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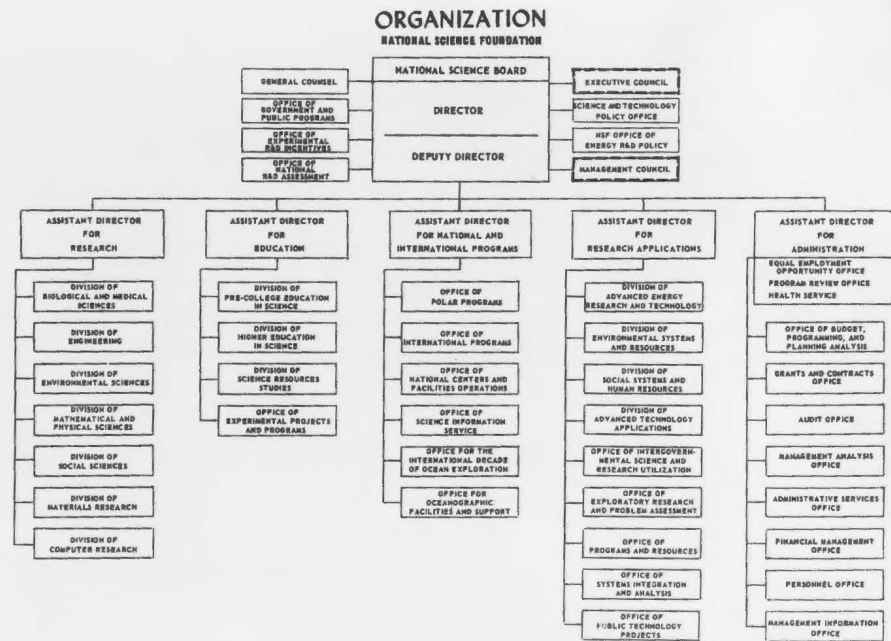
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National Science Foundation Databook



January 1974

NSF 74-3



DATABOOK

NATIONAL SCIENCE FOUNDATION

JANUARY 1974

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INTRODUCTION

The information contained in this booklet has been compiled as a convenient reference for members of the National Science Board and the staff of the National Science Foundation. In addition to data on activities of the Foundation, a number of tables have been included to present pertinent information on the national status of research and education in the sciences. Unless otherwise indicated, data are prepared by NSF sources. Fiscal data pertaining to NSF programs reflect obligations as reported at the end of each fiscal year.



Report of the Committee on the Status of the Biological Sciences in the United States, 1955-1956	1	Report of the Committee on the Status of the Biological Sciences in the United States, 1955-1956	1
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TABLE 1. LEGISLATIVE AND EXECUTIVE ACTION HIGHLIGHTS

Continued

The following table lists the legislative and executive actions taken by the Congress and the Executive Branch during the period from January 1, 1955, to December 31, 1956. The table is organized into two columns: "Legislation" and "Executive Action". The "Legislation" column lists the name of the bill, the date it was introduced, and the date it was passed. The "Executive Action" column lists the name of the executive action, the date it was taken, and the date it was signed.

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NATIONAL SCIENCE FOUNDATION—GENERAL

Table 1 LEGISLATIVE AND EXECUTIVE ACTION HIGHLIGHTS

Act or Executive Document	Content
The National Science Foundation Act of 1950, as amended through December 1, 1972, 42 U.S. Code 1861-1875	The NSF Act states that the Foundation is established "To promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense; and for other purposes." Its general functions are to: 1. Initiate and support basic scientific research and programs to strengthen scientific research potential and science education programs at all levels; and to appraise the impact of research upon industrial development and the general welfare. 2. Award scholarships and graduate fellowships in the sciences. 3. Foster the interchange of scientific information among scientists in the United States and foreign countries. 4. Foster and support the development and use of computer and other scientific

Table 1--Continued

ic methods and technologies, primarily for research and education in the sciences. 5. Evaluate the status and needs of the various sciences and take into consideration the results of this evaluation in correlating its research and educational programs with other Federal and non-Federal programs. 6. Maintain a current register of scientific and technical personnel, and in other ways provide a central clearinghouse for the collection, interpretation, and analysis of data on scientific and technical resources in the United States. 7. Determine the total amount of Federal money received by universities, and appropriate nonprofit organizations for the conduct of scientific research, including both basic and applied but excluding development, and report annually thereon to the President and the Congress. 8. Initiate and

support specific scientific activities in connection with matters relating to international cooperation, national security, and the effects of scientific applications upon society. 9. Initiate and support scientific research, including applied research, at academic and other nonprofit institutions and, at the direction of the President, support special applied research at other organizations. 10. Recommend and encourage the pursuit of national policies for the promotion of basic research and education in the sciences.

Table 1—Continued

Act or Executive Document

Executive Order 10900,
3 CFR 1959 Supp. p. 429

Public Law 85-864, 42
U.S. Code 1876-1879

Content

Executive Order 10900 authorized the Foundation to use surplus foreign currencies to collect, collate, translate, abstract and disseminate scientific and technological information under Public Law 83-480, as amended, commonly referred to as "PL 480" (7 USC 1704(b)(3)). This legislation authorized the Librarian of Congress to consult with the Foundation concerning foreign books and informational materials (7 USC 1704(b)(5)).

Title IX of Public Law 85-864 directed the National Science Foundation to establish a Science Information Service, and through such service to (a) provide or arrange for the provision of indexing, abstracting, translating and other services leading to a more effective dissemination of scientific information, and

Table 1—Continued

Act or Executive Document

Public Law 85-864, 42
U.S. Code 1876-1879

Executive Order 10521,
3 CFR 1954 Supp. p. 183
as amended by Executive
Order 10807, 3 CFR 1959
Supp. p. 329

Bureau of the Budget
Circular No. A-51

Content

(b) undertake programs to develop new or improved methods, including mechanized systems, for making scientific information available.

Executive Order 10521 and Executive Order 10807 defined Foundation responsibility for reviewing the basic scientific research programs and activities of the Federal Government and assigned the Foundation additional responsibility in providing leadership in the effective coordination of the scientific information activities of the Federal Government.

Provided that the Foundation will exercise the principal coordinating and management role in the development and carrying out of an integrated U.S. scientific program for Antarctica.

Table 1—Continued

Letter dated November 7, 1969, from the Vice President of the United States to the Director of the National Science Foundation

Public Law 93-96
(NSF Authorization Act, 1974)

Content

Designated the Foundation as lead agency for Arctic research and the International Decade of Ocean Exploration.

Authorization appropriations up to \$3,000,000 in excess foreign currencies in addition to regular fiscal year 1974 authorizations. These amounts are to be expended for needs of the Foundation outside the United States and have been used for collecting, translating, abstracting and disseminating scientific information, foreign scientific and technological information, and for support of research and other scientific purposes.

Table 1—Continued

Act or Executive Document

Reorganization Plan No. 1 of 1973
(effective July 1, 1973)

White House Announcement
of July 10, 1973

Content

Reorganization Plan No. 1 of 1973 abolished the Office of Science and Technology and transferred to the Director of the National Science Foundation all functions vested by law in the Office of Science and Technology.

In a press release by the White House on July 10, 1973, the President announced that he had designated Dr. H. Guyford Stever, Director of the National Science Foundation, as Chairman of the Federal Council for Science and Technology. The President also announced that Dr. Stever would serve as his Science Adviser.

Table 2

NATIONAL SCIENCE BOARD Membership and Terms of Appointment

Terms Expire May 10, 1974

R. H. Bing, Rudolph E. Langer Professor of Mathematics, University of Wisconsin, Madison, Wis.

Harvey Brooks, Gordon McKay Professor of Applied Physics, and Dean of Engineering and Applied Physics, Harvard University, Cambridge, Mass.

William A. Fowler, Institute Professor of Physics, California Institute of Technology, Pasadena, Calif.

Norman Hackerman, President, William Marsh Rice University, Houston, Tex.

Philip Handler, President, National Academy of Sciences, Washington, D. C.

James G. March, David Jacks Professor of Higher Education, Political Science, and Sociology, School of Education, Stanford University, Stanford, Calif.

Grover E. Murray, President, Texas Tech University, Lubbock, Tex.

Frederick E. Smith, Professor of Advanced Environmental Studies in Resources and Ecology, Graduate School of Design, Harvard University, Cambridge, Mass.

Terms Expire May 10, 1976

*H. E. Carter (Chairman, National Science Board), Coordinator of Interdisciplinary Programs, University of Arizona, Tucson, Ariz.

Robert A. Charpie, President, Cabot Corp., Boston, Mass.

Lloyd M. Cooke, Director of Urban Affairs, Union Carbide Corp., New York, N. Y.

*Robert H. Dicke, Cyrus Fogg Brackett Professor of Physics, Department of Physics, Princeton University, Princeton, N. J.

David M. Gates, Professor of Botany and Director, Biological Station, Department of Botany, University of Michigan, Ann Arbor, Mich.

*Roger W. Heyns (Vice Chairman, National Science Board), President, American Council on Education, Washington, D. C.

Frank Press, Chairman, Department of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Mass.

*F. P. Thieme, President, University of Colorado, Boulder, Colo.

Terms Expire May 10, 1978

W. Glenn Campbell, Director, Hoover Institute on War, Revolution, and Peace, Stanford University, Stanford, Calif.

T. Marshall Hahn, Jr., President, Virginia Polytechnic Institute and State University, Blacksburg, Va.

Anna J. Harrison, Professor of Chemistry, Mount Holyoke College, South Hadley, Mass.

Hubert Heffner, Chairman, Department of Applied Physics, Stanford University, Stanford, Calif.

William H. Meckling, Dean, The Graduate School of Management, The University of Rochester, Rochester, N. Y.

William A. Nierenberg, Director, Scripps Institution of Oceanography, University of California, San Diego, Calif.

Russell D. O'Neal, Special Assistant to the Chief Executive Officer, The Bendix Corp., Southfield, Mich.

Joseph M. Reynolds, Boyd Professor of Physics and Vice President for Instruction and Research, Louisiana State University, Baton Rouge, La.

Member Ex Officio

*H. Guyford Stever, Director, National Science Foundation, Washington, D. C. (Chairman, Executive Committee)

Vernice Anderson, Executive Secretary, National Science Board, National Science Foundation, Washington, D. C.

*Member, Executive Committee.

Table 3 SENIOR STAFF OF THE NATIONAL SCIENCE FOUNDATION

Director, H. Guyford Stever Deputy Director, Raymond L. Bisplinghoff				
General Counsel, Charles F. Brown		Science and Technology Policy Office, Director Russell C. Drew		
Office of Government & Public Programs, Director, Theodore W. Wirths		Office of Energy R&D Policy, Director, Paul F. Donovan		
Office of Experimental R&D Incentives, Director, ¹ C. Branson Smith				
Office of National R&D Assessment, Director, Leonard L. Laderman				
Assistant Director for Administration	Assistant Director for Education	Assistant Director for National and International Programs	Assistant Director for Research	Assistant Director for Research Applications
T. E. Jenkins	Lowell J. Paige	Thomas B. Owen	Edward C. Creutz	Alfred J. Eggers
Deputy Assistant Director	Deputy Assistant Director (Acting)	Deputy Assistant Director	Deputy Assistant Director	Deputy Assistant Director
Eldon D. Taylor	Keith R. Kelson	T. O. Jones	Edward P. Todd	Sidney Sternberg

Table 4 NATIONAL SCIENCE FOUNDATION EMPLOYMENT BY PROGRAM
Fiscal Years 1969-73

Division or Office	1969	1970	1971	1972	1973
Research	229	198	201	227	243
Education	219	213	183	167	158
National and International Programs	89	142	142	165	151
Institutional Programs	56	53	19	1	1
Administration	306	307	335	349	357
Research Applications	-	-	54	73	118
Others	44	57	71	74	118 ²
TOTAL	943	970	1,005	1,055	1,145

NOTE: Excludes full-time employees reimbursable from State Department (AID).

¹ Institutional Relations Directorate disestablished as of January 28, 1972.

² Includes the Office of Experimental R&D Incentives and the Office of National R&D Assessment.



NOTES

NATIONAL SCIENCE FOUNDATION—BUDGET AND FISCAL DATA

Budget and fiscal data are expressed in terms of net obligations and do not in all cases coincide with figures for grants and contracts reported by program administrators due to recoveries, reimbursements, etc.

Table 5 CONGRESSIONAL APPROPRIATIONS FOR THE NATIONAL SCIENCE FOUNDATION

Fiscal Years 1952-74 (Thousands of dollars)			
Fiscal Year	Appropriation	Fiscal Year	Appropriation
1952	\$ 3,500	1964	\$353,200
1953	4,750	1965	420,400
1954	8,000	1966	479,999
1955	14,250 ¹	1967	479,999
1956	53,000 ²	1968	495,000
1957	40,000	1969	400,000
1958	51,750 ³	1970	440,000 ⁵
1959	136,500 ⁴	1971	513,000 ⁶
1960	152,773	1972	622,000 ⁷
1961	175,800	1973	645,740 ⁸
1962	263,250	1974	577,400 ⁹
1963	322,500		

¹ Includes \$2.0 million supplemental for the International Geophysical Year Program (IGY).² Includes \$37.0 million supplemental for the IGY.³ Includes \$8.75 million and \$1.0 million supplementals and an additional \$2.0 million for IGY.⁴ Includes \$4.0 million supplemental and \$2.5 million for IGY.⁵ Includes \$2.0 million for Special Foreign Currency.⁶ Includes \$2.0 million for Special Foreign Currency.⁷ Includes \$3.0 million for Special Foreign Currency.⁸ Includes \$7.0 million for Special Foreign Currency and \$19.7 million for aircraft procurement for the U.S. Antarctic Research Program.⁹ Includes \$3.0 million for Special Foreign Currency and \$7.8 million supplemental for energy-related research.

Table 6 NATIONAL SCIENCE FOUNDATION OBLIGATIONS BY PROGRAM AREA

Fiscal Years 1965-74 (Thousands of dollars)											
Program	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	Est.
Scientific Research Project Support	\$120	\$158	\$168	\$171	\$176	\$162	\$175	\$249	\$268	\$291	
Specialized Research Facilities and Equipment	23	19	17	19	7	7	6	7	7	7	
National and Special Research Programs	42	35	12	15	13	39	50	86	112	92	
National Research Centers	19	23	24	31	29	27 ^a	37 ^a	40 ^a	40	43	
National Sea Grant Program	-	-	-	5	6	9	6	4	4	4	
Computing Activities	5	9	13	22	17	17	16	13	7	7	
Science Information Activities	11	11	10	14	11	11	11	10	8	8	
International Cooperative Scientific Activities	1	2	2	2	2	2	2	4	5	6	
Research Applied to National Needs	-	-	-	-	-	-	34 ^b	54	70	75	
Intergovernmental Science and Research Utilization	-	-	-	-	-	1	1	1	1	1	
Institutional Improvement for Science	50	70	80	83	38	45	34	21	9	10	
Science Education Improvement	120	124	123	125	115	120	99	73	47	67	
Graduate Student Support ^c	-	-	-	-	-	-	-	20	15	13	
Planning and Policy Studies	2	2	2	2	2	2	3	3	2	3	
Program Development & Management	13	13	14	16	17	20	22	24	29	32 ^d	
TOTAL	\$416	\$466	\$465	\$505^e	\$433^e	\$461^e	\$495^e	\$598^e	\$669^e	\$641^e	

^a Less than \$500,000.^b Includes Mohole Project recoveries.^c Does not include Special Foreign Currency Program.^d Includes reimbursables less than \$300,000.^e Established March 1971, includes research efforts such as Weather Modification, Earthquake Engineering and Interdisciplinary Research Relevant to Problems of Our Society (IRRPOS), all formerly under National and Special Research Programs and a number of activities formerly included in the Scientific Research Project Support Program.^f Program transferred to the National Oceanic and Atmospheric Administration, Department of Commerce on October 2, 1970.^g Combined with Scientific Research Project Support Program.^h This program was combined with Science Education Support Program until 1972.ⁱ Includes \$1,880,000 for proposed supplemental for pay increases.

NOTES

The number of grants and contracts awarded is determined by counting each NSF obligation of funds as an "award" regardless of whether the "award" is a new award, an amendment, a supplement, or an extension.

Table 7 SUMMARY OF NATIONAL SCIENCE FOUNDATION
OBLIGATIONS AND AWARDS BY PROGRAM

Fiscal Year 1973
(Thousands of dollars)

Program	Number of Awards	Total Amount Obligated
Scientific Research Project Support	6,138 ¹	\$268,057 ¹
National and Special Research Programs	593	112,464
National Research Centers	32	39,750
Science Information Activities	69	8,464
International Cooperative Scientific Activities	674	4,664
Research Applied to National Needs	616	69,887
Intergovernmental Science and Research Utilization	54	998
Institutional Improvement for Science	673	9,102
Graduate Student Support	1,630	15,309
Science Education Improvement		46,925
Planning and Policy Studies	82	1,690
Total — All Programs	10,561	577,310
Program Development and Management	—	28,619
Total — NSF	10,561	\$605,929 ²

¹ Does not include IBP. IBP is shown under National and Special Research Programs.

² Does not include Special Foreign Currency Program.

Table 8 SUMMARY OF NATIONAL SCIENCE FOUNDATION OBLIGATIONS AND AWARDS
IN SUPPORT OF SCIENTIFIC RESEARCH PROJECTS BY DISCIPLINE

Fiscal year 1973
(Millions of dollars)

Program	Number of awards	Total amount obligated
TOTAL	6,138	\$268.05
Biological Sciences	1,584	56.22
Astronomy	170	8.80
Mathematics	758	14.06
Chemistry	675	25.08
Physics	298	34.88
Engineering	663	26.16
Social Sciences	635	23.63
Atmospheric Sciences	232	11.93
Earth Sciences	296	9.76
Oceanography	287	12.66
Materials Research	409	34.97
Computing Activities	131	9.90

Table 9 SCIENTIFIC RESEARCH PROJECTS
AVERAGE DISTRIBUTION OF FUNDS BY TYPE OF EXPENDITURE
Fiscal Years 1971-73

	Fiscal Year 1971		Fiscal Year 1972		Fiscal Year 1973	
	Amount	Percent of total	Amount	Percent of total	Amount	Percent of total
Professional Personnel						
Faculty	\$ 6,560	15.0	\$ 6,194	14.1	\$ 6,506	14.9
Research Associates	2,668	6.1	2,987	6.8	3,342	7.7
Research Assistants	5,510	12.6	4,877	11.1	5,124	11.7
Other Professional	2,274	5.2	2,065	4.7	1,916	4.4
Total Professional Personnel	17,012	38.9	16,123	36.7	16,888	38.7
Other Personnel	3,499	8.0	3,383	7.7	3,342	7.6
Fringe Benefits	1,618	3.7	1,757	4.0	1,961	4.5
Total Salaries and Wages	22,129	50.6	21,263	48.4	22,191	50.8
Permanent Equipment	2,756	6.3	2,724	6.2	2,451	5.6
Expendable Equipment and Supplies	3,149	7.2	2,900	6.6	3,253	7.4
Travel	1,356	3.1	1,318	3.0	1,337	3.1
Publication Costs	612	1.4	615	1.4	668	1.5
Computer Costs	1,356	3.1	1,186	2.7	1,114	2.6
Other Costs	2,536	5.8	3,778	8.6	1,918	4.4
Total Direct Costs	33,894	77.5	33,784	76.9	32,932	75.4
Indirect Costs	9,840	22.5	10,148	23.1	10,739	24.6
Total Average Grant	\$43,734	100.0	\$43,932	100.0	\$43,671	100.0

Table 10 SUMMARY OF NATIONAL SCIENCE FOUNDATION OBLIGATIONS AND AWARDS
IN SUPPORT OF RESEARCH APPLICATIONS

Fiscal Years 1971-73
(Millions of dollars)

	Fiscal Year 1971		Fiscal Year 1972		Fiscal Year 1973	
	Number	Amount	Number	Amount	Number	Amount
RESEARCH APPLIED TO NATIONAL NEEDS (RANN)	213	\$33.95	338	\$53.77	616	\$69.88
Division of Advanced Technology Applications	122	14.65	163	18.35	262	28.94
Division of Environmental Systems and Resources	48	9.25	98	19.45	148	22.50
Division of Social Systems and Human Resources	15	7.10	25	11.28	122	13.35
Office of Exploratory Research and Problem Assessment	28	2.95	52	4.69	84	5.09
INTERGOVERNMENTAL SCIENCE PROGRAMS	28	.80	43	1.08	54	1.00
Total	241	\$34.75	381	\$54.85	670	\$70.88

Table 11 SUMMARY OF NATIONAL SCIENCE FOUNDATION OBLIGATIONS AND AWARDS
IN SUPPORT OF NATIONAL AND SPECIAL RESEARCH PROGRAMS
Fiscal Year 1973
(Thousands of dollars)

Program	Number of awards	Total amount obligated
National and Special Research Programs, Total	593	\$112,464
International Biological Program	30	9,195
Global Atmospheric Research Program	55	3,445
International Decade for Ocean Exploration	92	16,934
Ocean Sediment Coring Program	24	9,594
Arctic Research Program	62	3,435
U.S. Antarctic Research Program	130	44,004 ¹
Oceanographic Facilities and Support	62	10,994
1973 Solar Eclipse (Logistic Support)	10	682
Experimental R&D Incentives Program	78	11,890
National R&D Assessment Program	50	2,291

