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RANN UTILIZATION EXPERIENCE

REPORT TO
THE NATIONAL SCIENCE FOUNDATION

Case Studies 42 through 51

Washington, D.C.

March 1977

Compiled by:

R.M. Burger
M.F. Massoglia

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

As a Final Report on:
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This report contains case studies of the utilization of research results of ten Research Applied to National Needs (RANN) projects that were selected as representative of less utilized research efforts. The selection of these case studies was based on data obtained in a sample survey designed to determine the extent of utilization of RANN research projects that were initiated in the fiscal years 1972 and 1973. The case study is one utilization tool wherein an individual project is examined, its utilization determined, the various factors that apparently affect its utilization are identified, and conclusions are derived relative to its utilization experience. The objective of these case studies was to identify and describe the specific utilization of the projects in an accurate and comprehensive manner. In meeting this objective, it was necessary to some extent, to include a discussion of the nature of the research and the project itself. These case studies were preceded by forty-one other studies that were previously prepared and distributed in other volumes.

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SUMMARY

This report contains case studies of the utilization of research results of ten Research Applied to National Needs (RANN) projects that were selected as representative of less utilized efforts. The selection was based on data obtained in a sample survey designed to determine the extent of utilization of RANN research projects that were initiated in FY'72 and FY'73. These case studies follow forty-one that were previously prepared and distributed. Findings and analysis are confined to the individual cases. No general findings are given in this report.

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INTRODUCTION

Background

The research Applied to National Needs (RANN) Program of the National Science Foundation supports research on selected problems of national importance with the objective of contributing to their practical, timely solution. Various studies have been undertaken to assess the prompt utilization of RANN research. One utilization assessment tool is the case study wherein an individual project is examined, its utilization determined, the various factors that apparently affect its utilization are identified, and conclusions are derived relative to its utilization experience.

Research Triangle Institute (RTI) completed an initial group of twenty-one such case studies in 1975.* The projects selected for those case studies were among the better utilized ones as judged by RANN management. In that effort, and in subsequent analyses by NSF/RANN, much has been learned on how to conduct case studies so as to improve their effectiveness both in communicating the experience of the project and in revealing the features of the utilization process in general. This collective experience has been applied, albeit not with complete success, in the preparation of these new case studies.

Ten case studies were issued in September 1976** for projects that were indicated as being well utilized and ten more in November 1976 for projects selected by NSF.*** In this report, ten new case studies are presented. Essential information on these is given in Table 1.

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*R.M. Burger, RANN Utilization Experience Final Report to the National Science Foundation, Research Triangle Institute, June 16, 1975.

**R.M. Burger and M.F. Massoglia, RANN Utilization Experience, Report to the National Science Foundation, Case Studies 22 through 31, Research Triangle Institute, August 31, 1976.

***R.M. Burger and M.F. Massoglia, RANN Utilization Experience Report to the National Science Foundation, Case Studies 32 through 41, Research Triangle Institute, November 1976.

TABLE 1. RANN PROJECTS FOR WHICH CASE STUDIES ARE INCLUDED IN THIS REPORT

	PROJECT	PRINCIPAL INVESTIGATOR(S)	NSF PROGRAM MANAGER	TERM	FUNDING
42	Development of Analytical Methods for the Determination of Trace Elements	Philip W. West Institute of Environmental Sciences, Louisiana State University	Richard A. Carrigan	8/72-1/77	$304,900
43	The Delaware Estuary System: Environmental Impacts and Socioeconomic Effects	William S. Gaither University of Delaware Ruth Patrick The Academy of Natural Sciences, Philadelphia William Whipple, Jr. Water Resources Institute Rutgers University	Ralph Perhac (now with EPRI)	4/72-9/73	$380,000
44	Sequence Effects in Heterogeneous Nucleation	Roger L. Steele Desert Research Institute University of Nevada Systems	Currie Downie	6/72-9/72	$140,200
45	Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited by Earthquakes	Franklin Y. Cheng University of Missouri at Rolla	John B. Scalzi	7/72-9/75	$ 20,300
46	Investigation of Thin Film Solar Cells Based Upon Cu_2S and Ternary Compounds	Joseph J. Loferski Brown University	Tapan Mukherjee	7/73-8/76	$268,300
47	Fire Whirl and Firebrand in Mass Fires	Richard S. L. Lee State University of New York at Stony Brook	Ralph Long	2/73-8/75	$ 72,400

TABLE 1. (CONTINUED)

	PROJECT	PRINCIPAL INVESTIGATOR(S)	NSF PROGRAM MANAGER	TERM	FUNDING
48	A Study of Television Network Regulation	Stanley M. Besen Rice University	Allen Shinn	6/73- 6/75	$73,500
49	The Study of the Critical Problems of the Coastal Zone	Bostwick H. Ketchum Woods Hole Oceanographic Institution	Richard C. Kolf (Now with NOAA)	11/71- 4/73	$123,800
50	An Engineering Feasibility Study of an Ionospheric Technique to Improve Tsunami Warning Systems	Paul C. Yuen Kazutoshi Najita Augustine Furumoto University of Hawaii	John Scalzi	6/72- 5/74	$115,000
51	Photochemical Conversion of Solar Energy	Norman N. Lichtin Boston University	Tapan Mukherjee	6/73- 3/77	$461,000

An important application of the case studies is their usefulness for comparative analyses. To facilitate this, a degree of necessary uniformity is imposed. However, it must be emphasized that a case study is not constrained to a limited set of questions and answers. Flexibility in the pursuit of information is both desirable and necessary to obtain a valid measure of utilization. The Case Investigator must probe with zeal into the various nooks and crannies of the conceptualization-research-dissemination-utilization process in order to obtain an accurate and complete study.

What constitutes utilization of research results is a difficult question to answer. Measures of utilization that are operationally useful and are broadly applicable have eluded us so far. In the interim, we postulate that for RANN, utilization implies a contribution toward meeting a need of national importance. The research contributions might range from a minor influence to directly attributable important changes, actions, or decisions. In a case study, some or all of the research utilizations are identified; however, when utilizaiton is widespread, the less important categories can only be sampled. The extent of this sampling is determined by the case investigator on the basis of the results obtained and the effort available. Since utilization is frequently either feast or famine, this restriction is less severe than would appear.

These case studies were prepared under Contract NSF-C76-17165 with Research Triangle Institute. The project began on April 1, 1976, and is continuing.

Dr. Robert Burger is Principal Investigator for this study. Dr. Martin Massoglia is a Co-investigator and is administering the effort. These individuals were joined by 9 other professionals at RTI in performing these case

studies. This project team is identified in Table 2. The level of effort was such that, on the average, about 2.5 man-weeks were available to prepare each of the studies. This necessitates heavy reliance on information supplied by NSF/RANN program managers and on project principal investigators. The procedures employed are described in a following section of this report.

Dr. Samuel J. Raff of the NSF Division of Exploratory Research and Systems Analysis is Program Manager for this effort. He has selected the projects to be studied, assisted in arranging the many required liaisons with NSF staff, and has reviewed each of these case studies. This participation has had an important influence on the accuracy and completeness of the information provided in this report.

Project Selection

NSF made the selection of the projects studied here. The basis for selecting these 10 projects is a survey of RANN utilization conducted by RTI in 1975.* That survey was concerned with a randomly selected sample (stratified in accordance with several criteria) of 100 of the 512 research projects funded by Research Applications Directorate in 1972 and 1973. The survey procedure started by obtaining from the Principal Investigator a list of up to ten people who he thought might be using or were intending to use the results of his research. These people were then interrogated by a questionnaire regarding the details of their use or intended use.

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*Q.W. Lindsey & J.T. Lessler, Utilization of RANN Research Results: The Program and Its Effects - A Survey of the Research Applied to National Needs Program of the National Science Foundation, Research Triangle Institute, March 30, 1976.

TABLE 2. PROJECT PARTICIPANTS

	PROJECT	CASE INVESTIGATOR	TECHNICAL REVIEWER
42	Development of Analytical Methods for the Determination of Trace Elements	J. J. Wortman	K. Hanck (NCSU)
43	The Delaware Estuary System: Environmental Impacts and Socioeconomic Effects	M. Massoglia	C. J. Leith (NCSU)
44	Sequence Effects in Heterogeneous Nucleation	H. L. Hamilton	E. Droessler (NCSU)
45	Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited By Earthquakes	D. F. Tolman	J. C. Smith (NCSU)
46	Investigation of Thin Film Solar Cells Based Upon Cu_2S and Ternary Compounds	J. W. Harrison	J. R. Hauser (NCSU)
47	Fire Whirl and Firebrand in Mass Fires	S. Plotecia	R. Liepins (RTI)
48	A Study of Television Network Regulation	P. McMullan	D. Graham (DUKE)
49	The Study of the Critical Problems of the Coastal Zone	M. v.E. Rulison	B. J. Copeland (NCSU)
50	An Engineering Feasibility Study of an Ionospheric Technique To Improve Tsunami Warning Systems	R. Whisnant	W. A. Flood (NCSU)
51	Photochemical Conversion of Solar Energy	R. Alberts	K. DeArmond (NCSU)

A point system was devised for evaluating the degree of utilization indicated by questionnaire responses, e.g., five points were given for the combined statement that the research was in use and had a major impact on the operations of their organization; one point was given for the statement that the research increased the organization's quality of output, etc. The point total of each respondent was accrued to the proper project and the 100 projects were ranked in order of their point totals. The next step in the process of project selection was to form pairs of projects in the same substantive areas and with approximately the same funding level--with one project coming from the top of the ranking and the other from near the bottom. A few of the top projects were omitted because no suitable paired project could be found.

The intention is to perform case studies on both projects in each of the ten pairs, with each pair being studied by a single case investigator so as to obtain the maximum information available from such a comparison. The ten projects for which case studies are presented here constitute one member of each pair--the one near the bottom of the utilization ranking. Case studies for the top ranked member of the pairs were published in August.*

Procedures

The objective of a case study is to identify and describe the specific utilization of the project in an accurate and comprehensive manner. In meeting this objective, it is necessary to also discuss, to some extent, the nature of the research and the project itself. The Case Investigator, assigned from RTI's staff, obtains all relevant information on the project and prepares the case study.

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*R.M. Burger and M.F. Massoglia, op. cit., August 31, 1976.

Every case has a Technical Reviewer. He provides the Case Investigator with additional specialized background knowledge, should that be required. The Technical Reviewer also reviews the case study for technical accuracy and independently derives conclusions on the utilization factors relevant to the project. The Case Investigators and Technical Reviewers for the ten case studies included in this report are identified in Table 2.

The procedures employed in carrying out these utilization case studies were dominated by the schedule. Programmatic requirements of NSF necessitated rapid accomplishment. This in turn required close cooperation with and support from NSF. The procedures employed were as follows;

- Projects for which case studies were to be prepared were selected by the RANN Program Manager, Dr. Raff, in consultation with RANN management, as described in the previous subsection.
- Assignments of case investigators and technical reviewers were made to the individual cases as shown in Table 2, and interviews of NSF program managers were scheduled. In these interviews, the case investigators discussed the cases and asked questions as necessary to acquire information. In each case, the program manager was asked to inform the principal investigator of the project that the utilization study was being made.
- Case investigators provided technical reviewers with information on the case study, discussed with them the perspective of the research, and obtained guidance for the user interviews.

- Each case investigator subsequently contacted the project principal investigator to discuss the utilization study. In each case, first contact was by telephone. In a majority of the case studies, this was followed by a visit to the principal investigators for more intensive discussions. Cooperation of the principal investigators was very good.
- The identified users were contacted, primarily by telephone, but written communications and visits were also employed. Each was requested to provide an evaluation of the project as related to his needs and to relate the uses he had found for the research results.
- Each of the case investigators prepared a case study report, in most cases with the direct participation of the Technical Reviewer. The ten completed reports were reviewed by the Technical Reviewer and subsequently submitted to NSF and to the ten principal investigators for review.
- Burger, Massoglia, Raff, and, when necessary, the Case Investigator discussed the comments obtained from the reviewers. The case investigators prepared the final case studies, which are included in this report.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 42

DEVELOPMENT OF ANALYTICAL METHODS FOR THE DETERMINATION OF TRACE ELEMENTS

LOUISIANA STATE UNIVERSITY

Case Investigator:

J. J. Wortman

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:

K. Hanck

Department of Chemistry
North Carolina State University
Raleigh, North Carolina 27607

Prepared under:

Contract No. NSF C76-17165
National Science Foundation
Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

DEVELOPMENT OF ANALYTICAL METHODS FOR THE DETERMINATION OF TRACE ELEMENTS

Introduction and Summary

International concern for environmental protection over the past decade has resulted in the energence of a "legislated" technology revolving around pollution control. Reacting to a popular mandate, governments have set out to curb environmental pollution and protect public health. In the United States, the scientific community has responded to this national need by providing regulatory agencies with the tools needed to detect, sample, and analyze pollutants.

For much of his career Dr. Philip W. West, Boyd Professor of Chemistry and Director of the Institute of Environmental Sciences at Louisiana State University (LSU), has devoted himself to the development of simple, inexpensive techniques for performing analyses of the flow of pollutants through the environment. Since 1972, under two National Science Foundation (NSF) RANN grants, Dr. West has led a group of researchers who have contributed significantly to the referenced methodology for trace element determination and the measurement of sulfuric acid aerosol. Before 1972, similar work by Dr. West was supported by the Chemistry Division of NSF. Their research has dealt with the problem from sample acquisition through sample storage to analytical measurement, including instrument calibration and establishing standards. They have concentrated their efforts on methods and techniques that are at once simple and inexpensive and have been successful in developing many pieces of associated laboratory hardware.

According to one of his colleagues, Dr. Kenneth D. Reiszner, "It is difficult to quantify the exact extent of the utilization of Dr. West's work because it is usually addressed to a widespread need and the research results go into the open literature."

Utilization of analytical methods is difficult to assess directly. However, one indirect measure of utilization is the acceptance of methods and techniques by organizations charged with analyzing and recommending methodology to the user community. One such organization is the American Society for Testing Materials (ASTM). At present, the ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres is considering the adoption as tentative methods of Dr. West's "Total Proton Non-Volatile Acid Method" and the "Atmospheric Lead Method Using Dithizone and Ring Oven Technique." Additionally, eleven procedures developed by Dr. West's group have been incorporated in a manual prepared for the United Nations (UN) by the Scientific Committee for Problems of the Environment (SCOPE). The manual, entitled "Analytical Methods for the Determination of Selected Pollutants," contains the following LSU procedures:

1. Determination of Airborne Particulate Beryllium by the Ring Oven Technique
2. Determination of Sulfur in Air by the West-Gaeke Method
3. Spectrophotometric Determination of Nitrate in Air
4. Determination of Airborne Particulate Cobalt by the Ring Oven Technique
5. Determination of Airborne Particulate Cadmium by the Ring Oven Technique
6. Determination of Airborne Particulate Nickel by the Ring Oven Technique
7. Determination of Airborne Particulate Lead by the Ring Oven Technique
8. Determination of Airborne Particulate Zinc by the Ring Oven Technique
9. Determination of Airborne Particulate Copper by the Ring Oven Technique
10. Spectrophotometric Determination of Atmospheric Fluorides
11. The Determination of Atmospheric Sulfur Dioxide by Coulometric Titration

As far as the utilization of new equipment and laboratory apparatus is concerned, Dr. West has been successful, particularly with the commercialization

of the ring oven and the vinyl chloride personal monitor and, to a lesser extent, with the reverse permeation sulfur dioxide monitor. Utilization of such devices as the standard dust generator has been only marginal. Although Dr. West has worked hard to gain commercial acceptance for each of these devices, the utilization achieved has varied directly with the general acceptance of the analytical methodology associated with apparatus.

Thus the most significant factor affecting the utilization of an analytical method, apparatus, or technique is its acceptance by the user community, which is geared directly to its acceptance as standard methodology by such organizations as ASTM and the UN. Dr. West has concentrated heavily in this area, and his recent success with SCOPE should have a positive effect upon the utilization of his research products.

Research Description

Most analytical studies of the environment have dealt primarily with toxic materials that have deleterious effects upon human health. Other studies are concerned with evaluating nuisance effects and various economic factors associated with corrosion, staining, and damage to plant and animal life. A point not often considered is that many toxic and carcinogenic materials are naturally occurring trace elements. Not nearly enough is known of the chemical constituency of the natural environment, and it is, therefore, difficult to assess anthropogenic influences. Sound analytical methods for studying water and air quality are essential.

Accurate analyses, reproducible from one laboratory to another, are the basis of all observational research on trace contaminants. Yet the measurement of trace amounts of toxic impurities in the environment has long been a difficult

and frustrating endeavor. Analytical chemists are often embarassed when two operators are unable to reproduce results on the same sample within an order of magnitude. This is often due to the substance being measured already existing as an impurity in the sampling tools and containers, in the chemical reagents used in the analysis, or in the analytical apparatus itself. Also, relatively large losses of trace constituents are known to occur by volatilization during sample preparation, by adsorption onto filter papers and walls of laboratory vessels, and by chemical reactions during sample storage. As a result, there is a constant search for simplified methodologies and quantification of sample contamination and deterioration.

A large body of research in this area has been performed by Dr. Philip W. West's group at Louisiana State University under a National Science Foundation grant entitled "Development of Analytical Methods for the Determination of Trace Elements." Project information is shown in Table 42-1. Research goals are shown in Figure 42-1. Table 42-2 contains information on Dr. West's related NSF project.

As a co-developer of the well known West-Gaeke Method for the determination of atmospheric sulfur dioxide, Dr. West has long been recognized as a leader in the analytical determination of sulfur compounds in the atmosphere. With the recent interest in sulfuric acid aerosol now peaking because of the catalytic converter automobile muffler controversy, Dr. West's group has also become involved in this research area under another National Science Foundation grant entitled "Selective and Sensitive Methods for the Determination of Sulfuric Acid Aerosol."

The reason for noting the smaller sulfuric acid aerosol grant is that both efforts were performed simultaneously by the same group in the LSU Chemistry

TABLE 42-1. PROJECT INFORMATION

Project Title	Grant/Contract No.
Development of Analytical Methods for the Determination of Trace Elements	AEN 74-18932 A01
RANN Program Manager Richard A. Carrigan	**RANN Program Area** Chemical Threats to Man and the Environment
Principal Investigator(s) Philip W. West	**Schedule** Start: Aug. 1, 1972 End: Jan. 21, 1977
Institution Louisiana State University	**Funding** NSF: $304,900 Other:

Contributors/Collaborators

Foymae K. West	Roberta Mae Bustin
Venkatram Dharmarajan	Ronnie L. Thomas
Milton McDaniel	Gregory L. McClure
J. Jaime Chiang	David R. Bell
Ray F. Maddalone	Kenneth D. Reiszner
A.D. Shendrikar	G.I. Lundquist

User Advisory Committee

None

Precursor Activities

Work under the NSF Grant #GP018081 01 for "Selective and Sensitive Methods for the Determination of Sulfuric Acid Aerosol," which expired in 1974, was continued under the Trace Element Grant.

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Figure 42-1. RESEARCH GOALS

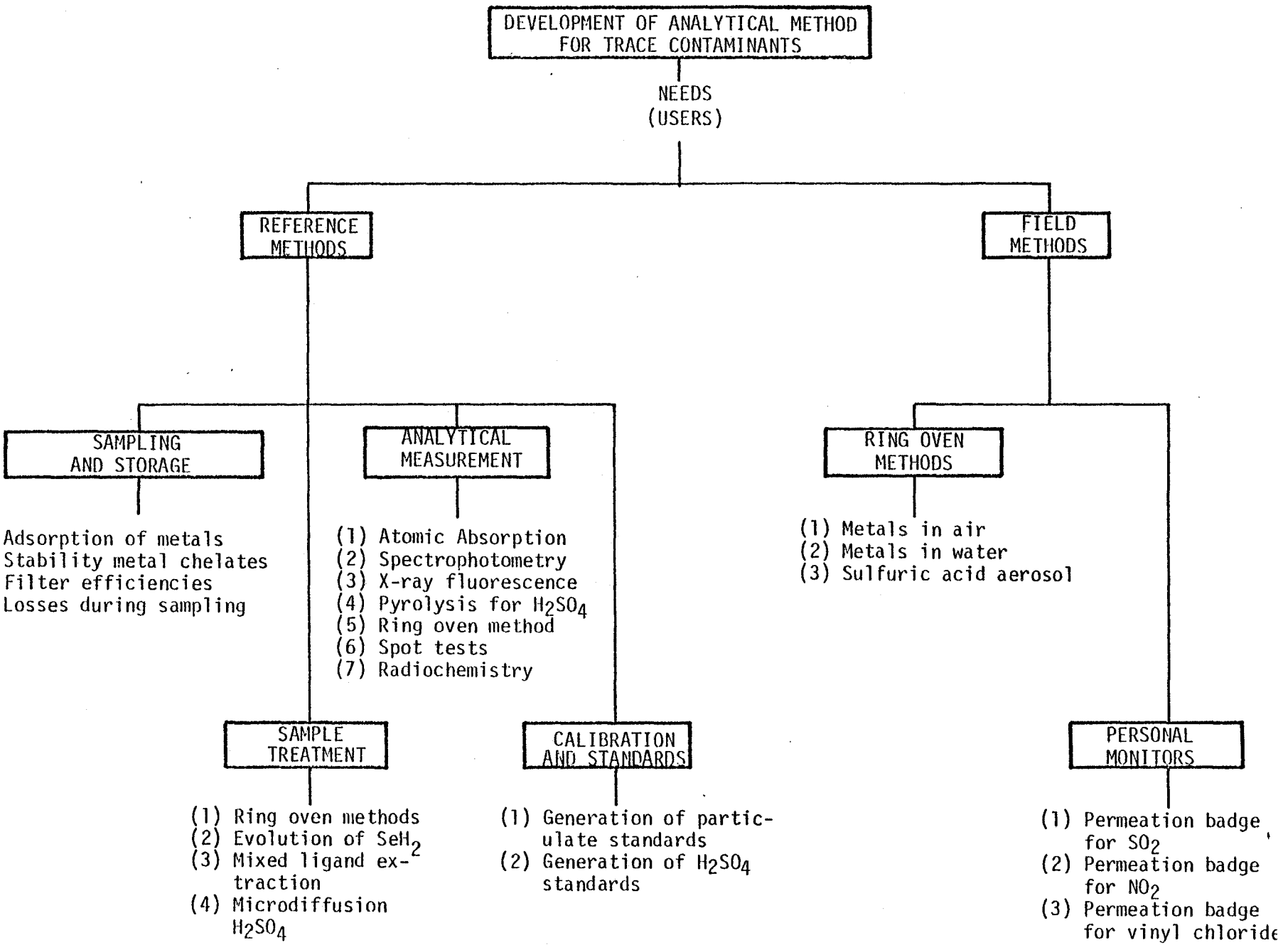

TABLE 42-2. INFORMATION FOR DR. WEST'S RELATED NSF PROJECT

Project Title	Grant/Contract No.
Selective and Sensitive Methods for the Determination of Sulfuric Acid Aerosol	GP018081 01
RANN Program Manager Richard A. Carrigan	**RANN Program Area** Chemical Threats to Man and the Environment
Principal Investigator(s) Philip W. West	**Schedule** Start: Sept. 1, 1972 End: Aug. 31, 1974
Institution Louisiana State University	**Funding** NSF: $41,000 Other:

Contributors/Collaborators

Kenneth D. Reiszner
A. D. Schendrikar
Nicholas Herrara
J. Jaime Chiang
Ray F. Maddalone
Ronnie L. Thomas
Venkatram Dharmarajan
Gregory L. McClure
G. L. Lundquist

User Advisory Committee

None

Precursor Activities

Work under this NSF grant was continued under NSF Grant #AEN 74-18932 A01, "Development of Analytical Methods for the Determination of Trace Elements."

