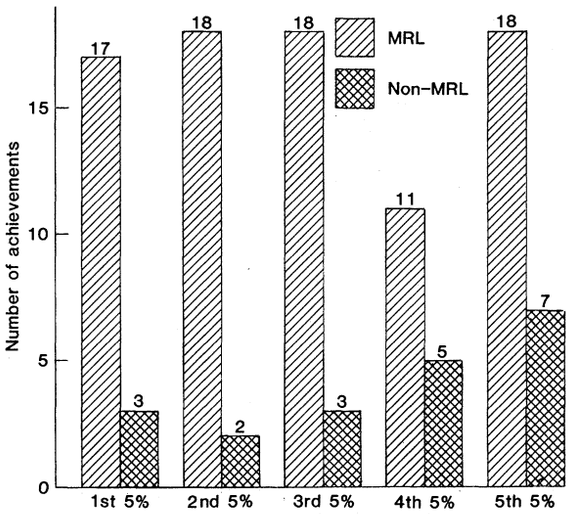

Fig. 2. Distribution of achievements in top 25 percent by ~ 5 percent increments (NSF-sponsored research activities only).

cross-checking of highly cited papers against peer reviews (when possible) showed that the citations were correlated with favorable comments by reviewers. The conclusions from the citation analysis were that (i) NSF project-funded papers at MRL's were cited more frequently than NSF/MRL core-funded papers; (ii) core-funded papers at MRL's under both ARPA and NSF sponsorship were cited with about the same frequency as papers from DOE/IDL's and NSF/non-MRL's without materials science centers; (iii) papers from NSF/non-MRL's with materials science centers were cited less frequently than MRL core-funded papers; and (iv) papers from NASA/IDL's were cited least frequently.

Productivity

The relative productivity of core-funded (MRL) and project-funded (non-MRL) institutions was examined by analyzing the research achievements and the level of effort associated with research publications. Research achievements were evaluated by compiling a list of 403 achievements that had been submitted by the universities and identified by them as being fully developed. This list was then evaluated by the same panel of 19 experts who rated the reputations of researchers.

On the basis of research projects in FY 1974 and FY 1975 that produced publications, it appears that the funding level of average MRL core-funded projects was $32,500, compared to $46,000 at non-MRL's. Thus the MRL's seem to have had about 30 percent more projects per unit of funding. However, the average level of research effort per publication was about the same for MRL's ($14,000) and non-MRL's ($15,000). At the non-MRL's, the average funding per project was $39,000 at universities with materials science centers and $50,700 at

Table 3. Summary of administrative costs.

Activity	Comparison		
	MRL core		Non-MRL
Principal investigator discusses research plans with MRL director or NSF program administrator	60 to 90 percent success rate		30 to 70 percent success rate
Principal investigator prepares proposal to MRL or NSF	2 to 20 man-hours		2 weeks to 2 months
MRL director and executive committee review	60 to 100 man-hours 0.07 to 0.11 hour per $1000		0
MRL director prepares the MRL proposal using the content of individual and emphasis area proposals	80 to 180 man-hours 0.09 to 0.02 hour per $1000		0
University offices review the proposals		~ 1:19	*
NSF reviews proposals and decides on finding		~ 1:2	*
NSF prepares notice of award or denial		~ 1:19	*
Grant account is set up by university accounting		~ 1:19	*
Grants without renewal funding are closed out by university administration		~ 1:19	*
Activities associated with normal grant expenditures require additional time of university personnel		~ 1:10	*
Expenditures requiring rearrangement of budget categories require university and NSF personnel		~ 1:19	*
Members of emphasized areas meet to discuss research progress	25 to 100 man-hours 0.03 to 0.12 hours per $1000		0
MRL directors meet twice each year	27 man-hours 0.03 hours per $1000		0
NSF program administrators conduct formal or informal site visits once each year	Informal 180 to 240 man-hours 0.20 to 0.26 hour per $1000		0†
	Formal (every third year) (420 to 480 man-hours)/3 (0.46 to 0.53 hour per $1000)/3		0†
Annual technical reports are prepared by principal investigators or MRL director	60 to 100 man-hours 0.07 to 0.11 hour per $1000		4 to 16 hours 0.00 to 0.34 hour per $1000
Annual fiscal reports are prepared by university accounting office		~ 1:19*	
Total for activities	1.0 to 1.7 man-hours per $1000		1.8 to 7.1 man-hours per $1000

*Relative magnitudes of effort per unit of funding. †Program administrators for project grants do conduct site visits but only in conjunction with other business travel. Travel funds for NSF staff are about the same per grant dollar for administering core grants or project grants.

those without such centers. The comparable levels of effort per publication were $14,300 and $15,400, respectively.

The MRL's had much more than a proportional share of achievements rated in the top 15 percent, based on total NSF funding from FY 1973 through FY 1976. However, the MRL's had slightly less than a proportional share of achievements rated in the top 25 percent. The MRL achievements rated in the top 25 percent reflect a greater emphasis on experimental work than those of non-MRL's. The results of this evaluation are shown in Figs. 1 and 2.