¹ Includes \$19,740, LC-130R Aircraft Procurement

Table 12 SUMMARY OF NATIONAL SCIENCE FOUNDATION OBLIGATIONS IN SUPPORT
OF NATIONAL RESEARCH CENTERS

	Fiscal Years 1971-73 (Thousands of dollars)								
	Fiscal year 1971			Fiscal year 1972			Fiscal year 1973		
	Capital obligations	Research operations and support services	Total	Capital obligations	Research operations and support services	Total	Capital obligations	Research operations and support services	Total
National Astronomy and Ionosphere Center	\$ 3,755,000	\$ 2,343,600	\$ 6,098,600	\$ 1,900,000	\$ 2,787,500	\$ 4,687,500	\$ 399,000	\$ 2,851,000	\$ 3,250,000
Kitt Peak National Observatory	127,000	7,072,600	7,199,600	456,000	7,243,881	7,699,881	70,000	7,780,000	7,850,000
Cerro Tololo Inter-American Observatory	313,000	1,967,000	2,280,000	385,000	2,115,000	2,500,000	216,000	2,484,000	2,700,000
National Radio Astronomy Observatory	-0-	6,837,400	6,837,400	80,000	6,589,900	6,669,900	3,000,000	6,950,000	9,950,000
National Center for Atmospheric Research	270,990	14,224,614	14,495,604	1,000,000	17,177,416	18,177,416	-0-	16,000,000	16,000,000
Total	\$ 4,465,990	\$32,445,214	\$36,911,204	\$ 3,821,000	\$36,913,897	\$36,734,897	\$ 3,665,000	\$36,065,000	\$39,760,000

Table 13 NATIONAL SCIENCE FOUNDATION SCIENCE INFORMATION SERVICE
OBLIGATIONS FOR GRANTS AND CONTRACTS AWARDED

Fiscal Years 1971-73

Program	Fiscal Year 1971	Fiscal Year 1972	Fiscal Year 1973
National Information Systems	\$ 9,424,070	\$8,136,330	\$5,463,537
User Support	136,250	243,650	1,498,536
Research	864,432	911,641	1,323,785
Foreign Science Information	270,146	419,301	176,550
Total	\$10,694,898	\$9,710,922	\$8,464,408

Table 14 SUMMARY OF NATIONAL SCIENCE FOUNDATION
OBLIGATIONS AND AWARDS FOR SCIENCE EDUCATION

Fiscal Year 1973
(Thousands of dollars)

Program	Number of Awards	Total Amount Proposed	Total Amount Obligated
SCIENCE EDUCATION IMPROVEMENT SUPPORT, TOTAL	1,304	\$103,906	\$46,925
Research, Development & Demonstration	149	35,486	15,565
Instructional Improvement Implementation	733	48,878	26,176
Talented Student Program	422	19,542	5,184
GRADUATE STUDENT SUPPORT	2,405	48,262	15,309

SUMMARY OF OBLIGATIONS BY DIVISION/OFFICE¹

Fiscal Years 1972-1973

Program	Fiscal Year 1972	Fiscal Year 1973	Participants 1973
Pre-College Education	\$34,404		
Undergraduate Education	28,267		
Graduate Education	22,996		
Experimental Projects & Programs (OEPP)		\$12,866 ²	10,467
Pre-College Education in Science (PES)		19,558	24,977
Higher Education in Science (HES)		30,010 ³	8,810 ³

¹ Education Directorate was reorganized in Fiscal Year 1973; OEPP supports projects at all levels of education, and HES at the undergraduate and graduate levels.

² Includes \$6,216 million for Technology in Education activities transferred to the Education Directorate in FY 1973.

³ Includes fellowships and traineeships.

Table 15 NATIONAL SCIENCE FOUNDATION FELLOWSHIP AND TRAINEESHIP PROGRAMS

Fiscal Year 1973					
Program	Number of traineeships requested	Number of institutions requesting traineeships	Number of traineeships awarded	Number of institutions awarded traineeships	Amount obligated
Graduate Traineeships	982	172	911	172	\$4,825,993
	Number of new fellowships requested	Number of new fellowships offered	Number of fellows entering tenure including prior year awardees		Amount obligated
Graduate Fellowships	5,713	457	1,488		\$10,482,902
Total, Traineeships and Fellowships			2,399		\$15,308,895

Table 15—Continued

NATIONAL SCIENCE FOUNDATION FELLOWSHIP AND TRAINEESHIP AWARDS BY FIELDS OF SCIENCE

Fiscal Year 1973
(Based on Awards Offered)

Program	Physics	Chemistry	Astronomy	Mathematical sciences	Environmental sciences	Life sciences	Social sciences	Engineering
Graduate Traineeships	87	88	8	105	47	173	197	206
Graduate Fellowships	107	112	15	225	72	320	433	204
Total Traineeships and Fellowships	194	200	23	330	119	493	630	410

Table 16 NATIONAL SCIENCE FOUNDATION GRANTS AND CONTRACTS BY STATES

Fiscal Year 1973 (Excluding Fellowships)
(Thousands of Dollars)

State	Total		Scientific Research Project Support		Nat'l & Spec. Prog.; Centers		RANN Ingov't'l Sci.		Science Info. Act.; Pl'g. & Poly. Study's.; Int. Coop. Sci. Act.; Institutional		Science Education Support	
	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$
ALABAMA	63	1,524	20	485	1	28	5	325	16	126	21	560
ALASKA	55	3,757	32	2,219	12	1,431	3	28	5	54	3	25
ARIZONA	121	14,284	74	2,848	11	10,583	4	333	17	188	15	352
ARKANSAS	32	512	8	230				12	108	12	174	
CALIFORNIA	1,320	81,728	905	47,554	87	16,414	104	12,011	139	2,173	105	3,575
COLORADO	234	38,459	129	7,321	23	23,751	19	5,348	22	214	41	1,825
CONNECTICUT	234	8,486	166	6,436	7	346	15	1,153	23	162	23	389
DELAWARE	32	1,142	21	630	1	49	1	10	4	30	5	423
DISTRICT OF COLUMBIA	483	24,631	110	3,028	89	6,161	96	3,203	122	8,995	65	3,243
FLORIDA	246	11,889	156	5,813	23	3,034	7	1,494	30	239	30	1,290
GEORGIA	137	4,802	66	1,783	12	1,149	4	266	23	380	32	1,224
HAWAII	84	4,220	61	2,256	8	1,379	3	423	8	78	6	85
IDAHO	19	437	5	198				5	47	9	192	
ILLINOIS	553	26,739	382	19,747	19	680	31	4,426	55	514	66	3,372
INDIANA	253	11,728	156	7,396	3	69	17	1,838	27	237	48	2,191
IOWA	114	3,022	50	1,708		3	254	27	164	34	896	
KANSAS	86	2,049	49	1,391				15	96	22	562	
KENTUCKY	53	783	18	283		4	89	11	92	20	318	
LOUISIANA	92	2,269	47	1,107	2	5	4	496	15	124	24	538

Table 16—Continued

State	Total		Scientific Research Project Support		Nat'l & Spec. Prog.; Centers		RANN Ingov't'l Sci.		Science Info. Act.; Pl'g. & Poly. Study's.; Int. Coop. Sci. Act.; Institutional		Science Education Support	
	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$
MAINE	38	813	12	381	1	5	2	24	6	34	15	389
MARYLAND	279	12,159	182	6,899	20	1,121	32	2,969	36	405	29	765
MASSACHUSETTS	805	44,901	559	27,376	34	6,443	55	6,887	81	1,263	76	2,951
MICHIGAN	329	13,832	207	9,383	9	535	12	2,076	37	243	64	1,595
MINNESOTA	133	4,457	74	2,410	5	219	9	1,058	22	134	23	627
MISSISSIPPI	57	1,339	10	188			3	135	9	79	35	937
MISSOURI	172	5,935	106	3,420	3	145	15	1,535	22	205	27	630
MONTANA	29	647	10	128			3	227	5	73	11	220
NEBRASKA	36	690	14	337	2	75	1	50	10	48	9	180
NEVADA	24	1,091	11	706			2	151	6	46	5	188
NEW HAMPSHIRE	56	1,437	28	887	1	21	2	213	7	62	18	254
NEW JERSEY	249	10,126	177	7,970	4	124	7	755	30	408	31	868
NEW MEXICO	60	3,393	35	1,103			5	1,950	10	121	10	220
NEW YORK	1,058	50,990	693	38,016	37	3,632	43	4,170	150	1,893	135	3,480
NORTH CAROLINA	193	8,589	105	4,248	7	1,282	10	686	32	360	39	2,012
NORTH DAKOTA	17	318	2	72					3	33	12	210
OHIO	334	11,424	187	7,215	13	362	6	582	54	1,012	74	2,253
OKLAHOMA	85	2,425	36	1,091	2	55	5	263	12	127	30	889
OREGON	158	7,866	90	3,408	15	2,824	2	195	17	189	34	1,250
PENNSYLVANIA	519	22,507	324	14,727	9	1,539	29	2,328	88	1,344	69	2,570
RHODE ISLAND	128	5,421	80	3,437	14	1,429	3	140	16	105	15	309
SOUTH CAROLINA	43	1,224	12	396	1	11	1	31	9	64	20	723
SOUTH DAKOTA	24	515	3	143	1	34	1	52	11	71	8	215

Table 16—Continued

State	Total		Scientific Research Project Support		Nat'l & Spec. Prog.: Centers		RANN Ingov't Sci.		Science Info. Act.: Pl'g. & Pol'y. Stdy's.; Int. Coop. Sci. Act.; Institutional		Science Education Support	
	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$	No.	\$
TENNESSEE	136	7,550	57	3,780	1	70	13	2,107	25	152	40	1,442
TEXAS	365	13,298	206	7,432	20	1,331	11	1,485	69	540	59	2,511
UTAH	93	4,107	60	3,116	3	51	4	431	10	128	16	381
VERMONT	14	138	4	87					5	35	5	35
VIRGINIA	207	7,500	79	2,818	24	621	15	566	50	279	39	3,215
WASHINGTON	224	13,899	147	7,443	13	3,851	11	1,179	22	177	31	1,049
WEST VIRGINIA	26	10,297	7	144	3	9,785	1	125	6	50	9	193
WISCONSIN	269	9,393	162	6,563	13	660	8	759	39	231	47	1,180
WYOMING	27	1,004	14	470	2	58	2	131	3	26	6	319
UNITED STATES TOTAL	10,396	523,526	6,129	278,186	533	101,363	633	64,942	1,478	23,736	1,623	55,299
FEDERAL GOVERNMENT TOTAL	119	52,609	14	1,043	51	44,546	37	6,269	14	712	3	39
U.S. POSSESSIONS TOTAL	15	3,472	5	202	3	3,144			4	61	3	65
FOREIGN COUNTRIES TOTAL	31	837	8	432	8	248			14	106	1	60
GRAND TOTAL	10,561	580,443	6,166	279,663	566	149,301	670	71,211	1,510	24,615	1,630	55,483

THE NATIONAL SCENE—R&D FUNDING

All tables showing dollar data are on an expenditure basis, except for those Federal Government tables which specify obligations. Obligations represent the amounts for orders placed, contracts awarded, services to be received, and similar transactions during a given period, regardless of when the funds were appropriated and when future payment of money is required. For any given year, obligations differ from expenditures because not all funds are expended during the year obligated.

Table 17 RESEARCH AND DEVELOPMENT
INTERSECTORAL TRANSFER OF FUNDS USED FOR PERFORMANCE, 1974 (est.)¹
(Millions of Dollars)

Source of funds	Federal Government	Industry ²	Performers			Total	Percent distribution, sources
			Universities and colleges ³	Associated FFRDC's ⁴	Other nonprofit institutions ⁵		
Federal Government	4,800	8,525	2,000	800	755	16,880	52.8
Industry		13,000 ⁵	85		115	13,200	41.2
Universities and colleges			1,480 ⁵			1,480	4.6
Other nonprofit institutions			195		245 ⁵	440	1.4
Total	4,800	21,525	3,760	800	1,115	32,000	
			4,560				
Percent distribution, performers	15.0	67.3	11.7	14.2	2.5	3.5	100.0

¹ All data are based on reports by performers.

² Expenditures for Federally Funded Research and Development Centers administered by both industry and by nonprofit institutions are included in the totals of their respective sectors.

³ Includes agricultural experiment stations.

⁴ Federally Funded Research and Development Centers administered by individual universities and colleges and by university-consortia.

⁵ Includes State and local government funds.

Table 18 BASIC RESEARCH
INTERSECTORAL TRANSFER OF FUNDS USED FOR PERFORMANCE, 1974 (est.)¹
(Millions of Dollars)

Source of funds	Federal Government	Industry ²	Performers			Total	Percent distribution, sources
			Universities and colleges ³	Associated FFRDC's ⁴	Other nonprofit institutions ⁵		
Federal Government	620	170	1,560	265	145	2,760	57.6
Industry		600	58		30	688	14.4
Universities and colleges			1,115 ⁵			1,115	23.3
Other nonprofit institutions			132		95 ⁵	227	4.7
Total	620	770	2,865	265	270	4,790	
			3,130				
Percent distribution, performers	13.0	16.1	59.8	5.5	5.6		100.0
			65.3				

¹ All data are based on reports by performers.

² Expenditures for Federally Funded Research and Development Centers administered by both industry and by nonprofit institutions are included in the totals of their respective sectors.

³ Includes agricultural experiment stations.

⁴ Federally Funded Research and Development Centers administered by individual universities and colleges and by university-consortia.

⁵ Includes State and local government funds.

Table 19 FEDERAL OBLIGATIONS FOR RESEARCH AND DEVELOPMENT,
BY CHARACTER OF WORK AND R&D PLANT, FISCAL YEARS 1964-1974

(Thousands of Dollars)

Fiscal year	Total R&D	Research		Development	R&D plant
		Basic	Applied		
1964	\$14,225,424	\$1,566,571	\$2,897,892	\$ 9,760,961	\$1,098,516
1965	14,614,323	1,689,931	3,163,953	9,760,439	1,131,603
1966	15,320,446	1,839,589	3,431,251	10,049,606	858,306
1967	16,529,265	2,003,605	3,269,416	11,256,244	620,087
1968	15,921,424	2,056,316	3,304,238	10,560,870	603,830
1969	15,641,111	2,077,124	3,151,274	10,412,713	669,012
1970	15,340,302	2,041,521	3,555,384	9,743,397	524,448
1971	15,564,194	2,132,348	3,941,680	9,490,166	611,244
1972	16,552,649	2,410,849	4,168,229	9,973,571	602,056
1973 ¹	16,965,771	2,475,261	4,167,891	10,322,619	850,801
1974 ¹	17,383,316	2,420,857	4,373,037	10,589,422	859,334

¹ Estimated.

Table 20 FEDERAL OBLIGATIONS FOR RESEARCH AND DEVELOPMENT,
BY AGENCY, FISCAL YEARS 1964-74

(Millions of Dollars)

Agency	1964	1965	1966	1967	1968	1969	1970	1971	1972	(est.) 1973	(est.) 1974
Total	\$14,225.4	\$14,614.3	\$15,320.4	\$16,529.3	\$15,921.4	\$15,641.1	\$15,340.3	\$15,564.2	\$16,552.6	\$16,965.8	\$17,383.3
Department of Agriculture	189.0	224.6	234.9	252.6	253.5	280.1	281.2	304.9	349.6	369.8	343.7
Atomic Energy Commission	1,236.0	1,240.7	1,212.4	1,257.3	1,369.0	1,405.9	1,346.0	1,302.9	1,297.7	1,358.4	1,411.4
Department of Defense	7,261.9	6,796.5	7,023.6	8,049.2	7,709.3	7,696.3	7,360.4	7,509.0	8,318.1	8,361.9	8,833.3
Department of Health, Education and Welfare	776.9	869.4	1,014.4	1,146.6	1,251.8	1,297.4	1,221.0	1,476.1	1,751.1	1,807.7	1,900.2
Department of the Interior	106.4	113.2	143.2	170.4	190.6	207.6	157.9	193.7	220.3	260.3	262.0
National Aeronautics and Space Administration	4,286.6	4,951.5	5,050.0	4,867.0	4,429.4	3,963.3	3,799.9	3,257.9	3,157.2	3,199.6	2,969.2
National Science Foundation	170.2	187.2	243.7	262.4	283.5	273.8	289.0	336.9	454.8	462.4	525.1
Department of Transportation ¹	—	—	171.7	283.6	171.7	231.8	327.8	497.2	351.2	366.9	425.1
Other Departments and Agencies	198.4	231.2	226.5	240.2	262.6	304.8	557.1	685.6	662.5	779.8	713.2

¹ Prior to 1968, obligations to component parts of the Department are included in amounts shown for "Other Departments and Agencies."

Table 21 FEDERAL OBLIGATIONS FOR RESEARCH AND DEVELOPMENT BY FUNCTION¹
FISCAL YEARS 1970-74

(Millions of Dollars)

Function	1970	1971	1972	(est.) 1973	(est.) 1974
Total	\$15,340.3	\$15,564.2	\$16,552.6	\$16,965.8	\$17,383.3
National security	7,976.3	8,106.1	8,897.7	8,951.2	9,429.0
Space	3,509.9	2,893.0	2,714.3	2,691.4	2,457.5
Health	1,138.3	1,347.5	1,590.6	1,624.1	1,676.9
Transportation and communications	592.9	822.3	667.1	732.8	765.0
Science and technology base	529.7	531.7	605.9	618.9	653.5
Natural resources	464.1	555.4	658.2	696.2	624.0
Environment	329.6	404.9	478.9	566.3	589.4
Energy development and conversion	317.3	323.6	383.2	461.8	526.0
Education	151.4	198.4	208.0	245.3	253.3
Area and community development and housing	90.9	108.3	102.1	116.9	125.6
Economic growth and productivity	98.4	109.2	79.0	95.5	119.6
Income security and social services	100.8	121.0	113.1	100.4	78.8
Crime prevention and control	8.6	10.3	25.0	35.8	54.2
International cooperation and development	32.2	32.3	29.5	29.1	32.5

¹ R&D plant excluded.

Source: National Science Foundation.

Table 22 FEDERAL OBLIGATIONS FOR BASIC RESEARCH, BY AGENCY,
FISCAL YEARS 1970-74

(Thousands of Dollars)

Agency	1970	1971	1972	(est.) 1973	(est.) 1974
Total	\$2,041,521	\$2,132,348	\$2,410,849	\$2,475,261	\$2,420,857
Department of Agriculture	115,709	118,414	137,311	145,852	134,882
Atomic Energy Commission	286,669	276,897	268,289	277,460	289,966
Department of Defense	246,670	261,545	270,336	270,069	274,200
Department of Health, Education, and Welfare	387,940	397,316	461,062	463,633	481,184
Department of the Interior	49,923	52,690	57,086	64,839	65,345
National Aeronautics and Space Administration	637,034	680,264	768,131	787,048	691,117
National Science Foundation	244,977	272,566	367,691	380,825	400,101
Other Departments and Agencies	72,599	72,656	80,943	85,735	84,062

Table 23 FEDERAL OBLIGATIONS FOR BASIC RESEARCH, BY AGENCY AND FIELD OF SCIENCE
FISCAL YEAR 1974 (est.)

(Thousands of dollars)

Agency	Total	Physical sciences										
		Physics	Chemistry	Astronomy	Other Phys. Sci.	Mathematics	Environmental Sci.	Life Sci.	Soc. Sci.	Psychology	Engineering	Other
Total	\$2,420,857	\$411,996	\$153,192	\$200,624	\$7,666	\$58,593	\$440,279	\$750,111	\$110,810	\$57,321	\$193,018	\$7,247
Dept. of Agriculture	134,882	3,041	16,576	—	—	544	2,126	92,591	11,714	28	8,262	—
Atomic Energy Commission	289,966	204,049	32,498	—	—	4,000	—	37,092	—	—	12,327	—
Dept. of Defense	274,200	37,931	12,961	6,720	1,481	26,890	59,611	34,288	1,652	14,258	75,553	2,885
Dept. of Health, Ed. and Welfare	481,184	34	22,896	—	—	1,476	26	367,303	53,239	29,859	4,304	2,047
Dept. of the Interior	65,345	2,903	7,296	—	—	760	41,957	9,546	1,663	—	889	331
Nat'l Aero. & Space Adm.	691,117	108,539	52,991	159,347	—	—	216,543	110,676	—	1,574	39,447	—
Nat'l Science Foundation	400,101	53,123	33,571	29,037	5,932	24,266	95,461	68,838	29,915	10,689	47,346	1,924
Other Depts. & Agencies	84,062	2,376	4,403	5,520	253	667	22,555	29,777	12,627	913	4,891	80

Table 24 FEDERAL OBLIGATIONS TO UNIVERSITIES AND COLLEGES, BY AGENCY AND TYPE OF PROGRAM, FISCAL YEARS 1971-72
(Millions of Dollars)

Agency	Total Federal Obligations		Academic Sciences Obligations							
	1971	1972	1971				1972			
			Total	R&D	R&D plant	Other science	Total	R&D	R&D plant	Other science
Total	\$3,487.4	\$4,130.6	\$2,343.1	\$1,551.4	\$29.9	\$761.8	\$2,599.0	\$1,853.0	\$36.9	\$706.1
Department of Agriculture	214.6	238.6	214.6	74.8	—	139.8	238.6	88.6	—	150.0
Atomic Energy Commission	105.8	95.3	105.8	95.9	4.8	5.2	95.3	86.8	4.1	4.4
Department of Commerce	9.7	26.0	7.6	6.9	—	.8	26.0	23.6	—	2.4
Department of Defense	249.0	243.9	249.0	249.0	—	—	243.9	243.9	—	—
Environmental Protection Agency	27.2	23.3	27.2	17.0	—	10.1	23.3	17.7	—	5.6
Department of Health, Education, and Welfare	2,263.4	2,827.9	1,142.3	696.7	15.2	431.5	1,318.4	879.3	22.2	416.9
Department of the Interior	22.6	24.4	22.6	21.3	—	1.3	24.3	23.0	—	1.2
Nat'l Aeronautics and Space Administration	134.1	119.0	134.1	128.5	.2	5.3	119.0	112.4	.6	6.0
Nat'l Science Foundation	387.7	458.7	387.7	216.9	9.7	161.1	458.7	334.7	10.0	113.9
Other	73.3	73.5	52.2	45.4	—	6.8	51.6	43.0	—	8.7

Table 25 DISTRIBUTION OF FEDERAL R&D OBLIGATIONS, BY STATE,
FISCAL YEARS 1965, 1970, and 1972¹

(Thousands of Dollars)

State	1965		1970		1972	
	Amount	Percent distribution	Amount	Percent distribution	Amount	Percent distribution
Total	\$14,386,775	100.0	\$14,980,751	100.0	\$16,261,803	100.0
Alabama	370,719	2.6	357,221	2.4	358,999	2.2
Alaska	14,415	.1	43,179	.3	46,042	.3
Arizona	76,557	.5	72,803	.5	89,901	.6
Arkansas	6,619	—	9,787	.1	13,223	.1
California	4,553,252	31.7	3,871,053	25.8	3,473,093	21.4
Colorado	212,332	1.5	274,113	1.8	369,107	2.3
Connecticut	184,532	1.3	160,027	1.1	169,158	1.0
Delaware	7,140	—	16,299	.1	17,371	.1
Dist. of Columbia	374,270	2.6	468,493	3.1	462,107	2.8
Florida	459,798	3.2	824,785	5.5	1,022,522	6.3
Georgia	58,406	.4	72,265	.5	71,881	.4
Hawaii	41,524	.3	43,815	.3	47,374	.3
Idaho	63,553	.4	75,008	.5	75,926	.5
Illinois	191,741	1.3	239,563	1.6	291,017	1.8
Indiana	71,879	.5	91,905	.6	100,520	.6

—less than 0.05 percent.