Department. As a result, considerable overlap occurred during the development of the analytical methods and apparatus discussed below.

Several of these analytical methods resulted from improvements made by Dr. West's group in the impervious barrier-ring oven technique for trace-element determination. Of primary importance was perfecting the manufacture of impervious wax barrier rings on filter paper and marking their exact center. The ring oven technique is a procedure for identification and quantification of trace amounts of particulate metal pollutants collected by standard paper tape samplers. The paper upon which the sample is deposited is placed on the heated annular top of the oven. A dissolving agent is applied to the center of the spot. The dissolved contaminants are concentrated in a sharp ring zone by evaporation of the solvent at the 120° C temperature of the oven. The paper is then dried and cut into sectors for separate tests with reagents specific for the pollutants being sought. A concentration of 50x is attained. Previous users of the ring oven experienced difficulties in obtaining well-defined rings for quantitative analysis. Dr. West and his project team developed improved sampling papers by the supplemental use of an impervious wax barrier ring. This permits more rapid addition of dissolving agents, and enables the formation of sharp, intense colors, and reproducible ring thickness by elimination of overrunning at the heated ring zone. Prepared barrier rings based on Dr. West's improvements are now available commercially from Arthur Thomas Company, Philadelphia, Pa. 19105.

Armed with this inexpensive laboratory tool, Dr. West and his associates developed microdetermination methods for the following trace elements utilizing the impervious barrier-ring oven technique:

1. Manganese in airborne particulate samples
2. Copper in waters

3. Cadmium in waters

4. Zinc in waters.

Another device that has played a prominent role in Dr. West's research is the standard dust generator developed under NSF funding. The dust generator allows the chemist to produce dust samples of any desired trace element composition, allowing for the preparation of the precisely standardized samples required for interlaboratory comparisons, for standardizing test protocols, and for inhalation studies in toxicological research. By modifying the operating procedures, the dust generator has also been used to produce sulfuric acid aerosol. A method was then developed for producing standard sulfuric acid aerosol samples for calibration and interlaboratory methodology comparisons. Using similar techniques, the dust generator can be used to construct complex atmospheric samples containing prescribed amounts of soot, metal particulate, sulfuric acid aerosol, and gaseous pollutants. Such skill is valuable in toxicological, industrial hygiene, and air pollution studies.

The West group's work with sulfuric acid aerosol resulted in a number of new analytical techniques:

1. A spectrophotometric method for determining atmospheric acidity that is particularly suited to determination of sulfuric acid aerosol.
2. A method for determining trace amounts of sulfate by precipitating and then thermally reducing perimidylammonium sulfate to yield SO_2 which can then be measured by either the West-Gaeke method or the flame photometric procedure.
3. A method for determining sulfuric acid aerosols in air samples collected on a sequential tape sampler. Sequential tape samplers, used by many air pollution control agencies for measuring hourly total aerosol

concentrations, consist of mechanisms that periodically step an area of clean filter tape into an air sampling stream for collection of the impinging aerosols.

4. A method for determining total acidity in sequential tape samples, including sulfuric acid and volatile acids together with salts that hydrolyze to produce protons.

5. A method for determining sulfuric acid aerosols (also sulfur trioxide and soluble sulfate salts) in ambient air after collection on perimidylammonium bromide impregnated filters with which the sulfuric acid reacts topochemically, forming perimidylammonium sulfate which is then pyrolyzed to produce stoichiometric amounts of SO_2, a direct measure of the sulfuric acid aerosol content of the sample. During this research, the West group made a number of evaluations of equipment and procedures. One such study was a radiochemical evaluation of the separation of sulfuric acid aerosol by microdiffusion from various filter media. Some work was done in optimizing the procedure and the separation apparatus after which it was determined that the best diffusion characteristics were exhibited by Mitex and Poco graphite filters.

An area in which Dr. West and his associates have exhibited considerable skill is in sampling by means of permeation. Permeation sampling methods, including calibration of the permeation devices and subsequent laboratory analysis, were developed for the following pollutants:

1. Sulfur dioxide in the ambient air, permeated through a silicone membrane, trapped, and stabilized as dichlorosulfitomercurate (II) using the West-Gaeke method;

2. Nitrogen dioxide in the ambient air; and

3. Carbon monoxide in air using a silver sol colorimetric reagent.

While working with permeation sampling techniques, Dr. West developed the first of what may well become a whole family of personal monitoring devices for industrial hygiene application. Earlier this year, the West group introduced a small permeation device for measuring vinyl chloride. These badge dosimeters will be worn by workers in the vinyl plastic industry so that their exposure to this debilitating pollutant can be both monitored and controlled. According to Dr. West, this same technology can be expanded to develop personal monitors for a variety of hazardous industrial pollutants.

Another area investigated is the integrity of trace element determination in aqueous media, particularly when the sample is retained for some period of time before laboratory analysis is performed. They have quantified and documented adsorption losses on various types of container walls for the following trace elements in solution:

1. chromium (III) and chromium (VI)

2. selenium

3. zinc, cadmium, barium, beryllium, and manganese.

After developing an improved heated graphite atomizer (HGA) for use in atomic absorption measurements, the West group developed a procedure, using this improved HGA for measuring selenium, in which the volatile hydride of that element is evolved from aqueous solution by action of a reducing agent. In previous work, they had already developed a method for collecting selenium samples from ambient air by impingement in water.

Since trace metals may be found in natural waters as citrate complexes, Dr. West's group developed a fluorimetric method for the determination of trace concentrations of citrate in aqueous systems.

Utilization Objectives

The users of the products of Dr. West's research fall basically into three major categories: practicing analytical chemists, groups charged with setting standards, and chemical equipment manufacturers.

The analytical chemist user group is primarily interested in new or improved analytical methods and new equipment. This group includes the State and local regulatory agencies and private laboratories charged with monitoring environmental pollution, private consulting chemists, and fellow researchers in analytical methodology. The standards setting user group is working to expand and improve standard reference methodology, and each new West method and technique is evaluated in this context. This group includes such major government regulatory agencies as the National Institute for Occupational Safety and Health (NIOSH), the Environmental Protection Agency (EPA), and National Bureau of Standards (NBS); and such private testing groups as ASTM. The chemical equipment manufacturers' interest in Dr. West's work is obvious in that his group is constantly developing new and improved sampling and laboratory apparatus. Two products that have attracted considerable attention from manufacturers are the ring oven and the vinyl chloride personal monitor.

A key and underlying goal of all of Dr. West's efforts has been to develop simple, inexpensive techniques for monitoring environmental pollutants. He has not attempted to develop complex automated instrumentation which is often

needed for research accuracy; rather, he has tried to develop methods and procedures that are within reach of the private and institution sector of the world as well as regulatory agencies. He has aimed his research toward the users and not the highly technical literature. For example, when Dr. West's group develops a new monitor, they make a number of the devices available directly to users for evaluation.

Dr. West's information dissemination techniques have been varied and are usually geared to the specific product or interest group. For example, since there has been considerable public concern about the health effects of vinyl chloride, Dr. West, in addition to using normal scientific channels, used the public news media to announce the vinyl chloride personal monitor. Several users first read about the Vinyl Chloride Monitor (VCM) in their local newspaper. In addition, Dr. West's group has published 17 papers since 1972 based on work supported by NSF (see Appendix) and currently has several others in press. Dr. West also utilizes well the lecture/workshop tour in spreading the word about the LSU research activities.

The West group is very strong in personal contact and following up leads on potential users. This is an inference made from examining his list of contacts for this calendar year to date, which contains some 56 names of persons and organizations. Prior to 1976, Dr. West did not keep organized records of correspondence and personal contacts.

To aid in securing acceptance of a method, the LSU group actively supports field evaluation studies of their methods and devices by independent investigators and testing groups. They also actively pursue users who will commercialize a method and, consequently, increase its utilization potential.

Since the LSU work is geared to the development of techniques that should have widespread appeal to the user community (both private and government) because of simplicity and economy, Dr. West has been acutely aware of the necessity to publicize his work both in and out of the scientific community.

Utilization Obtained

The key to widespread utilization of an analytical method or technique is in having it accepted as a standard procedure. In this area, Dr. West has managed to achieve some very excellent results, particularly in having 11 methods recognized by the Scientific Committee for Problems of The Environment (SCOPE). It should be noted that Dr. West is a member of SCOPE. Two of his methods are also very close to acceptance by the ASTM.

Basically, the products of Dr. West's research are either currently being used or are being evaluated for potential use. Users fall into either or both of these categories: Some are using established West methods, others are evaluating new work, and still others are doing both.

Dr. James P. Lodge, Jr., falls into the latter group. An independent consulting chemist in Boulder, Colorado, Dr. Lodge states: "I am a close follower of Phil West's work, which I have generally found to be very carefully executed and very dependable. I am one of the first people he converted to the ring-oven technique and have been using the West-Gaeke method since it was introduced." Dr. Lodge says that he always reads Dr. West's latest publications because he has found so much of West's past work to be useful to the consulting chemist.

A similar sentiment was expressed by a former colleague of West's, Dr. George Lyles, who is President of Kem-Tech Laboratories in Baton Rouge, Louisiana. Long a proponent of the West-Gaeke method, Kem-Tech is heavily involved in ring-oven work and is currently expanding into atomic absorption work pioneered by the West group. Dr. West was once part owner of Kem-Tech and communicates with its staff on a regular basis.

Dr. G. C. Gaeke, co-developer of the West-Gaeke method for sulfur dioxide determination (1956), also communicates regularly with Dr. West. From his position as Senior Research Associate in charge of the development of analytical methods for the Ethyl Corporation in Baton Rouge, Dr. Gaeke has followed West's work over the years with interest. One research area of particular interest to Ethyl is in determination of sulfuric acid aerosol, which is a byproduct of the new catalytic mufflers. Since Ethyl is a manufacturer of leaded, premium gasoline, they are extremely interested in the fate of the catalytic converter and are closely following West's sulfuric acid aerosol work. As a potential user, Ethyl Corporation has also helped Dr. West in the development of his vinyl chloride personal monitor by performing several field evaluation studies of the device. Although Ethyl Corporation has never given Dr. West direct financial support, they have encouraged his work through the loan of laboratory equipment.

Another current user and close follower of Dr. West's research is Dr. Benjamin T. Levadie, Chief of the Occupational Health Laboratories of the Vermont Department of Health, Barre, Vermont. Dr. Levadie could not seem to say enough about "the splendid work that Phil is doing . . . a tremendous man. I particu-

larly like his permeation approach to ambient air monitoring." Although he considers the approach a bit "exotic," he is, nevertheless, impressed with the ring-oven technique for trace element determination and considers West's work in sulfur dioxide and sulfuric acid aerosol determination "intriguing." Dr. Levadie was originally introduced to Dr. West because of Levadie's position as Chairman of the ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres. Dr. Levadie reports that the "Lead Method" and "Total Proton Non-Volatile Acid Method" are progressing through his committee and will soon be voted on as ASTM Standard Methods.

Dr. Robert S. Braman is a research chemist at the University of South Florida in Tampa and is also involved with the development of analytical methods and techniques. Even though they are "after a piece of the same pie," there has been a certain amount of "cross-pollination" with Dr. West's LSU group, particularly in the comparison of techniques. Both groups have studied the environmental trace element selenium and have openly exchanged data and information.

As Environmental and Chemical Product Manager for the Arthur H. Thomas Company in Philadelphia, Mr. C. E. Matthews was approached a few years ago by Dr. West who offered them an improved ring oven, an item that the Thomas Company had dropped from its line because it was not selling. Using Dr. West's experience and guidance, the firm developed the "Pollution Trace Oven" and the associated chemical kit for determining eight trace elements. Mr. Matthews indicated that Dr. West's manual of ring-oven techniques for determining eight toxic metals is being used for instructional purposes by EPA at the Research Triangle Park (North Carolina) National Environmental Research Center (NERC). This was confirmed by Dr. John D. Clements, who is Chief of the Quality Assurance

Branch of the Environmental Monitoring Support Laboratory at EPA/RTP. Dr. Clements indicated there seemed to be a growing acceptance of the ring-oven approach to trace element determination, an opinion corroborated by steadily increasing sales of ring ovens by the A. H. Thomas Company. Mr. Matthews, who is also Third Vice Chairman of ASTM's Committee D-22 concluded, "Dr. West's most important contributions stem from his continual efforts to develop analytical techniques that are sound and, at the same time, inexpensive."

The National Bureau of Standards, Analytical Chemistry Division in Washington, D.C., is currently involved with compiling standard reference materials for trace elements found in the environment. Knowing this, Dr. West has kept this group up to date on his trace element research findings. According to former Division Chief, Dr. Donald A. Becker, now Scientific Assistant to the Director of the Institute of Materials Research, Dr. West has done significant work with the determination of trace elements and also with losses of trace elements on container walls during storage. The latter work is of particular immediate interest to the National Bureau of Standards as they have a cooperative program with the Environmental Protection Agency called the National Environmental Specimen Bank. In this program, the two agencies are studying the feasibility of long-term storage of samples. According to Dr. Becker, Dr. West has quantified the rate of loss to container walls and the maximum sample to analysis time for a number of common trace elements. He has also developed several techniques for preventing trace element losses during periods of sample storage.

Dr. James E. Hunt, Special Studies Research Officer for the Ontario Ministry of the Environment in Toronto, is heavily involved with field testing promising new instrumentation and techniques. Two such field evaluation studies currently nearing completion involve Dr. West's "Reverse Permeation Sulfur

Dioxide Monitor" and his "Impregnated Filter Sulfuric Acid Aerosol Method," both of which are being compared to current state-of-the-art techniques and monitoring devices. Hunt learned of the So_2 monitor from the open literature and has since maintained regular personal contact with West regarding new devices and methods. Dr. Hunt mentioned that a similar study conducted by Collin Killick in England produced a favorable comparison between West's SO_2 permeation device and a continuous SO_2 monitor.* Dr. Hunt is now designing an experiment to evaluate Dr. West's new sensitive turbidimetric technique for sulfate which, although temperature dependent to the point of only being operable above 0°C, is nonetheless a promising device in that it is extremely inexpensive.

Another field evaluation study of the reverse permeation sulfur dioxide monitor has been conducted by the Phoenix, Arizona, branch of Dames and Moore. Senior Chemist Dr. John Gordon read about the device in Environmental Science and Technology and shortly thereafter met with Dr. West to discuss testing the device. The test was conducted in the Arizona desert, and the results were quite satisfactory, particularly since the monitor required no power supply and could operate in sub-freezing temperatures. Dames and Moore sees considerable potential for the device in remote monitoring applications, but recognizes that its use will be somewhat limited until the technique is accepted in the United States as a standard method. Dr. Gordon points out that its approval by SCOPE has made it tenuously acceptable and hopes that ASTM will follow suit.

In addition to the Ethyl Corporation, a number of companies have expressed an interest in the vinyl chloride personal monitor. Mr. Gordon Engdahl, an industrial hygienist with Dow Chemical in Midland, Michigan, is responsible for

*Environmental Science and Technology, Vol. 10, p. 473, May 1976

monitoring small amounts of toxic chemicals to which Dow workers may be exposed. Mr. Engdahl met Dr. West last March at the ASTM meeting in Orlando, Florida, where West made a short presentation on the vinyl chloride monitor (VCM). Mr. Engdahl returned to Dow with several of the badges for testing. Dow is now experimenting with different storage chemicals and membrane materials and, although they feel they can improve the device, they are not altering the basic design concept. Mr. Engdahl points out that although the National Institute of Occupational Safety and Health is doing some of this type of work, "they are basically understaffed and are thus concentrating their efforts on setting standards rather than on scientifically sound monitoring." He considers Dr. West's VCM a "definite step in the right direction" in industrial hygiene air monitoring devices and says that "this is an area that should receive more funding."

Dr. Jess Patton, Engineering Manager for Environmental and Health/Safety Products for Bendix Corporation in Louisburg, West Virginia, is a chemist who has worked with many of Dr. West's analytical techniques over the years and holds West in the highest regard. When the VCM was announced in the news media last February, it seemed to Dr. Patton to be a "fantastic idea," far superior to the plumbing-incumbered dosimeters currently in use. Shortly thereafter, Dr. Patton went to LSU to discuss the VCM and to express Bendix Corporation's interest in marketing the device. After a round of testing, Bendix remains enthusiastic. However, Dr. Patton did point out that calibration of the VCM is causing some problems and more development is needed in this area.

Other companies have expressed interest in marketing the device after learning of it through the news media. Ms. Sue Kurtz, an Environmental Analyst in B.F. Goodrich's Research and Development Center in Brecksville, Ohio,

indicated that Goodrich was interested in the VCM both as a commercial product and for industrial hygiene application in their own plants. Goodrich is currently testing the VCM, and further action is pending the results. Similar interest was expressed by Dr. David L. Braun, Environmental Monitoring Supervisor for 3-M Corporation in St. Paul, Minnesota, and by Mr. Michael A. Sweet, Market Development Manager for Instruments for the Edmont-Wilson Company of Coshocton, Ohio.

Mr. Joseph R. Williams, an analytical chemist for the National Institute for Occupational Safety and Health in Morgantown, West Virginia, was also present at the Orlando ASTM meeting in March when Dr. West introduced the VCM. Since the permeation principle for personal monitors is an area of particular interest to Mr. Williams, he brought two of the devices back to Morgantown for further testing. His current experiment involves using the VCM to monitor hydrogen sulfide.

The above contacts represent typical users of monitors developed by Dr. West's team. For example, some 30 to 40 VCM's are currently in the field for tests.

In some cases, there are requirements for large numbers of monitors. The Canadian government is considering utilizing some 200 SO_2 monitors to survey the potential pollution from a nickel production facility at Sudbury, Ontario. This study will cover a 300+ mile radius from the factory. The need for inexpensive monitors in applications such as this is obvious. Dr. West's team will provide filters and make the measurements for some 50 monitors in the initial part of this program.

Dr. West is himself a user of the research products developed under the RANN program. He routinely works with industry on studies that are company

confidential. A typical program which falls into this category is one recently performed for a major petrochemical company in conjunction with the State of Louisiana Air Pollution Control Commission in which an aircraft was used to survey a large area for ozone, sulfate, and hydrocarbons. RANN-developed methods and techniques were used in the study.

Features

A number of factors have influenced the utilization of the research products from this RANN program. The Principal Investigator, Dr. West, made every effort to see that his research was made available to the user community both during and following developmental efforts. The nature of the user community is such that they, on the one hand, were extremely interested in new techniques but, on the other, were reluctant to use a new, unproven method. Also, many users may be using Dr. West's research without being aware of it. For example, Dr. West often showed how not to do an analysis, which is of extreme value to the user community.

Early in his work Dr. West became aware of the often extreme gap existing between the research community in the environmental field and the often unsatisfied industrial or institutional people who have the problems. He, therefore, made every effort to direct his research to the latter community of users. In keeping with this philosophy, he often turned to the news media to call attention to his research products. He also made every effort to work through such organizations as ASTM and SCOPE to make his research products available to the public.

NSF management did not appear to play any major role in the dissemination of the research products from this effort. Their participation was primarily

as a funding agency and was aimed at filling a definite gap in a needed field. The investigator was hampered from time to time by lack of funds needed to maintain continuity in his work.

By making monitors available to the user community for field testing, Dr. West was able not only to spread the word that a new monitor or method was available, but also to show that it had been proven in the real world. Dr. West spends considerable time corresponding by telephone and letter in addition to seeing large numbers of potential users during visits to his laboratories. For example, in the short period of time between January and June 1976, he had over 57 contacts concerning his VCM. Between March and June 1976, he had some 18 visitors to his laboratories.

The quality of the research certainly enhanced its acceptance by the user community in all cases. The very fact that Dr. West's research was aimed at simple, inexpensive techniques for monitoring pollutants in the environment is in the users' interest. Again, he did not aim for highly sophisticated instrumentation; hence, he did not attract the attention of that group of basic researchers.