Administrative Costs

The cost for the administration of grants includes the time and resources of both the university and the sponsor. The actual time involved may not necessarily be reflected in the costs charged for administration. Therefore, both the dollar costs for administration and the actual time involved in administrative activities were examined, with greater emphasis on the latter, since it represents true costs.

A summary of administrative costs is presented in Table 3. Where similar activities are involved, the table shows that these activities cost less per grant dollar for MRL core grants. This is due in large part to the decentralization of management to the university personnel, who have more detailed knowledge of the activities being managed.

Due to nonhomogeneous units of measure, the overall cost of administration cannot be determined for the two types of grants. Nevertheless, for all activities estimated in man-hours (Table 3), the total cost per thousand grant dollars for MRL administration is between 1.0 and 1.7 hours, compared with a range of 1.8 to 7.1 hours for non-MRL administration. If the cost per man-hour is assumed to be $20, then MRL costs range from $20 to $34 per thousand grant dollars while non-MRL costs range from $36 to $142 per thousand. The major source of this difference is the time required for preparation of project grant proposals (whether of an experimental or theoretical nature), which amounts to more time per dollar than that for all MRL administrative activities. Unfortunately, this time difference can be equated almost exactly with lost research effort at the non-MRL's. Furthermore, for all other activities where costs were estimated only proportionately, the MRL administration is from 2 to 19 times less costly. Therefore, in terms of time and costs involved in administering grants, the MRL core, or institutional, grant mechanism is much more efficient than the project grant mode.

Conclusions

Research at the institutionally funded MRL's is not more integrated when measured in terms of the concentration and duration of support of research areas. On the basis of the publication reviews, there is no significant difference between MRL's and others on interdisciplinarity or utilization of essential specialized equipment. However, the MRL's are different as the sole contributors to certain research areas and in their emphasis on experimental work. There is little difference in terms of level of effort per research paper between MRL's and non-MRL's. The MRL's appear to be more productive than non-MRL's in terms of major achievements, and are more successful than non-MRL's in attracting researchers with reputations measured as high in terms of scientific honors and esteem among peers. Institutional grants, in the form of core grants to MRL's, involve much less total (federal and university) administrative cost per grant dollar than project grants. In terms of program oversight, the MRL program administration at NSF stresses evaluation of accomplishments, whereas the project grant emphasis is on proposal evaluation.

Setting aside qualitative differences between universities, it appears from this study that institutional grants result in different types of work (for example, more experimental) in MRL's compared with that in non-MRL's. The institutional grants are aimed, in part, at providing extensive experimental facilities. These facilities are apparently put to good use. It is possible that the facilities are also influential in attracting top-quality researchers. The variable costs of administering grants are small in comparison to fixed costs. Thus the institutional grants, which on average are 19 times higher than the project grants, result in much lower costs per unit of funding. Finally, the institutional grant mechanism provides more systematic feedback on research accomplishments (*1*).

References and Notes

1. There have been five formal evaluations of the IDL/MRL program. The first was an internal review performed by ARPA, "Report on the IDL's," submitted to the director of ARPA on 30 August 1966. The others were as follows: M. J. Sinnot, O. C. Trulson, H. H. Test, "The ARPA interdisciplinary laboratory program" (Institute for Defense Analyses, Arlington, Va., 1 February 1971); "Materials research laboratories: summary evaluation" (Paper 27-54, National Science Foundation, Washington, D.C., 2 March 1972); Management and Cost Analysis Staff, "Materials research laboratories study" (National Science Foundation Grants and Contracts Office, Washington, D.C., January 1974); Committee on the Survey of Materials Science and Engineering, "Summary report and supplementary report of materials and man's needs" (National Academy of Sciences-National Research Council, Washington, D.C., 1974), vol. 3. In the latter report (the so-called COSMAT report), the following observations were made: (i) There is little or no correlation between magnitude of block funding and development of an institution as a "materials school." (ii) There is only a modest correlation between the availability of block funding and the existence of specialized laboratory buildings, central facilities, or facilities on their scale. (iii) There is a negative correlation between the availability of block funding and interaction with industry. (iv) There is no correlation between large block grants and degree of interdisciplinary interaction. (v) Excellence was achieved at many of the block-funded centers in the very same areas, while other important areas were neglected. However, the COSMAT report recommended that support of materials research centers through block grants be accepted as an established funding method; that block grants be awarded and renewed on a competitive basis and provide for forward or step funding; that, in addition to support for individual scientists, some effort be made to take advantage of local research specializations; and that appropriate parts of the center programs be oriented toward materials systems (integrated combinations of materials), processing, and applications.

2. We thank M. T. Lethi, B. B. Stokes, J. Verhoeff, R. S. Greeley, J. B. Wachtman, Jr., and W. R. Prindle for their contributions and assistance. We also thank H. J. Piccariello and W. D. Commins for their contributions to the statistical analysis and for their review and oversight of the entire study. This article is based on a report by J. G. Ling, M. A. DeBolt, M. T. Lethi, B. B. Stokes, and J. Verhoeff ["Evaluative study of the materials research laboratory program (Technical Report 7764, Mitre Corp., Bedford, Mass., September 1978] under NSF contract OAO 7624069.