¹ Represents eight Federal agencies in fiscal year 1965, ten agencies in fiscal year 1970 and 11 agencies in 1972 whose combined obligations for Federal research and development represented more than 98 percent of the Federal total.

Table 25—Continued

State	1965		1970		1972	
	Amount	Percent distribution	Amount	Percent distribution	Amount	Percent distribution
Iowa	28,774	.2	32,661	.2	37,932	.2
Kansas	25,676	.2	16,646	.1	31,299	.2
Kentucky	17,123	.1	20,413	.1	32,100	.2
Louisiana	377,068	2.6	146,488	1.0	103,603	.6
Maine	4,257	—	13,262	.1	16,341	.1
Maryland	876,624	6.1	1,063,359	7.1	1,318,100	8.1
Massachusetts	733,672	5.1	760,920	5.1	961,178	5.9
Michigan	155,153	1.1	162,818	1.1	186,273	1.1
Minnesota	106,341	.7	109,270	.7	126,960	.8
Mississippi	36,677	.3	28,276	.2	60,658	.4
Missouri	231,718	1.6	291,181	1.9	679,459	4.2
Montana	8,577	.1	11,646	.1	19,006	.1
Nebraska	7,652	.1	10,648	.1	11,712	.1
Nevada	154,525	1.1	190,948	1.3	140,255	.9
New Hampshire	28,767	.2	27,268	.2	21,452	.1
New Jersey	410,676	2.9	742,526	5.0	763,073	4.7
New Mexico	425,322	3.0	444,089	3.0	451,511	2.8
New York	1,289,270	9.0	1,235,594	8.2	1,075,607	6.6
North Carolina	57,752	.4	63,908	.4	83,275	.5

Table 25-Continued

State	1965		1970		1972	
	Amount	Percent distribution	Amount	Percent distribution	Amount	Percent distribution
North Dakota	5,003	—	8,878	.1	10,503	.1
Ohio	379,076	2.6	457,342	3.1	521,730	3.2
Oklahoma	28,379	.2	29,483	.2	29,092	.2
Oregon	25,584	.2	33,848	.2	53,732	.3
Pennsylvania	528,697	3.7	538,761	3.6	642,300	3.9
Rhode Island	37,532	.3	29,911	.2	68,877	.4
South Carolina	17,104	.1	17,804	.1	26,339	.2
South Dakota	3,467	—	6,091	—	8,126	—
Tennessee	203,733	1.4	193,814	1.3	187,105	1.2
Texas	731,009	5.1	649,122	4.3	652,950	4.0
Utah	44,997	.3	61,052	.4	58,868	.4
Vermont	3,951	—	9,452	.1	22,772	.1
Virginia	284,215	2.0	352,685	2.4	529,599	3.3
Washington	214,258	1.5	412,230	2.8	537,939	3.3
West Virginia	19,614	.1	19,631	.1	29,387	.2
Wisconsin	125,838	.9	87,143	.6	80,105	.5
Wyoming	4,204	—	7,161	—	9,850	.1
Outlying Areas	9,247	.1	17,280	.1	18,421	.1
Offices Abroad	28,508	.2	56,826	.4	46,073	.3

Table 26 EXPENDITURES FOR INDUSTRIAL BASIC RESEARCH, APPLIED RESEARCH, AND DEVELOPMENT PERFORMANCE, 1964-74

(Millions of Dollars)

Year	Total	Basic research	Applied research	Development
1964	\$13,512	\$549	\$2,600	\$10,363
1965	14,185	592	2,658	10,935
1966	15,548	624	2,843	12,081
1967	16,385	629	2,915	12,841
1968	17,429	642	3,124	13,663
1969	18,318	618	3,287	14,413
1970	18,062	629	3,399	14,034
1971	18,314	625	3,388	14,301
1972 (Prelim.)	19,521	625	3,439	15,457
1973 (Est.)	20,300	705	3,750	15,845
1974 (Est.)	21,300	745	3,900	16,655

Table 27 PERFORMANCE OF INDUSTRIAL RESEARCH AND DEVELOPMENT,
BY INDUSTRY AND SOURCE OF FUNDS, 1960, 1971 and 1972 (prelim.)

(Millions of Dollars)

Industry	Total Funds			Federal Funds			Company Funds		
	1960	1971	1972	1960	1971	1972	1960	1971	1972
Total	\$10,509	\$18,314	\$19,521	\$6,081	\$7,671	\$8,274	\$4,428	\$10,643	\$11,247
Food and kindred products	104	245	257	9	2	2	95	243	255
Textiles and apparel	38	58	59	9	(NA)	(NA)	29	(NA)	(NA)
Lumber, wood prod. & furn.	10	48	57	1	—	—	9	48	57
Paper and allied products	56	187	184	(NA)	(NA)	(NA)	(NA)	185	182
Chem. & allied products	980	1,822	1,913	171	183	196	807	1,639	1,719
Petro. refining & extraction	296	505	475	20	17	15	276	488	462
Rubber products	121	230	259	38	20	27	83	210	232
Stone, clay and glass products	88	156	165	(NA)	3	3	(NA)	153	163
Primary metals	177	275	268	15	6	13	162	269	255
Fabricated metal products	145	230	241	36	8	9	109	222	231
Machinery	949	1,775	1,962	391	286	328	558	1,489	1,634
Electrical equip. & communications	2,532	4,523	4,875	1,675	2,293	2,519	847	2,230	2,355
Motor veh. & other transp. equip.	884	1,759	1,994	216	301	310	668	1,458	1,684
Aircraft & missiles	3,514	4,940	5,177	3,150	3,928	4,250	364	1,012	927
Professional & sci. instruments	329	725	781	153	158	154	176	567	627
Other mfg. & non-mfg. industries	287	836	854	182	(NA)	(NA)	105	(NA)	(NA)

(NA)—Not separately available, but included in total.

Table 28 SELECTED FINANCIAL DATA ON INTRAMURAL R&D PERFORMANCE OF
INDEPENDENT NONPROFIT INSTITUTIONS, BY TYPE OF INSTITUTION, 1969

(Thousands of Dollars)

	Total R&D	Research Institutes	FFRDC's ¹	Voluntary Hospitals	Societies and Academies of Science	Science Exhibitors	Foundations	Other Nonprofit Organizations
Total	\$845,299	\$361,019	\$277,314	\$130,246	\$37,643	\$8,094	\$14,230	\$16,753
Source of Funds:								
Federal government	608,595	224,379	262,564	84,228	26,306	2,302	1,307	5,509
State government	10,795	7,265	477	1,723	1,001	138	23	168
Local government	6,059	2,430	2,912	193	260	27	—	237
Foundations	28,431	12,744	1,423	9,069	1,066	199	1,141	2,789
Voluntary health agencies	8,297	4,255	—	3,890	100	8	2	42
Industry	81,272	73,566	3,419	1,773	880	10	—	1,624
Institution's own funds	81,484	25,904	5,003	24,222	5,367	3,438	11,674	5,876
Other sources	22,366	10,476	1,516	5,148	2,663	1,972	83	508
Area of Science:								
Engineering	257,697	113,648	138,459	153	5,143	15	118	161
Physical sciences	103,743	47,990	46,561	2,137	5,367	85	1,573	30
Environmental sciences	16,770	8,293	5,045	79	667	1,217	1,369	100
Mathematics	35,401	14,252	20,195	738	77	—	—	139
Life sciences	265,967	101,073	14,073	123,166	12,516	4,419	6,655	4,065
Psychology	29,843	14,741	5,717	3,192	732	148	534	4,781
Social sciences	99,931	53,724	32,049	415	3,576	2,202	3,981	3,984
Other sciences, NEC	35,947	7,298	15,215	366	9,565	10	—	3,493

¹ Federally Funded Research and Development Centers administered by nonprofit organizations.

Table 29 SELECTED FINANCIAL CHARACTERISTICS OF SCIENCE AND
ENGINEERING ACTIVITIES IN UNIVERSITIES AND COLLEGES,
BY STATE AND TYPE OF EXPENDITURE, 1970
(Millions of Dollars)

State	Total Selected Activities	Current Expenditures for Separately Budgeted Research and Development			Current Direct Expenditures for Instruction and Departmental Research	Capital Expenditures for Research and Development and Instruction		
		Total	Federally financed	Other		Total	Federally financed	Other
U.S. Total	\$6,655.5	\$2,356.8	\$1,658.3	\$698.5	\$3,346.9	\$951.9	\$279.3	\$672.6
Alabama	77.2	19.2	13.4	5.8	45.3	12.6	5.2	7.5
Alaska	12.5	9.2	5.9	3.3	3.0	.3	.1	.1
Arizona	68.8	16.8	9.5	7.2	32.8	19.3	9.9	9.3
Arkansas	25.6	8.9	4.6	4.3	14.7	2.0	.7	1.4
California	691.0	266.6	200.3	66.4	354.8	69.7	23.3	46.4
Colorado	139.2	51.3	41.0	10.2	49.5	38.4	14.4	24.0
Connecticut	141.3	51.2	39.6	11.7	65.1	25.0	3.8	21.2
Delaware	18.6	4.8	2.9	1.9	10.4	3.5	.4	3.1
District of Columbia	64.1	24.8	20.6	4.2	32.0	7.3	3.9	3.4
Florida	146.1	55.8	28.6	27.2	70.5	19.8	7.1	12.7
Georgia	134.0	44.5	25.2	19.3	68.7	20.8	3.1	17.7
Hawaii	43.0	18.0	10.4	7.6	11.9	13.1	5.1	8.0
Idaho	15.9	6.5	2.8	3.7	7.8	1.6	.3	1.3
Illinois	319.7	103.9	77.2	26.7	178.7	37.1	8.8	28.3

Table 29—Continued

State	Total Selected Activities	Current Expenditures for Separately Budgeted Research and Development			Current Direct Expenditures for Instruction and Departmental Research	Capital Expenditures for Research and Development and Instruction		
		Total	Federally financed	Other		Total	Federally financed	Other
Indiana	156.9	45.9	33.4	12.5	84.0	27.0	10.5	16.5
Iowa	97.6	28.2	17.2	11.1	55.1	14.3	5.2	9.1
Kansas	79.0	28.1	18.1	10.0	42.8	8.2	3.4	4.7
Kentucky	72.6	14.2	10.0	4.2	40.7	17.6	7.2	10.4
Louisiana	88.5	35.2	21.2	13.9	44.1	9.2	3.6	5.6
Maine	14.3	3.4	1.6	1.8	9.6	1.3	.3	1.0
Maryland	118.2	52.8	42.0	10.8	53.4	12.0	5.3	6.7
Massachusetts	432.3	204.0	173.8	30.2	189.1	39.2	7.5	31.7
Michigan	280.4	86.5	65.0	21.5	146.5	47.3	16.0	31.3
Minnesota	136.3	40.4	27.8	12.5	64.9	31.0	5.2	25.9
Mississippi	44.1	15.3	9.1	6.2	22.9	5.9	2.2	3.7
Missouri	170.3	64.1	43.7	20.4	79.9	26.3	5.5	20.8
Montana	24.6	8.6	4.7	3.9	13.7	2.4	.4	2.0
Nebraska	53.9	18.3	6.6	11.6	28.5	7.1	2.7	4.3
Nevada	12.8	5.5	2.9	2.7	4.9	2.3	.6	1.7
New Hampshire	30.2	9.0	7.5	1.5	13.3	7.8	1.5	6.3
New Jersey	136.6	44.5	31.3	13.2	66.7	25.4	7.0	18.3
New Mexico	34.5	19.8	16.9	3.0	11.4	3.3	.9	2.4
New York	731.6	274.1	202.6	71.5	358.4	99.1	17.8	81.3
North Carolina	171.7	59.3	42.4	16.9	73.2	39.2	16.3	22.9

Table 29—Continued

State	Total Selected Activities	Current Expenditures for Separately Budgeted Research and Development			Current Direct Expenditures for Instruction and Departmental Research	Capital Expenditures for Research and Development and Instruction		
		Total	Federally financed	Other		Total	Federally financed	Other
North Dakota	20.9	4.5	1.8	2.6	15.4	1.0	.6	.4
Ohio	247.2	72.0	50.3	21.7	137.4	37.9	12.9	24.9
Oklahoma	54.4	17.8	8.7	9.1	32.6	4.0	1.2	2.8
Oregon	80.9	30.7	21.8	8.9	41.9	8.3	4.5	3.8
Pennsylvania	411.0	130.1	89.5	40.6	215.2	65.7	20.0	45.7
Rhode Island	30.0	12.4	8.7	3.7	15.1	2.5	1.4	1.1
South Carolina	38.6	8.8	4.6	4.2	24.9	4.9	1.9	3.0
South Dakota	22.4	9.8	3.6	6.1	9.9	2.7	1.0	1.7
Tennessee	90.2	31.1	23.1	8.0	51.3	7.8	2.5	5.4
Texas	290.4	102.7	61.8	40.8	148.9	38.8	10.6	28.1
Utah	49.8	20.1	15.7	4.5	22.6	7.1	2.9	4.1
Vermont	27.5	5.0	3.9	1.1	16.6	5.8	1.1	4.8
Virginia	101.2	25.4	17.8	7.6	53.5	22.3	5.3	17.0
Washington	127.3	47.4	33.2	14.2	65.2	14.7	2.6	12.1
West Virginia	42.2	8.3	5.8	2.5	28.7	5.2	2.4	2.8
Wisconsin	186.2	76.5	39.9	36.6	88.2	21.5	1.8	19.6
Wyoming	19.6	6.2	3.4	2.8	9.1	4.2	1.2	3.0
Outlying areas	32.3	9.0	4.5	4.5	22.0	1.3	.2	1.1

Data may not add to total because of rounding.

Table 30 STATE AGENCY EXPENDITURES FOR RESEARCH AND DEVELOPMENT IN THE 10 LEADING STATES, BY FUNCTIONAL AREA, FISCAL YEAR 1968

(Thousands of Dollars)

State	Total	Health and hospitals	Natural resources, other than agriculture	High- ways	Education, other than institutions of higher education	Agricul- ture	Police protection and correction	Financial adminis- tration and general control	Public welfare	All other
Total	\$154,724	\$66,570	\$38,978	\$20,400	\$15,631	\$2,994	\$2,653	\$2,477	\$1,904	\$3,117
New York	36,631	31,484	394	2,182	1,410	—	202	144	—	816
California	28,536	12,897	10,031	2,759	431	48	1,469	11	674	216
Illinois	8,756	4,364	3,163	1,020	100	—	—	109	—	—
North Carolina	7,221	720	336	241	4,728	965	—	78	—	154
Pennsylvania	6,802	2,092	1,808	988	324	507	18	244	124	697
Texas	6,644	1,833	207	2,217	2,186	200	—	—	—	—
Michigan	3,369	905	962	877	291	—	240	—	62	33
Washington	3,222	353	1,628	505	183	350	176	17	—	11
Florida	3,190	1,189	1,627	362	—	—	—	—	12	—
New Jersey	3,079	1,863	388	196	503	—	69	48	—	12
All other	47,274	8,870	18,434	9,053	5,475	924	479	1,826	1,032	1,178

NOTE: Detail may not add to total because of rounding.

NOTES

TABLE 1.1. SCIENTIFIC MANPOWER IN THE UNITED STATES: 1960-1980											
Source: U.S. Department of Commerce, Bureau of Economic Analysis, "Scientific Manpower in the United States, 1960-1980," in "Science and Technology in the United States, 1960-1980," p. 10.											
Year	Total	Physicists	Chemists	Engineers	Mathematicians	Biologists	Medicine	Agriculture	Other	Unemployed	Retired
1960	1,000,000	100,000	150,000	200,000	50,000	100,000	100,000	50,000	100,000	50,000	100,000
1970	1,200,000	120,000	180,000	240,000	60,000	120,000	120,000	60,000	120,000	60,000	120,000
1980	1,400,000	140,000	200,000	280,000	70,000	140,000	140,000	70,000	140,000	70,000	140,000

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TABLE 1.2. SCIENTIFIC MANPOWER IN THE UNITED STATES: 1960-1980											
Source: U.S. Department of Commerce, Bureau of Economic Analysis, "Scientific Manpower in the United States, 1960-1980," in "Science and Technology in the United States, 1960-1980," p. 10.											
Year	Total	Physicists	Chemists	Engineers	Mathematicians	Biologists	Medicine	Agriculture	Other	Unemployed	Retired
1960	1,000,000	100,000	150,000	200,000	50,000	100,000	100,000	50,000	100,000	50,000	100,000
1970	1,200,000	120,000	180,000	240,000	60,000	120,000	120,000	60,000	120,000	60,000	120,000
1980	1,400,000	140,000	200,000	280,000	70,000	140,000	140,000	70,000	140,000	70,000	140,000

Table 31 TOTAL EXPENDITURES BY REGULAR EDUCATIONAL INSTITUTIONS,
AND FEDERAL FUNDS INVOLVED BY LEVEL OF INSTRUCTION,
1962-63 TO 1971-72

(In Billions of Current Dollars)

Year	Elementary and secondary education				Institutions of higher education			
	Expenditures			Federal funds involved ¹	Expenditures			Federal funds involved
	Total ¹	Current expenditures ²	Capital outlay		Total	Current expenditures ³	Capital outlay	
1962-63	\$22.5	\$19.1	\$ 3.1	(NA)	\$10.2	\$ 7.7	\$ 2.5	(NA)
1963-64	24.6	20.8	3.5	\$ 1.1	11.3	8.8	2.5	\$ 2.2
1964-65	27.0	22.5	4.2	1.1	12.9	10.1	2.8	2.7
1965-66	30.0	25.4	4.3	2.2	15.2	11.9	3.3	2.9
1966-67	32.2	27.4	4.5	2.2	17.5	13.6	3.9	3.3
1967-68	37.3	32.2	4.8	3.0	19.9	15.8	4.1	3.8
1968-69	39.9	34.4	5.2	2.9	22.1	17.8	4.3	3.7
1969-70	45.5	40.0	5.2	3.6	24.7	20.3	4.4	4.1
1970-71	49.2	43.3	5.6	4.0	27.1	22.8	4.3	4.3
1971-72	53.3	47.4	5.6	4.3	29.5	25.2	4.3	4.5

¹ Includes expenditures by other than regular institutions, such as Federal schools for Indians, Federally operated schools on military posts, and residential schools for exceptional children (approximately \$300 million in each year) which are not separately reported by current and capital outlay expenditures.

² Includes interest.

³ Excludes expenditures from current funds for capital outlay.

NA—Not available.

Source: Office of Education.

Table 32 FINANCIAL STATISTICS OF INSTITUTIONS OF HIGHER EDUCATION, 1970-71 AND 1971-72

Current Fund Income					Current Fund Expenditures				
1970-71		1971-72 ¹		1970-71		1971-72 ¹			
Millions	Per- cent	Millions	Per- cent	Millions	Per- cent	Millions	Per- cent		
Total	\$24,021.4	100.0	\$26,361.9	100.0	Total	\$23,515.1	100.0	\$25,718.5	100.0
Educational and general purposes	18,517.2	77.1	20,343.0	77.2	Educational and general	17,738.9	75.4	19,337.7	75.2
Tuition and fees	5,043.0	21.0	5,824.2	21.3	Instruction and departmental research	7,854.4	33.4	8,494.3	33.0
Federal Government ²					Operation and maintenance of physical plant	1,739.9	7.4	1,937.7	7.5
Research grants	1,476.5	6.2	1,573.4	6.0	Libraries	720.8	3.1	769.4	3.0
Other	1,367.9	5.7	1,548.9	5.9	Organized research	2,222.9	9.5	2,278.3	8.9
State and local governments	7,487.9	31.2	8,195.5	31.1	Other ³	6,200.8	22.1	5,858.0	22.8
Private gifts and grants ⁴	1,563.9	6.5	1,690.6	6.4	Major public service programs ⁵	1,672.1	7.1	1,939.4	7.5
Other	1,578.0	6.6	1,710.4	6.5	Auxiliary enterprises	2,994.1	12.7	3,185.1	12.4
Major public service programs ⁵	1,852.8	6.9	1,960.4	7.4	Student aid expenditures ⁶	1,110.1	4.7	1,256.3	4.9
Auxiliary enterprises	3,130.8	13.0	3,277.5	12.4					
Student aid income ⁶	720.5	3.0	781.0	3.0					

¹ 1971-72 data are preliminary.