There is a major barrier to the work performed on this effort simply because it is new and must be proven. There is a reluctance by the community to use a technique until proven; hence, a time delay is automatically limiting to the application of the research.

The major strength of the work is that it definitely fills a gap in the environmental and health monitoring fields; low cost techniques. Dr. West retained throughout, the goal of simplicity and low cost as a guide. The major weakness probably was tackling many of the problems instead of specializing on some of the more urgent ones.

Conclusions

The research effort described in the preceding discussion has resulted in a number of definite research products. Some of these products have found immediate application and utilization, while others are still being evaluated and studied for future use. An underlying theme of this total effort has been the development of reliable analytical methods for the determination of trace elements that are simple and inexpensive. The techniques and methods developed during the program have, in fact, kept to this goal; consequently, they are not as sophisticated and complex as those being developed for refined research programs. Since they are, in general, simple, they are not as likely to be as accurate as the more complex methods. Many users will undoubtedly be small businesses, monitoring laboratories of small towns, laboratories of underdeveloped countries, and others who cannot make the financial commitment for modern instrumentation and the personnel to use them. Many of the techniques (seven of the eleven methods adopted by SCOPE and two under consideration by ASTM) involve "ring-oven" procedures. A more precise method for calibrating the ring oven is needed before it will be accepted by the majority of analytical chemists. Data obtained by the simple techniques will likely be reliable when collected by trained personnel under ideal conditions, but this has not been proven for the field applications with nontechnical workers. Again, it should be emphasized that the goals of the work were not to compete with the sophisticated methods. There are many applications in which order-of-magnitude answers are what is required.

The motivation and enthusiasm of Dr. West and his colleagues resulted in a dissemination effort that was highly successful. There was every effort made by

the researchers to make the results of their work immediately available for use. They tried and proved that the unusual use of the news media could be effective in dissemination of results to the user community when that community was not part of the scientific community. Considerable time and energy was expended by the West team in communicating their results to the outside world. Whether the specific research products are accepted by the user community will not depend on the efforts made by the investigators. It will depend more on whether the regulatory agencies adopt the methods.

Dr. West and his associates feel that the funding level was definitely below that required for maximum program efficiency. They also feel that undue time and effort was required to prepare material for review and to wait for review processes in a case where the investigators had a proven and demonstrated capability and reputation.

A better defined goal and expected research product on the part of RANN followed up by publicity by RANN could have resulted in a more directed and successful program to meet an immediate national need. For example, had the work been directed to the simple and inexpensive methods as a focal point from the beginning with publicity directed to those users outside the scientific community, the program would certainly have been enhanced.

From a utilization view, the research effort has been successful. The degree of ultimate success will depend on a sanction by regulatory agencies as well as agencies such as SCOPE, ASTM, and other such organizations. In this field of work, there is a great reluctance to change, and new methods, procedures, and devices are always slow to be accepted and slow to be replaced once accepted.

Appendix

PAPERS PUBLISHED BY DR. WEST'S GROUP, 1972-76, BASED ON NSF-SUPPORTED WORK:

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3. Dharmarajan, V. and West, P.W., "A Precise Method for the Generation of Standard Metal Salt Particulates," Analytica Chimica Acta. Vol. 69 (1974), pp. 43-48.

4. West, P.W., et al., "The Determination of Sulfuric Acid Aerosols," Analytica Chimica Acta. Vol. 69 (1974), pp. 111-116.

5. McDaniel, M. and West, P.W., "Microdetermination of Manganese in Airborne Particulate Samples by Means of the Ring Oven Technique," Analytica Chimica Acta. Vol. 70 (1974), pp. 482-484.

6. West, P.W. and Chiang, J.J., "Spectrophotometric Determination of Atmospheric Acidity by Means of the Displacement of the Equilibrium of Acid-Base Indicators," Journal of the Air Pollution Control Association. Vol. 24, No. 7 (1974), pp. 671-673.

7. "Radiochemical Evaluation of the Separation of H_2SO_4 Aerosol by Microdiffusion from Various Filter Media," Mikrochimica Acta [Wien] (1974), pp. 391-402.

8. Bustin, R. and West, P.W., "Determination of Trace Concentrations of Citrate in Aqueous Systems," Analytica Chimica Acta. Vol. 68 (1974), pp. 317-320.

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10. Thomas, R.L., et al., "Convenient Method for Generation of Sulfuric Acid Aerosol," Environmental Science and Technology. Vol. 8 (1974), p. 390.

11. Shendrikar, A.D. and West, P.W., "The Rate of Loss of Selenium from Aqueous Solution Stored in Various Containers," Analytica Chimica Acta. Vol. 74 (1975), pp. 189-191.

12. Maddalone, R.F., "Determination of Sulfate by Thermal Reduction of Perimidylammonium Sulfate," Analytica Chimica Acta. Vol. 47 (1975), p. 2.

13. West, F.K. and West, P.W., "Determining Trace Metals by the Ring Oven Technique--Part 1, Copper, Cadmium, and Zinc," Journal of the Air Pollution Control Association. Vol. 67 (1975), pp. 15-19.

14. "A Permeation Method for the Determination of Average Concentrations of Carbon Monoxide in the Atmosphere," Analytica Chimica Acta. Vol. 77 (1975), pp. 245-254.

15. "Sulfuric Acid Aerosol," The Science of the Total Environment. Vol. 4 (1975), pp. 279-298.

16. Maddalone, R.F., et al., "Measurement of Sulfuric Acid Aerosol and Total Sulfate Content of Ambient Air," Environmental Science and Technology. Vol. 10 (1976) p. 162.

17. Thomas, R.L., et al., "Measurement of Sulfuric Acid Aerosol, Sulfur, Trioxide, and the Total Sulfate Content of the Ambient Air," Analytical Chemistry. Vol. 48 (1976), p. 639.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 43

THE DELAWARE ESTUARY SYSTEM:

ENVIRONMENTAL IMPACTS AND SOCIOECONOMIC EFFECTS

UNIVERSITY OF DELAWARE

Case Investigator:
M. Massoglia

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:
C. J. Leith

Head of the Department of Geosciences
North Carolina State University
Raleigh, North Carolina 27607

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THE DELAWARE ESTUARY SYSTEM:

ENVIRONMENTAL IMPACTS AND SOCIOECONOMIC EFFECTS

Introduction and Summary

The national concern with conflicts between socioeconomic benefits and environmental deterioration is quite apparent in estuary development. While the "quality of life" benefits in many ways from economic development, it is adversely affected by the often concomitant deterioration of environmental quality. To make rational decisions relative to estuary development that optimize the balance between socioeconomic benefits and environmental deterioration requires knowledge of the effects of and the trade-offs between various development strategies. That was the broad purpose of this research.

Economic expansion in an estuary requires:

- increased electric power generation;
- water transportation improvements;
- expansion of residential and industrial facilities.

Environmental quality and attendent social needs that often conflict with the above include:

- increased recreational facilities;
- maintenance or restoration of environmental quality; and
- maintenance or restoration of fisheries.

In 1972, responding to a proposal submitted by a consortium consisting of the University of Delaware, Rutgers University, and the Philadelphia

Academy of Natural Sciences, NSF/RANN funded a study of environmental quality and socioeconomic development for the Delaware estuary system that would address these conflicts. Project information is given in table 43-1. Because all estuary systems are faced with the same basic needs, it was anticipated that the results of the study, in addition to contributing to the balanced development of the Delaware estuary, also could be applied to other estuarine systems in the United States. The primary product of the research was to be an initial assessment of the management problems of the Delaware Bay and various aspects of the environment.

The basic research objective was to determine if and how the Delaware estuary could be managed both to satisfy socioeconomic demands for growth and to maintain or upgrade evironmental quality. Phase I of the project, funded for 18 months, was an exploratory and planning study designed to cover a wide range of subjects, assess the state-of-the-art, and prepare a detailed proposal for Phase II. Upon the completion of Phase I, a detailed proposal for the implementation phase (Phase II) was submitted to NSF/RANN. However, this second phase was not funded primarily because of its high cost--over $5,000,000. Certain components of the proposed Phase II were funded by NSF/RANN as individual projects, e.g., "Effects of Crude Oil Transfer and Up-stream Refineries on the Delaware Bay," "Multi-Purpose Off-shore Industrial-Port Islands for the Atlantic and Gulf Coasts," and "Petroleum Industry in the Delaware Estuary."

The output of the Phase I research is a description of the then current status of knowledge about the information needs for management of the estuary, and a plan of research that would fulfill these needs. The Principal Investigators were reluctant to give wide dissemination to the results

Table 43-1. PROJECT INFORMATION

Project Title The Delaware Estuary System, Environmental Impacts and Socioeconomic Effects	Grant/Contract No. GI 33369
RANN Program Manager Dr. Ralph Perhac (now with EPRI)	RANN Program Area Regional Environmental Systems
Principal Investigator(s) Ruth Patrick William S. Gaither William Whipple, Jr.	Schedule Start: 1 April 1972 End: 30 Sep. 1973
Institution(s) The Academy of Natural Sciences, Philadelphia, Pa. University of Delaware, Newark, Delaware Rutgers University, New Brunswick, New Jersey	Funding NSF: $380,000 Other:
Contributors/Collaborators Over forty researchers from the co-principal investigators' institutions, University of Pennsylvania, and Princeton.	
User Advisory Committee See Appendix A	
Precursor Activities None	

of Phase I research because of the danger that hasty action might be taken without adequate scientific foundation. Thus, the primary users are the investigators themselves who used the results as background for the development of a detailed research plan for what was to have been the implementation phase of the study as originally envisioned. In this sense, the research results can be considered as having been well utilized in that they formed the basis for subsequent research that was proposed to RANN and other potential sponsors.

Indirect utilization of the results, in the form of outputs from the subsequent research projects, appears to be mixed, with some agencies using them and others not. Final evaluation of utilization must await completion of the research currently underway.

Research Description

Management of the Delaware River system involves both water resource and environmental problems. Federal, State, regional, and other regulatory agencies have been and are addressing these problems. To assist planners and decisionmakers in estuary management, a consortium--the University of Delaware, Rutgers University, and the Philadelphia Academy of Natural Sciences--proposed a research study consisting of two phases. Phase I was to be a preliminary planning study to analyze the state-of-the-art in relevant disciplines, to evaluate and describe the particular situations that were developing in the Delaware River basin, and to prepare a detailed proposal for the research identified as being necessary for the sound management of the estuary system. Phase II was to be the implementation of the recommendations generated during Phase I.

Phase I, an 18-month program, was initially funded by NSF/RANN for $370,000. In 1973, a supplemental $10,000 was provided for a special survey of key estuary managers and their problems. Dr. Gaither (Delaware), General Whipple (Rutgers), and Dr. Patrick (Academy of Natural Sciences) served as Co-principal Investigators with joint responsiblity for overall performance, for assessing the adequacy of performance of other investigators, and keeping the program on schedule. In addition, General Whipple and Dr. Patrick actively engaged in the research while Dr. Gaither served as project administrator.

The program began on April 1, 1972 and was completed in September 1973 with the submission of a series of reports and a proposal for Phase II research. Upon completion of Phase I the consortium found it mutually advantageous to dissolve and an informal agreement was reached as to research responsibilities in the Delaware River basin based on institutional interests and expertise. The University of Delaware assumed responsibility for the lower estuary, and Rutgers and the Academy of Natural Sciences, the upper estuary. Phase II was not funded as an entity. However, selected components of the proposed research were funded individually.

Specific problem areas addressed by the project were (1) the sources and fates of pollutants in the estuary, (2) the future net increases in wastes resulting from increased population growth and development, (3) the possibilities of reduction in net pollution residuals through treatment, (4) the impacts of present and future pollution residuals upon estuarine ecosystems and recreational water quality, and (5) the socioeconomic impacts of the above. The research was preliminary in nature, being designed to assemble relevant information, provide an assessment of certain key situations and relationships, and set the stage for further more definitive research.

The emphasis in the Phase I research effort was on the synthesis of existing knowledge and on the identity of research requirements as they pertained to the following specific topics in the Delaware estuary:

- biological value of the marshlands,
- impacts of a deepwater terminal,
- ecological effects of thermal additions,
- effects of pollutants on fish and shellfish, and
- problems in evaluating environmental quality.

To accomplish this, an interdisciplinary-interinstitutional task force of researchers from the consortium, the University of Pennsylvania, and Princeton University, was organized into seven working groups.

1. Economic and Social Analysis. Chairman: General Whipple, Rutgers University

   The objective of this group was to determine the nature of existing and projected economic activities. Research areas included projection of demographic, population, and industrial growth in order to assess future pollution impacts; and the determination of economic and social impacts of environmental degradation or improvement.

2. Water Quality and Transfer Relationships. Chairman: General Whipple Rutgers University

   The task of this group was to consider in-depth evaluation of existing pollution as impacted by economic activity, and dynamic changes within the river itself. The development of more accurate methods of analysis of the complex processes through which pollutants change physically, chemically, and biochemically as they move back and forth in the estuary was to be emphasized.

3. Upper Estuary Biology. Chairman: Dr. Patrick, Academy of Natural Sciences

This task was designed to evaluate potential threats to the upper estuary and to determine areas requiring further study to more accurately estimate the threats.

4. Marsh Biology. Chairman: Dr. Patrick, Academy of Natural Sciences

Phase I marsh studies were concerned with the compilation and evaluation of published and unpublished data concerning marshes in the estuary. Each of the marshes was to be visited to determine present type and condition, imminency of alteration from man's activity, type of man's activity that would alter it, and seriousness of the proposed alterations.

5. Triple Bend Study. Chairman: Dr. Kupferman, University of Delaware

The Triple Bend area is the tortuous section of the estuary just below Wilmington that forms the transition between the river-like upper estuary and the wide bay below. Because the Triple Bend is a transition zone, it possesses its own unique characteristics and requires special study. Studies were to be conducted on the effects of deepening the Chesapeake and Delaware Canal, especially on rates of transfer of fish eggs and larvae, and on the thermal effects of the Salem nuclear power plant.

6. Lower Estuary Hydrodynamics and Modeling. Chairman: Dr. Kupferman, University of Delaware

This group focused its attention on the applicability of different mathematical modeling techniques to the physical dynamics of the Delaware Bay. An understanding of the physical dynamics would assist in the solution of biological, chemical, and geological problems in the lower estuary.

7. Deepwater Biology, Lower Estuary. Chairman: Dr. Maurer, University of Delaware

Major project questions were to be posed and tentative answers postulated through a survey of the availability of data of prior and ongoing research in the lower estuary. Plans for Phase II would be based on analysis of data-rich and data-poor areas identified during the performance of this task.

Dr. Gaither coordinated tasks 5, 6, and 7. Publications generated by the project are listed in Appendix B.

As previously mentioned, Phase II of the project was not funded as an entity. The following components were funded separetely by the RANN Division of Environmental Research and Technology as part of the Regional Environmental Systems Program.

The Petroleum Industry in the Delaware Estuary
Principal Investigator: General William Whipple, Jr., Rutgers University
NSF Grant No. GI 42282

This project has three main goals: (1) to measure the amounts and types of petroleum pollutants entering the Delaware estuary, (2) to evaluate the effects of the pollutants on estuary fauna, and (3) to evaluate the economic impact of pollution damage in terms of cost-benefit analysis. The principal value of the project lies in advancing existing knowledge of the various elements of petroleum derived pollution on the organic environment, and identifying pollution sources and the magnitude of contributions from these sources. Initial funding for this five-year program was $284,000 (March 1974-June 1975). Second- and third-year funding was $450,000 and $350,000, respectively.

Research on the Effects of Crude Oil Transfer and Upstream Refineries on Delaware Bay
Principal Investigator: Dr. Robert B. Biggs, University of Delaware*
NSF Grant No. CI 41896

This project has the goal of conducting timely studies on refinery residuals and oil transfer operations as they impact on the Delaware Bay. The project was conceptualized in three components: (1) a planning study for a four-year research program designed to provide operational management criteria, (2) a nineteen-month study designed to provide biological baseline data on the ecology of marine biota prior to anticipated increases in crude oil transfer, and (3) a nineteen-month study designed to provide a user-oriented predictive model for oil slick movement in the Delaware Bay. Initially funded for $308,000 (March 1974-May 1975), the project received continuation funding of $24,598 (June 1975-august 1975). A separate grant for $160,000 (April 1976-March 1977) was awarded to refine and complete the mathematical model for oil spill trajectories (Grant 7610618, Computer Model for Oil Movement in Delaware Bay.)

An Evaluation of Multi-Purpose Offshore Industrial Port Islands
Principal Investigator: Dr. Robert B. Biggs, University of Delaware
NSF Grant No. GI 42282

This project addressed the need for expanding the deep draft cargo transfer capacity on the East Coast of the United States. The objective was to determine the economic feasibility of multi-purpose offshore industrial port islands for the Atlantic and Gulf coasts as a means of providing deep-water facilities with a minimum of adverse environmental and social impacts. The project was funded for $216,830 for 12 months beginning May 1, 1974 and

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*Dr. Biggs was a member of the University of Delaware component of the consortium.

extended for three months at no added cost. No continuation funds were provided at the conclusion of the grant period.

Utilization Objectives

The agencies involved in the regulation and management of the Delaware estuary were considered to be the primary users of the results of the overall research program, Phase I and Phase II. The output from Phase I research was to be used by the project team in developing the requirements for the total research deemed necessary for the effective management of the estuary. The Principal Investigators planned a conservative approach to the dissemination of research results as evidenced by this statement from the proposal covering the dissemination of research results: "The responsible scientist must move with care so as not to arouse public expectations which cannot be fulfilled, and he should avoid controversies in favor of persuasion."

The audience to which results were to be disseminated included the scientific communities concerned with the study, other concerned professionals, and the public. A climate favorable to the dissemination of the research results was to be created through contacts with action agency representatives and the advisory council. As interim reports neared completion, small, restricted attendance conferences would be held at which the reports could be reviewed prior to public release. The results would then be published as reports, in abbreviated form in professional journals, and presented at professional meetings and public meetings as appropriate.

A narrow approach to utilization of the research results would involve an assessment of only the primary utilization of the Phase I output and the

impact it may have had on the initiation and funding of subsequent research. A broader outlook, and the one that is followed in this utilization case study, involves consideration of not only the primary utilization of, but also the secondary utilization of research results emanating from the individual research studies that were funded following completion of Phase I.

Utilization Obtained

With the exception of the offshore port research project, the research projects initiated as a result of Phase I are still underway. Thus, all of of final products of the research are not available to the potential user communities. However, interim results have been made available to agencies both within and outside the Delaware River basin.

Reactions of reported users of the research are presented below.

Federal Agencies

Dr. John Burns, Chief, Environmental Resources Branch, Engineering Division, U.S. Army Engineer District, Philadelphia, Pennsylvania

Dr. Burns is aware of and familiar with the RANN sponsored research in the Delaware estuary. He obtains his information on the research through personal contact with the investigators at Rutgers and Delaware. Dr. Burns observed that there appears to be no preplanned dissemination program for lower level personnel. He realizes that the advisory and review committees serve as a dissemination mechanism, but are composed of senior top-level people from the action agencies. As a result, he questions how broadly the research results have been disseminated. The research results which he has seen have served as background data and information sources for his work. Dr. Burns also has doubts as to whether the research results are directly

reaching the industries that pollute the water in their manufacturing operations.

Mr. J. Murphy, Engineering Division, U.S. Army Engineer District
Philadelphia, Pennsylvania

Mr. Murphy was aware of the research projects being conducted in the Delaware estuary under RANN sponsorship through attendance at semi-annual briefing sessions. The work to date was not sufficiently mature to be of immediate value to him.

Mr. Edward Geismar, Basin Commission Coordinator, Water Division.
Environmental Protection Agency, Region III, Philadelphia, Pennsylvania

Mr. Geismar is only peripherally acquainted with the Delaware estuary research. He has not used any of the results and is not aware of their use by other activities in EPA Region III. He has seen an occasional report. Mr. Geismar's contacts with the project have been serendipitous through reports that may reach his desk.

Mr. Richard Black, Office of Port and Intermodal Development
U.S. Maritime Administration

While familiar with Dr. Gaither's work and the offshore island study, Mr. Black had not had occasion to use any of the results of the research.

Mr. Robert Mandancy, Chief, Engineering Systems Division
Office of Water Research and Technology
U.S. Department of the Interior

Mr. Mandancy reported that he could immediately identify three studies of the Delaware upper estuary funded by his office, that were based on recommendations of the Phase I study of the Delaware estuary: B059-NJ Delaware Estuary Runoff and Unrecorded Pollution, B063-NJ Follow-on to B059; and B063-NJ Nitrogen Cycle in the Delaware Estuary.

Captain K. Wyman, U.S. Coast Guard
Port of Philadelphia, Glouster, New Jersey

In his previous assignment at Coast Guard Headquarters as Project Manager, Deepwater Ports, Captain Wyman was aware of the University of Delaware offshore island study and found it of interest even though he did not use any of the research results.

Lt. Daniel Wood, Port Safety and Pollution Officer
Port of Philadelphia, Glouster, New Jersey

Lt. Wood has seen and is familiar with the University of Delaware work on crude oil transfer in the lower estuary. In its present form, the model is of marginal value, but does have potential use when it is completed. The work to date confirms the USCG knowledge of oil spill trajectories.

Regional Agencies

Mr. Herbert A. Howlett, Chief Engineer
Delaware River Basin Commission
West Trenton, New Jersey

The research studies generated by Phase I of the Delaware Estuary Study are still underway and have not yet reached the state where the results are useful to the Delaware River Basin Commission (DRBC). Mr. Howlett expressed the opinion that the studies should have high potential use when they are carried out to completion. Many aspects of the studies resulted from proposals made by DRBC, e.g., productivity of the marshes in the food chain, and the modeling work.