² Does not include recovery of indirect costs. They are included in "other."

³ Includes endowment income.

⁴ Includes public service hospitals (expenditures \$998.6 million and 3.9 percent in 1971-72), and also includes Federally Funded Research and Development Centers.

⁵ For scholarships, fellowships, and prizes.

⁶ Includes extension and public services (\$623.7 million and 2.4 percent) and other sponsored programs (\$1,075.6 million and 4.2 percent in 1971-72).

Source: Office of Education

Table 33 NUMBER OF INSTITUTIONS OF HIGHER EDUCATION
AND INSTITUTIONS BY HIGHEST DEGREE AWARDED IN
SCIENCE AND ENGINEERING, 1963-64 to 1972-73

Year	All institutions	All 4-year	4-year institutions				3-year institutions
			Granting science or engineering degrees				
			All levels	Bachelor's and 1st professional	Master's	Doctor's	
1963-64	2,148	1,509	1,147	757	218	172	637
1964-65	2,189	1,532	1,165	754	233	178	657
1965-66	2,247	1,565	1,178	745	246	187	632
1966-67	2,347	1,592	1,217	752	271	194	755
1967-68	2,392	1,603	1,223	746	281	196	789
1968-69	2,503	1,636	1,254	756	292	206	867
1969-70	2,544	1,654	1,274	762	292	220	890
1970-71	2,573	1,681	1,276	760	287	229	892
1971-72	2,626	1,689	(NA)	—	—	—	937
1972-73	2,689	1,722	(NA)	—	—	—	967

NA—Not available.
Source: Office of Education and NSF.

Table 34 FALL ENROLLMENT IN EDUCATIONAL INSTITUTIONS, BY LEVEL,
SELECTED YEARS 1960 TO 1972

Year (Fall)	Elementary	Secondary	Higher Education (degree-credit enrollment)								
			Total			Undergraduate			Graduate		
			Total	Full-time	Part-time	Total	Full-time	Part-time	Total	Full-time	Part-time
			Number (Thousands)								
1960	29,150	13,031	3,583	2,466	1,117	3,227	2,323	904	366	143	213
1965	31,570	16,904	5,526	3,911	1,615	4,907	3,654	1,253	619	256	363
1966	32,005	17,334	5,928	4,232	1,696	5,247	3,940	1,306	682	285	397
1967	31,972	17,919	6,406	4,556	1,850	5,653	4,239	1,414	753	317	436
1968	31,763	18,981	6,928	4,937	1,991	6,101	4,606	1,496	797	342	455
1969	31,655	19,463	7,484	5,259	2,230	6,656	4,890	1,766	828	364	464
1970	31,601	19,708	7,920	5,489	2,431	7,020	5,110	1,910	900	379	521
1971	31,588	19,693	8,116	5,676	2,440	7,206	5,289	1,920	908	387	520
1972	31,026	19,728	8,265	5,647	2,618	7,322	5,253	2,068	943	394	550
Average Annual Percent Change											
1960 to 1965	1.6	5.3	9.1	9.7	7.7	8.7	9.5	6.7	11.7	12.3	11.3
1965 to 1970	¹	3.1	7.5	7.0	8.5	7.4	6.9	8.8	7.8	8.2	7.5
1970 to 1972	¹	.1	2.2	1.4	8.5	2.1	1.4	4.1	2.4	7.5	2.8

¹ Less than 1/10 of 1 percent.

Source: Office of Education (includes data provided in advance of publication).

Note: Data are for the 50 States and District of Columbia; excludes outlying areas.

Table 35 POPULATION OF 17-YEAR-OLDS, HIGH SCHOOL GRADUATES, COLLEGE ENTRANTS, BACHELOR'S DEGREES, AND FIRST-YEAR GRADUATE STUDENTS (TOTAL AND IN SCIENCE AND ENGINEERING) AND RATIOS, SELECTED YEARS 1949-50 TO 1971-72

Year	17-year-olds ¹	High school graduates	College entrants	Bachelor's degrees ³		First-year graduate students ⁴	
				All fields	Science and engineering	All fields	Science and engineering
1949-50	Number (000) (Per 100 17-year-olds)	2,185 (100)	1,200 (55)	512 (23)	282 (13)	82 (4)	NA (NA)
1959-60	Number (000) (Per 100 17-year-olds)	2,773 (100)	1,864 (67)	923 (33)	502 (18)	153 (6)	318 (11)
1965-66	Number (000) (Per 100 17-year-olds)	3,516 (100)	2,672 (76)	1,378 (39)	833 (24)	264 (8)	528 (15)
1966-67	Number (000) (Per 100 17-year-olds)	3,517 (100)	2,679 (76)	1,439 (41)	884 (25)	271 (8)	528 (15)
1967-68	Number (000) (Per 100 17-year-olds)	3,571 (100)	2,702 (76)	1,630 (46)	NA (NA)	NA (NA)	NA (NA)
1968-69	Number (000) (Per 100 17-year-olds)	3,675 (100)	2,829 (77)	1,749 (48)	NA (NA)	NA (NA)	NA (NA)
1969-70	Number (000) (Per 100 17-year-olds)	3,820 (100)	2,896 (76)	1,780 (47)	NA (NA)	NA (NA)	NA (NA)
1970-71	Number (000) (Per 100 17-year-olds)	3,925 (100)	2,943 (75)	1,766 (45)	NA (NA)	NA (NA)	NA (NA)
1971-72	Number (000) (Per 100 17-year-olds)	4,005 (100)	3,043 (76)	NA (NA)	NA (NA)	NA (NA)	NA (NA)

¹ Age as of 1 October before high school graduation.

² In fall following high school graduation.

³ In spring four years after the reported year.

⁴ In fall four years after the reported year.

Source: Office of Education and NSF.

Note: Data for the first three columns is for United States only—excludes outlying areas.

Table 36 PERCENT OF FULL-TIME FRESHMEN ENTERING COLLEGE EXPECTING TO MAJOR IN A SCIENCE OR ENGINEERING FIELD, BY SEX AND TYPE OF INSTITUTION, FALL 1967 AND FALL 1972

Probable major	Total		Men		Women		2-year colleges		4-year colleges		Universities	
	1967	1972	1967	1972	1967	1972	1967	1972	1967	1972	1967	1972
Total, all fields	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total, science and engineering fields	33.2	32.0	42.5	41.1	21.4	22.0	30.8	27.2	33.2	37.1	35.5	34.6
Physical sciences	3.0	1.9	4.5	3.0	1.1	.8	1.3	.7	3.5	2.5	4.0	2.8
Engineering	9.5	6.9	17.0	12.7	.3	.4	10.9	7.1	7.1	6.2	11.9	7.6
Mathematics and statistics	4.2	2.2	4.1	2.2	4.3	2.2	1.6	.8	6.0	3.2	4.3	2.6
Life sciences ¹	6.1	7.1	8.3	10.0	3.3	3.8	6.7	7.2	5.4	5.7	6.3	8.9
Social sciences	7.8	7.8	4.9	4.9	11.2	11.1	5.5	5.3	9.5	10.1	7.4	8.1
Other technical fields ²	2.6	6.1	3.7	8.3	1.2	3.7	4.8	6.1	1.7	9.4	1.6	4.6
Health professions ³	5.2	10.6	1.4	3.4	9.9	18.7	6.8	13.7	3.5	8.6	6.1	9.2
All other fields ⁴	61.6	57.4	56.1	55.5	68.7	59.3	62.4	59.1	63.3	54.3	58.3	56.2

¹ Includes agriculture, forestry, and biological sciences.

² Includes computer science, electronics, industrial arts, and other technical fields.

³ Includes health technology, nursing, pharmacy, and therapy; excludes premedical.

⁴ Includes arts and humanities, education, business, and prelaw.

Source: American Council on Education longitudinal research program.

Table 37 ENROLLMENT FOR ADVANCED DEGREES IN SCIENCE AND ENGINEERING
BY FIELD OF SCIENCE AND ATTENDANCE STATUS,
SELECTED YEARS 1960-1971

(Thousands)										
Field	Fall 1960		Fall 1965		Fall 1970		Fall 1971		Percent change 1970 to 1971	
	Total	Full-Time	Total	Full-Time	Total	Full-Time	Total	Full-Time	Total	Full-Time
All fields	314.3	124.7	535.3	230.9	816.2	373.0	836.3	388.5	2.5	4.2
Total, science and engineering	120.6	61.8	195.3	109.2	252.2	149.3	246.1	151.1	-2.4	1.2
Agriculture and forestry	4.4	2.9	6.4	4.3	8.7	6.1	9.2	6.5	5.7	6.6
Biological sciences ¹	15.3	9.8	28.3	18.8	37.6	25.7	38.5	26.2	2.4	1.9
Engineering	36.6	14.7	57.5	24.9	64.8	31.6	59.3	31.4	-8.5	-.6
Mathematical sciences ²	11.8	5.1	21.0	10.1	30.6	15.2	28.8	14.7	-5.9	-3.3
Physical sciences	25.7	15.0	36.5	23.6	40.1	27.8	38.9	27.7	-3.0	-.4
Psychology	10.7	5.2	15.6	9.3	25.3	15.4	26.7	16.7	5.5	8.4
Other social sciences ³	16.1	9.0	30.0	18.1	45.0	27.6	44.6	27.9	-.9	1.1
Health fields	5.8	4.3	8.9	6.8	14.2	11.3	20.6	15.3	45.1	35.4
All other fields	187.9	58.6	331.1	114.9	549.8	212.5	569.6	222.1	3.6	4.5

¹ Includes sciences, general program.

² Includes mathematics, statistics, and computer sciences (fall 1965 and later).

³ Includes anthropology, economics, agricultural economics, sociology, linguistics, political science, and geography.

Source: Office of Education (latest available data).

Table 38 EARNED DEGREES IN SCIENCE AND ENGINEERING, BY FIELDS OF SCIENCE
AND LEVEL, 1960-61, 1970-71, AND AVERAGE ANNUAL INCREASE

Field	Thousands of degrees						Average annual percent increase					
	1960-61			1970-71			1960-61 to 1965-66			1966-66 to 1970-71		
	Bachelor's ¹	Master's	Doctor's	Bachelor's ¹	Master's	Doctor's	Bachelor's ¹	Master's	Doctor's	Bachelor's ¹	Master's	Doctor's
All fields	401.8	78.3	10.6	884.4	231.5	32.1	6.7	12.4	11.5	9.7	10.5	12.0
Total, science and engineering	121.7	22.8	6.5	271.2	50.6	18.5	7.4	10.8	11.6	9.3	5.9	10.3
Agriculture and natural resources ²	5.7	1.2	.5	11.5	2.0	.9	4.7	6.1	5.5	9.9	4.1	8.3
Biological sciences ³	18.2	2.8	1.2	39.9	6.3	3.7	10.3	11.9	12.0	6.1	4.7	11.7
Engineering ⁴	35.9	8.2	.9	45.4	16.3	3.7	.0	10.8	19.6	4.9	3.6	9.7
Mathematical sciences ⁵	13.1	2.2	.3	27.3	6.8	1.3	9.0	17.5	18.4	6.2	6.3	10.6
Physical sciences	15.5	3.8	2.0	21.5	6.4	4.4	2.1	5.6	8.9	4.6	5.0	7.6
Psychology	8.5	1.7	.7	38.2	4.4	1.8	14.8	8.0	8.3	17.5	11.9	11.2
Other social sciences ⁶	24.7	2.8	.9	87.3	8.3	2.8	13.4	13.5	9.2	13.5	9.9	14.6
Health fields	24.8	1.6	.1	40.7	5.9	.5	2.7	11.7	13.5	7.6	15.5	13.2
All other fields	255.3	53.8	3.9	549.5	175.0	13.2	6.7	13.1	11.2	10.1	11.9	14.5

¹ Includes first-professional degrees.

² Includes forestry.

³ Includes sciences, general program prior to 1970-71. Includes "biological and physical sciences" in 1970-71.

⁴ Includes "engineering and other disciplines" in 1970-71. Excludes degrees in engineering technologies.

⁵ Includes mathematics, statistics, and (1964-65 and later) computer sciences.

⁶ Includes anthropology, economics, agricultural economics, sociology, linguistics, political science, and geography.

Source: Office of Education and National Science Foundation.

Table 39 EMPLOYMENT OF NATURAL SCIENTISTS¹ AND ENGINEERS, ALL ACTIVITIES, AND RESEARCH AND DEVELOPMENT, SELECTED YEARS² 1955-70
(Thousands)

Occupation	1955	1960	1962	1964	1966	1968	1970
All activities							
Total	812.6	1,104.0	1,210.3	1,327.0	1,417.5	1,525.0	1,594.7
Engineers	601.4	801.1	873.2	945.5	999.6	1,062.4	1,098.2
Scientists	211.2	302.9	337.1	381.5	417.9	462.6	496.5
Chemists	73.9	99.7	106.8	115.0	119.6	127.3	132.9
Mathematicians	21.1	34.2	39.8	47.2	53.9	67.1	74.3
Physicists	19.9	29.8	33.9	39.0	42.1	46.2	49.1
Other physical scientists	34.5	42.5	45.3	49.7	55.3	62.6	66.8
Agricultural scientists	22.2	30.4	35.3	41.5	46.9	47.2	49.3
Biological scientists	27.3	44.8	49.0	54.4	56.9	65.8	71.1
Medical scientists	12.3	21.5	27.2	34.6	43.2	46.4	53.0
Research and development							
Total	248.8	386.4	441.9	497.9	525.8	552.8	535.4
Engineers	156.0	248.5	284.4	321.6	339.4	359.2	341.6
Scientists	92.9	137.9	157.4	176.1	186.4	193.7	193.8

¹ Excludes social scientists.

² As of January.

Source: Bureau of Labor Statistics.

Table 40 EMPLOYMENT OF SCIENTISTS AND ENGINEERS IN THE FEDERAL GOVERNMENT, BY OCCUPATIONAL GROUP, AND SELECTED AGENCY, OCTOBER 1972
(Thousands)

Occupational group	Total	Defense	Agriculture	Interior	NASA	Commerce	HEW	Transportation	Environmental Protection Agency	VA	All other
All scientists and engineers	168.7	75.2	25.8	14.1	12.5	7.6	6.3	6.3	3.6	3.8	13.6
Scientific personnel ^a	79.7	21.1	22.5	9.5	2.3	6.8	5.5	.6	2.0	2.7	6.7
Physical science	27.4	11.0	1.7	3.6	1.4	4.2	1.9	.2	1.2	.7	1.5
Mathematics and statistics	9.7	5.2	.6	.1	.6	1.2	.7	.2	.1	.1	.7
Biological sciences	29.2	1.2	19.0	5.1	.1	.6	1.7	(b)	.6	.5	.6
Social sciences	7.5	.7	1.1	.3	(b)	.6	.8	.1	.1	.2	3.6
Geography and cartography	3.0	2.3	.1	.4	(b)	.2	(b)	(b)	(b)	-	(b)
Psychology	2.5	.8	(b)	(b)	(b)	(b)	.3	(b)	(b)	1.2	.1
Engineering personnel	87.0	54.1	3.3	4.6	10.2	.8	.8	4.7	1.6	.6	6.2
Electrical and electronic	23.5	16.9	.2	.9	2.1	.4	.1	1.4	(b)	.1	1.4
Mechanical	23.1	15.2	.1	.2	5.2	.1	.1	.5	.1	.1	1.5
Civil	17.3	8.4	2.2	2.1	(b)	.1	.3	2.1	1.0	.1	1.1
All other	23.2	13.7	.8	1.5	2.9	.2	.3	.7	.5	.4	2.3

^aIncludes several hundred personnel in Urban Planning, not shown separately.

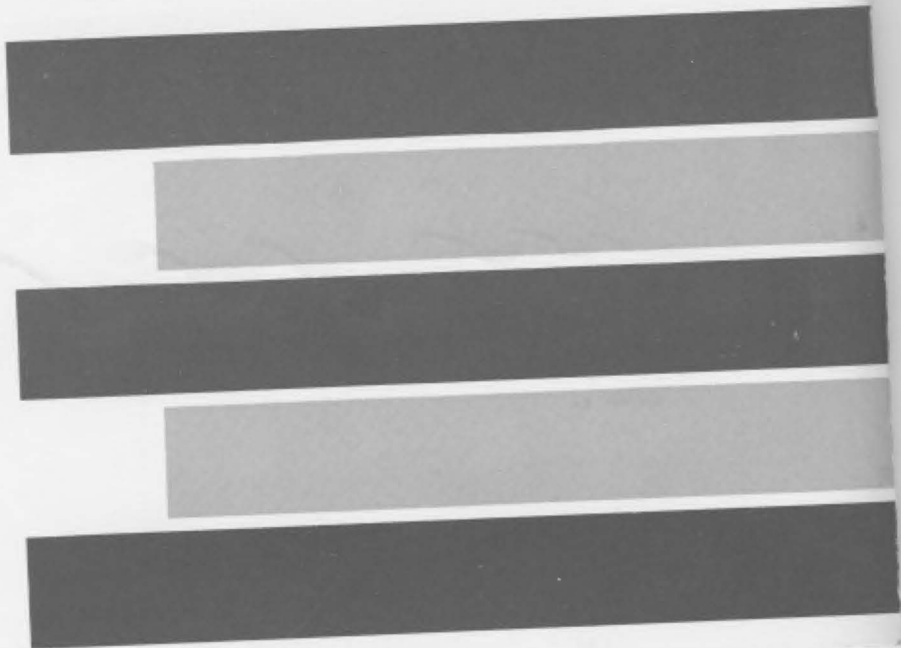
^bLess than 50 personnel.

Source: Civil Service Commission and NSF.

Table 41 SCIENTISTS, ENGINEERS, AND PHYSICIANS ADMITTED TO THE UNITED STATES AS
IMMIGRANTS, FISCAL YEARS 1963-73

Fiscal year	Scientists and engineers				Physicians and surgeons
	Total	Engineers	Natural scientists	Social scientists	
1963	5,933	4,014	1,688	231	2,093
1964	5,762	3,725	1,754	283	2,249
1965	5,345	3,446	1,597	302	2,012
1966	7,205	4,915	1,949	341	2,549
1967	12,523	8,821	3,158	544	3,325
1968	12,973	9,313	3,110	550	3,060
1969	10,255	7,150	2,601	504	2,756
1970	13,337	9,305	3,264	768	3,155
1971	13,102	9,015	3,456	631	5,748
1972	11,323	7,436	3,271	616	7,143
1973	6,632	4,443	1,790	399	7,119

Source: Immigration and Naturalization Service.



THE WHITE HOUSE
WASHINGTON

11/8

Phyllis:

Please send a copy of the
Attached to Russ Drown and
file a copy.

did 11/9
[signature]

NOV. 6, 1973

Dear Mr. Nixon:

I want to thank you for your recent letter to the President concerning the reorganization of the Federal Government and the means for assuring that the Government receives the best scientific and technological information and advice. I certainly agree that we do need to have the full contribution of the scientific community in arriving at decisions where there is a significant scientific or technological dimension.

The key question is what the best mechanism is for gaining such information and advice. We have, in the past, looked at the kinds of organizational steps outlined in your resolution, including a Department of Science and Technology and a Council of Science and Technology. For a number of reasons, we are convinced that such steps would not be meaningful. For example, a Department of Science and Technology would tend to isolate R&D from close association with the mission agencies that science and technology are supposed to aid.

My belief is that it is better to move in the direction of strengthening the R&D capability of the mission agencies or to create new agencies with a strong R&D component in response to specific national problems. This latter approach is best illustrated by the Administration's proposal to create an Energy R&D Administration, as a move to bring together the necessary strong scientific and technological base for the solution of long-term energy problems.

There has been a strong reaction to the abolition of the Office of Science and Technology. Our belief is that the Director of the National Science Foundation can be more effective than the Director of the Office of Science and Technology in the role of Science Advisor. The Foundation now has expertise in many areas of science and technology beyond basic research. Moreover, it has strong ties through



its staff and the National Science Board to a widening community of scientists and engineers, not only in universities but also in other nonprofit organizations and in industry.

Since the adoption of Reorganization Plan #1, significant steps have already been taken by Dr. Stever that indicate he will be an effective voice in Government circles.

Dr. Stever, both directly and through his Office of Energy R&D Policy, is heavily involved in efforts to develop a long-term R&D strategy to deal with our energy problems. Outside of the energy area, through his Science and Technology Policy Office, Dr. Stever is becoming heavily involved in a wide range of policy issues with a scientific or technological dimension. I would encourage you and the Committee of Scientific Society Presidents to work with Dr. Stever to help him strengthen his contacts with all segments of the scientific and technological community.