Mr. Howlett considered the project team to be of high caliber. Their work fits into the overall DRBC program, but usefulness and actual use cannot be evaluated until the research is more advanced.

Mr. David Palmer, Ecologist, Environmental Unit
Delaware River Basin Commission
West Trenton, New Jersey

Mr. Palmer reports that he has used the conceptual approaches developed by the crude oil transfer study in his current efforts to develop an overall water quality research program for the DRBC. The work has contributed to his understanding of the cumulative effects of petroleum refineries on the estuary. The research results to date serve as one input to his planning. Of particular value is the exposition of areas in which further research is needed. Mr. Palmer qualified his remarks with the caveat that the Delaware studies are only one part of the whole picture.

State Agencies

Mr. N. C. Vasuki, Division of Environmental Control
Department of Natural Resources
State of Delaware

According to Mr. Vasuki, the Delaware Estuary Study identified gaps in the data base for the lower Delaware estuary. As a result, Delaware undertook various projects to compile data to fill these gaps. The State has completed a mapping of the wetlands and is currently delineating fragile areas as part of the State coastal zone planning process.

The modeling results of the crude oil transfer study, while not used, are of interest and would be considered for use in the event of a disaster in the estuary. Also of particular interest is the information developed during the crude oil transfer study (grant CI 41896, see p. 43-11 for description) on foam lines that form between waters of varying densities and concentration of heavy metals in the foam. This work added to the understanding of the distribution and fate of heavy metals that may find their way into the estuarine system.

The offshore port island study conclusions on the cost of developing such a facility reinforced Delaware's opinion that the costs of this type of facility are excessive.

The biological survey of the bay, which constitutes the first complete listing of biological abundance and distribution, is anticipated to be of considerable value in the evaluation of environmental impact statements and future projects involving the estuary. The listing provides a baseline that can be used in evaluating Environmental Impact Statements and the impact of other projects.

The expertise developed by the project team has been applied to other problems in the Delaware estuary through State sponsored projects at the University.

Clifford H. McConnel, Department of Environmental Resources
Commonwealth of Pennsylvania

While not having actually used the results of the Delaware Estuary Study, Mr. McConnel has found the exposition of the alternatives in estuary development useful in decisionmaking and regulatory activities.

Mr. Richard Boardman, Department of Environmental Resources
Commonwealth of Pennsylvania

Mr. Boardman has not received any interim reports of the research currently underway. He had heard of the various studies through briefing sessions, but had not used any of the results in his work on water quality within the Department of Environmental Resources.

Dr. Glenn Paulson, Assistant Commissioner for Science and
Environmental Protection, State of New Jersey, Trenton, New Jersey

Dr. Paulson stated that he found the work accomplished to date on petroleum industry in the upper Delaware estuary useful. He has been kept

informed of the research through individual discussions with General Whipple, through interim reports, and attendance at periodic briefing sessions. The analysis of institutional arrangements associated with the establishment of effluent standards and water quality standards for petroleum refineries provided Dr. Paulson with insight into such actions in the upper estuary, oriented him on the history and chronology of previous actions, and provided him with input that would not otherwise have been available. The data provided by the research were a valuable input to the development of New Jersey water quality and effluent standards that are currently under review by the Environmental Protection Agency.

Industry

Mr. Ralph Brown, Scientific Advisor
Exxon Research and Development Laboratories, Linden, New Jersey

Mr. Brown's principal concerns are with refinery effluents. The analytical methods and findings developed in the Rutgers project have helped Exxon R&D Labs in evaluating similar problems in other areas. Some of the measurements, e.g., organic materials in runoff water, and bio-measurements, are filling gaps in overall data requirements.

Mr. Brown considers the work timely and appropriate. The study results to date serve to place the impact of refinery effluents in proper context with relation to other sources of pollutants in the estuary.

Dr. Fred T. Weiss, Senior Staff Research Scientist
Shell Development Company, Houston, Texas

Dr. Weiss has followed the Rutgers project, Petroleum Industry in the Delaware Estuary, as a member of the Advisory Committee, as a member of various research committees of the American Petroleum Institute (API), and

in his capacity with Shell Development. Some of the significant results of the research (in Dr. Weiss' opinion) are:

- behavioral aspects of oil under differing conditions, the finding that crude oil does not become phytotoxic while No. 2 refined crude does, is important.
- the floating biological testing lab, developed as a part of the project, permits the on-site analysis of outfall samples, thereby eliminating the potential errors involved in the transport of samples to a shore-based lab.
- studies on the response of marine microorganisms to toxicants.
- calculation of hydrocarbons amount and type, coming into the estuary.
- indications that storm sewer runoff is a major source of petroleum pollutants.

The Whipple/Patrick work addresses the systems as a whole and permits a rational evaluation of the impacts in the estuary.

Dr. Weiss reported that he had been present at hearings in Pennsylvania and New Jersey at which the study results were considered in the regulatory actions of these states.

Mr. D. Kelly O'Day, Chester-Betz Engineers
Philadelphia, Pennsylvania

Mr. O'Day is Project Director for the development of the 208 plan for the Delaware Valley Regional Planning Commission. He is aware of the research that was and is being conducted in the Delaware estuary. He has not used any of the research results to date, but anticipated that the work being done by Rutgers in non-point sources of petrochemical pollutants will be of use to him in the 208 planning process.

Features

The stature of the three Co-principal Investigators in their individual fields and the high caliber of the research staff lend credence to the research and enhance utilization. In many instances, the investigators were sought by potential users to discuss problems of immediate concern. This close and cooperative relationship between the user community and the researchers should facilitate dissemination and utilization of research results when the currently ongoing projects are carried through to completion.

While the initial proposal indicated that a conservative approach to dissemination was contemplated, to preclude hasty action being taken without adequate scientific foundation, the activities of the project team indicate an active program of disseminating research results. The use of an advisory committee, periodic briefings, and an interim report review by a restricted audience appear to be effective vehicles for bringing the research results to the attention of interested persons. The Rutgers/Academy of Natural Sciences team hold semiannual public meetings for potential users. There are indications, however, that the target audience could be broadened to include representatives from the production segment of the industries located on the estuary.

The location of the consortium in relation to the area under study contributed to the research team's awareness of the problems encountered by the agencies involved in estuary management. Considering the multiplicity of Federal, State, regional, and local agencies involved in the area, no institutional or technical barriers to utilization were identified during this case study investigation. While the intense interest in the estuary by

all concerned is certainly one reason for the absence of such barriers, the project team's awareness of the problems involved and the needs of the various agencies in the area can be considered as also being a contributory factor.

Of special interest are the results of the supplemental $10,000 funding for a study of estuary management problems.* The work included 33 interviews with 65 key estuary managers and the codification of resources obtained. This provided an excellent summary of the management problems encountered in the estuary.

Conclusions

The immediate objective of the Phase I research was the identification of research needs and the generation of a proposal to satisfy them. This objective was met. While NSF/RANN did not fund the Phase II research as a package and the consortium dissolved, components were funded by RANN as well as by other agencies. In this sense, the results of the exploratory research phase can be considered as having been well utilized. This resulted in some Phase II research that produced utilizable secondary results.

Some agencies have made considerable use of the secondary results of the research--other responsible action agencies, little or none. However, there are indications that the secondary research results will be utilized once the projects are carried through to completion. An exception to this is the results of the offshore port island study. Although completed, no

*The Delaware Estuary System, Environmental Impacts and Socioeconomic Effects. Annex to Volume 1, Management Agency Problems in the Delaware Estuary. April 1973. Prepared by William V. McGuinness, Jr., Consultant in Environmental Management under letter contract with the Water Resources Institute, Rutgers University.

evidence of utilization of the research results was identified. However, the fact that the study verified previously made estimates as to the high cost of such an activity could be considered valuable.

There appears to be some indications that the research results are not reaching some of the action-level persons in the agencies concerned with management and regulation of the Delaware estuary. The entire blame cannot be laid on the project, however, because the top-level managers were aware of the research through attendance at periodic briefings and review sessions. Breakdown in the dissemination mechanism could have occurred at that level.

There were some allusions that the production personnel in the industries using the waters of the estuary in their manufacturing process were not receiving data on the research. This is understandable, however, when consideration is given to the ongoing nature of the research and the focus on petroleum related activities. Upon completion of the research, the results will be made available to the American Petroleum Institute.

While not so stated in the Phase I proposal, the principal emphasis appeared to be directed toward energy-related waste product pollutants. This is not inappropriate considering the concentration of petroleum and pertroleum-based industries in the Delaware River Basin. There appears to be a need for study of the impact of pollutants from other industries or at least a rationale for the primary concentration on petroleum-derived pollutants.

Appendix A

Advisory Council

The Delaware Estuary, Environmental Impacts and Socio-Economic Effects

Dr. Maruice Rattray
Dept. of Oceanography
University of Washington
Seattle, Washington

Dr. Gilbert F. White
Professor of Geography and
Director, Institute of Behavioral Science
University of Colorado
Boulder, Colorado

Dr. Henry P. Caulfield
Dept. of Political Science
Colorado State University
Fort Collins, Colorado

Dr. Allen Kneese
Economist
Resources for the Future, Inc.
Washington, D. C.

Dr. Luna B. Leopold
U.S. Geological Survey
Dept. of Geology
University of California
Berkeley, California

Dr. John Brooks
Program Director, General Ecology Program
National Science Foundation
Washington, D. C.

Dr. Abel Wolman
Professor Emeritus
Sanitary Engineering
Johns Hopkins University
Baltimore, Maryland

Dr. Bostwick Ketchum
Woods Hole Oceanographic Institute
Woods Hole, Massachusetts

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Appendix B

Delaware Estuary Study Published Reports

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Delaware River Estuarine Marsh Survey (Final Report partial)
University of Delaware
Rutgers University
Academy of Natural Sciences — December 1973
Walton, T.E. III; Patrick, R. — GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Upper Estuary Pollution and Transfer Relationships (Final Report partial)
University of Delaware
Rutgers University
Adademy of Natural Sciences — September 1973
Baker, H. — GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Management Agency Problems in the Delaware Estuary (Final Report)
University of Delaware
Rutgers University
Academy of Natural Sciences — April 1973
McGuinness, W.V. Jr. — GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: A Discussion of the Effects of Certain Potential Toxicants on Fish and Shellfish in the Upper Delaware Estuary (Final Report partial)
University of Delaware
Rutgers University
Academy of Natural Sciences — December 1973
Scheier A., Kiry P. — GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Environmental Quality and its Evaluation (Final Report partial)
University of Delaware
Rutgers University
Academy of Natural Sciences — January 1974
Whipple, W. Jr. — GI33369

Biological Condition of Deepwater Portion of Lower Delaware Bay
University of Delaware at Newark — 1974
Maurer, D. — GI33369-1

Coastal Vegetation of Delaware: The Mapping of Delaware's Coastal Marshes
University of Delaware, College of Marine Studies
Klemas, V.,Daiben, F.C., Bartlett, D.S., et al.
March 1973
GI33369

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Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Impacts of a Deepwater Terminal; Volume I: Environmental Problems Associated with a Deepwater Port in the Delaware Bay Area
University of Delaware, College of Marine Studies
Maurer, D. May 1974
GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Biological Condition of the Deepwater Portion of Lower Delaware Bay (Final Report partial)
University of Delaware, College of Marine Studies
Maurer, D. May 1974
GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Situation Report on Triple Bend and Lower Bay Hydrodynamics (Final Report partial)
University of Delaware, College of Marine Studies
Kupferman, S., Ditmars, J., Polis, D., et al.
May 1974
GI33369

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: Volumes 1-3
Academy of Natural Sciences of Philadelphia
1973

Delaware Estuary System, Environmental Impacts and Socio-Economic Effects: First Semi-Annual Progress Report, Academy of Sciences
University of Delaware October 25, 1972
GI33369

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 44

SEQUENCE EFFECTS IN HETEROGENEOUS NUCLEATION

DESERT RESEARCH INSTITUTE

Case Investigator:
H. L. Hamilton, Jr.

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:
E. G. Droessler

Department of Geosciences
North Carolina State University
Raleigh, North Carolina 27607

Prepared under:
Contract No. NSF C76-17165
National Science Foundation
Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

SEQUENCE EFFECTS IN HETEROGENEOUS NUCLEATION

Introduction and Summary

The development of the capability to beneficially modify several scales of meteorological systems--generally referred to as weather modification--has been a goal of researchers for many years. Beneficial modification may result in an increase in the precipitation amount, the reduction in the size and/or quantity of hail, or the alleviation of the damaging effects of severe storms.

Since 1946, experimental evidence has been available to show that certain substances introduced into liquid water clouds at temperatures below freezing will act as freezing nuclei and cause the growth of ice crystals within the cloud. In clouds at temperatures below freezing, ice crystal formation is considered a necessary prelude to the development of water droplets large enough to precipitate.

In the 25 years following the first demonstration of intentional cloud modification by the introduction of ice crystal nuclei, various techniques and procedures evolved for cloud seeding. These included the generation of nuclei on the ground with the expectancy that they would be carried into the cloud by convective currents, the generation and release of nuclei from an airplane either below the cloud base or at a selected temperature level within the cloud, or the delivery of the nuclei to the selected location within the cloud by means of a rocket-borne pyrotechnic device. Proponents of one procedure raised questions concerning other techniques; in particular, the relative effectiveness of seeding in cloud-free air or within the

cloud was questioned. The question actually concerned the possibility of reduced effectiveness of the nucleating agent that had been exposed to the sequence of events that occur during the convection process--specifically, the process of condensation might cause the coating of each nucleating agent particle with condensed water at higher than optimum temperatures for ice crystal formation.

In 1972, Dr. Roger L. Steele of the University of Nevada System Desert Research Institute received a grant under the National Science Foundation, Research Applied to National Needs (NSF/RANN) program to investigate the "Sequence Effects in Heterogeneous Nucleation." Project information is given in table 44-1. This study required the simulation of a convective current (updraft) through stages of successively lower temperature and pressure (adiabatic process) and permitting condensation to occur as appropriate to the controllable initial total water content of the air. The updraft speed (rate of pressure reduction) and the microstructure of the simulated cloud were also controllable variables.*

The research was performed over a two-year period with the conclusion that the sequence of events to which the introduced nucleating agent was exposed had no significant effect (from an operational standpoint) on its nucleating efficiency.

Identification of the utilization of the results of this project is difficult. The results were not such as to encourage anyone engaged in cloud seeding to change his procedures. Rather, the results served to

*The dynamic cloud chamber used in this study had been developed by Dr. Steele under an NSF grant while he was at Colorado State University. As a matter of interest, the chamber was moved to the Desert Research Institute and has not been used since the conclusion of the study under discussion.

Table 44-1. PROJECT INFORMATION

Project Title Sequence Effects in Heterogeneous Nucleation	Grant/Contract No. GI 34807
RANN Program Manager Currie Downie	RANN Program Area Weather Modification
Principal Investigator(s) Roger L. Steele	Schedule Start: 6/1/72 End: 9/30/74
Institution University of Nevada System Desert Research Institute	Funding NSF: $140,200 Other: none
Contributors/Collaborators: Howard Dunsmore	
User Advisory Committee: None	
Precursor Activities: Dynamic cloud simulation chamber used was developed by Dr. Steele while at Colorado State University under an NSF grant.	

confirm to any operator that his techniques (in which he already had confidence) were suitable and effective.

Judging by responses from responsible and knowledgeable individuals in a group of organizations actively engaged in weather modification activities either for research or commercial purposes, the study report either received little attention, or the results were noted at the time and quickly forgotten since they did not affect operations.

Research Description

Following the demonstration by Vincent Schaefer in 1946 that solid carbon dioxide would convert a cloud of supercooled water droplets to ice crystals and the discovery by Bernard Vonnegut that silver iodide (AgI) would produce similar effects, many operational as well as experimental programs in cloud modification and precipitation augmentation were undertaken. In 1957, the President's Advisory Committee on Weather Control* concluded, on the basis of statistical evaluations, that cloud seeding in mountainous areas of the western United States "produced an average increase of 10 to 15 percent. . . with a satisfactory degree of probability that the increase was not the result of the natural variations in the amount of precipitation." While this conclusion was not universally accepted as valid since the data available were not produced by randomized experiments, Congress, on the basis of the Committee's report, charged the National Science Foundation to support studies needed to provide a broad scientific base for weather modification (PL 85-510).

With its reorganization in the mid-60's, the special responsibilities of NSF under PL 85-510 were eliminated with some of these responsibilities reassigned to the National Oceanic and Atmospheric Agency.

Throughout the last 30 years, periodic assessments of the state of knowledge and of technology of weather modification have been made. The previously mentioned Report of the President's Advisory Committee on Weather Control, 1957; the 1966 Final Report of the Panel on Weather and Climate

*The President's Advisory Committee on Weather Control was established in 1953 to determine "the extent to which the United States should experiment with, engage in, or regulate activities designated to control weather conditions."

Modification to the Committee on Atmospheric Sciences, National Academy of Sciences (NAS)-National Research Council (NRC); the 1971 Report, The Atmospheric Sciences and Man's Needs, Priorities for the Future, by the NAS-NRC Committee on Atmospheric Sciences; and the NAS-NRC 1973 Report, Weather and Climate Modification, assessing programs in weather modification since the 1966 report of the same title, have all discussed the then current state-of-the-art, the requirements for additional research, and the institutional and legal implications of weather modification activities.

In the 1973 NAS-NRC report, it was stated that "Optimal use of AgI in seeding can be attained when its mode (or modes) of nucleation is clearly understood; but uncertainty still surrounds that important question two decades after the discovery of the ice-nucleating properties of AgI." The report went on to identify the modes of nucleation as "(1) direct deposition of ice from the vapor stage onto dry AgI; (2) condensation of water vapor onto AgI particles to form an enveloping liquid droplet, followed by nucleation of the droplet by freezing nucleation; and (3) collision of a dry AgI particle with a pre-existing cloud droplet and nucleation of freezing from the point of collisional contact."

Knowledge of the mode that is effective for a particular nucleating agent is important since it might determine the location within the cloud, in terms of temperature and liquid water content, at which the agent must be injected in order to achieve the planned modification. From a practical standpoint, operators of field programs needed to know whether convective clouds could be seeded more effectively using ground-based or airborne nucleating agent generators. The study of Sequence Effects in Heterogeneous Nucleation was designed to answer this question.

The study design required the injection of a known concentration of nucleating agent into an adiabatic expansion chamber in which the total water content could be controlled. The adiabatic expansion rate is produced by chamber pressure and temperature control and is effective through the +10° C to -10° C temperature range. Chamber cooling rates as high as 5C min^{-1} (five centigrade degrees per minute) are possible, but for this study, rates of about 2C min^{-1} were used to simulate vertical air speeds of about 5m sec^{-1}. The chamber and raw air introduced--either to fill the chamber or as a carrier for the nucleating agent--are meticulously scrubbed to remove spurious cloud condensation or ice nuclei.

Essentially two types of experiments were performed. In the first, the test nucleating agent was introduced into the warm, cloud-free chamber. Controlled pressure reduction and cooling permitted a cloud to form. The cloud optical density was measured using a laser transmissometer. At the selected temperature (e.g., -10° C) ice crystal counts were made using a vidicon system. This experiment simulated operation of a nucleating agent generator at ground level, or some other level below the cloud base, and the carrying of the agent into the cloud by corrective currents.

For the second type of experiment, the test nucleating agent was introduced into a liquid water cloud held at a predetermined temperature in the chamber. Cloud density and ice crystal counts were measured as in the first experiment.

The study was funded by NSF/RANN during the period June 1, 1972 through September 30, 1974. The first year was used to prepare the dynamic cloud chamber for the experimental program conducted during the second year.

More than 200 of these experiments were conducted using AgI, or AgI

complexed with NaI or with NH_4I, and dissolved in isopropylamine (IPA), kerosene, or a mixture of the two.

The major findings from the study may be summarized as:

1. No significant influence on seeding effectiveness was found for temperature or sequence of seeding; for AgI dissolved in IPA, kerosene, or IPA and kerosene; or for AgI complexed with NaI.
2. AgI complexed with NH_4I proved to be more effective when used to seed supercooled clouds than when used to seed prior to cloud formation. The difference in effectiveness was greater at cooler temperatures. The magnitude of the difference in effectiveness was not so great as to be a factor in operational cloud seeding.

As a result of this work, it was concluded that, with the nucleating agents studied, the sequence of conditions experienced by the agent prior to reaching the temperature of maximum effectiveness had no significant effect on the nucleating efficiency. In brief, seeding at a predetermined temperature level within a cloud or seeding below the cloud should be equally effective if the nucleating agent introduced below the cloud does reach the required temperature level within the cloud.

Utilization Objectives

The objective of this study was to develop information that would be useful to either researchers investigating the modification of convective clouds or operational groups engaged in convective cloud modification. A question had been raised concerning the effectiveness of below-cloud-base seeding of convective clouds (see, for example, G. K. Sulavelidze and

J.A. Donnan*). Many research and operational convective cloud modification programs designed to use ground-based nucleating agent generators were in progress. Until the utility of below-cloud seeding was established, the efficiency and, in fact, the usefulness of these programs were in question.

No specific plan for the utilization of the results of the investigation was developed. The worldwide community of scientists involved in cloud physics, precipitation augmentation, hail suppression, severe storm abatement, or other forms of weather modification activities is small, well known to one another, and reasonably prolific in the publication of research results. Direct discussion with other researchers, publication of technical papers, and participation in symposia and conferences were the primary mode of dissemination of reports of activities and results under this program.

Utilization Obtained

It is difficult to identify the utilization of the results in the investigation of the sequence effects in heterogeneous nucleation. The results of the study were such that a group engaged in cloud seeding for beneficial weather modification probably would not have changed its operational procedures--seeding from below the convective cloud base (from the ground or from an airplane) was shown to be as effective as seeding within the cloud at an altitude corresponding to a specified temperature.