Finally, in relation to the issue of the concerns of this Administration for science and its progress in the national interest, I cite the recent award of the National Medal of Science and the remarks of the President as a visible indication of the continuing concern of this Administration for the advancement of science in the national interest.

In summary, while we cannot support the specific actions advocated in this resolution, we are in agreement with the spirit of this resolution and the concerns that underlie its adoption.

Thank you again for your interest in this important matter.

Sincerely yours,

(Signed) George P. Shultz

George P. Shultz
Assistant to the President

Mr. Alan C. Nixon
President, American
Chemical Society
2140 Shattuck Avenue
Berkeley, California 94704

CEP:KWDam:grd:10-30-73 ferom OMB HPLoweth draft 10-24-73





American Chemical Society

OFFICE OF THE
PRESIDENT

Room 511, Wells-Fargo Building
2140 Shattuck Avenue
Berkeley, California 94704
Phone (415) 848-0513

Alan C. Nixon, *President*

October 12, 1973

President Richard M. Nixon
The White House
Washington, D.C.

Dear Mr. President:

Earlier this year the presidents of the major scientific societies in the country decided to form a committee to coordinate activities, exchange information, and make recommendations on scientific matters of particular public interest and importance.

At the initial meeting great concern was expressed about the way science and technology was handled within the government. The view was advanced that the country had no coherent policy for science and technology and had no consistent on-going mechanism to plan and implement policy decisions made in this sphere.

Accordingly, we scheduled further debate for our second meeting which occurred on October 6. Although we did not come up with a nice compact statement on what the national policy on science and technology should be, we did agree that the scientific community should be given a stronger voice in the decision making process regarding such policy.

This decision was embodied in the following motion which was passed unanimously:

Preamble

Major problems facing the people of the United States increasingly require the effective utilization of science and technology. It is essential that all levels of government have a continuing source of scientific and technical information and advice. For example, the energy crisis, food supply, and preservation of environmental quality, require scientific and technical solutions. The resolution of these problems demands the integrated action of the various subdivisions of science now partially represented in various departments, and day-to-day contact with Congress and the White House.

Resolution

Be it resolved, that in order that the government be provided with the best scientific and technological information and direction, the Committee of Scientific Society Presidents urges a step such as creation of a Department of Science and Technology, the establishment of a Council of Science and Technology in the White House, or the elevation of the position of the Science Advisor to cabinet rank.



October 12, 1973

The rationale for such a statement can be understood by considering the present energy problem. Clear and timely advice was tendered to the government on numerous occasions by scientific bodies and experts within the technical community. There was no mystery about what was going to happen. What was lacking was a mechanism within the government apparatus to ensure that programs would be initiated and directed so that steps could be taken to avoid the present crisis.

I want to emphasize that in adopting this point of view, we are not attacking your Administration or this Congress. In fact, we are not attacking any administration or any congress. We are simply pointing out that the time has come to adjust our administrative apparatus and procedures to the realities of our increasingly technological world. Any of the three alternatives would ensure a stronger focus for science and technology within the government with a consequent greater probability that the correct decisions would be made.

Yours sincerely,



Alan C. Nixon
President

ACN:ev

Chairman, Committee of Scientific
Society Presidents

cc: Dr. H. Guyford Stever

CEP#10-14



NATIONAL SCIENCE FOUNDATION *note jlb*
WASHINGTON, D.C. 20550



SCIENCE AND TECHNOLOGY
POLICY OFFICE

April 17, 1974

MEMORANDUM

TO : Mr. Norman E. Ross, Jr.
Domestic Council

FROM : Mr. A. Wade Blackman *awb*
Science and Technology Policy Office (STPO)

SUBJECT : Unsolicited proposal entitled
"A Methodological Framework for Assessing
Non-Renewable Resource Policy Issues:
General Development and Application to Copper"

The subject unsolicited proposal has been received from Pugh-Roberts Associates. It is proposed to develop a system dynamic model which would form the methodological framework for the evaluation of policy options relating to the non-renewable resources issues.

As STPO is considering the sponsorship of this work, I would like to elicit your review and comments on this proposal. I would greatly appreciate receiving your comments on the enclosed form by April 22, 1974.

Thank you for your help.

send note - (form saying the proposal from a final review seemed acceptable, when time permits will go into it more thoroughly & let him know your cats.

Enclosures

called 4/23 to let Blackman know we'd respond 4/24



PUGH-ROBERTS ASSOCIATES, INC.

BLACKMAN

REC'D.

APRIL 16, 1973

Unsolicited Research Proposal Submitted to the
National Science Foundation
Office of Science and Technology Policy

by

Pugh-Roberts Associates, Inc.
Five Lee Street
Cambridge, Massachusetts 02139

"A Methodological Framework for Assessing
Non-Renewable Resource Policy Issues:
General Development and Application to Copper"

Proposed
Starting Date 1 June, 1974

Proposed
Duration 12 months

Principal Investigator (correspondent)

Name William R. Killingsworth, Ph.D.

Title Consultant

Social Security No. 423-58-2086

Endorsements:

Principal Investigator

Institutional Admin. Official

William R. Killingsworth, Ph.D.

Edward B. Roberts, Ph.D.

Name

William R. Killingsworth

Edward B. Roberts

Signature

Consultant

President

Title

617/864-8880 (Pugh-Roberts Assoc., Inc.) 617/864-8880 (Pugh-Roberts Assoc., Inc.)
617/646-2019 (home) 617/527-2704 (home)
Telephone Number

FIVE LEE STREET

Date

CAMBRIDGE, MASSACHUSETTS 02139

617-864-8880



ABSTRACT

The objective of the proposed effort is the development of a methodological framework for generating and evaluating strategic policy alternatives in the area of non-renewable natural resources. This is to be accomplished by the parallel development of a generic systems dynamics model of international resource utilization and a specific systems dynamics model of the international supply and consumption of copper. Development of the general framework will be guided and tested by the development of the specific copper model. The models incorporate exploration, recovery, refining, and production, and the energy flows and environmental impact associated with the technologies of each stage. An international market sector is included that models the dynamics of international interaction between demand, supply, price, political factors and government controls. The output of this effort will be a methodological framework adaptable for use in generating and evaluating strategic alternatives for specific non-renewable natural resources. Policy evaluation may be based on policy impact regarding resource price, energy requirements, environment impact, or international considerations. A second major output will be a dynamic simulation model of the international copper production and utilization system. The model will provide specific policy analysis simulations and insights into non-renewable resource issues.



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I. INTRODUCTION: PROBLEM DESCRIPTION

The energy crisis has dramatically raised two severe problems to the attention of federal policy-makers and U.S. citizens:

There exists a significant dependence on other countries for non-renewable natural resources, and

There is an on-going and increasingly rapid depletion of non-renewable natural resources.

In this light, the current energy difficulties reflect a serious generic resource problem that the United States will face in future years.

Because of the long lead time in exercising policy aimed at this problem, for example developing new technology or increasing domestic capacity, alternate policy consideration, analysis, and evaluation must begin now. Pugh-Roberts Associates proposes to develop a methodological framework that will allow such policy development to proceed in a systematic manner.

The United States is the world's largest consumer of energy, aluminum, coal, copper, and other natural resources. However, domestic production has generally not kept pace with this demand. As a result, the U.S. became an importer and increasingly vulnerable to international factors such as market conditions and the policies of exporting countries. The oil embargo and subsequent raising of prices imposed by the Middle East oil producing countries clearly brought this dependence to light. The embargo and output restrictions arose because of several reasons -- political, concern over the rate of reserve depletion, and an inability to absorb the tremendous oil production revenues into the producing, largely underdeveloped nations (1). As a result of these issues, energy and oil dependency has become deeply enmeshed in some very real conflicts



of economic and political interests between the industrialized importers and the underdeveloped exporting countries.

However, as recently pointed out to Congress by Senators Nelson and Ribicoff (2), the energy or oil crisis is only symptomatic of a much broader and potentially much more serious phenomenon encompassing a series of approaching crises involving many non-renewable resources vital to all nations. For example, the U.S. is moderately to heavily dependent on foreign sources for minerals such as aluminum and bauxite, chromium, zinc and copper. There exists the very real possibility that a handful of raw-material exporting countries (for example, the four that control seventy per cent of the world's supply of copper) could bind together in an Arab-oil-producers OPEC-type agreement to dramatically raise prices or even withhold resources from the rest of the world. In fact, "third world" nations have already led to a current special meeting of the United Nations General Assembly to discuss the world distribution and price of raw-materials (3). Widespread resource "ransom" could obviously seriously disrupt the U.S. economic system.

Compounding these difficulties between the industrialized importing countries and the underdeveloped exporting nations is the increasingly rapid utilization and depletion of non-renewable resources; both domestic and foreign. For example, at its present rate, cumulative U.S. consumption of iron ore in the next 41 years would equal the total previous consumption throughout our history. For aluminum, it would be only 14 years at the 1971 rate to equal our total previous consumption (4). In another light, if the copper usage rate remained constant (an unlikely assumption in a growth oriented economy), the known global resources would be depleted in thirty-six years (5).

The continual depletion of domestic sources will most likely necessitate increasing use of lower-grade source materials, rising prices, and probably dependence on foreign sources. The impact on domestic costs and investments of energy and pollution issues might well hasten the shift toward the utilization and depletion of foreign sources. To a certain extent this has been occurring. However, before foreign resources are largely depleted by industrialized nations, it is likely that political and economic issues will arise, such as nationalization of mines in the underdeveloped nations.

Thus there are two broad issues related to the problem of non-renewable resources: i) the dependency of the United States on foreign sources, and ii) the increasingly rapid depletion of raw-material sources. The implications of these problems are critical to the economy of the United States, the general level of world tension and international relations.

However, those broad policies suggested for dealing with these difficulties (for example, substituting other materials, expanding domestic production, increased recycling, improved product design, etc.) are not fully understood, their impact somewhat uncertain, and the means for evaluation unclear. Equally important, those system, technological, environmental and energy aspects that may prevent implementation of policy have not been systematically identified and assessed. In the following sections, Pugh-Roberts Associates, Inc. proposes to develop a methodological framework for policy generation, analysis, and evaluation in the area of non-renewable natural resources.

Our approach to the proposed study is detailed in the following sections. Section II introduces a general systems approach to non-renewable resource issues, discusses methodological considerations, and presents the detailed study plan. Section III presents project schedule and milestones,

Section IV presents project management and organization, and finally, Section V presents personal resumes and the qualifications and related experience of Pugh-Roberts Associates.

The financial proposal for achieving this methodological framework, including its illustrated application to the copper situation, is appended as a separate document.



II. METHODOLOGICAL CONSIDERATIONS AND THE PROJECT STUDY PLAN

In this section, the many factors and interrelationships involved in the international production and consumption system of non-renewable resources are discussed, an analytical technique appropriate for complex systems analysis and policy generation and evaluation is indicated, and a detailed study plan for the proposed effort is presented.

2.1 A SYSTEMS PERSPECTIVE OF NON-RENEWABLE RESOURCE ISSUES

As indicated in the Introduction, the United States faces serious difficulties regarding non-renewable natural resources. The National Science Foundation can provide valuable information to decision-makers by more fully assessing the current and potential roles of science and technology regarding the management of non-renewable resources, by assisting in the recognition of the many consequences of alternate policies, and by aiding in the understanding of those system aspects preventing policy implementation. However, this is an extremely difficult task because of the great complexity of the non-renewable resource utilization and production system.

This complexity takes two forms. First is static or structural complexity, that is, the sheer number of physical, social and economic factors which are involved. Second is dynamic or behavioral complexity, i.e., the many ways in which these numerous factors can interact with one another over time to produce the various possible modes of behavior exhibited by the system, for example, growth, stagnation, decay, or short-term instability. To illustrate these types of complexity, a specific issue regarding reduction of resource consumption will be briefly examined.

As a particular resource becomes either very expensive or unavailable, some consumers will consider substituting another resource for the one they have been using. The factors affecting their decision to substitute are many, for example: the domestic price of resource, the foreign price of the resource, the feasibility of substitution, the cost of necessary re-tooling, the price of the substitute, the environmental impact of the substitution, energy considerations, user acceptance of and confidence in the substitution, etc. Anticipating the level of substitution and the consequent reduction in demand for the resource is a very difficult task because of the interaction of the many factors. However, even if some of these factors are rather compelling, complex dynamic behavior of the substitution phenomena can result in unexpected behavior, for example, slow rates of substitution with perhaps low levels of substitution achieved. As pointed out above, the rate of substitution is influenced by user acceptance of and confidence in the substitution. By this we mean that user acceptance is generally a "bandwagon" type effect that builds up as more and more users successfully substitute. However, with the level of substitution low as in the beginning of the process, the acceptance and confidence tends to be low, inhibiting risk-taking and substitution. This loop is illustrated in Figure 2.1 and is intimately related to the diffusion of technology and a gradual learning phenomenon. Pugh-Roberts Associates has successfully approached this type of problem dealing with the diffusion of innovation and new technology via a systems framework (6).

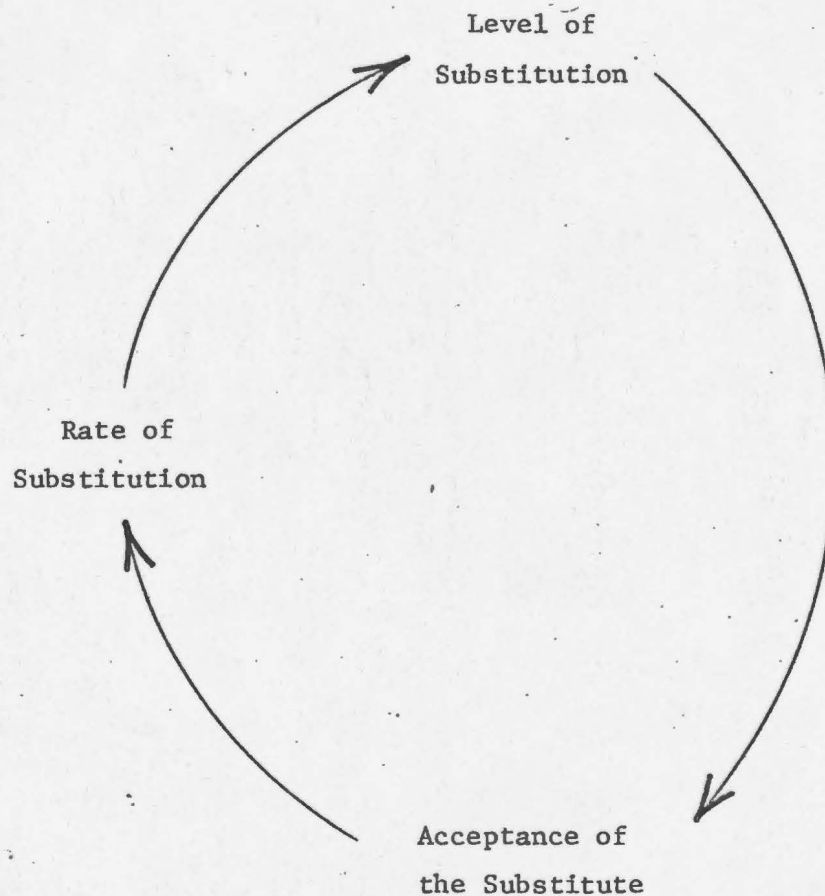


Figure 2.1

Another feedback loop comes into play as the rate of substitution leads to increasing levels of substitution. This substitution creates higher levels of demand for the substitute but correspondingly reduces the demand for the resource under consideration.



This reduced demand on the commodity market then leads to reduced price for the resource and, hence, less motivation for substitution. In addition as demand for the substitute goes up, the price also tends to increase, again lessening the motivation for substitution. These loops are illustrated in Figure 2.2.

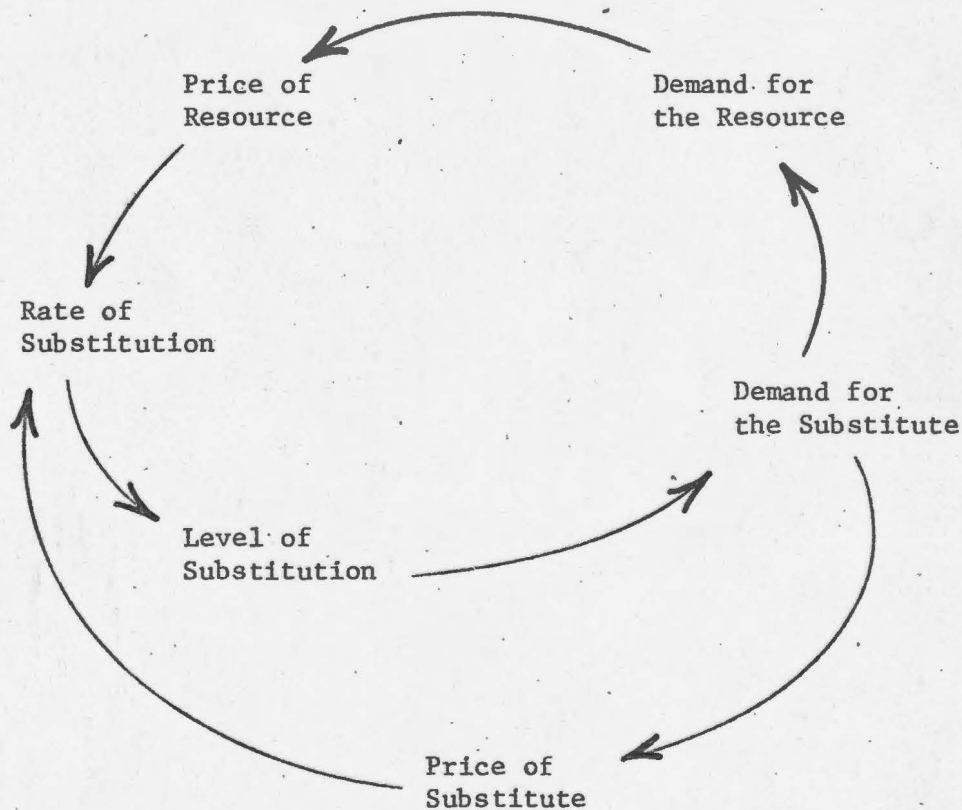


Figure 2.2

The combination of the price dynamics and the gradual, slow winning of acceptance illustrates the complex behavior possible, even for a simple sector of the model.

The overall non-renewable resource utilization and production system is a complex structure involving generally both a domestic commodity market, a foreign commodity market, and a linkage between the two markets created by U.S. import demands. On these markets, price of the resource is a primary determinant of demand, although other factors such as price of substitutes, recycling, and measures of industrial activity also enter into demand determination. In addition to influencing demand for the resource, price over time gradually influences the production of the resource and the construction of additional capacity. On the other hand, price is largely established by the level of inventory coverage which is fed by production and diminished by consumption, thus forming loops of interactions over time. The behavior of the system, the interaction of demand and supply, and the impact of policy are difficult to intuit because of the complex dynamic interactions and the influence of many factors. Policy generation and evaluation for non-renewable resources requires a methodology appropriate for such complexity.

2.2 SYSTEMS DYNAMICS AS AN ANALYTIC TECHNIQUE

Considerable work has been done on the development of conceptual and analytical tools that facilitate comprehensive examination of complex systems, discovery of leverage points, and assessment of policy impact. One such approach, systems dynamics, has been used successfully to study other complex, counter-intuitive socio-economic phenomena such as regional economic development (7), urban decay (8), technology generation and transfer (9), and physical pollution phenomena (10). However, the following applications of systems dynamics are of particular importance and relevance: the copper industry dynamics work of Ballmer (11) and Schlager (12);

Baughman's (13) inter-fuel competition model; Meadow's effort regarding the dynamics of growth (14); and an on-going Dartmouth effort (15) analyzing the dynamics of coal utilization. It is felt that this systems dynamics approach is directly applicable to the non-renewable resource utilization and production system.

Systems dynamics is the application of a feedback systems approach to business, social, and economic problems. The basic analytical techniques were first conceived within the engineering disciplines. They were required to design complex feedback control systems for aircraft, industrial and chemical processes. It was later realized that these techniques could be applied to the study of socio-economic systems whose behavior is controlled by the feedback nature of their intrinsic structure (16).

In implementing this concept, the original engineering approach was modified to place more emphasis on analysis through simulation and less on calculating mathematical solutions. The result of this effort was a methodology that analyzes the behavior of complex systems through the development of structure-dominated causal models, feedback systems analyses, and computer simulation.

Pugh-Roberts Associates believes that systems analysis, and particularly systems dynamics, is especially well-suited as a framework for a study of non-renewable resources because:

1. As discussed and illustrated in the preceeding section, many of the factors that determine policy impact and system behavior form a closed-loop feedback-type system of interrelationships.
2. With systems dynamics, it is possible to model qualitative behavioral relations such as attitudes, resistance to change, and incentives. These behavioral factors are key to all social systems, but they cannot be tested analytically by most methodologies.

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3. Systems dynamics provides a powerful vehicle for testing behavioral sensitivity to variations in assumed relationships. Thus, it focuses data-gathering and statistical analysis on those areas of the system formulation that must be specified with precision.
4. A powerful, easy-to-use systems dynamics simulation language permits models to be manipulated on-line in an interrogative "what-if" model.

For these reasons, application of systems dynamics to non-renewable resource issues holds great promise for policy generation and evaluation.

2.3 THE STUDY PLAN

In this section a detailed plan of the proposed study is presented. This plan outlines the sequence of steps involved in the development of a methodological framework for policy generation and evaluation in the area of non-renewable resources. This methodological framework will be in the form of a generic model that may be adapted and made specific for a non-renewable resource of interest. To aid in the development of the broad framework, Pugh-Roberts Associates proposes to develop a systems dynamics model of the copper production and utilization system. Although for a specific resource, this model will provide guidance and input to the development of the generalized framework. Thus, in a very real sense, the development of the methodological framework and the development of the copper model will proceed in a parallel fashion.