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*G. K. Sulaveĭidze, Rainstorms and Hail, Israel Program for Scientific Translations. U.S. Department of Commerce, TT68-50466 (1969).

J. A. Donnan, et al., "Nucleation Efficiencies of AgI-NaI Acetone Solutions and Pyrotechnique Generators as a Function of LWC and Generator Flame Temperature," a preliminary report, J. Wea. Modification, Vol. 2, No. 1 (1970).

A group of organizations* engaged in cloud seeding for either research or operational (commercial) purposes was queried concerning their knowledge of the results of this study and possible application of such knowledge. The results were unanimous. None of the people (see table 44-2) questioned recalled the results of the study, although most had available the volume of preprints of the conference** that included a discussion of the study. Because the potential users who were queried are those who would most likely have had application of the results, it was deemed to be of little purpose to broaden the scope of this study to include additional potential users.

Features

The apparent lack of utilization of the results of this project arises from the findings of the research. Establishing that the sequence of conditions experienced by a nucleating agent had no (or very limited) influence on the ultimate effectiveness of that agent obviously would have little impact on the actions of those engaged in convective cloud seeding. (Had the results shown that some condition in the sequence of possible conditions--e.g., liquid water condensation on the nuclei at warm temperatures--destroyed the ultimate effectiveness of an agent, radical changes in operational

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*These organizations were selected from those users of the Colorado State University nucleating agent test facility known to be engaged in seeding activities (as opposed to agent development). See Case Study No. 24, Laboratory Cloud Simulation to Support Weather Modification Research and Field Programs in RANN Utilization Experience, Case Studies 22 through 31, compiled by Burger, R.M. and M.F. Massoglia, Research Triangle Institute. Final Report to the National Science Foundation on contract NSF-C76-17165. August 1976.

**Fourth Conference on Weather Modification (November 18-21, 1974, Ft. Lauderdale, Florida), American Meteorological Society, Boston.

Table 44-2. WEATHER MODIFICATION ORGANIZATIONS AND INDIVIDUALS QUERIED WITH REGARD TO SEQUENCE EFFECTS IN HETEROGENEOUS NUCLEATION

ORGANIZATION	INDIVIDUAL CONTACTED
Weather Modification, Inc. Bowman, North Dakota	Wilber Brewer, President Lynn Rose, Meteorologist
National Oceanic Atmospheric Administration (NOAA), National Hurricane and Meteorology Laboratory Coral Gables, Florida	Dr. W. L. Woodley Acting Chief, Cumulus Group
Colorado Corporation of Delaware Boulder, Colorado	Ralph Papania, President
San Bernardino Valley Municipal Water District San Bernardino, California	Larry Rowe Water Resources Engineer
Atmospherics, Inc. Fresno, California	Don Duckering, Vice President

procedures could have been expected.) The assurance that the study gave as to the suitability of each of the several modes of nuclei injection probably limited the attention given to the results.

The lack of identifiable utilization of the study results in no way detracts from the caliber of the study or from the need for the study. The study results provided justification based on controlled laboratory experimentation for operating procedures that had been developed on an empirical and perhaps intuitive basis.

Conclusions

The results of this study have contributed to the body of knowledge requisite to the development of effective techniques for the beneficial modification of convective clouds by removing the uncertainty associated with locational procedures or introducing nucleating agents into the cloud. The fact that the study showed that there was no significant dependence between cloud nucleating efficiency and the stage in the sequence of the convective process at which the agent was introduced makes the identification of "utilization" difficult. The proponents of each mode of nucleating agent injection would accept the study results as justifying their operating procedure--in which they already had confidence--and discussion would be limited.

Finding that none of the queried individuals--all of whom held responsible positions in organizations actively engaged in either research or commercial cloud seeding--had knowledge of the study results is disturbing. It is highly probable that the published volume of preprints of the 1974 Fourth Conference on Weather Modification is in the libraries of all of these organizations and that many of the individuals attended the conference. This suggests that results of scientific investigations that are confirmatory rather than controvertible in nature do not receive the attention they should, even when published in appropriate, highly specialized volumes.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 45

DYNAMIC INSTABILITY AND ULTIMATE CAPACITY OF INELASTIC SYSTEMS PARAMETRICALLY EXCITED BY EARTHQUAKES

UNIVERSITY OF MISSOURI

Case Investigator:
D. F. Tolman

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:
J. C. Smith

Department of Civil Engineering
North Carolina State University
Raleigh, North Carolina 27607

Prepared under:

Contract No. NSF C76-17165
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Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

DYNAMIC INSTABILITY AND ULTIMATE CAPACITY OF INELASTIC SYSTEMS PARAMETRICALLY EXCITED BY EARTHQUAKES

Introduction and Summary

In recent years the theory of dynamic instability has become one of the newest areas in the study of the structural dynamics and mechanics of deformable solids. The problems that are studied focus on the response history of a solid or structure resulting from lateral, time-dependent excitations and utilize the classical theory of vibrations and structural dynamics. It is known, for example, that when a rod is subjected to an axially compressive force varying periodically with time with a definite frequency, transverse vibrations of the rod will increase. The study of the formation of this type of vibration and the formulation of methods for its prevention are of interest to researchers and practitioners in various areas of mechanics, transportation, industrial construction, and earthquake engineering.

The purpose of this study has been to develop an analytical method for determining the nature of dynamic instability and for studying the response of structural systems subjected to vertical pulsating loads and lateral dynamic forces of foundation movements resulting from earthquakes. The mathematical formulation is general enough for computer analysis of large structural systems, of geometric nonlinearities, and of bilinear materials having different moduli of elasticity governing their behavior at different stress ranges.

The scope of the Missouri-Rolla effort is briefly stated to be the formulation of instability criteria, the derivation of finite element matrices, and the evolution of numerical methods for computer solution, all for structures excited by vertical pulsating forces and lateral forces from foundation movement.

The Principal Investigator was Dr. Franklin Y. Cheng, Professor of Civil Engineering, University of Missouri-Rolla. Additional project information is given in table 45-1.

The project was conducted between July 1972 and September 1975. It was funded by the National Science Foundation (NSF) for $20,300. In addition to the NSF funding, the University of Missouri-Rolla contributed $11,650 to the project.

The products of the research include eight papers and presentations, two dissertations, five reports, several short courses, and information inputs to government officials, research workers and practicing engineers. Ultimate utilization in engineering designs to date has been very limited. Also, the abstract and theoretical nature of the research makes it difficult for other researchers and particularly practitioners to follow because of the complex mathematical nature of the problem.

However, a second Ph.D. student began participating in the project in 1974 and since then the scope of the research project has been expanded to include more features than originally proposed. Consequently, Part II of the technical report is still in preparation and will be published in August 1976. The forthcoming report and papers should provide more informative results of this research.

Considering the many published articles in national journals, international conference proceedings, and other peripheral benefits resulting

Table 45-1 - PROJECT INFORMATION

Project Title: Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited by Earthquakes	Grant/Contract No. NSF-GI-34966 P-313303
RANN Program Manager Dr. John B. Scalzi	RANN Program Area Disaster and Natural Hazards
Principal Investigator(s) Dr. Franklin Y. Cheng, Professor of Civil Engineering	Schedule Start: July 1, 1972 End: Sept. 30, 1975
Institution University of Missouri at Rolla Rolla, Missouri 65401	Funding NSF: $20,300.00 Other: $11,650.00
Contributors/Collaborators: Graduate School and Computer Center - University Extension Division-University of Missouri-Rolla of Missouri	
User Advisory Committee: Civil Engineering Faculty, Extension Faculty and Practitioners (F.Y. Cheng, J.H. Senne, J.B. Heagler and others)	
Precursor Activities:	

from this small NSF grant, the overall utilization is considered relatively high.

Research Description

The behavior of structural systems subjected to both lateral and vertical excitations is largely unknown. Most prior research has been concentrated on the problem of an elastic column subjected to a periodically varying axial load for the purpose of searching for the dynamic instability conditions of doubly symmetric columns (two axes of symmetry) as well as nonsymmetric columns (no axes of symmetry).

Very little work has been found in the literature on either the criteria of dynamic instability or the response behavior of framed structures subjected to dynamic lateral and vertical excitations.

In this research, Dr. Cheng and his colleagues developed an analytical procedure for investigating dynamic instability and response of framed structures subjected to pulsating axial loads and time-dependent lateral forces, or foundation movements. The instability criteria for structural systems were included in the analytical work by utilizing the finite element technique of structural matrix formulation and the resulting computer solution. The end result of the research is a computer program for performing the combined analyses.

Research results may be classified into three categories: (1) published mathematical and numerical information ready for individual use; (2) a computer program developed in this project and available to research workers and practitioners; and (3) the principal investigator's conducting of continuing education in earthquake engineering.

The products of the research and the Principal Investigator's related accomplishments that are associated with the research are given in Appendixes A and B.

Utilization Objectives

Analytical procedures developed in this research project permit identification of the susceptibility of certain structural designs to earthquake shock. The intended users are primarily professional engineers, scientists, and researchers in the field of structural engineering. These professionals are concerned with the dynamic response of structures subjected to earthquake loading.

Existing or potential user organizations would include:

- Government agencies involved in or utilizing research in structural dynamics.
- Other university researchers
- Private structural design engineers
- Local building code officials (for checking purposes)

Utilization Obtained

To reach the potential user community, e.g., engineers, researchers and educators in the United States and abroad, the research results have been published in national journals and international conference proceedings.

The following people were contacted by telephone to determine the nature of their utilization of the research products. The contacts include a wide range of individuals and agencies concerned with the earthquake resistance of structures.

Mr. V. B. Venkayya
Design and Analysis Branch
Structural Division
Air Force Flight Dynamics Laboratory
Wright-Patterson Air Force Base

Mr. Venkayya is familiar with the research and has attended and participated in several of Dr. Cheng's short courses and conferences on computer methods of optimum structural design. He has read most of Dr. Cheng's papers and reports and found the paper entitled "Dynamic Matrix of Timoshenko Beam Columns" to be particularly helpful in his research and development on future aircraft systems.

Mr. James Lefter
Director of Civil Engineering Services
Veterans Administration
Washington, D. C.

Although Mr. Lefter is not familiar with the research he is interested in the research subject area and is ordering a copy of the final report directly from the Principal Investigator.

Mr. John Ferritto
Project Engineer
Facilities Engineering Laboratory
U.S. Naval Civil Engineering Laboratory
Ventura, California

Mr. Ferritto is involved in research and development on structural steel and reinforced concrete buildings including earthquake effects. He attended Dr. Cheng's 4th annual short course in computer methods of optimum structural design and has used some of the methods and techniques from the course in his recent analytical work and has read some of Dr. Cheng's publications.

Professor N. Khachaturian
Department of Civil Engineering
University of Illinois

Professor Khachaturian is involved in the computer optimization of reinforced concrete buildings and has written a book on prestressed concrete. He has been one of the principal lecturers in Dr. Cheng's short courses in computer methods of optimum structural design. He has read the results of Dr. Cheng's research and has utilized the results in his related research.

Professor Khachaturian thought that his former student, the Principal Investigator, had an excellent background in structural analysis and that his enthusiasm and contribution to the field of earthquake engineering research was tremendous.

Professor Otto W. Nuttli
Geophysics Department
St. Louis University

Professor Nuttli is involved primarily in seismicity and ground motion studies. He is scheduled to be a lecturer on specifications for a design earthquake at the upcoming International Symposium on Earthquake Structural Engineering in August 1976, conducted by Dr. Cheng. He knows of the research and short courses conducted by the Principal Investigator, but has not yet used any of the results, because they are not directly related to Dr. Nuttli's personal research.

Professor V. V. Bertero
Earthquake Engineering Research Center
University of California, Berkeley

Professor Bertero is in the Department of Civil Engineering, Division of Structural Engineering and Structural Mechanics. He is involved in both analytical and experimental earthquake engineering research--particularly in computer programs for nonlinear seismic analysis of buildings of steel and reinforced concrete. He has read several publications by Dr. Cheng, but has not seen the final report-Part I. Professor Bertero believes that the work is very good conceptually, but should be integrated into related experimental earthquake engineering projects for verification.

Mr. J. H. Hubbard, P. E.
Cincinnati Technical College
Cincinnati, Ohio

Mr. Hubbard is training structural engineers in a two year program leading to an associate engineering degree. He attended the most recent short course in computer methods of optimum design conducted by Dr. Cheng and found the course potentially very valuable as an effective teaching tool for classroom demonstration to show how computers are used in structural engineering design practice.

Mr. L. O. Whitworth, President
Whitworth, Foust and Stearnes Inc.
Sikeston, Missouri

Mr. Whitworth heads an architectural and engineering consulting firm and is familiar with Dr. Cheng's research work at the University and his work as a consulting engineer. Although Mr. Whitworth is now involved with administrative functions, other engineers in his firm have used some of the results of the research in the design of high rise residential buildings designed to withstand earthquakes. Mr. Whitworth was present at one of Dr. Cheng's short courses, although he did not take the entire course. He expressed the opinion that "Dr. Cheng was setting the pattern for earthquake engineering research, had a great capacity for work, and was an asset to the civil engineering profession."

Mr. John A. Tesero
Computer Applications Division
American Electric Power Service Corporation
New York, New York

The corporation is a holding company which provides engineering and management services to several operating electric companies in the mid-west. some of which are in earthquake risk zones. Mr. Tesero is responsible for computer applications in support of civil engineering design. He attended the short course in computer methods of optimal structural design in 1974. The methods covered in this course have helped in the optimization of sizing structural members in transmission tower design where there are significant weight constraints and many design variables.

Mr. B. L. Goepfert
Senior Civil Engineer and Head
Computer Technology Section
Shell Oil Company
Houston, Texas

Mr. Goepfert is primarily involved with computer programs in

structural analysis and is part of a central design group for offshore drilling platforms and other facilities.

He attended the 1975 annual short course in computer methods of optimum structural design at Rolla, Missouri and describes the course as "helpful, but not directly applicable" for his use. He has, however, incorporated some of the course principles in computer programs for optimal design. He is on the mailing list of the civil department of the University of Missouri-Rolla and has read some of the reports and papers.

Features

It is clear from the foregoing that many of the users contacted did not distinguish the products of this grant from the activities of Dr. Cheng. Most of those contacted mentioned Dr. Cheng's one-week course on "Computer Methods of Optimal Structural Design" as being helpful to them. This annual short course has been conducted by Dr. Cheng since 1971. Each year, between 30 and 40 participants have attended from all over the United States as well as from Canada, Mexico, Puerto Rico, Peru, Jamaica, France, Nigeria, Chile, Dominican Republic, Panama, and Nicaragua. Computer programs are distributed to the short course participants who use the programs directly or modify the program according to their individual needs.

It should be pointed out that the course is not part of the NSF research. However, it was stimulated by the NSF grant and by the funding provided by the Extension Division of the University of Missouri-Rolla.

Dr. Cheng has extensive experience in directing short courses and has prepared lecture notes for a short course entitled "Computer Matrix Methods in Structural Dynamics and Earthquake Engineering," which is published by the University of Missouri-Rolla, and is related to the research.

He is currently organizing an "International Symposium on Earthquake Structural Engineering" to be held in St. Louis on August 19-21, 1976. The symposium is sponsored by the University of Missouri-Rolla Extension Service. NSF is assisting in the publication of the proceedings. The objective is to provide a means for interaction and cooperation among researchers, educators, practitioners, and others in the field of earthquake structural engineering and to focus attention on structural design for minimizing the disruptive and damaging effect of earthquakes. International attendance and participation is a major part of the symposium. According to the pre-registration record, international participation includes 23 countries of Japan, U.S.S.R., Israel, Romania, New Zealand, Greece, West Germany, England, Sweden, Thailand, Republic of China, Switzerland, India, Dominican Republic, Columbia, Puerto Rico, Brazil, Turkey, Venezuela, Mexico, Peru, Canada, and U.S.A. The U.S. participants will be from more than 20 states. Two volumes of the conference proceedings containing 1310 pages will be available at the symposium. The information of the symposium has been disseminated by a number of news media including interviewing articles with Dr. Cheng appearing in Rolla Daily News and St. Louis Post-Dispatch, etc; television interview by KSD TV station in St. Louis; and discussion programs on KUMR and KMOS radios in Rolla and St. Louis, respectively.

Direct utilization of the research results by professionals has been limited. This is because the conceptual and theoretical nature of the research makes it difficult for other researchers and particularly practitioners to follow. Another limiting factor is that Part II of the final report on the research has not yet been published. However, Dr. Cheng has made extensive use of the results in his personal consulting activities, as indicated in Appendix B.

Conclusions

If utilization is viewed only as that resulting from the technical report, Part I of the research, it would be concluded that utilization by other professionals is limited. However, if utilization is viewed to include all uses and benefits (such as consulting activities and teaching others) which have been stimulated from the small grant of $20,300, it must be concluded that utilization is relatively high.

Although direct utilization has been somewhat limited on this project, many peripheral benefits have resulted from the small grant. In view of the many published articles in national journals, international conference proceedings, and other peripheral benefits resulting from this small NSF grant, the overall utilization is considered relatively high.

It does appear, however, that an analytical mathematical model, without experimental verification, is likely to have limited utilization, regardless of dissemination techniques. It may be that the work to date, without Part II of the final report, is not attractive to other researchers and particularly practitioners, because the results are highly theoretical and relatively difficult for the general practitioner and researcher to follow.

This may indicate a need for more coordination among the various universities for an integrated approach to various aspects of analytical and experimental earthquake engineering research.

Appendix A

PAPERS AND PRESENTATIONS

(1) F. Y. Cheng, and K. Oster, "Ultimate Instability of Earthquake Structures," presented at the Structural Engineering Research Session, ASCE Meeting, Kansas City, Oct. 1974, Preprint 2357.

(2) F. Y. Cheng, "Finite Element Analysis of Structural Instability by Association of Pulsating Excitations," presented at the 1974 International Conference on Finite Element Methods in Engineering, August 1974, Sydney, Australia, Proceedings, pp. 597-610.

(3) F. Y. Cheng, and K. Oster, "The Effect of Parametric Earthquake Motions on Structural Ultimate Capacity," National Meeting of Universities Council for Earthquake Engineering Research, University of Michigan, May, 1974.

(4) F. Y. Cheng, W. H. Tseng, and J. H. Senne, "Dynamic Instability and Ultimate Capacity of Parametrically Excited Structures," preprints, No. 22, Vol. 1, presented at the Fifth World Conference on Earthquake Engineering, June 25-29, 1973, Rome, Italy, Proceedings.

(5) F. Y. Cheng, and W. H. Tseng, "Dynamic Matrix of Timoshenko Beam Columns," Journal of Structural Division, American Society of Civil Engineers, Vol. 99, ST3, pp. 527-549, March 1973.

(6) F. Y. Cheng, and K. B. Oster, "Ultimate Instability of Earthquake Structures," Journal of Structural Division, American Society of Civil Engineers, Vol. 102, No. ST5, pp. 961-972, May, 1976.

(7) F. Y. Cheng and K. B. Oster, "Effect of Coupling Earthquake Motions on Inelastic Structural Models," Proc. of Intl. Symp. on Earthquake Structural Engineering, Vol. I, pp. 107-126, St. Louis, Mo., August, 1976.

(8) F. Y. Cheng and K. B. Oster, "Ductility Studies of Parametrically Excited Systems," 6th WCEE, paper No. 3-98, India, Jan., 1977.

Dissertations:

(1) W. H. Tseng, "Primary Studies of Dynamic Instability and Ultimate Capacity of Structural Systems," Ph.D. Thesis (Advisor: Professor Franklin Y. Cheng), Civil Engineering Department, University of Missouri-Rolla.

(2) K. B. Oster, "Behavior of Inelastic Multi-story Structures Subjected to 2-D Earthquake," Ph.D. Thesis (Advisor: Professor Franklin Y. Cheng), Civil Engineering Department, University of Missouri-Rolla (in progress).

Reports:

(1) F. Y. Cheng, and W. H. Tseng, Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited by Earthquakes--Part I, Technical Report prepared for the National Science Foundation under Grant No. NSF-GI-34966, August, 1973, Civil Engineering Department, University of Missouri-Rolla.

(2) F. Y. Cheng, and W. H. Tseng, Dynamic Matrix of Timoshenko Beam-Columns, Technical Report No. 2 prepared for Grant No. NSF-GI-34966, August 1973, Civil Engineering Department, University of Missouri-Rolla.

(3) F. Y. Cheng, W. H. Tseng, and J. H. Senne, Dynamic Instability and Ultimate Capacity of Parametrically Excited Structures, Technical Report No. 3 prepared for Grant No. NSF-GI-34966, August 1973, Civil Engineering Department, University of Missouri-Rolla.

(4) F. Y. Cheng, and K. B. Oster, Dynamic Instability and Ultimate Capacity of Inelastic Systems Parametrically Excited by Earthquakes--Part II. Technical Report in preparation for the National Science Foundation under Grant No. NSF-GI-34966, Civil Engineering Department, University of Missouri-Rolla.

(5) F. Y. Cheng, "Report of the Research Project Grant No. NSF-GI-34966 for the Period 1973-1974," submitted to the National Science Foundation, January 1975.

Appendix B

RELATED ACCOMPLISHMENTS OF

PRINCIPAL INVESTIGATOR

I. Input to governmental officials:

(1) Consulted by engineers associated with the city of Sikeston, Missouri, on connection with high-rise building design requirements for seismic loads in Sikeston and its neighboring cities.

(2) Consulted by engineers associated with Missouri State Highway Headquarters, concerning the necessary considerations of bridge and building design for earthquakes.

(3) Consulted by the United States Geological Survey (USGS) at Rolla, Missouri, concerning some seismic faults in Midwest caused by vertical earthquake motions in rocks.

(4) Consulted by the U.S. Bureau of Mines at Rolla, Missouri, in connection with the effect of vertical earthquake motions in rocks.

(5) Consulted by the state officials on the subject of Code and Regulations of Seismic Structural Design in Missouri, various occasions in 1973 and 1974, sponsored by the University of Missouri and the Missouri State Highway officials.

(6) Consulted by the Technical Services Division, Building Codes and Standards and by the regional engineer for the International Conference of Building Officials in the area of diagrams for seismic loads.

II. Input to general public:

(1) Interview article, "Seismic Zoning Map of Missouri," appeared in community news, August 1973.

(2) Interview article "A Case of the Shakes," Magazine of Interfact, July 1975.

III. Consulting practice relating to the project:

(1) Consulting activities for Buchmueller, Whitworth & Foust, Inc., Sikeston, Missouri, in the area of determination of seismic load with consideration of dynamic instability.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 46

INVESTIGATION OF THIN FILM SOLAR CELLS BASED UPON Cu_2S AND TERNARY COMPOUNDS

BROWN UNIVERSITY

Case Investigator:
J. W. Harrison

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:
J. R. Hauser

Department of Electrical Engineering
North Carolina State University
Raleigh, North Carolina 27607

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Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

INVESTIGATION OF THIN FILM SOLAR CELLS BASED UPON Cu_2S AND TERNARY COMPOUNDS

Introduction and Summary

The direct conversion of sunlight into electrical power by photovoltaic cells (solar cells) may possibly provide a significant portion of the Nation's electrical energy needs by the end of this century. In order to meet this objective, technology must develop solar cells that are economical and efficient. A solar cell is composed of a two-element (diode) structure that converts photons from sunlight into an electrical charge that is separated at an electrical potential (voltage) determined by the electrochemical properties of these two materials. The amount of charge flowing (current) and the voltage developed by the cell for a given input level of solar radiant power determine the conversion efficiency.

Silicon solar cells, composed of a layer of n-type silicon on a layer of p-type silicon as the diode elements, represent the most highly developed technology. With special antireflection coatings, these cells are capable of up to 18 percent conversion efficiency. These are the premium cells which are used as highly reliable, and correspondingly expensive, power sources for satellites. Silicon solar cells for terrestrial applications typically exhibit 10 to 12 percent efficiency. Although these are considerably less expensive than those qualified for space applications, they are still 40 to 50 times as expensive as the 50 cents per peak watt cost target of ERDA's Photovoltaic Program.

A large part of this expense is due to the present manufacturing methods. These are based upon sawing single crystal silicon ingots into slices which are

then polished, and diffused with a dopant to change the conductivity type. These operations precede the contacting and coating operations which must be performed on any solar cell, however made. The present method is labor intensive and highly wasteful of the single crystal silicon. Past NSF/RANN-sponsored research into methods for mass production of silicon ribbon or sheet to prevent waste and reduce costs has been continued under ERDA sponsorship. However, NSF/RANN has sponsored research into a variety of other methods for significantly reducing the cost of solar cells.

Alternative solar cell structures have been intensively investigated in recent years to determine efficiency and economy tradeoffs. Many of these investigations have been under NSF/RANN sponsorship. Some of these have examined the effect of changing from the n-silicon-on-p-silicon "homojunction" structure to heterojunction structures which use another semiconductor such as tin oxide, indium oxide, cadmium sulfide, or gallium phosphide deposited on silicon. These variations have yielded cells with efficiencies ranging from 6 percent to as high as 12 percent. Another variation is the Schottky barrier cell formed by depositing a thin metallic layer, such as aluminum, directly on silicon. This relatively cheap and simple approach has yielded cells with up to 8 percent conversion efficiency.

In addition to these silicon-based solar cells, another structure that has been studied for many years is the cadmium sulfide/copper sulfide heterojunction. Because of their relatively low conversion efficiency, 6 to 8 percent typically, these heterojunctions were previously regarded as noncompetitive with silicon. However, this low efficiency may be significantly offset by the low cost of producing such cells. Much of the previous work on the cadmium sulfide/copper sulfide heterojunction material-system had been aimed toward

making solar cells under various processing conditions and then evaluating them for efficiency. There was considerable doubt, and controversy, as to the exact composition of the copper sulfide layer formed on cadmium sulfide and whether careful processing could alter this composition to achieve higher efficiencies while keeping production costs down.

Furthermore, the semiconductor copper sulfide and other copper-containing semiconductors such as copper indium disulfide, $CnInS_2$, appear to also have the potential as the basis for low cost, mass produced solar cells because of their ability to be deposited or grown as thin films on metal foils.

The need for materials that will permit production of low-cost photovoltaic conversion devices that are economically competitive with fossil fuel energy systems was specifically addressed by Dr. Joseph J. Loferski of the Brown University Division of Engineering. He and his coworkers at Brown undertook the investigation of thin films of several different semiconductor materials and their application to terrestrial photovoltaic conversion in low-cost, long-life solar arrays. The project was directed toward investigation of solar cells based on thin films of Cu_2S and certain ternary compounds such as $CuInS_2$ and $CuInSe_2$. Project information is given in table 46-1.

Administrative and technical problems have confronted the Brown University research team from the outset. Dr. Loferski's sabbatical during the second year of the study proved the effort of his direction and leadership, and relatively little progress was made during his absence. There were two changes in NSF program management during this same period. The major technical problem the team faced was their inability to successfully produce the stable and reproducible thin films required to make photovoltaic devices of useful conversion efficiencies. Their inability to do this is not surprising since the difficulty

TABLE 46-1. PROJECT INFORMATION

Project Title	Grant/Contract No.
Investigation of Thin Film Solar Cells Based Upon Cu_2S and Ternary Compounds	GI-38102X
RANN Program Manager T. Mukherjee	**RANN Program Area** Energy
Principal Investigator(s) Dr. Joseph J. Loferski	**Schedule** Start: 1 July 1973 End: 28 August 1976
Institution Division of Engineering Brown University	**Funding** NSF: $268,300 Other:

Contributors/Collaborators

Aaron Wold	E. A. DeMeo	E. E. Crisman
John Shewchun	J. Gan	
A. Loshkajian	C. C. Wu	
R. Beaulieu	H. L. Hwang	
R. Arnott	R. Kershaw	

User Advisory Committee

Precursor Activities

/oc

in preparing stable thin films of precisely controlled composition is well documented. Six of the researchers contacted during the user survey said that they were not surprised at the difficulties experienced by the research team. The consensus was that this is certainly no reflection on Dr. Loferski's ability as a scientist, but is rather an indicator of his excessive optimism when he undertook the project. Although the team has coped with and overcome many technical problems, there were more problems than anticipated. This combination of problems has slowed the research effort considerably; consequently, research results are less substantial than anticipated.

At present, there appears to be little concrete evidence of utilization of the research results of this project despite efforts to keep government research organizations and other solar cell researchers informed. Dissemination efforts have included distribution of progress reports and presentation of papers at conferences and workshops. As the user survey that is presented later in this report indicates, these efforts by Dr. Loferski have created a group of potential users who follow the research, await its completion, and benefit from the experience acquired in the research.

Research Description

The Principal Investigator for this project was Professor Joseph J. Loferski, Division of Engineering, Brown University, who has a long and distinguished career of research into photovoltaic phenomena and devices, both in industry and in the University. Important contributions were made by Dr. Aaron Wold, Professor of Chemistry and Engineering and Director of the NSF-MRL Materials Preparation Facility at Brown University; and by Dr. John Shewchun, Visiting

Professor of Engineering (Professor of Materials Science, McMaster University, Hamilton, Ontario, Canada). In addition, a number of other people have contributed to the technical effort, as indicated by the list in table 46-1, adapted from a recent progress report for the project.

The project was initiated with $76,900 funding on July 1, 1973. The second year was funded at $100,400. Funding of $91,000 for the third year, bringing the total to $268,300, was not authorized until August 28, 1975. The first NSF/RANN Program Manager was Dr. H. R. Blieden. When Dr. Blieden assumed broader responsibilities in NSF/RANN, program management was transferred to Dr. Leonard Magid. When Dr. Magid transferred to the Energy Research and Development Administration (ERDA) in 1975, program management responsibilities were transferred to Dr. T. Mukherjee, who is still the Program Manager. Technical work on the project terminated in August 1976.

The original proposal by Dr. Loferski to NSF/RANN envisioned research into the six different material/device structure systems based on Cu_2S and ternary compounds that are listed in table 46-2. The overall objective was to determine the potential of these materials for low-cost, continuous production of solar cells that would exhibit a conversion efficiency, of about 6 percent. Two major milestones were envisioned: (1) demonstration of a stable Cu_2S solar cell with a conversion efficiency of 5 percent or greater; and (2) development of stable homojunction or heterojunction solar cells based on a ternary semiconducting compound such as $CuInS_2$.

The rationale for studying the chalcocite (Cu_2S) form of copper sulfide was as follows. This semiconductor has an energy band gap of about 1.2 electron volts, a value which is close to that for silicon at 1.1 electron volts. This means that the utilization of the solar spectrum will be about the same in the

TABLE 46-2. PROPOSED PHOTOVOLTAIC CELL SYSTEMS

Materials	Type
Cu_2S/Cu	Semiconductor-metal Schottky Barrier
$CuInS_2/Cu$	Homojunction in semiconductor
$CuInS_2/Cu$	Semiconductor-metal
$(p)Cu_2S/(n)CuInS_2$ or $(p)Cu_2S/(n)CuAlS_2$	Heterojunction
Cu_2S/Si	Heterojunction
$CuInSe_2$ and $CuInSe_xS_{1-x}$	Homojunction

two materials. Copper sulfide has an advantage, however, in that a very thin layer, on the order of 0.2 micrometer, suffices because of the much higher absorption coefficient than that of silicon, which requires several micrometers to absorb the same amount of solar radiation. Both copper and sulfur are relatively abundant materials. Furthermore, copper sulfide can be relatively easily formed as a thin film, whereas silicon cannot.

The foremost problem confronting the research team was to control the composition of a copper sulfide film to achieve the desired Cu_2S while forming the film on a suitable substrate. Since there are several other phases of copper sulfide which may be formed, the task of achieving the desired Cu_2S was very difficult. Experiments in sulfurizing thin copper films were performed, using hydrogen sulfide as the sulfur source in an atmosphere of hydrogen and argon at elevated temperature. The concentration of hydrogen sulfide in the gas mixture was varied to assess the effect on the copper sulfide composition.

Another problem was the determination of film composition by a nondestructive test method. This was solved by using cathodoluminescence. This analytical technique requires that the sample be maintained at a relatively low temperature (about 80° K) while being bombarded by a beam of high energy (about 8,000 volts) electrons. The beam current is maintained at a low level, on the order of a few microamperes distributed over a circular area of about 1 mm diameter. The high-energy electrons excite the emission of radiation in the near infrared region of the spectrum. The spectral distribution of this radiation is characteristic of the material, and it is very sensitive to imperfections and impurities. Since it was known that only slight deviations from the desired stoichiometric ratio of 2:1, copper to sulfur, would drastically affect the semiconductor properties, a sensitive measurement technique for composition was needed.

This form of analysis was also applied to $CuInS_2$ in an effort to distinguish between n-type and p-type conductivity in thin films of this ternary semiconductor. Research on this application was in progress as the first year of funding was ending.

Another parallel effort that was undertaken during the first year was to perform measurements of the potential difference of Schottky barriers formed by various metals on Cu_2S. Since the efficiency of a solar cell depends upon the voltage developed, identification of those metals which give the highest potential (i.e., greatest Schottky barrier height) was necessary to determine if any of these metal/Cu_2S combinations could provide an efficiency comparable to the aluminum/silicon Schottky barrier cell.

In yet another parallel effort, deposition of Cu_2S on silicon to form a heterojunction cell was attempted. Also during the year, a measurement system for characterizing photovoltaic cells exposed to any spectral distribution was designed and fabrication was essentially completed. Progress on the grant was considered excellent by the Program Manager and the second year's effort was authorized.

Shortly after the start of the second year, Dr. Loferski left Brown University for a year's sabbatical in Poland during the 1974-75 academic year. Project coordination responsibility during this time was initially transferred to Dr. Wold until other commitments limited his participation in this capacity. About midway through the second year, Dr. John Shewchun accepted project leadership responsibility until Dr. Loferski's return in August 1975.

During the second year, research continued on methods for converting the surface of copper foil to copper sulfide (or chalcocite). It was found that the resulting thin films of sulfide were poorly defined. However, a method of

complete conversion of a copper layer deposited on cadmium sulfide was developed resulting in Cu_2S/CdS solar cells with 0.5 percent efficiency and Cu_2S cells with 1 percent efficiency. In the research into heterojunctions, problems with the adherence of Cu_2S thin films on Si were experienced and the cause was identified. In the research on ternary semiconductors, thin films of $CuInS_2$ were prepared by sputtering Cu-In alloy and then sulfurizing. The cathodoluminescence (CL) technique was developed to distinguish between p- and n-type $CuInS_2$.

Work on the third year's effort commenced upon Dr. Loferski's return from his leave of absence in August 1975. One aspect of this phase of the research has been the fabrication and evaluation of Cu_2S/CdS heterojunction solar cells formed by sulfurization of thin Cu films deposited on either thin film CdS or single crystal CdS. These have been compared to cells prepared by the more "standard" methods for conversion of CdS in a hot copper chloride solution, or conversion following evaporation of Cu_2Cl_2 onto CdS with subsequent heat treatment. Cathodoluminescence (CL) studies of the materials formed by the different processes have revealed a difference in the luminescence characteristics for Cu_2S formed on CdS as compared to the spectra of Cu_2S from other sources. Although it was hypothesized that this might be due to excess Cu or Cd, or possibly even Cl, deliberate doping of Cu_2S with these elements has not resulted in the magnitude of shift observed. However, these dopants do give shifts in the same direction. Also, the CL studies have been used to characterize the effect of various heat treatments after film fabrication. Typically, this treatment is a 30-hour soak in air at 170° C.

Another phase of the research has focused on Cu_2S/Si(n) heterojunction solar cell structures. A cell of 0.6 cm^2 area has yielded a 6 percent efficiency when the Cu_2S was deposited by evaporation. Deposition of a thin film of

Cu on Si, followed by sulfurization, yields solar cells with about 1 percent efficiency.

Although the efforts on the chalcopyrite compound $CuInS_2$ were reduced, there was some investigation of $CuInS_2$ formed by the sulfurizing of a thin film of Cu-In alloy.

As of the date of preparation of this report, the research was still in progress.

Utilization Objectives

It was anticipated that the results of research performed during this project would be useful to a variety of users including electric utility companies, home and commercial builders, power equipment manufacturers, and several Federal and State government agencies. User involvement was planned through formal and informal communications at NSF-sponsored photovoltaic device workshops and annual grantee meetings, at various technical conferences, and through technical publications. In addition, semiannual reports were to be distributed to all persons who indicated an interest in the research. More general report distribution was to be achieved through the National Technical Information Services (NTIS).

Utilization Obtained

A utilization assessment for products of a research project that is as yet incomplete is unlikely to yield significant utilization. With this in mind, the user survey sought persons who were following the progress of the research and who were potential users of the products. The thrust of the interviews was toward assessing utilization potential and determining if any serendipitous

products of value had emerged during the course of the research to date.

From a list of some 44 persons provided by the Principal Investigator, 15 people were contacted representing the following types of organizations:

1. government (6)
2. research and development (2)
3. industry (5)
4. university (2)

These persons are identified in table 46-3. The results of this survey follow. Because some of the respondents did not want to be attributed to directly, their statements are not individually identified.

Six individuals representing four different government agencies were contacted during the course of the user survey. Three representatives of one agency, the Army Research Office (ARO), were highly complimentary of Dr. Loferski's effort, although one pointed out that his agency was making no direct use of any of the research products at present since little was currently being done by ARO in solar energy conversion. One of them pointed out that ARO has funded the basic materials research performed by the Loferski group prior to his attempt to construct the first cuprous sulfide thin films. Another ARO representative was familiar with Dr. Loferski's work through his professional association with Dr. Aaron Wold, the solid state chemist who conducted much of the materials research on the program. He pointed to the extreme difficulty in preparing a well-characterized, reproducible Cu_2S thin film as being a major obstacle in this research effort. He commented that while progress to date is somewhat disappointing, the best films have yielded conversion efficiencies

TABLE 46-3. USER SURVEY CONTACTS

NAME AND TITLE	ORGANIZATION	CATEGORY
Gilbert Walker Aerospace Technologist	Environmental & Space Sciences Division Langley Research Center National Aeronautics and Space Administration	Government
Dr. Douglas Warschauer Program Manager	Solar Energy Division Energy Research and Development Administration	Government
Richard Statler Chief, Satellite Components Section	Radiation Technology Division Naval Research Laboratory	Government
Arthur Tauber Team Leader, Magnetics Materials Team	Electronics Technology & Devices Laboratory U.S. Army Research Office	Government
Dr. John C. Hurt Chief Scientist	Metallurgy & Ceramics Division U.S. Army Research Office	Government
Dr. Jack Bond Chief Scientist	MERADCOM U.S. Army Research Office	Government
John Goldsmith Supervisor, Solar Energy Technology Group	Jet Propulsion Laboratory	Research & Development
Dr. Donald P. Snowden Principal Physicist	Solid State Physics Division Intelcom Rad Tech	Research & Development
Denis J. Curtin Design Engineer	Comsat Laboratories	Industry
Malcolm G. Miles Project Supervisor	Corporate Research Department Monsanto Corporation	Industry
Fred A. Shirland Project Leader	Research & Development Center Westinghouse Corporation	Industry
Paul Rappaport Director	Process & Materials Research Laboratories RCA Laboratories	Industry

TABLE 46-3. USER SURVEY CONTACTS (CONTINUED)

NAME AND TITLE	ORGANIZATION	CATEGORY
Peter Iles Engineer	Research & Development Division Optical Coatings Laboratories, Inc.	Industry
Dr. Richard L. Anderson Professor of Electrical Engineering	Department of Electrical & Computer Engineering Syracuse University	University
Dr. Karl Böer Chief Scientist	Institute for Energy Conversion University of Delaware	University

considerably less than the 5 percent figure anticipated. However, success could lead to a terrestrial solar cell that would be an order of magnitude less expensive than the conventional silicon cell.

Another government representative was quite familiar with the research because Dr. Loferski is currently performing research for his agency under a separate grant. This respondent was enthusiastic about the potential of Loferski's thin films because of their potential economy, but noted that the research was incomplete. The person contacted at a third agency was highly complimentary of Dr. Loferski as a scientist, having followed his work for years. He was apparently familiar with the circumstances of Dr. Loferski's recent sabbatical and was critical of the way certain aspects of the thin film work were handled in Loferski's absence. He feels Loferski had not made up the ground lost as of the time of this survey.

A representative of a fourth government organization who was also a long-time follower of Dr. Loferski's work believes that the semiconductor photovoltaic process has considerable potential for terrestrial applications. He was quick to note that working with films of one or more compounds is considerably more complex than the making of a conventional homojunction silicon solar cell and, as a consequence, he feels that funding agencies should exercise more patience with researchers in this area. He also pointed out that Dr. Loferski is responsible for the development of a significant amount of the basic knowledge on photovoltaic conversion. Current work in his agency's laboratory, involving thin film Schottky barrier silicon cells, relies heavily on work Loferski had done previously as well as some that he is accomplishing on the current NSF project.

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Representatives of two research and development facilities questioned the validity of judging Dr. Loferski's current thin film work on the basis of "research products." They felt that this would overlook much of the esoteric value of Dr. Loferski's efforts. One of them explained that investigators in the field of photovoltaic conversion, although working in many different areas, are continually exchanging information and ideas. In this respect, an idea may be as valuable to another researcher as a new analytical method. Although this respondent is working specifically with vacuum vapor deposition, whereas Loferski's work involves chemical conversion from the vapor phase, he says that the basic physics are in many respects similar, particularly adsorption, carrier transport, and trapping. The other research and development respondent characterized Dr. Loferski as one of the "leading lights" in photovoltaic research, a man who is "constantly blazing new ground...a real heavyweight." He says that the basic principles developed by Loferski are being used by everyone in the field, although it would be difficult to pinpoint specific NSF-funded research products. At any rate, this researcher feels that Dr. Loferski's current work with thin films should be continued with adequate funding.

Spokesmen for five industrial organizations contacted, with only one exception, stated that they were following Dr. Loferski's progress, but were not specifically using the results of his work. One industry was involved primarily with space applications of solar cell technology, thus their interest in Dr. Loferski's work was purely academic. They had worked with thin films in the late sixties and, consequently, still keep abreast of current developments. Another industry, although heavily involved with the development of terrestrial solar cells, has yet to use any of Dr. Loferski's current work although they follow his progress closely.

A third industry respondent described Dr. Loferski's research as a typical university effort not geared to the immediate manufacture of a marketable product. However, since the work may eventually lead to a marketable, low-cost terrestrial solar cell, his company is following the research. This respondent pointed out that Dr. Loferski has been delayed by a problem common in the production of Cu_2S thin films. While no film other than pure chalcocite has adequate photovoltaic properties for solar cell application, the production of pure chalcocite (Cu_2S rather than some other copper sulfide phase) is a difficult procedure at best.

The fourth industry spokesman was enthusiastic about the potential of Dr. Loferski's work, stating that success in putting a layer of CdS on top of a thin film of chalcocite would constitute a major breakthrough in terrestrial solar cell technology. He consequently feels that the research should be continued based upon its promise. He also pointed to Dr. Loferski's cathodoluminescence method for identifying pure chalcocite as a potentially valuable analytical tool when fully developed through application to other semiconductors.