Copper was chosen as the first case for a variety of reasons. Approximately seventy per cent of the world's supply of copper is

controlled by the relatively underdeveloped, unstable countries of Chile, Zambia, Zaire, and Peru. Nationalization of mines is largely completed in these countries (17). As a result, pressures exist on domestic and other foreign sources of copper. However, land conservation measures and pollution standards have seriously impacted domestic production and expansion (18). Lower-grade ores are continually being turned to. Rising copper prices have created extreme interest in substituting aluminum for copper in some applications, for example, even the U.S. penny. Because of these many issues, copper seems to present an unusually rich opportunity to consider many aspects of the non-renewable resource problem and to provide broad inputs to the development of the general methodological framework. The stages of the proposed effort are presented in the following sub-sections.

2.3.1 Model Conceptualization: Stage I

The first stage of the proposed effort will be the development of a qualitative, conceptual model. This "model" will be an integrated description of system parameters, exogenous forces, and the cause-effect relationships which generate the behavior of the system as a whole. Qualitative models are constructed from verbal, written, or mathematical descriptions (for example, econometric relationships) and need no precise quantitative links between variables, since they represent relationships verbally. This type of model has two important contributions. First, it can indicate in a general fashion the various modes of behavior that may be expected of

a system. Second, it can form the basis for mathematical, quantitative models that are able to more accurately project the behavior of the system.

The literature review will address both the methodological literature and the problem-specific literature. The methodological literature will address those efforts considering systems analysis of resource issues and will permit us to take advantage of and build upon the work of others. For example, Baughman (19) has modeled inter-fuel competition and investigated the decision process in the substitution of one fuel for another. In this effort, the economic cost structure, investment decisions, and physical constraints are included specifically in the supply models for coal, oil, natural gas, and nuclear fuels. The model simulates the development of supply, the fuel selection process in the consuming sectors, the depletion of the resources, and resolves these into fuels consumed cost-price trends. The methodology of Baughman's treatment will provide a useful input into the proposed effort. Similarly, the work of Naill (20) and others at Dartmouth regarding the dynamics of coal utilization are applicable as methodological guidelines. The segment of this effort by Choucri (20a) dealing with the dynamics of international politics is of particular interest. A final example of a relevant methodological effort is the work of Meadows (21) in which the depletion of resource reserves is studied as a function of industrial and world growth.

Problem-specific literature will aid us to understand the issues of the copper system more completely. Two early works

by Ballmer (22) and Schlager (23) are of particular interest. Ballmer developed an industrial dynamics model investigating the fluctuations in the copper market. Schlager built upon this work and introduced the nature of multifirm competition and its impact on market instability. Schlager also developed a model of the aluminum industry so that comparison might be made. These efforts provide extremely useful information regarding the production of refined copper and pricing policies. Both of these models only considered the domestic industry. However, Fisher (24) has developed an econometrics model of the world copper industry that considers the domestic market and that of the London Metal Exchange. In this effort, supply and demand equations are estimated and predictive simulations are performed. This effort has been built upon by the work of McNicol (25). More general information is available from a variety of sources such as corporate annual reports, business journals, and publications of investment analysts.

In addition to a literature review, interviews are considered a critical source of inside insight and information. For example, Dr. Roberts has met with Mr. Frank R. Milliken, President of Kennecott Copper Corporation, who has assured us of his and his staff's cooperation in this effort. Mr. Ballmer, mentioned previously as an early modeler of the copper industry, is now the General Manager of the world's single largest copper mine. Pugh-Roberts personnel are well acquainted with Mr. Ballmer and will attempt to gain his assistance. These types of interviews will provide valuable contributions to the development of a rich and valid conceptual model.

To make more explicit the output of Stage I in the proposed effort, the following pages present a preliminary qualitative model for parts of the copper system. The following descriptions and diagrams are not all-inclusive; they were developed in the course of preparing the proposal and are provided to indicate the types of causal loops and relations that will be identified in the literature review and interviews. However, they will provide a valuable starting point for the proposed effort.

Copper refiners may be considered the link between copper producers (mine, concentrator, and smelter) and copper consumers (26). As such, the copper refiner significantly affects the operation of the industry through actions in

- a. production policy
- b. pricing policy.

The production policy of refiners generally reflects the commodity point of view, i.e., that there is a market that will be capable of absorbing all the copper produced. In this mode of operation, little inventory of raw-material is maintained and the market serves as a clearinghouse for the exchange of the total supply on the market. The pricing policy is not as clear. In the copper industry, the pricing policy has been used in the past to regulate the outflow of refined copper from the finished goods inventory. The inventory coverage, that is, the months of supply calculated by dividing inventory by the demand rate, has been noted as a primary input to the price-changing process (27). Thus, for example, with any increase in inventory coverage

displaying itself, prices will tend to be reduced. However, other factors also influence the pricing policy with governmental regulations and controls being perhaps most important. Other inputs to the pricing are production costs and speculation regarding the expected future availability of the resource.

The price determined by the interaction of these factors then propagates to influence both the demand for the refined copper, and over time, the production desired at the mine. Changes in mine production generally respond to the historical, or time average, price of copper rather than an instantaneous current price. This filters out rapid fluctuations in copper price but permits response to longer-term trends. The changes in production then feed into the domestic inventories and influence the inventory coverage. This closes a basic feedback loop that is illustrated in Figure 2.3.

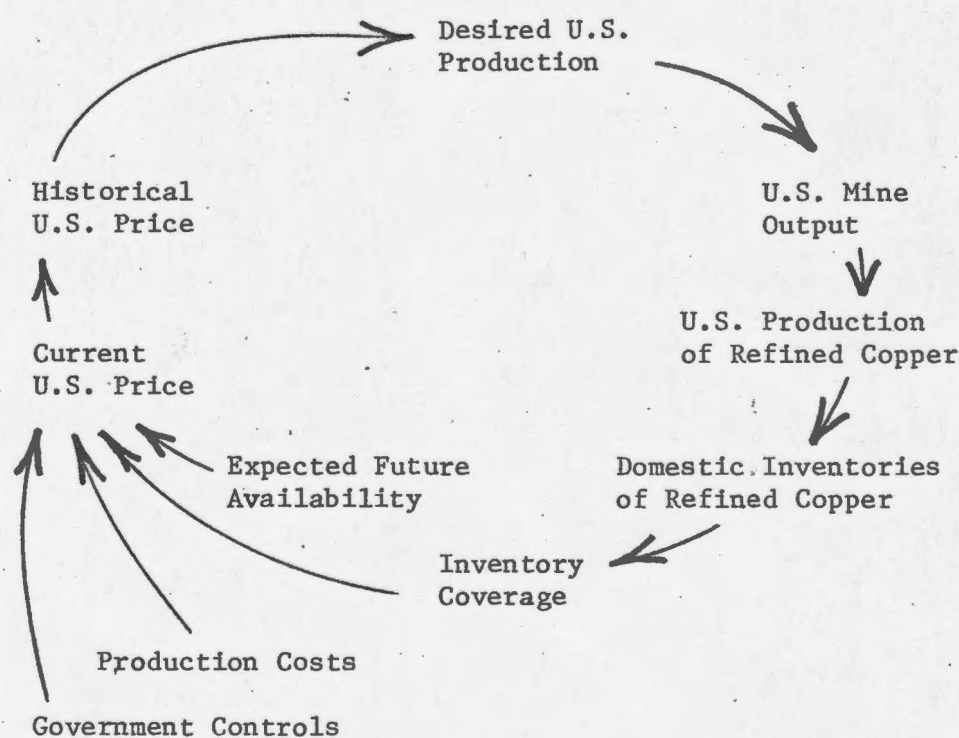


Figure 2.3

As indicated, the current and the historical price also propagates to affect the U.S. demand for copper. This domestic demand is also influenced by the historical world price since some consumers rely on imports (28). The fraction of U.S. demand that is satisfied from U.S. production is determined by the U.S. demand for copper, the U.S. production, the U.S. price, the world price, and, critically, the availability of foreign copper. This demand or consumption of copper depletes the U.S. inventories and tends to reduce inventory coverage. Thus another basic feedback loop is identified for the model structure. This loop is illustrated in Figure 2.4.

If domestic inventories are such that domestic demand cannot be met, some U.S. customers will import, or attempt to import, foreign copper. This copper is frequently purchased through the London Metal Exchange. This exchange generally operates as a free market in which the level of foreign inventory coverage is a primary determinant to the LME price of copper. This price then influences both the foreign demand for foreign copper and the U.S. demand for foreign copper. This total demand over time then gradually affects the foreign mining and production of copper. This loop is illustrated in Figure 2.5 and is very similar to the loop shown for the U.S. in Figure 2.3.

A critical aspect of the linkage between the U.S. market and the world market is the ability of the U.S. to satisfy its needs from imports. If the U.S. is unable to obtain the

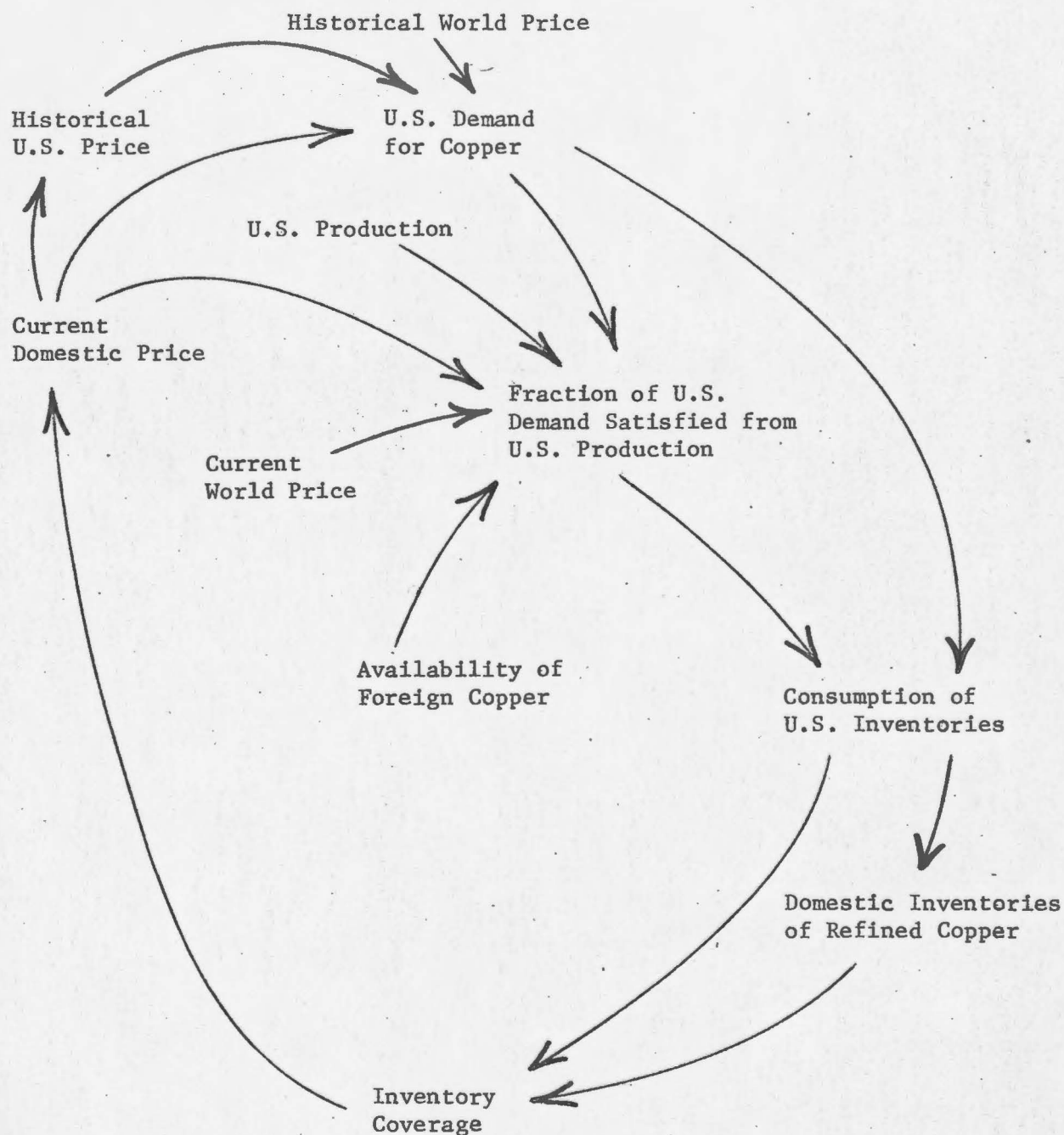


Figure 2.4

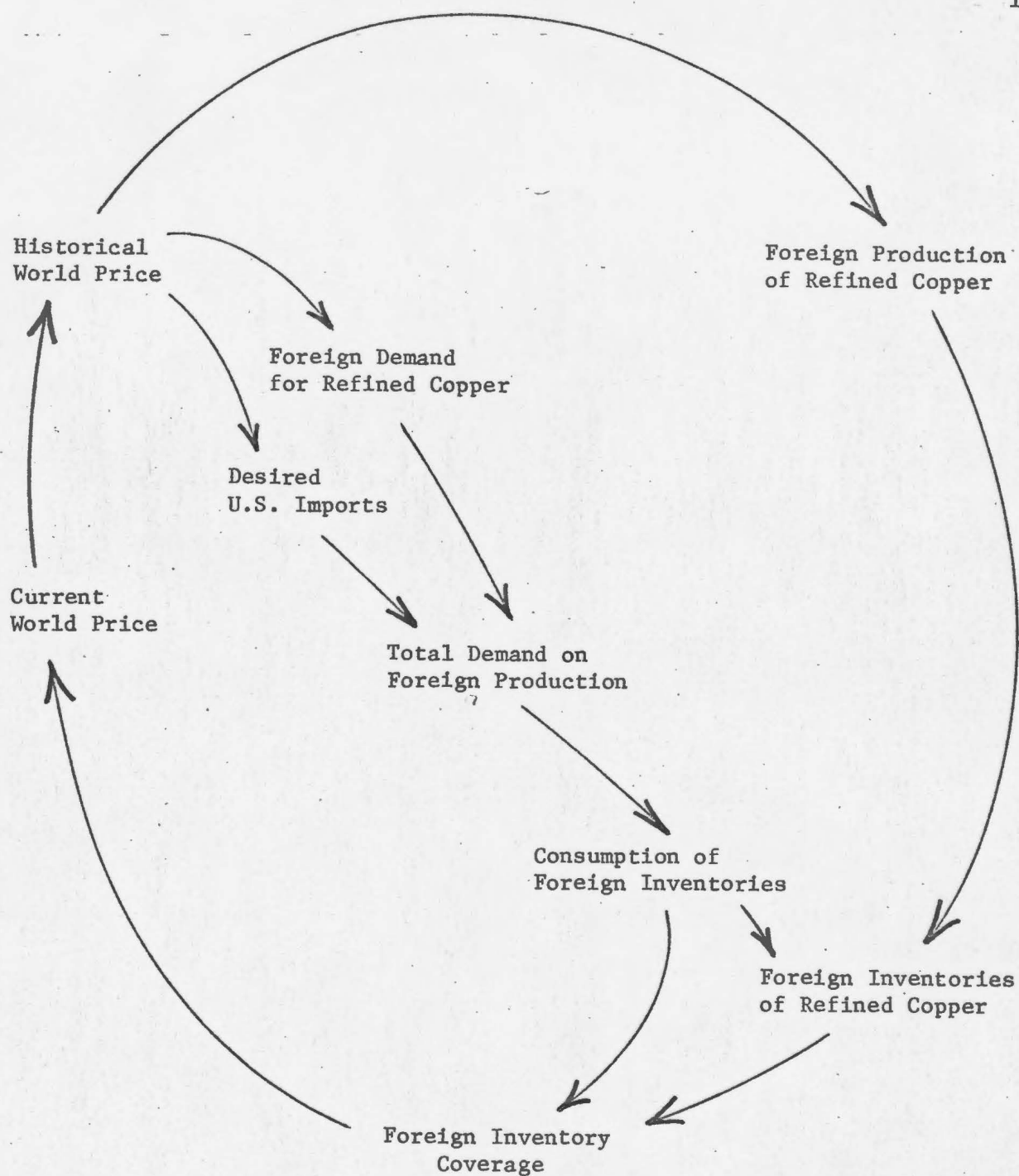


Figure 2.5



desired imports, motivations are created for means, generally domestic, to satisfy this demand, for example: investment in recovery technology, investment in exploration in the U.S.; and investment in demand-reducing technology (substitution, recycling). In addition, the inability to satisfy needs would likely tend to force domestic prices upward. The ability of the U.S. to satisfy its needs from imports is primarily determined by the current availability of foreign copper and the level of desired U.S. imports. As recently demonstrated in the oil crisis, the availability of foreign resources can be substantially reduced by political factors that accord extremely low priority to the U.S. demand that is established to a large extent by the prices on the world market. This interrelationship and feedback loop is illustrated in Figure 2.6.



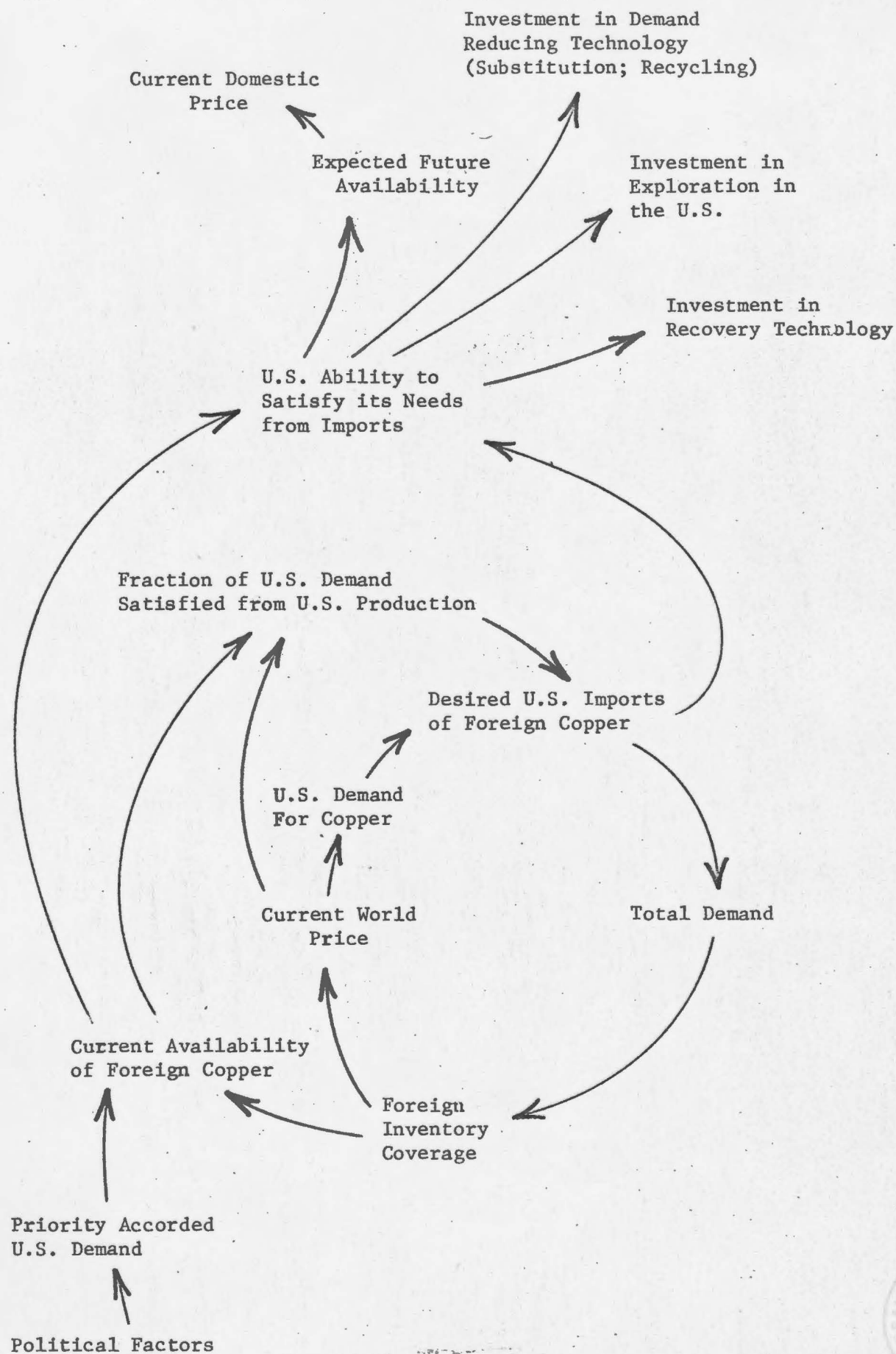


Figure 2.6

An additional preliminary causal diagram linking the profits of U.S. producers and the ability of the U.S. to obtain desired inputs to investment in domestic expansion of reserves and production is shown in Figure 2.7.