The fifth industry respondent has followed Dr. Loferski's work with thin film solar cells from the beginning, as he is Project Leader for a similar research effort with CdS and Cu_2S thin film solar cells (formerly funded by NSF and to be continued by ERDA). Although he said it would be an oversimplification to identify specific utilization of Loferski's work, his group found it a useful guide. He also said that the cathodoluminescence chalcocite identification method will be used extensively by his company once it is fully developed. At present, his company is sending thin film samples to Dr. Loferski for analysis by the cathodoluminescence method. Results of these analyses are pending.

Neither of the two university respondents was directly using any of Dr. Loferski's research products, although both were closely following the Brown University work. One stated that he was also performing experiments with various thin film processes for terrestrial solar cell application, and that he and Dr. Loferski regularly exchanged data and papers. The other university researcher voiced considerable enthusiasm for the potential of Loferski's non-destructive cathodoluminescence thin film composition analysis method, as current analysis methods are totally inadequate.

In summary, three major points have come out of this user survey:

1. the research has promise for a low-cost terrestrial solar cell and, therefore, potential users of this technology are following the progress of the research; however, the results are not yet directly usable in terms of solar cell fabrication;
2. the nondestructive cathodoluminescence method for analyzing thin films will be a valuable analytical tool when fully developed; and
3. the research shows promise and should be continued.

Features

The dissemination of semiannual and quarterly progress reports has continued on a regular basis throughout the course of the research effort. The dissemination list includes four individuals at the National Science Foundation, fifteen at other government research facilities, eight at universities, five at private research and development facilities, and fifteen industrial recipients.

In addition to the progress reports, two papers have been presented. The first, "Preparation and Characterization of Cu_xS and $CuInS_2$ Films on Various

Substrates for Photovoltaic Junction," was presented in May 1975 at the Eleventh Photovoltaic Specialists Conference held in Phoenix, Arizona. Later that same month, a second paper "Electrical and Optical Properties of Cu-S Compounds and Their Preparation in Thin Film Form," was presented at the First International Workshop on Thin Film CdS Cells held at the University of Delaware.

In short, the major factor influencing utilization is the state of completeness of the research itself. The dissemination of information by both the Principal Investigator and the National Science Foundation appears adequate. The work itself also appears adequate and is progressing, but is considerably behind schedule and, consequently, incomplete at this stage of the project. Utilization, as a consequence, cannot be accurately assessed, unless one says that there has been no utilization. This latter statement, though correct, should not be taken out of the context of the circumstances under which the research is being performed.

Conclusions

At present, there is little utilization of the research results. The long-range impact is difficult to assess because the extent of the use of Cu_2S in mass-produced solar cell arrays is, to date, problematical. If ERDA proceeds with a planned extensive effort using CdS based cells in the coming fiscal year (FY '77), it is probable that the fabrication and evaluation research performed by the Brown University research team will have an important impact on the course of this program.

The problems in fabricating thin film semiconductor devices with stable properties are well known and were well known prior to the subject research program. In view of this, it could be said that the initially proposed

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program was too broad. Requiring certainty on every funded research effort is a price too great to pay since it stifles the challenges that stimulate the creative efforts necessary to produce significant achievements. However, the breadth of the initially proposed program, therefore, could just as well have been its strength, had any of the alternatives turned out technically promising.

There is also evidence that the project suffered from the discontinuity in management at a critical juncture in the research. This may have been compounded by two changes in RANN Program Manager during the same period.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 47

FIRE WHIRL AND FIREBRAND IN MASS FIRES

STATE UNIVERSITY OF NEW YORK AT STONY BROOK

Case Investigator:
S. Plotecia

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:
R. Liepins

Research Triangle Institute
Research Triangle Park
North Carolina 27709

Prepared under:

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National Science Foundation
Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

FIRE WHIRL AND FIREBRAND IN MASS FIRES

Introduction and Summary

One of the most potentially hazardous fire phenomena is the "Mass Fire," a large-scale conflagration exhibiting extremely violent fire behavior. Examples of this type of serious fire include those like the fire in Chelsea, Massachusetts in 1973 which consumed 17 city blocks in just a few hours, or the large-scale forest fire which runs over many square miles in a short time. The social, environmental, and economic importance of fires such as these is profound.

In order to better understand the behavior of mass fires, Dr. Richard Lee, Department of Mechanics, State University of New York (SUNY) at Stony Brook, received a $72,400, 18-month grant from NSF/RANN in February 1973. Dr. Ralph Long was the NSF Program Manager for the study. Additional project information is shown in table 47-1.

Dr. Lee, interested in identifying the physical mechanism by which mass fires spread so rapidly, built upon previous work he had conducted for NSF. One known aspect of fire spread, previously researched by Dr. Lee, is spotting, a phenomenon that occurs when burning pieces of fuel material (firebrands) such as leaves, tree branches, or burning pieces of paper are carried by ambient and/or fire-induced wind to a new location. Under certain conditions of fuel, wind, and topography, firebrands can spot-ignite large areas miles ahead of the fire. This phenomenon has been especially prevalent in wildland mass fires where discontinuous spread makes the fire-fighting job much more difficult. Similarly, in the Chelsea fire of 1973,

Table 47-1. PROJECT INFORMATION

Project Title Fire Whirl and Firebrand in Mass Fires	**Grant/Contract No.** NSF-GI: 1037201
RANN Program Manager Dr. Ralph Long	**RANN Program Area** Disaster and Natural Hazard
Principal Investigator(s) Dr. Richard S. L. Lee	**Schedule** **Start:** Feb. 1, 1973 **End:** Aug. 1, 1975
Institution State University of New York at Stony Brook Stony Brook, New York	**Funding** **NSF:** $72,400 **Other:** None
Contributors/Collaborators: Graduate Students: Anthony P. Modafferi, Walter M. Frank W. Otto, Philip J. Pritchard, Orzel	
User Advisory Committee: None	
Precursor Activities: Previous NSF Studies in the Fire Research Program	

fires broke out in buildings three blocks away from the main fire due to firebrand ignition. In the course of this project, Dr. Lee noticed the similarities exhibited in both types of mass fires, the wildland or forest fire, and mass urban fires, and sought to apply known theories about forest fires to the urban environment. Using two burning wood piles to simulate urban fires, Dr. Lee was able to replicate and document these phenomena in the laboratory--his being the first research to ever do this.

In addition to the analysis of major recent fires and experimental study of gross vortex activities in a simple simulated urban fire, he also conducted experimental studies of the effect of external vortex activity on

the internal flow field in high-rise building fires with and without ventilation, and a study of the formation of multiple fire whirls.

The major product of the project activity, description of fire spread phenomena, is a significant contribution to the state-of-the-art in fire research which was disseminated to other researchers through extensive publication in professional journals. Through Dr. Lee's cooperation and close relationships with the National Fire Protection Association and the U.S. Forest Service, the research results were put to practical use. The work has applicability in other areas, e.g., (1) pollution-oriented problems from stack gases, and (2) behavior of the plume from the cooling towers of nuclear power generating plants.

Factors contributing to the utilization of this work by the scientific community include the wide dissemination of the research results through immediate publication in technical journals, participation in symposia in this country and abroad, and an invitation to Dr. Lee by the University of Queensland, Australia to serve as Distinguished Visiting Professor of Mechanical Engineering. Success in this area is primarily due to the fact that Dr. Lee himself is internationally known and a recognized authority in fire research, and is one of few, if not the only, scientist engaged in research on fire whirl and firebrand in mass fires.

At the outset, this project was designed to be a basic and abstract scientific research endeavor. Due to the encouragement of the Program Manager and the receptivity of the Principal Investigator, the effort was addressed more specifically to fire whirl and firebrand activity in wildland and urban fires. Because of this initial research orientation, the SUNY-Stony Brook project under Dr. Lee is not as well utilized as might otherwise be the case. It should be emphasized, however, that Dr. Lee's work is

recognized by the scientific community as being of the highest scientific quality. A mid-project attempt to enhance utilization by establishment of dialogue with potential users was achieved successfully, considering the project's relatively small research funding level and the lack of funds for utilization. This was due primarily to the quality of the work and the far-ranging contacts and reputation of both the Principal Investigator and Program Manager.

Research Description

Dr. Lee has been involved in fire research since 1962. His early work has been amply documented in the technical literature (see Appendix A). One of the hallmarks of the work has been the rapid publication of research results, which is indicative of extensive preplanning and attention to detail.

The major goal of this NSF/RANN sponsored research has been to understand the generation of vortices and their role in spreading fire in wildlands as well as urban fire environments. The work was conducted mainly by graduate and undergraduate students under the direction of Dr. Lee.

The experimental facilities consisted of a new fire research and suspension flow laboratory in a new, modern Heavy Engineering Laboratory Building on the campus of the State University of New York at Stony Brook. The laboratory is a two-story-high room containing a sophisticated exhaust gas removal system, a two-phase flow system that can incorporate suspended liquids or solids and a two-dimensional laser-doppler anemometer system necessary for precision measurements of flows. The fire research laboratory was provided through matching funds from the University at an approximate cost of $40,000.

One major topic studied under the grant was an analysis of major recent fires. A collaborative effort between Dr. Lee and Mr. Anthony Granito, Director of Research at the National Fire Protection Association (NFPA), was begun shortly after the mass fire of historical proportion in Chelsea, Massachusetts that occurred on October 14, 1973. The behavior of this fire was so violent and unpredictable that 17 city blocks were consumed in just a few hours. After a series of intensive interviews with fire fighting personnel and careful examination of slides, photographs, maps and news films, together with records on an almost identical mass fire over practically the same city area in 1908, a comprehensive picture of the development of that fire gradually emerged. A joint paper by the Principal Investigator and Mr. Granito provided an analysis involving such items as the fire load condition, the location of the initial ignition point, the intensity of the fire, the violent air movement and firebrand spotting and the rapid spread during the main run. The first evidence of occurrence of shedding vortex phenomena in a large-scale fire was discovered during the analysis and subsequently was reproduced by hydraulic simulation in the laboratory. An initial analysis of the more important flow problems in high-rise fires was also performed and suggestions for more detailed flow problem studies were made. The high-rise fires do not appear to have been studied from this perspective before.

Experimental studies, using two wood piles to simulate the behavior of large urban fires, indicate that urban fires develop in five stages, the last of which results in the development of firewhirl and spotting activities, the most dangerous with respect to fire spread. This emphasizes the importance of firefighting efforts and plans to contain the fire prior to its reaching this critical stage.

Other experimental studies involving gross vortex activities in a simulated urban fire showed that the flow and temperature fields in a corridor, with and without interior ventilation, of two simulated burning buildings facing each other across a street, are strongly controlled by the vortex in the street. Furthermore, the vortex in the street, under certain conditions, oscillates back and forth between the two buildings in a regular, periodic fashion.

The study of the origin of vortex generation leading to multiple fire whirl formation was continued from previous grant efforts. The phenomenon of the formation of multiple fire whirls lies at the basis of some of the main fire spread mechanisms of large-scale mass fires. Two excellent reviews on the phenomena of fire, "Fire Research," Applied Mechanics - Reviews, 503, May 1972, and "Heat and Mass Transfer in Fire Research, " Advances in Heat Transfer, 10, 219 (1974), have been written by the Principal Investigator--one singly, the other as a co-author. The further studies in this area have led to the development of theories for multiple fire whirl formation and swirling plume. The realization and subsequent skillful demonstration that the phenomena related to hydrodynamic instability can also be applied to multiple fire whirls is one of the most significant accomplishments of this project. These findings should have significant implications in any future research in this area.

At the conclusion of this project, fire research had been transferred to the National Bureau of Standards. Thus, RANN was unable to fund a continuation proposal.

Utilization Objectives

The "Fire Whirl and Firebrand in Mass Fires" research project was a continuation of earlier work in fire research conducted by Dr. Lee for NSF. There was no utilization plan in the proposal submitted to NSF in late 1972. At that time, RANN was a newly formed division of NSF, the fire research program had been transferred to RANN, and the emphasis on a utilization strategy was not strong. Also, the proposed work was to contribute essentially to the theoretical understanding of the behavior of forest fire storms with no apparent emphasis on study of urban mass fires in its design. No advisory committee or similar activities existed during the course of the project.

As the research progressed, however, the Program Manager, Dr. Ralph Long, encouraged the involvement of the National Fire Protection Association (NFPA) and collaboration with the New York City Fire Department. Dr. Long encouraged shift of emphasis from wildland fires to application of the research to the urban environment. A relationship between NFPA and Dr. Lee evolved and provided useful information to the researchers at NFPA and its constituency. Involvement with the New York City Fire Department was restricted primarily to meetings with senior officials of the Department, including the Commissioner, John T. O'Hagan.

Primary users of the results of Dr. Lee's study are other scientists interested in fire research involving a basic theoretical approach. The major dissemination technique has been through technical articles in journals devoted to heat transfer, combustion, and mechanical engineering as well as fluid mechanics. Also, presentations to both domestic and international symposia and conferences by Dr. Lee have served to inform the

scientific community of the work. A bibliography of articles and a list of presentations made as a result of this project are presented as Appendix A.

Utilization Obtained

Although results of Dr. Lee's study have been primarily utilized by other scientists, his contribution to the state-of-the-art of fire whirl and firebrand behavior has been useful to such practically oriented groups as the U.S. Forest Service and the National Fire Protection Association. Involvement of each of these groups is detailed in the sections that follow. In addition, however, another contribution of the SUNY-Stony Brook project has been the education of graduate and undergraduate students in engineering who were research collaborators with Dr. Lee. This has a tremendous potential utilization effect as these students graduate, find jobs in industry or academia and continue the research investigations.

At the suggestion of the Program Manager, Dr. Lee contacted Anthony R. Granito, then Director of Research for the National Fire Protection Association (NFPA), in order to broaden Dr. Lee's perspectives on the problem of urban fires. Dr. Lee and Mr. Granito co-authored two articles, one in Fire Command describing the Chelsea fire, and one in Fire Journal analyzing flow problems in high-rise fires. These two journals are the professional magazines distributed to all members of the National Fire Protection Association, the trade association for professional fire fighters.

Mr. Granito, now Deputy Superintendent of the National Fire Academy of the National Fire Prevention and Control Administration, indicated that Dr. Lee's work was effective in applying the mass fire spread factors to

large-scale urban conflagrations. He stated that Dr. Lee's essentially theoretical contribution to the state of knowledge would be extremely useful if a predictive model were developed from the research findings. Such a model would enable fire fighters to better understand how to fight fires in relation to the critical aspects of urban mass fires. It would also be useful in setting architectural standards for structures and building materials or to reinforce restrictive zoning codes.

Mr. Granito expressed extreme regret that Dr. Lee has not continued work in this area and that his continuation proposal was not funded because little research is being conducted in this very important problem area.

Mr. C.M. Countryman, a researcher and project leader at the Forest Fire Laboratory of the U.S. Forest Service in Riverside, California has been involved with Dr. Lee for several years because of their mutual interest in forest fire behavior. Mr. Countryman indicated that although he was not professionally interested in the urban implications of Dr. Lee's work, he did find the research on fire whirls very useful. "Dr. Lee contributed more about fire whirl to the state-of-the-art than any other," Mr. Countryman stated. He added that the forest fire work completed by Dr. Lee has been used in designing training material for fire fighters in their forest fire control operations and in prescribed burning activities. Mr. Countryman stated that he was "sorry to hear" that Dr. Lee is no longer focusing on fire research. He said, "I have followed Dr. Lee's work in wildland fire research with considerable interest for a number of years. In contrast to much of the research being conducted at academic and in private research organizations, the work at the State University of New York appears to be strongly oriented toward realistic solutions of practical problems. The research being done on fire whirls and fire spotting are examples of this."

Richard Rothermel and H. E. Anderson, researchers at the U.S. Forest Service's Northern Forest Fire Research Laboratory, have followed Dr. Lee's work on wildland fires for several years. Mr. Anderson indicated that Dr. Lee's explanation of the behavior of fire whirls and firebrand transport was useful to him in his investigations of the flammability of various potential firebrand materials and their potential for firebrand generation. Mr. Rothermel feels that Dr. Lee's explanations of the fibrebrand transport mechanism can be used in an attempt to simulate and/or model the firebrand transport or spotting phenomenon. He indicated that the U.S. Forest Service has given Dr. Murasvew at The Aerospace Corporation a contract to build such a model. Dr. Murasvew's use of Dr. Lee's work is documented in the next paragraph. Mr. Rothermel concluded that Dr. Lee is "accepted by his colleagues as the acknowledged expert on fire whirl."

Dr. Murasvew, a researcher at The Aerospace Corporation, a non-profit research firm in El Segundo, California, has received funding for modeling fire spread from the Northern Forest Fire Research Laboratory. He indicated that Dr. Lee's publications have been useful in gaining understanding of the fluid dynamics of fire whirl and their trajectories. Specifically, he has used and modified some of Dr. Lee's analytical work on fire whirl and firebrand trajectories for use in a heat and probability simulation model of fire spread. Dr. Murasvew is attempting to explain wildland and urban fire behavior in a form similar to Dr. Lee's basic research. Dr. Murasvew added that he has not only used the results of Dr. Lee's research, but also that of other NSF/RANN fire research awardees such as Dr. Howard Emmons at Harvard University.

The researcher-user relationship between Dr. Lee and the New York City Fire Department (NYCFD) is somewhat tenuous in that the primary role played

by Fire Department officials was in providing access to information regarding high-rise fires for use in Dr. Lee's analytical work. Deputy Chief Sidney Ifshin of the NYCFD indicated that Dr. Lee met with him, Commissioner John O'Hagan, and officials from the Plans and Operations Unit of the Fire Department to describe his work on the high-rise building fire problem. Dr. Lee discussed how wind movement relates to high-rise burn conditions and the implications for fire-fighting. The Commissioner suggested that Dr. Lee attempt to coordinate his work on the external air flow phenomena in high-rises with the work on internal high-rise flows being conducted at the Polytechnic Institute of New York. Dr. Paul DeCicco at the Polytechnic Institute indicated that a cooperative effort was attempted in the preparation stages for Dr. Lee's continuation proposal to put into perspective the practical applications of the research endeavors of both organizations for high-rise legislation. Since the proposal was not funded, however, and researchers at Polytechnic are not currently investigating external phenomena of high-rise fires, no mutual activity has commenced. While officials at NYCFD felt that Dr. Lee's work had potential for application in the fighting of high-rise urban fires, no further contact or application of research results was obtained.

Features

Two factors have contributed most significantly to the utilization experience of Dr. Lee's study of "Fire Whirl and Firebrand Transport in Mass Fires." First is the reputation and scientific merit of the Principal Investigator and his research, and his extensive publication of his research results in the scientific literature. Second, the utilization-oriented

activities of the Program Manager, Dr. Ralph Long, have been extremely valuable in providing information dissemination and exchange among all NSF/RANN fire research awardees and the various user communities. For example, annual conferences of fire researchers funded by NSF have been held for purposes of facilitating information flow.

In addition to the above two factors, Dr. Lee has participated in numerous conferences and symposia and it is through these mechanisms that additional utilization has occurred. Dr. Lee's insights into the applications of wildland fire behavior for urban mass fire spread has resulted in his reaching two distinct and diverse user groups--members of the National Fire Protection Association and the U.S. Forest Service--as well as other academically oriented researchers. In addition, it should be re-emphasized at this time that this project was initiated when the utilization emphasis of RANN was not as overt as it is today. Thus, while there was no user advisory board or similar technique employed, the involvement of NFPA in a collaborative role resulted in the dissemination of results to fire fighters who are members of that organization.

There are barriers to utilization in a broad sense even though the research was of the highest quality. Unfortunately, the subject matter is of specific interest to a relatively small user community of academicians and forest fire researchers, even though the implications of the work are profound. For example, knowledge of fire whirl and firebrand transport as documented on the Chelsea fire is potentially useful knowledge for architects and urban planners. This, coupled with the work on external air flow about high-rise structures, could be useful in either planning new communities or rehabilitating older urban environments. Such uses, however, are limited by the political and financial constraints imposed by all

rigorous planning, zoning, and code enforcement activities, as well as the fact that there appears to be little interest on the part of funding agencies to continue this type of investigation. This is especially true since NSF/RANN is no longer the lead agency for fire research.

The apparent weakness of this project is that the short- and long-term benefits of this field of investigation were not addressed by the Principal Investigator in his proposal. Dr. Lee stated, "the use of this highly technical product is up to society." This supports the hypothesis that there was a need for more formal transfer mechanisms to move basic research to the application or implementation stage. RANN has since taken steps in that direction.

Conclusions

"Fire Whirl and Firebrand Transport in Mass Fires" is well-utilized research given its research orientation and the fact that the only overt utilization activity was publication in scientific journals and conference attendance. Collaboration with the National Fire Protection Association was a contributing factor to the diversity of audiences for information dissemination.

Dr. Lee has made a significant contribution to the state-of-the-art of fire spread behavior. His work was never intended for any other application than the discovery of fire spread mechanisms, specifically fire whirl and firebrand transport, and the use of such knowledge in subsequent scientific investigations. It will be the investigation of these implications, based on the contributions of Dr. Lee, that will provide direct applications for both urban and forest fire service personnel, architects, urban planners and other practitioners interested in minimizing loss to life and property due to fire.

Appendix A

PROJECT PRESENTATIONS AND PUBLICATIONS

P.R. DioGiovanni and S. L. Lee, "Impulsive Motion in a Particle-Fluid Suspension Including Particulate Volume, Density, and Migration Ellects," Journal of Applied Mechanics, Vol. 41, pp. 35-41, 1974.

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C. A. Garris and S. L. Lee, "A Theory for Multiple Fire Whirl Formation," The Fourteenth International Symposium on Combustion, pp. 1063-1071, 1973.

S. L. Lee, "Fire Whirl and Firebrand in Mass Fires," RANN Conference on Fire Research, sponsored by the National Science Foundation, Atlanta, Georgia, May 1974.