The qualitative models that will form the output of Stage I will thus take the form of annotated cause-effect flow diagrams and accompanying text. The diagrams will be similar to those presented above but will be far more detailed. They will depict all of the important effect-producing feedback loops and elements in each chain of cause and effect. They will indicate exogenous factors and identify the discrete points at which they enter the system. The entry points of various technologies, specifically substitution, pollution control, energy, and recovery, will be carefully indicated in the model. Because of the increasing importance of energy and pollution, specific techniques of mining, refining, and production will be characterized by energy demands and environmental impact. For example, environmental issues are strongly affecting domestic copper production (29). Some smelters have had to reduce capacity in order to conform to pollution control standards, especially sulfur dioxide. This characterization will be done for both the primary resource of interest and potential substitutes. For example, the increasing use of aluminum as a substitute for copper may be increasingly inhibited because of its nature as a very energy-intensive process (30). Recycling techniques will be similarly characterized (31). The model will thus indicate the interactions of price, energy usage,

and environmental impact on the production, recycling, and substitution of a resource. Demand will be carefully delineated to indicate that portion substitutable with today's technology. Radcliffe (32) presents data detailing the flow of copper (both domestic and foreign) to the various consuming sections, i.e., electrical equipment and supplies, construction, industrial machinery except electrical, transportation, ordnance, and miscellaneous. The substitutable portion will be identified by interviews and literature review. Specific technologies that could increase the substitutable portion will be identified. The model will be structured so as to permit the dynamic assessment on the overall system of such changes in levels of substitution arising from competitive, environmental, or international reasons. The accompanying text of the qualitative model will explain each causal relationship, citing supporting data and other evidences of connection. It will also discuss the implications of the overall structure of relationships represented by the model for the behavior of the real-world system.

2.3.2 Model Development: Stage II

The qualitative model of Stage I is an essential first step in the development of a methodological framework. The second step is the further development of these models into quantified mathematical models capable of more accurate analysis and projections. This step is described in this section.

First, the model will be programmed in the DYNAMO computer simulation language (33). DYNAMO is a powerful,



easy-to-use simulation package that permits models to be manipulated on-line in an interrogative "what-if?" mode. DYNAMO was specifically designed for simulation of dynamic feedback systems. It represents such systems as a set of difference equations that closely approximate the actual differential equations, the difference equations being more suited to digital computers and more easily understood. Because of its syntactical simplicity, generous use of macro functions, and extensive built-in error checking, it greatly accelerates the process of model implementation. The DYNAMO language was developed by Mr. A. L. Pugh of Pugh-Roberts Associates. He will provide valuable assistance in the development and implementation of an efficiently programmed and structured model.

Information from the literature review, interviews, and data sources such as the Copper Development Association (34) will be used to quantify the model. This will be, in a sense, a "rough" quantification of the model that will be used for "debugging" and for preliminary analysis. A critical part of this analysis will be sensitivity testing. Parameters, exogenous factors, and inputs will be varied systematically to determine relationships where a relatively small change in a variable produces a large change in model behavior. This will illustrate both the sensitivity of projections to the assumptions underlying them, and the relationships in the model that should be defined with greater accuracy. The latter will serve as an important basis for recommending further data collection and research. Statistical techniques may well be

required for accurate definition of some model relationships and parameters. A variety of such techniques exist. For example, in some instances, the literature or interviews will suggest a general causal relationship between several factors, but it will not be clear exactly how they interrelate. In cases where regression techniques do not show any statistically significant direct relationship between the set of variables, the Simon-Ballock method of causal analysis may be used to discover indirect causal relationships (35). Recently, powerful modern analytical techniques (36) have been developed specifically for use in dynamics model parameter identification. If appropriate, they may also be utilized.

In summary, the output of Stage II will be: i) a running computer simulation model, ii) a sensitivity analysis and a listing and discussion of the critical parameters, and iii) definition of additional data needs.

2.3.3 Model Refinement and Policy Analysis

The final stage of the proposed effort will involve refinement of the Stage II model, the use of the final model for policy analysis simulation, and the recommendation of further research.

The additional data and information requirements specified by the sensitivity analysis of Stage II will be used to more accurately estimate the critical relationships and parameters of the model. The Copper Development Association (37) and the American Metal Market Company (38) and Kennecott Copper Company should be useful sources for obtaining guidance in data collection and for detailed

data regarding the industry. The refinements arising from these considerations will be used to update the preliminary model and will result in the final version of the model.

The model will be used to simulate a past period of time. In so doing, the projective adequacy and validity of the model will be explored. The adequacy and validity testing will be explored at several levels:

- a. micro structure -- is it reasonable; are the appropriate variables included; are the directions of cause and effect correct;
- b. statistical -- have sensitive parameters been statistically derived or verified;
- c. overall dynamic behavior -- is it reasonable; can past history be reproduced.

Formal statistical comparison of simulation results with historical time series will be performed. We will test for bias in the simulation results and identify the sources of any biases that exist. This testing will further identify necessary refinements.

The final version of the model will incorporate exploration, recovery, refining, and production sectors and the energy flows and environmental impact associated with the technologies of each stage. An international market sector will be included that models the dynamics of international interactions between demand, supply, price, political factors and government controls. The final version of the model will be used to assess the environmental, energy, price, and international impacts and consequences

of various policies. Those policies to be carefully studied will be jointly developed and suggested by NSF and Pugh-Roberts personnel. Such policies might include:

Reduction of demand through substitution and recycling and the investment in substitution and recycling technology development;

Increase of domestic supply through expansion of capacity and the investment in technology to increase yield from domestic sources; or

Reduction of demand through improved product design.

The model will assess the overall impact of these policies and will indicate the lead times necessary for the exercise of these policies. Simulations will be performed for these various policies under a variety of "what-if" assumptions. These simulations will be described in detail and interpreted so that the critical aspects are highlighted.

The final sub-task of the effort is the identification of the most important gaps in the present state of knowledge regarding non-renewable resources to provide a focus for future research undertakings. In many respects, Stages I, II, and III may be viewed as the first cycle of what might be an iterative process. In its most general form, that process is depicted in Figure 2.8.

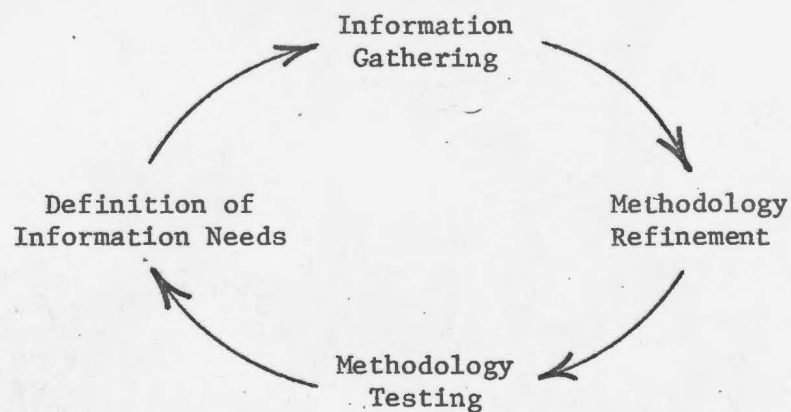


Figure 2.8

The sensitivity testing described in the previous section is the heart of this heuristic. The requirement for each additional iteration is indicated by the results of model testing. The model itself is the unifying thread that ties together each round of additional studies. It is a highly directed, deliberate and coherent process.

Recommendations for future research projects will be precisely stated in terms of:

- a. the objectives of the research;
- b. the exact set of questions to be addressed; and
- c. recommended methodologies to be employed in carrying out the research.

Because of the process by which these recommendations will be generated, they will form a tight, integrated program of common focus.

2.3.4 Work Statement of the Proposed Effort

The following statements summarize the work to be performed on the proposed effort:

STAGE I.

Pugh-Roberts Associates, Inc. will conduct a thorough methodological and problem-related literature review. Interviews will be conducted to gather supplemental data and inside insights. A detailed qualitative generic resource model will be developed and a detailed qualitative model of the international supply and consumption of copper will be developed. These models will be presented in the form of annotated flow diagrams and an accompanying text explaining linkages and citing references and information sources.

STAGE II.

The preliminary qualitative copper model will be quantified and translated into the DYNAMO simulation language. Extensive testing and debugging will be carried out. A thorough sensitivity testing of the model will be performed. The impact of critical parameters will be analyzed and discussed. Additional data requirements will be defined.

STAGE III.

Additional data will be acquired and used to refine the model. Appropriate statistical techniques will be utilized in this process. Validation will be addressed through structure analysis, parameter definition, and considerations of overall dynamic behavior. Final versions of the generic and copper models will be developed. Policy analysis simulations will be carried out with the copper model and the resulting impacts described and interpreted. Recommendations for further research will be made.

2.3.5 An Optional Task: Inter-Resource Competition

Substitution of one resource for another is an important variable in the determination of demand. However, substitution is, in one sense, a somewhat narrow view of inter-resource competition. For this reason, Pugh-Roberts Associates proposes an

optional task that both complements and extends the proposed effort. The optional task is the development of a preliminary inter-resource competition model.

Some portion of the consumers of a resource can use one resource as well as another. Under these conditions of substitutability, the user must choose one resource over another. The choice may be influenced by price, but issues such as convenience in handling, environmental aspects, availability, and energy demands can enter into the decision process. Thus purchase decisions in the market must be modeled taking these various competing aspects into account. The more general the ability to substitute, the more likely it is that inter-resource competition should be included in the discussion of supply, demand, and price dynamics of a given resource. For copper, substitution is somewhat limited at present to aluminum so that only considering substitution rather than inter-resource competition should not degrade the qualitative and quantitative copper model. However, for the generic model, it is probably desirable to include to some extent inter-resource competition. The proposed optional effort would develop a preliminary qualitative and quantitative systems dynamics model incorporating the dynamic interactions of inter-resource competition. It would be designed to complement the methodological framework developed in the effort. Such a model would build upon the basic systems dynamics work of Baughman (39) investigating the dynamics of inter-fuel competition. It is anticipated that this optional task would require approximately two months of effort, and would more specifically

focus primarily on copper-aluminum competition. This phase of effort would follow Stage III of the proposed activity.

III. PROJECT SCHEDULE

The project will be conducted in three stages, each stage consisting of multiple sub-tasks, with an additional optional fourth stage. This schedule is outlined below and presented in graphical form in Figure 3.1.

STAGE I: MODEL CONCEPTUALIZATION; Three Months Duration

- 1.1 Methodological and problem-related literature review
 - 1.2 Conducting interviews
 - 1.3 Development of qualitative generic model and copper model
- Products: Detailed qualitative models in the form of annotated flow diagrams and an accompanying text explaining linkages and citing references or information source.

STAGE II: MODEL DEVELOPMENT; Four Months Duration

- 2.1 Quantification and equation writing
 - 2.2 Development of successfully-running simulation model
 - 2.3 Conducting sensitivity analyses
 - 2.4 Definition of additional data
- Products: Preliminary quantified simulation model successfully running; results of the sensitivity analyses and a discussion of the critical parameters; and the definition of additional data requirements.

STAGE III: MODEL REFINEMENT AND POLICY ANALYSIS; Five Months Duration

- 3.1 Acquisition of additional data and refinement of model
 - 3.2 Conducting policy analysis simulations
 - 3.3 Description and interpretation of simulation results
 - 3.4 Development of recommendations for further research
- Products: Final versions of the qualitative generic model and quantitative copper model; results and interpretations of policy analysis simulations; and recommendations for further research

STAGE IV: OPTIONAL; INTER-RESOURCE COMPETITION MODEL DEVELOPMENT; Two Months Duration

- 4.1 Model conceptualization
- 4.2 Quantification of additional model sector
- 4.3 Development of successfully-running simulation model
- 4.4 Conducting sensitivity analyses

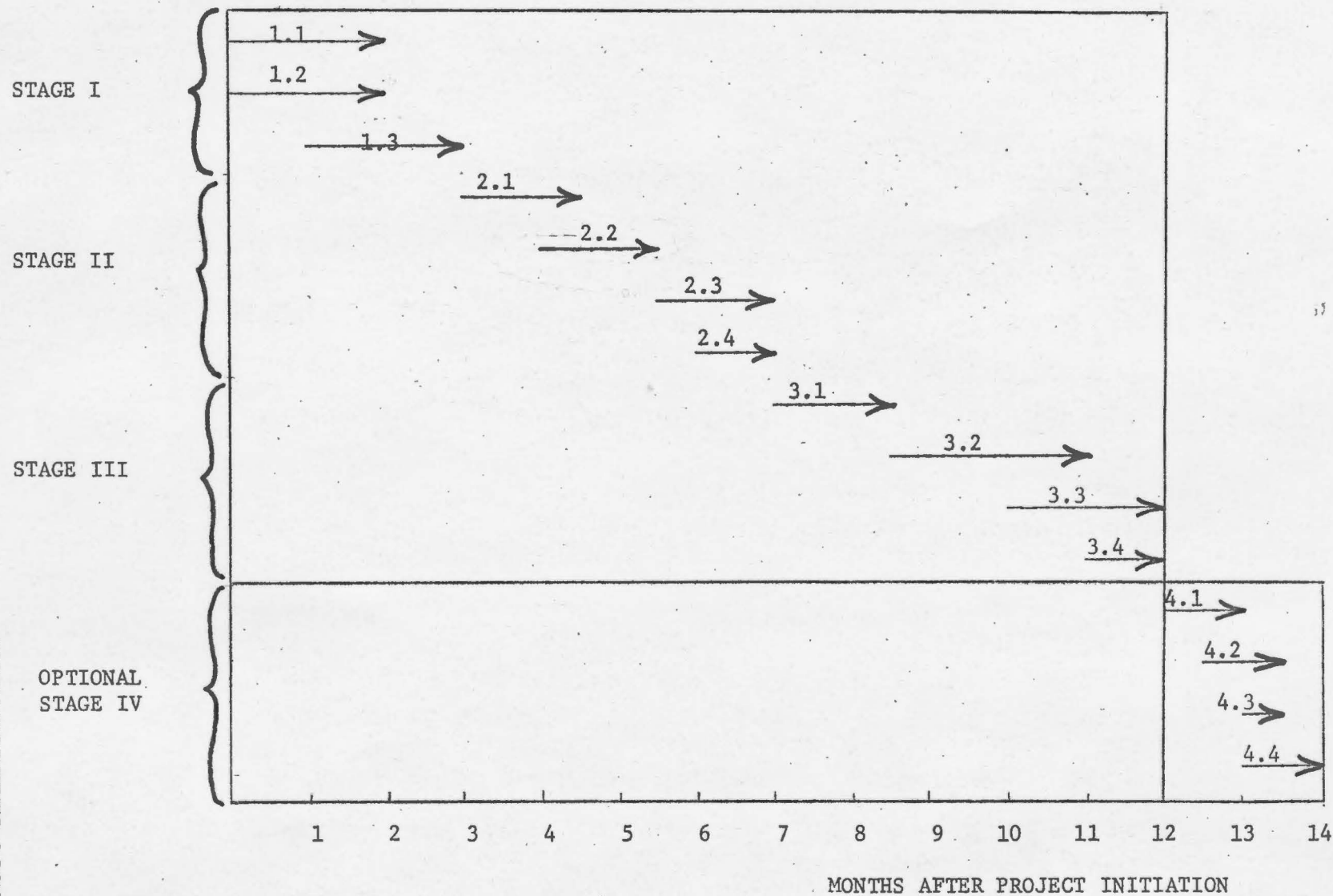


Figure 3.1

IV. PROJECT STAFFING AND MANAGEMENT

The Pugh-Roberts project team is to be composed of the following personnel. Indicated are their roles in the study and the percentage of their time devoted to the proposed effort.

Dr. William R. Killingsworth; Consultant
Project Manager/Principal Investigator
40% Time Commitment

Dr. Edward B. Roberts; President
Senior Technical Resource
10% Time Commitment

Alexander L. Pugh, III; Vice-President
Senior Technical Resource
10% Time Commitment

Henry B. Weil; Vice-President
Senior Technical Resource
15% Time Commitment

One additional staff member will be devoting essentially full time to the project in a supporting role. Uncertainties surrounding future workload make it impossible to specify such a person at this time. Only a person with appropriate experience and training would be selected for this role on the project team.

Resumes of the key members of the project team are enclosed at the end of Section VI of this proposal.

This Pugh-Roberts team will be supplemented by academic consultants mutually agreed upon with the NSF Office of Science and Technology Policy. These consultants will most likely be of two types: one group to provide economic expertise and advice and another group to provide insights into material technology. In addition, it is hoped that NSF will actively develop and appoint an Advisory Group for the effort. The Group will be composed of people knowledgeable and concerned about various non-renewable resource issues. The Group, meeting approximately quarterly with the project team, will provide assurance that current thinking on many fronts is taken into account in the modeling effort.

PUGH-ROBERTS ASSOCIATES, INC.

V. PROJECT REPORTING

Pugh-Roberts Associates, Inc. will submit to the National Science Foundation:

- (a) Brief progress reports on a two-months interval
- (b) Comprehensive mid-term reports at the completion of Stages I and II.
- (c) A comprehensive final report at the completion of Stage III.
- (d) An additional report on the Stage IV optional effort, if NSF decides to sponsor that supplemental activity.

VI. CAPABILITIES OF PUGH-ROBERTS ASSOCIATES AND VITAE OF PROJECT STAFF

6.1 GENERAL BACKGROUND AND EXPERIENCE

In 1963 two of the co-founders of the M.I.T. Industrial Dynamics program, Dr. Edward B. Roberts and Alexander L. Pugh III, formed Pugh-Roberts Associates, Inc. to meet the needs of government and industry for a broad range of systems analysis, organization modeling and simulation services. In particular, Pugh-Roberts Associates, Inc. specializes in the application of System Dynamics simulation modeling techniques to the major problems of policy-makers and system designers. Staff members of Pugh-Roberts Associates are expert in all phases of simulation modeling research, application, and teaching, with experience in managing and carrying out a wide range of socio-economic systems analyses. Comparable capabilities are not available in any other organization.

Pugh-Roberts Associates' initial years were devoted largely to industrial systems studies, while the more recent past has witnessed a broadening of both our professional disciplines and our areas of activity. The firm presently has a core staff of professionals with skills in simulation modeling, management information system design, statistical analysis, behavioral sciences, finance, and economics. This core is supported by a resource pool of eminent academic consultants and by specialized affiliated companies. Pugh-Roberts Associates has greatly expanded its activity in the public sector, with a particular emphasis on major issues of policy analysis.

Dr. Edward B. Roberts, President of Pugh-Roberts Associates Inc., has been actively involved in policy analysis, particularly science-related policy, since 1958. He served as co-founder and Associate

Director for 10 years of M.I.T.'s Research Program on the Management of Science and Technology, and now serves as Chairman of M.I.T.'s Technology and Health Management Group. His Federal governmental advisory positions on the Air Force Scientific Advisory Board, the Commerce Technical Advisory Board, and the President's Advisory Council for Management Improvement provided 10 years of cumulative experience in studying science and technology policy issues at the national level. As indicated by his resume at the close of this statement of qualifications, Dr. Roberts has published over 30 journal articles and books in this general subject area. Under his direction, Pugh-Roberts Associates has developed extensive expertise and experience in policy analysis.

Alexander L. Pugh III, Vice-President of Pugh-Roberts, is the principal developer of the DYNAMO compiler-simulator language for large-scale continuous simulation of systems models. Not only is that basic system maintained and distributed exclusively by Pugh-Roberts Associates Inc., but all major extensions to it have been generated by Mr. Pugh and his colleagues. Proprietary versions of DYNAMO are available from Pugh-Roberts Associates to support a wide variety of computer configurations, including a major FORTRAN version that permits ready access to DYNAMO on most machines. Time-sharing access to the system is available on a world-wide basis, and DYNAMO installations have been operating successfully for many years in most of the developed countries of the world. Special DYNAMO versions have been created to permit interactive computer gaming, compatible interfacing with other computer programs (such as linear programming routines, or large data bases), and to provide for output formats as

needed by different users. Pugh-Roberts Associates Inc. has the unique capability of being the sole supplier of these important simulation tools.

Pugh-Roberts Associates has undertaken numerous analyses of science policy-related problems in industry and government. The focus of the industrial efforts has usually been on the productivity and diffusion of research results, and on normative means for enhancing the beneficial impact of research expenditures. These activities have been carried out on a consulting basis for such firms as: Dupont, Exxon, General Motors, IBM, Polaroid, and Polymer Corporation of Canada. In a number of other cases strategic modeling of policy analyses was focused on such topics as allocation of research funds, management of large-scale technological programs, development and impact of new products. Such projects have been conducted for: Dow, IBM, and Xerox. Further system models have examined the interrelationships among technological change and the marketing, manufacturing and financial aspects of integrated organizations. Examples in this area include the Pugh-Roberts Associates projects with General Radio and Texas Instruments.

At the governmental level, Pugh-Roberts Associates has researched the measurement and improvement of public service productivity for the National Council on Productivity, and has examined the diffusion of public-related innovations in work for the National Bureau of Standards. Working with a Task Force of the Province of Quebec, Pugh-Roberts Associates has developed a prototype framework for examining health research policies, and now has under consideration a proposal to develop a structural model for priority setting for the H.E.W.

Bureau of Health Services Research. More recently, Pugh-Roberts has initiated research aimed at better understanding the international flow of technology.

In summary, the staff of Pugh-Roberts Associates, Inc. has had eleven years of corporate and six prior years of academic experience in the development and application of policy/systems analysis methods to broad issues of science policy. The experiences cited throughout this statement demonstrate both subject area and functional capability depth.

The unique situation of Pugh-Roberts Associates proprietary development, distribution and maintenance of the DYNAMO simulation language, and its enhancements, is a special consideration. The numerous sole-source contract awards by varied government agencies, shown in the following references list, testify to the repeated judgment by the U.S. Government of our unique capabilities. The attached personnel resumes further detail our organizational strengths.

6.2 RELEVANT FEDERAL GOVERNMENT CONTRACTS

A. The following Federal government contracts were all* awarded to Pugh-Roberts Associates Inc. on a sole-source basis, based upon its unique capability in the area of System Dynamics.

1. Agency for International Development
 - (a) A.I.D./otr-C-73-2 February 13, 1973
System Dynamics Model of the Agency's Project Management Process
 - (b) A.I.D./CM/otr-C-73-243 June 29, 1973
Application of System Dynamics Techniques to the Manpower/Organizational Change Process
2. Central Intelligence Agency
 - (a) C.I.A. XG-3838 (75-16) 74P September 7, 1973
 - (b) C.I.A. XG-3928 (75-044) 74P December 21, 1973
Training Programs in System Dynamics for Policy Analysis

* Only contract item #3 (b) was awarded following a competitive procurement.

3. Health, Education and Welfare
 - (a) Health Resources Administration, Division of Dental Health
Purchase Order PD-222281-4 September 26, 1973
Causal Model of Dental Manpower Sector Using System Dynamics
 - (b) National Center for Health Services Research and Development
HSM-110-70-356 June 19, 1970 to Organization for Social and Technological Innovation, Inc.; subcontract to Pugh-Roberts Associates Inc.
Simulation Model for Evaluating Alternative Approaches to Ambulatory Care Delivery
 - (c) National Institute of Mental Health
Grant 1-ROI-MH 1658601 April 1969 to Albert Einstein College of Medicine; subcontract to Pugh-Roberts Associates Inc. Systems Simulation of Community Mental Health Centers
4. National Academy of Sciences, Institute of Medicine
10M-22-71-09 December 5, 1971
Feasibility Model for Study of Universal Entitlement to Health Care
5. National Bureau of Standards
 - (a) N.B.S./CST-1259 January 11, 1965
Advanced Systems Analysis of Textile Industry Problems
 - (b) N.B.S./CST-192 January, 1966
Systems Analysis for Textile Management
 - (c) N.B.S./CST-240 April 13, 1966
A Systems Approach to Apparel Industry Problems

B. The following Federal contracts were all awarded to Pugh-Roberts Associates, Inc. on a sole-source basis, based upon its extensive capabilities in the area of technological innovation, transfer and productivity.

6. National Bureau of Standards
N.B.S. 1-35905 June 21, 1971
Factors Affecting Innovations in Fire Safety Equipment
7. National Commission on Productivity
GS-035-39315 December 1, 1972
Techniques for Measurement and Analysis of Productivity of Providing Selected Public Services
8. National Science Foundation
Grant dated June 29, 1973 to Forecasting International Ltd.; subcontract to Pugh-Roberts Associates Inc.
Technology Transfer through Licensing and Foreign Investment and their Impact on the Firm

6.3 RESUMES OF KEY PROJECT STAFF MEMBERS

Resumes are included for the following persons:

Dr. William R. Killingsworth

Alexander L. Pugh, III

Dr. Edward B. Roberts

Henry B. Weil

WILLIAM ROBERT KILLINGSWORTH, JR.

Born: March 18, 1945

Education:

Ph.D. (1972) and S.M. (1968) from M.I.T., Interdepartmental Systems Analysis Program with emphasis at the Sloan School of Management; Specialization in the dynamics of social and industrial systems and modern analytical systems analysis techniques.

B.S. (1966) from Auburn University, Auburn, Alabama; Engineering Science.

Professional Experience:

August 1973-

Pugh-Roberts Associates, Inc.

Participated in the planning of organizational change for a major Government Agency. Effort focused on task differentiation, interaction of divisions, and the utilization of research. A systems dynamics model was developed and used as a strategy evaluation tool.

Developed a systems dynamics model of the dental health sector that was used to project changes in the number and type of arriving patients, the impact of this demand on dental practices, and the type of treatment delivered. Primary consideration was the establishment of dental manpower requirements for meeting future demand.

Conducted for an international association an analysis and survey of the social applications of dynamic models. The effort considered specific cases and focused on the interaction between the decision maker and the consultant and the processes which contributed to successful use of the model.

Feb. 1972-July 1973

Systems Control, Inc.

Participated in study that determined information requirements for human control of complex systems.

Investigated human decision making and control activities in energy control centers.

Developed a preliminary systems dynamics model of a rehabilitation center.



May 1968-Sept.1968

The Analytic Sciences Corp.

Developed a stochastic simulation model of a computerized control system.

Honorary Societies:

Phi Kappa Phi, Sigma Xi, Tau Beta Pi

Major Writings:

Application of Contraction Mappings to the Control of Nonlinear Systems, Measurement Systems Lab Report TE-49, Feb. 1972; M.I.T.

"Application of Contraction Mappings to Societal Systems Analysis," Presented at the IEEE Systems, Man, and Cybernetics Conference, Boston, Mass., Nov., 1973.

"A New Framework for Projecting Dental Manpower Requirements," (with Gary B. Hirsch), Presented at the Division of Dental Health, HEW, Advisory Workshop on Productivity and Demand Indices, Dec. 13, 1973.



PUGH-ROBERTS ASSOCIATES, INC.

ALEXANDER L. PUGH, III

Education

B.S. in Electrical Engineering from the University of Pennsylvania, 1952.

S.M. in Electrical Engineering from M.I.T., 1953.

Electrical Engineer (professional degree) from M.I.T., 1959.

Positions Held

Research Assistant, M.I.T. Operations Research Group, 1953-54
Research Assistant, Lincoln Laboratory, 1954-55
Electronics Engineer, Electronics Research Directorate, 1955-59
Research Assistant, M.I.T. Industrial Dynamics Group, 1957-59
Research Associate, M.I.T. Industrial Dynamics Group, 1959-
Vice President, Pugh-Roberts Associates, Inc., 1963-

Professional Experience

1959-65 Contributed to the design and maintenance of the DYNAMO I compiler.

1965- Conceived and programmed the DYNAMO II compiler.

1971- Conceived and supervised the development of DYNAMO II F.

1973- Conceived and supervised the development of DYNAMO III F.

1960-62 Studied cycles in the demand for electrical power generation equipment.

1961-63 Developed model of pulp wood harvesting operation.

1962-64 Contributed to the design of an asset management system for a major New York Bank.

1964-68 Major contributor to the Model of the Susquehanna River Basin.

1965-67 Managed the development of an I.D. model of the United States Economy.

1967-69 Supervised the design and development of an engineering information system.

1968-70 Developed product line strategy game including price, production rate, capital investment and product improvement.

1968-70 Created a production scheduling model.

1968-70 Supervised the design of a management information and control system for a financial investment department.

1971 Supervised the development of a model of universal entitlement to health care.

1971-72 Managed the construction of a model of land usage in a river basin.

1971-72 Participated in an analysis of policies to introduce minorities into the management of a major corporation.

1972-73 Supervised the construction of a model of land usage in a metropolitan area.

1972-73 Supervised the development of models of a conventional and a systems housing construction company.

1973- Supervised an analysis of growth strategies for a financial institution.

Honorary and Professional Societies

Institute of Electrical and Electronic Engineers, Association for Computing Machinery, Society for Computer Simulation; and a member of Eta Kappa Nu, Pi Mu Epsilon, Tau Beta Pi, Sigma Xi, and Sigma Tau.

Publications:

DYNAMO II User's Manual (Cambridge: The M.I.T. Press, 1973).

System Simulation for Regional Analysis (co-author) (Cambridge: The M.I.T. Press, 1969).

Problems in Industrial Dynamics (contributor) (Cambridge: The M.I.T. Press, 1963).

PUGH-ROBERTS ASSOCIATES, INC.

EDWARD B. ROBERTS

Education

S.B., M.I.T., 1958
S.M., M.I.T., 1958
S.M., M.I.T., 1960
Ph.D., M.I.T., 1962

Professional Experience

1958- Systems Dynamics Group, M.I.T.
1961 Consultant, National Aeronautics and Space Administration
1961-65 Assistant Professor of Industrial Management, M.I.T.
1963-73 Assoc. Director, M.I.T. Research Program on the Management of Science and Technology
1963-69 Consultant, The RAND Corporation
1963- President, Pugh-Roberts Associates, Inc.
1965-70 Associate Professor of Management, M.I.T.
1967-70 Member, Air Force Scientific Advisory Board
1967-72 Member, Department of Commerce Technical Advisory Board
1970- Professor of Management, M.I.T.
1972-73 Consultant, President's Advisory Council for Management Improvement
1973- Chairman, Technology and Health Management Group, M.I.T.

Honorary and Professional Societies

American Economic Association, Institute of Electrical and Electronic Engineers, The Institute of Management Sciences (National Council, 1967-1969), Sigma Xi, Tau Beta Pi.

Publications on Policy/Systems Analysis(non-Science & Technology)

"Industrial Dynamics and the Design of Management Control Systems", Management Technology, December, 1963.

Problems in Industrial Dynamics (contributor) (Cambridge: The M.I.T. Press, 1963).

"New Directions in Industrial Dynamics", Industrial Management Review, Fall, 1964.

"Systems Methodology for Evaluating Industrial Projects in the Context of National Strategies", M.I.T. Sloan School of Management Working Paper #141-65, 1965.

"A Systems Study of Policy Formulation in a Vertically Integrated Firm" (with D. Abrams and H. Weil), Management Science, August, 1968.

Systems Simulation for Regional Analysis (co-author) (Cambridge: The M.I.T. Press, 1969).

"Analyse Fonctionnelle des Problemes d'une Entreprise de Confections", Direction et Gestion, January-February, 1970.

"Implementing New Educational Technology for the Military" (with H. Weil), Naval War College Review, April, 1971.

"Narcotics and the Community: A System Simulation" (with G. Levin and G. Hirsch), American Journal of Public Health, June, 1972.

"Strategies for Effective Implementation of Complex Corporate Models", in Model and Computer-Based Corporate Planning (Cologne, 1974).

Heroin and the Community: A Computer-Aided Search for Policy (with G. Levin and G. Hirsch) (in preparation for publication).

Publications on the Management of Technology

I. Dynamics of R&D Projects and Organizations

"Toward a New Theory for Research and Development", Industrial Management Review, Fall, 1962.

The Dynamics of Research and Development (N.Y.: Harper & Row, Publishers, 1964).

"Research and Development Policy-Making", Technology Review, June, 1964.

A Systems Analysis of Multi-Laboratory Management (with S. Pathak), M.I.T. Research Report to Office of Naval Research, September, 1967.

"The Problems of Aging Organizations: A Study of R&D Units, Business Horizons, Winter, 1967.

"The Dynamics of R&D Strategy" (with H. Weil and T. Bergan), in Proceedings of the 1973 Summer Simulation Conference (Montreal: July, 1973).

"A Simple Model of R&D Projects" (submitted to R&D Management), November, 1973.

II. Management of R&D Contracting

"How the U.S. Buys Research", International Science and Technology, September, 1964.

"Marketing and Engineering Strategies for Winning R&D Contracts", in Adaptability for Survival in the Defense Industries (Boston: Boston College Press, 1965).

"Questioning the Cost-Effectiveness of the R&D Procurement Process", in Research Program Effectiveness (N.Y.: Gordon & Breach Science Publishers, Inc., 1966).

"The Measurement and Improvement of R&D Marketing Effectiveness", in Changing Boundaries of the Defense Industry (Boston: Boston College Press, 1966).

"Effects of Incentive Contracts on Research and Development: A Preliminary Research Report" (with J.B. Sloat), IEEE Transactions on Engineering Management, December, 1966.

"Follow-on Contracts in Government-Sponsored Research and Development: Their Predictability and Impact" (with W. Dyer), Industrial Management Review, Winter, 1968.

"The Management of DoD Laser Research" (with W. Davis), Journal of Business, January, 1970.

III. Technical Entrepreneurship

"Technology Transfer and Entrepreneurial Success" (with H.A. Wainer), in Proceedings of the 20th National Conference on the Administration of Research (Denver: Denver Research Institute, 1967).

"Entrepreneurship and Technology", Research Management, July, 1968.

"New Enterprises on Route 128" (with H. Wainer), Science Journal, December, 1968.

"Unutilized Ideas in University Laboratories" (with D. Peters), Academy of Management Journal, June, 1969.

"Recognizing and Keeping Entrepreneurs", Innovation, 1969.

"How to Succeed in a New Technology Enterprise", Technology Review, December 1970.

Financing New Technological Enterprise (co-author), (Washington, D.C.: U.S. Department of Commerce, 1970).

"Some Characteristics of Technical Entrepreneurs" (with H. Wainer), IEEE Transactions on Engineering Management, August, 1971.

Videotape: "Making Entrepreneurs a Corporate Asset" (N.Y.: The Innovation Group, 1971).

The Care and Feeding of Entrepreneurs: A Technology Management Seminar (N.Y.: Technology Communications, Inc., 1971).

"Internal Entrepreneurship: Strategy for Growth" (with A. Frohman), The Business Quarterly, Spring, 1972.

"Influences upon Performance of New Technical Enterprises", in Technical Entrepreneurship: A Symposium (Milwaukee: Center for Venture Management, 1972).

IV. General R&D Management

"Research on the Management of Technology-Based Enterprises", IEEE Transactions on Engineering Management, September, 1964.

"Facts and Folklore in Research and Development Management", Industrial Management Review, Spring, 1967.

"Myths of Research Management", Science & Technology, August, 1968.

"Exploratory and Normative Technological Forecasting: A Critical Appraisal", Technological Forecasting, Fall, 1969.

"Le Controle de l'Avancement des Travaux de Recherche et Developpement", Synopsis, May-June, 1971.

"Correlatie Tussen Innovaties en Investerings in R&D Ontbreekt", Financieel-Economisch Magazine, August, 1972.

"Technology Strategy for the European Firm" (submitted to European Business), November, 1973.

PUGH-ROBERTS ASSOCIATES, INC.

HENRY BIRDSEYE WEIL

Born: September 8, 1942

Education:

S.B. (1965) and S.M. (1967) in Management from M.I.T.; specialization in Industrial Dynamics, management information systems, and finance.

Courses from the Industrial College of the Armed Forces and the Naval War College.

1969-70 Special Student at M.I.T.'s Sloan School of Management.

Professional Experience:

1964-65 Arthur D. Little, Inc., Cambridge, Mass.: economic analyst and consultant.

1965-66 M.I.T., Cambridge, Mass.: research assistant in development finance (participated in the preparation of the OECD Global Directory of Development Finance Institutions; performed research into the financing, management, and operation of development banks).

1966-67 Pugh-Roberts, Associates, Inc., Cambridge, Mass.: management and economic consultant specializing in simulation and management information systems design (participated in industry and company modeling and simulation analyses; development of a banking-oriented macro-economic model for the FDIC; and design of an interactive engineering information system for a large manufacturer).

1966-67 Self-employed as an individual consultant in economic analysis and finance (work included market research and demand analysis; application of computer sciences techniques to investment decision making; and development finance studies for the OECD).

1967-69 Active duty as a Lieutenant in the U.S. Navy: assigned to the staff of the Secretary of the Navy, the staff of the Special Assistant to the Secretary of the Navy, and the Office of Information Systems Planning and Development (participated in the development of concepts and plans for a Dept. of the Navy Management Information and Control System; in several important organization studies and reorganizations; and in preparing, analyzing, and defending before Congress portions of the Navy budget).

1969- Pugh-Roberts Associates, Inc., Cambridge, Mass.: Vice President with corporate management responsibilities for coordinating opera-

tions and performing strategic planning; professional specialization in System Dynamics simulation modelling, organization and management system design, and new venture consulting and finance (directed the analysis and reorganization of the real estate investment operations of a major financial institution; the analysis of merchandising management in a large national retail firm; the analysis and reorganization of a state criminal justice planning agency; planning for the introduction of innovative criminal corrections programs in a large city; the analysis of strategic R&D management in a leading technically-based corporation; studies of approaches and opportunities for improving productivity in the delivery of key public services; the development of analytical methods for predicting the impacts of investment in transportation and sewer infrastructure on regional growth; analysis of management of U.S. foreign aid efforts; the conduct of an in-house training program in System Dynamics for a federal agency; the analysis of growth strategy options for a major financial institution).

Honors:

Navy Achievement Medal

Invited Lectures --

Massachusetts Institute of Technology

Harvard Graduate School of Business Administration

Boston University

Industrial College of the Armed Forces

Central Intelligence Agency Senior Seminar

Major Writings:

"Workload Fluctuations in a Management Consulting Firm", unpublished S.B. thesis, M.I.T., 1965.

"Capital Market Development in Emerging Nations - A Simulation Analysis", unpublished S.M. thesis, M.I.T., 1967.

Contribution to Global Directory of Development Finance Institutions, J. D. Nyhart and E. F. Jansens, editors, O.E.C.D. Development Center, Paris, 1968.

"A Systems Study of Policy Formulation in a Vertically Integrated Firm" (with E. Roberts and D. Abrams), Management Science, August 1968.

"Let's Bring Economic Choice to ADP" (with J. Carabello), Navy Management Review, January/February 1969.

"Implementing New Educational Technology for the Military"
(with E. Roberts), Naval War College Review, April 1971.

"Industrial Dynamics and MIS", Proceedings of the 1971 Summer Computer Simulation Conference.

"Feedback Structures and the Tenacity of Crime: A Fresh Look at Cause and Control", (with G. Hirsch), unpublished working paper, 1971.

"A New Methodology for Assessing Environmental Impact", unpublished working paper, 1971.

"The Dynamics of Environmental Impact" (with A.L. Pugh III), Proceedings of the 1972 Summer Computer Simulation Conference. Also published in Impact (distributed by the Institute of Water Resources, U.S. Army Corps of Engineers), Vol. 1, No. 7, April 1973.

"The Dynamics of R&D Strategy" (with T. A. Bergan and E. B. Roberts) Proceedings of the 1973 Summer Simulation Conference.

Contribution to Opportunities for Improving Productivity in Police Services, National Commission on Productivity, Washington, 1973.

March, 1974

PUGH-ROBERTS ASSOCIATES, INC.

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3. "Raw Materials Nations Plan Solid Front," Christian Science Monitor, April 5, 1974.
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5. Meadows, Dennis L., The Limits to Growth, Potomac Associates, Universe Books, New York 1972.
6. Frohman, A., Schulman, M., Roberts, E., "Factors Affecting Innovation in the Fire Services," National Bureau of Standards, March, 1972.
7. Hamilton, H.R., Goldstone, S.E., Milliman, J.W., Pugh, A.L., Roberts, E.B., and Zellner, A., System Simulation for Regional Analysis, M.I.T. Press, Cambridge, Mass., 1969.
8. Forrester, J.W., Urban Dynamics, M.I.T. Press, Cambridge, 1969.
9. Roberts, E.B., The Dynamics of Research and Development, Harper and Row, New York, 1964.
10. Randers, J. and Meadows, D.L., "Systems Simulation to Test Environmental Policy: A Sample Study of DDT Movement in the Environment," Unpublished Working Paper, M.I.T., Cambridge, Mass., 1971.
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12. Schlager, K.J., A Systems Analysis of the Copper and Aluminum Industries, An Industrial Dynamics Study, Unpublished M.S. Thesis, M.I.T., Cambridge, 1961.
13. Baughman, M.L., Dynamics Energy Modeling - Interfuel Competition, Report 72-1, Energy Analyses and Planning Group, M.I.T., Cambridge, 1972.
14. Meadows, D.L., op. cit.
15. Naill, Roger F., "Long-Term Natural Resource Availability," First Annual Report NSF-RANN Grant No. GI-34808X, Dartmouth College, Sept. 1973.
16. Forrester, J.W., Industrial Dynamics, M.I.T. Press, Cambridge, 1961.
17. "Chile: The Economic Crisis in Allende Country," Business Week, August 12, 1972.
18. "An Ex-Banker Treats Copper's Sickest Giant," Business Week, Feb. 19, 1972.

19. Baughman, M.L., op. cit.
20. Naill, R.F., op. cit.
- 20a. Choucri, Nazli, and Ross, D. Scott, "A Forecasting Model of Energy Imports and International Politics: Costs, Resistance, and Conflict; A Preliminary Report," Research Project on Long-Term Resource Availability in the United States, M.I.T., August, 1973.
21. Meadows, D.L., op. cit.
22. Ballmer, R.W., op. cit.
23. Schlager, K.J., op. cit.
24. Fisher, Franklin M., "An Econometric Model of the World Copper Industry," The Bell Journal of Econometrics and Management.
25. McNicol, David L., The Two Price Systems in the Copper Industry, Unpublished Ph.D. Dissertation, M.I.T., 1973.
26. Schlager, K.J., op. cit.
27. Fisher, Franklin M., op. cit.
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30. Hannon, Bruce, "Options for Energy Conservation," Technology Review, February, 1974.
31. Abert, J.G., et al., "The Economics of Resource Recovery from Municipal Solid Waste," Science, Vol. 183, March 15, 1974.
32. Radcliffe, S.V., "The Total Materials Cycle in the U.S. Economy," Third Inter-American Conference on Materials Technology, Rio de Janeiro, Brazil, August, 1972.
33. Pugh, A.L., III, DYNAMO II Users' Manual, M.I.T. Press, Cambridge, 1970.
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36. Peterson, David W., and Schweppe, Fred C., "Code for a General Purpose System Identifier and Evaluator (GPSIE)," Submitted for publication in the IEEE Transactions on Automatic Control, Dec., 1974. Authors are with the Department of Electrical Engineering, M.I.T.
37. Copper Development Association, op. cit.

38. The American Metal Market Company, Metal Statistics: The Purchasing Guide of the Metal Industries, New York.
39. Baughman, M.L., op. cit.