S. L. Lee and A. R. Granito, "An Analysis of Important Flow Problems in High-Rise Fire," to appear in Fire Journal, National Fire Protection Association, 1975.

S. L. Lee and A. R. Granito, "Research Analysis-Conflagration Fire Behavior, the 1973 Chelsea, Massachusetts Fire," Fire Command, Vol. 41, No. 3, pp. 12-14, 1974.

S. L. Lee, and J. M. Hellman, "Heat and Mass Transfer in Fire Research," Advances in Heat Transfer, Vol. 10, Academic Press, pp. 219-284, 1974.

S. L. Lee and F. W. Otto, "Effect of External Vortex Activities on the Internal Flow Field in High-Rise Building Fires," accepted for presentation at The Fourth International Symposium on the Combustion Processes, Czestochowa, Poland, September 15-18, 1975, and accepted for publication in Archives of Thermodynamics and Combusion, 1975.

S. L. Lee and F. W. Otto, "Gross Vortex Activities in a Simple Simulated Urban Fire," presented at The Fifteenth International Symposium on Combustion, Tokyo, Japan, August 25-31, 1974.

S. L. Lee and D. J. Pritchard, "Vortex Shedding from Turbulent Jet in a Cross Flow," in preparation for publication.

F. W. Otto, and S. L. Lee, and A. P. Modafferi, "Effect of External Vortex Activities and Ventilation on the Internal Flow Field in High Rise Building Fires," an abstract under preparation for publication.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 48

A STUDY OF TELEVISION NETWORK REGULATION

RICE UNIVERSITY

Case Investigator:

P. McMullan

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:

D. Graham

Department of Economics
Duke University
Durham, North Carolina

Prepared under:

Contract No. NSF C76-17165
National Science Foundation
Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

A STUDY OF TELEVISION NETWORK REGULATION

Introduction and Summary

The American television industry is widely acknowledged to be a highly successful commercial endeavor. Most of its stations are profitable and its news and entertainment programs are watched by vast audiences. Despite its success, it is widely criticised on the grounds that "its reporting is biased, its advertising misleading, and its programming monotonous and tasteless" (ref. 1). Telecommunications policy has attempted to meet the criticisms in a number of ways, but the primary strategy has been to technically and economically encourage more local stations, more local programming, and more alternatives to the programming domination of the three national networks. This case study is concerned with one aspect of these numerous issues within telecommunications policy--the regulation of television networks and the economic consequences of regulation. Specifically, this is a study of the utilization of research produced under a Rice University project entitled, "A Study of Television Network Regulation."

In fiscal year 1972, the National Science Foundation (NSF) began its Telecommunications Policy Research Program. Its scope was much broader, but it included television network regulation as one of its issues. As described in the FY 1972-1975 program summary (ref. 2):

> The program was undertaken because of a perception on the part of officials concerned with telecommunications issues that there was a need for increased research and analysis of these issues. Although it was recognized that decisions in this area almost always involve important questions of political values, there was a conviction, which remains, that objective analyses using tools of social sciences could sharpen choices to be made, illuminate their effects, and in general improve the quality of these choices.

One of the first sub-programs initiated under the Telecommunications Policy Research Program was classified as Telecommunications Planning Grants. Grants were awarded to eight institutions which had no previous organized telecommunications research programs. This "seed money" was to develop capability for future research in telecommunication policy. Preference was given to institutions with potential capability for analysis in the full spectrum of relevant disciplines, but this was not a firm requirement.

One of the eight telecommunications planning grants (GI-38909) was awarded to Rice University for "A Study of Television Network Regulation," under the project leadership of Dr. Stanley M. Besen. Project information is given in table 48-1. This grant of $73,500 for two years was to support professors of economics and their graduate students as they developed their capability in the telecommunications area. For example, the grant permitted Dr. Besen and his collaborators to continue to develop and apply econometric models for analyses of television network regulations. One such model is used in analyses of the implications of the monopsony power of networks to counter Federal Communications Commission (FCC) regulations. Another explains the number of television stations a market will support as a function of the population of the market and the number of Very High Frequency (VHF) allocations to the market. The first model was used in several studies to examine network-affiliated relationships and the economic impact of federal regulations on this relationship. The second model was used in several studies to examine alternative proposals by federal policy agencies to expand the number of VHF and/or Ultra High Frequency (UHF) stations serving the public.

The products of the research were academic papers submitted and published by journals of business and economics, papers distributed to policy

Table 48-1. PROJECT INFORMATION

Project Title A Study of Television Network Regulation	**Grant/Contract No.** GI-38909
RANN Program Manager Dr. Allen Shinn	**RANN Program Area** Telecommunications Policy Research Program
Principal Investigator(s) Dr. Stanley M. Besen	**Schedule** **Start:** June 1, 1973 **End:** June 30, 1975
Institution Rice University Houston, Texas	**Funding** **NSF:** $73,500 **Other:**
Contributors/Collaborators	Ronald Soligo Kenneth J. White P. J. Hanley H. Deegan
User Advisory Committee	None
Precursor Activities	Previous model development for analysis of TV Network Regulation Dr. Besen was Brookings Economic Policy Fellow at the Office of Telecommunications Policy.

agencies, and a dissertation in progress. Specific utilization included: (1) adoption of the second model by Rand Corporation for a study related to expanding the number of UHF stations; (2) placing of two of the papers in the docket of the FCC proceedings on an Office of Telecommunications Policy (OTP)* plan to increase the number of VHF stations; and (3) use of the papers by the staffs of the House Subcommittee on Commerce and OTP in their continuing investigations and analyses of television network regulation.

This project is more basic than most that are funded under RANN. From its inception through its conclusion, the project emphasized the development of a research capability rather than the solution of a specific problem. Within this context, it is concluded that the utilization of the research was significant within its limited scope. The research was judged to be useful and important by the small group of researchers and policy groups who deal with television network regulation. Although no formal institution for telecommunications policy research was established at Rice University, the research was partially "institutionalized" by its participants. The grant allowed the principal investigator to accelerate the development of his research and add several new members to the telecommunication policy research community. Professors and students involved in the project have continued to perform research in the field at Rice or at other institutions.

The research may have a significant indirect effect at some later time on the national need for more varied tasteful programming, but the effect may not be measurable in this slow moving policy area. Policy related research findings from the Rice University study may later surface in other programs and policy agencies, such as in the Rand Corporation and OTP. The

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*Executive Office of the President.

Principal Investigator serves as a consultant to both of these organizations as he continues his research about TV regulation at Rice.

Research Description

The U.S. television industry, throughout the little more than thirty years of its existence, has been exposed to persistent criticism. Noll, Peck, and McGowan divide the criticisms into four categories (ref. 1):

1. The cultural criticism. Television, it is said, has failed to exploit its potential as a medium for educating, informing and elevating tastes.

2. The concentration criticism. Television is dominated by a few organizations and individuals.

3. The wasteland criticism. Because television programming consists primarily of entertainment shows appealing to large audiences, it is not sufficiently diversified to entertain such minorities as symphony lovers or motorcycle racing fans.

4. The Lawrence Welk Show criticism. There is a limited choice even within the standard form of commercial broadcasting.

Throughout the history of FCC regulation of TV broadcasting, the FCC has declared that one of its policy objectives is to provide a wide range of programming choices. The FCC has concentrated upon policy options which were expected to accomplish this by increasing the number of local TV stations in the United States. Although a number of policy options have been considered and several have become law, the overall effect of FCC actions is that the number of stations has not been significantly increased, programming choices have not widened, and the criticisms have not diminished.

The problem of providing new stations is a combination of technical, economic, and regulatory factors. The initial technical difficulty was the limited number of VHF allocations which could be assigned free of interference to any given broadcast market. This was compounded by the Dumont Television Network decision by FCC in 1952, which established limits on the

sizes of broadcast markets (ref. 4). Dumont had proposed to establish a relatively small number of powerful regional stations to serve wide areas with up to four channels. The system would have produced a large number of choices to most viewers within the VHF spectrum. However, the Commission argued that it was more important that stations serve local communities than that the number of viewing alternatives be maximized. With the technological limits on VHF, FCC increased the potential for growth of stations by assigning radio frequency space, thus creating 70 channels in the UHF band. With this new assignment, FCC planned for 1700 commercial stations with 1200 on UHF. The VHF and UHF stations were to be "intermixed" in multi-station markets, and as many cities as possible were to have at least one station.

By 1954, 121 commercial UHF stations were on the air; but by 1960, the number was reduced to 76. The 1952 plan was not succeeding. Proposals were made in 1961 to "short-space" VHF allocations to make room for more stations; but this was rejected after existing stations objected to potential interference. Another proposal in 1962 would have "de-intermixed" stations so that UHF and VHF would not compete directly. Under this proposal, some existing VHF stations would become UHF stations. The existing VHF stations also objected to this plan because UHF was believed to be technically inferior and unavailable on many receivers at the time. The latter objection was met by a 1964 law requiring all-channel receivers; and by 1973, the number of UHF stations had grown to 180--but was still far below the projected 1200 of the 1952 FCC plan. New options were still needed if the FCC objectives were to be met.

When NSF/RANN began its Telecommunications Policy Research Program in 1972, the FCC and the Television Broadcasting industry were still without a viable answer to the major criticisms listed earlier. The television

broadcasting industry was and is dominated by the three national networks that account for almost forty percent of the industry's profits. The news programming of the three networks was receiving severe criticism by the Executive Branch, and interest in the creation of a fourth national network was very high. Technology was well advanced for signal-importing cable, cable subscription TV, and videocassettes. The time appeared right for broad new approaches and interdisciplinary studies to accomplish national objectives with full use of available technology.

This case study is a utilization evaluation of the Rice University project, "A Study of Television Network Regulation." The project is part of the NSF/RANN Telecommunications Policy Research Program which completed its fourth full year of operations in 1975. The highlights of this program are presented to provide a context for evaluation of the Rice University project.

The program began in 1971 with the following general objectives (ref. 5):

1. It should support research on telecommunications policy issues in the areas of: (a) public service application of telecommunications technology; (b) analysis of the social impacts of telecommunications technology; and (c) analysis of current issues in the regulation of the telecommunications industry.

2. It should provide midterm (2 to 10 years) research response to the information needs of policymakers concerned with telecommunication issues.

3. It should seek to improve research methodologies appropriate to the above tasks.

At the beginning of the NSF Telecommunication Policy Research Program, it was generally considered that the nation's research institutions possessed adequate numbers of people with the required skills, but they were not organized to apply these skills to telecommunications policy issues. Substantial efforts were made at the beginning to encourage the development

of groups of researchers from a number of disciplines to work continually on the complex and interdisciplinary issues of telecommunications policy. It was assumed that from two to five years would be required to produce significant increases in knowledge on a particular topic or issue area.

In November 1972, NSF solicited Telecommunications Planning Grant proposals as a part of the Telecommunications Research Program. The first year objectives of these grants were to:

1. Create new groups capable of continued research on issues of telecommunications policy.
2. Generate substantive research on telecommunications policy and long-range planning.
3. Develop research agenda and detailed proposals for further research, based on the substantive research.

Those invited to bid were universities, colleges, and non-profit organizations without already organized telecommunication research programs. Thus, the objective of developing new institutional capability was to be achieved through the grants. Eight of ninety-three proposals for telecommunications planning grants were funded, including that of Rice University. Telecommunications Planning Grants were also awarded to Lehigh University, Massachusetts Institute of Technology, University of Michigan, Michigan State University, North Carolina State University, University of Pennsylvania, and the University of Southern California. The focus of the planning grants varied and included: cable TV development policy, service delivery via cable, telephone regulations, television network regulation, transportation-telecommunications tradeoff, general telecommunications policy (planning and research), and urban telecommunications experiments. The Telecommunications Policy Research Program over the first four years also

included research in telemedicine, citizen feedback, public services and cable television, cable experiment competition, regulatory issue analysis, development of teleconferencing systems, and the social impact of broadcast television. The overall program thus involved a number of institutions and a variety of issues and approaches.

The Telecommunications Planning Grant (GI-38909) of $73,500 awarded to the Department of Economics, Rice University, for the period June 1, 1973 to June 30, 1975 was entitled, "A Study of Television Network Regulation." Dr. Stanley M. Besen was the Principal Investigator for the project. The purposes were: (1) to develop a telecommunications policy study group at Rice University: (2) to investigate the impact of federal regulation on the economic success and performances of television networks; and (3) to assess the opportunity for formation of a fourth national television network.

Dr. Besen reports that his project was atypical in discipline, subject matter, and policy issues. Unlike other proposals for telecommunication planning grants, the Rice University proposal involved only economists and interdisciplinary studies were not proposed. Unlike more applied RANN grants, the proposed approach emphasized theoretical models and empirical analysis, and no experiments in innovative uses of telecommunication technology were involved. Unlike other RANN studies with more immediate applicability, there was no user advisory committee and no involvement in the research by policymaking bodies. The researchers prepared, presented, and published refereed papers. Some were designed to influence the deliberations of committees of the House of Representatives and the staffs of the Federal Communications Commission and the Office of Telecommunications Policy, but this was not a primary objective of this basic research.

The telecommunications planning grant to Rice University provides half-time support to Professor Besen and Professor Ronald Soligo. Professor Kenneth J. White and two graduate assistants were also participants in the project. The research approach built upon previous work by Professor Besen as Brookings Economic Policy Fellow at the Office of Telecommunications Policy. Also, Professors Besen and Soligo had previously collaborated on several papers related to the performance of the broadcasting industry. Their planning objectives during the first year were to further develop models applicable to the research, collect literature and empirical data for their studies, perform preliminary empirical analyses, develop preliminary policy recommendations, and construct an agenda for future research. In this manner, they intended to develop a capability for continuing independent policy research in TV network regulation. As planned and carried out, the project met the announced objectives of NSF telecommunications planning grants with one exception: the study team did not include "expertise in the several disciplines relevant to telecommunications policy studies" (ref. 6).

The products of the research were the following papers and reports:

1. S. M. Besen and P. J. Hanley, "Market Size, VHF Allocations and the Viability of Television Stations," Journal of Industrial Economics, Vol. XXIV, No. 1, pp. 41-54, September 1975.

   In this paper, the authors present their "reduced form" model of relevant parts of the television industry and use it to examine effects of several policy options on potential growth in the number of viable television stations. Specific application is made to the "drop-in" proposal by OTP (i.e., the OTP plan for increasing VHF allocation by technical adjustments in antenna patterns and reduction in co-channel separation criteria). The OTP study argued that

63 VHF stations could be "dropped-in" to the top 100 markets. The Besen and Hadley paper did not question the technical feasibility, but the model predicted that a net gain of only three stations would be realized. Any other VHF stations which might be organized would serve only to replace those existing UHF stations that could not survive the additional competition.

2. Stanley M. Besen and Paul J. Hanley, "A Further Analysis of OTP Drop-In Plans," Rice University, June 1975 (unpublished).

This short paper was essentially an appendix to number 1 of this list, which also had been submitted to the Commissioners (FCC) and members of the Commission staff. The paper responded to a new set of "drop-in" proposals by OTP in 1974. The paper again concludes that, "...in the overwhelming majority of cases, drop-in results in the replacement of a UHF station by a VHF station or it remains idle." The paper concludes that the growth in markets and in customers served would not be sufficient to support a fourth television network.

3. S. M. Besen and R. Soligo, "The Economics of the Network-Affiliate Relationship: Reply," American Economic Review, pp. 1037-1038, December 1975.

Another of the models developed by the researchers was designed to analyze the effects of FCC policy on the network-affiliate relationship. This model was used to examine the effectiveness of different policies which FCC has employed to restrict the control of the networks over local programming on existing stations. Policies such as the Prime Time Access Rule are among the policies subjected to analysis with the model. The monopsony power of networks to counter FCC regulations with network policies is demonstrated.

4. S. M. Besen, "Regulated Broadcasting and the Compensation Question," presented at Public Choice Society meetings, April 1975.

This paper argues that compensation is appropriate when FCC policy removes part of the broadcast coverage (market) of a station, but not when FCC policy only adds competition to a market.

5. K. J. White, "An Empirical Analysis of Television Market Viewing Shares," submitted to the Journal of Business.

This study uses factor analysis to examine the determinants of viewer choice, i.e., the reasons for choosing one network program over another. The author looks at both program characteristics and station characteristics in the factor analysis of audience distribution. National television ratings (Nielson) were used to determine audience distribution in 199 markets. The analysis showed that station characteristics are the dominant factor explaining variations in program ratings and that frequency assignment (VHF, UHF) is the dominant station characteristic. For example, any program on UHF is at a distinct disadvantage in a market which has competing VHF stations (intermixed market).

Other less significant factors are: network affiliation, broadcast time, competition of non-network programs, and ratings of programs in previous time slots.

6. H. Deegan and K. J. White, "An Analysis of Nonpartisan Election Media Expenditures Decisions Using Limited Dependent Variable Methods," presented at Western Economic Association meetings, June 1975, and submitted to the Social Science Quarterly.

Empirical data on media expenditures in Houston for nonpartisan local elections were examined using Tobin's limited dependent variables estimation technique. The results provided

an estimate of the probability that candidates used television advertising, and of the magnitude of candidates' television expenditures.

7. P. J. Hanley, "An Analysis of the Federal Communications Commission's Sixth Report and Order: Resource-Allocation and Television Channel Assignment," Ph.D. dissertation in progress.

This document was not reviewed.

As shown by the list of reports and brief reviews above, the Rice University project directed its efforts in several different, but related directions. Each was intended to expand staff and graduate student capabilities in economic analysis related to TV broadcast regulations. Professor Besen states that his project was designed to have a long-term impact on a "slow-moving" policy area rather than to have immediate impact upon current policy deliberations.

The study's emphasis on the "drop-in" VHF allocation plans proposed by OTP was not anticipated at the time of the proposals, but was well within the scope of the intended research. Professor Besen heard of the OTP proposal through a paper published on the subject and found that it was well-suited to analysis with the model which he was developing. The resulting papers were submitted to FCC for review during the OTP Proposal Proceedings.

Utilization Objectives

In the short run, the objectives of the Rice University project were to develop a policy research capability at Rice in the field of telecommunications. This was to be done by conducting exploratory research in the field, directing graduate students in related studies and research, and preparing research proposals for continuation of the developed program.

In the long run, the objectives of the project were to influence the deliberations of policymakers in the field of television network regulation. Those to be influenced include staffs and decisionmakers of the Office of Telecommunications Policy, the Federal Communications Commission, and relevant subcommittees of the U.S. Congress. This influence was to take place directly by submission of papers to appropriate Commissioners and staffs and by filings in FCC proceedings. It was to take place indirectly through publication of papers and by collaboration with other researchers in the field. The primary focus is upon moving the policymakers toward a more rational approach to TV network regulation which fully considers the economic consequence of policies.

Utilization Obtained

The short run objectives were essentially realized. Three professors of economics and several graduate students participated in the research and have continued their research in the field. Dr. Besen has continued to consult extensively with the Rand Corporation Telecommunication Program and with OTP, as he had prior to the Rice project. He and Dr. Soligo are continuing to publish and work with graduate students. Previous students have continued their involvement at other universities. There is no "institutionalized" program in Telecommunication Policy Research at Rice University in any formal sense, but the research effort continues without NSF/RANN support at a reduced level of effort.

With regard to the long-term objective, it is not possible to provide a clear determination of the policy impact of the Rice University project. Academic papers do not often have a direct impact on policy decisions in fields such as telecommunications. The papers prepared under the study did

not cover all aspects of any telecommunications policy decision. Rather, they attempted to clarify some of the economic advantages and disadvantages of broad policy issues and some specific regulations related to these issues. Primary attention was given to economic reasons why some past policies and regulations had not succeeded and why some proposed policies were unlikely to succeed. They may, in time, influence others in and out of government toward more rational approaches to television network regulation; but their completed research has more influence on methodology than on policy, as will be seen from the comments of those interviewed concerning utilization.

Dr. Allen Shinn was the Program Manager for NSF at the initiation of the Rice University project. He reports that the proposal was well received by the reviewers and was appropriate to the objectives of the solicitation. The grant was to be "seed money" for developing research capability; but as discussed above Dr. Shinn does not remember any particular efforts by Dr. Besen to obtain additional funds. He has not been in sufficiently close contact with potential users in FCC or OTP to evaluate utilization of the project's products.

Dr. Charles Brownstein replaced Dr. Shinn as Program Manager at NSF after the Rice University project was completed. He has had no direct contact with the Principal Investigator, but he advises that evaluation of its utilization be done with full consideration of the specific objectives and scope of Telecommunications Planning Grants.

Dr. R. E. Park of the Rand Corporation provided an example of how the study may eventually influence policy. Dr. Park became aware of the project's modeling work through the Besen and Hanley publication of "Market Size, VHF Allocations and the Viability of Television Stations," in the

Journal of Industrial Economics, followed by contacts with Dr. Besen. In a federally supported study of projected UHF stations, Dr. Park uses a model which is an extension of the Besen-Hanley model.

Two of the project's papers were entered in the docket of the FCC proceedings on the OTP "drop-in" proposal. These proceedings have not yet resulted in an FCC policy decision, but Dr. Harvey Levin of Hofstra University reports that the two project papers are the only economic analyses in the docket.

Because of his service as a consultant, and his previous work with them, OTP is familiar with Dr. Besen's research interests. However, OTP staff were not involved in any way in the Rice University project other than to receive copies of the papers. A general comment was received from OTP that NSF/RANN Principal Investigators should work more closely with OTP in formulating their research and preparing utilization plans. In most cases, they have found that independent research seldom deals with all of the relevant issues in any adversary proceedings, and research with appropriate focus can be a critical input to such proceedings.

Dr. Larry Darby, Chief Economist, OTP, was complimentary regarding Dr. Besen's work and reports that he and his staff are very familiar with it. His staff has made use of the Rice University project's papers in preparing proposals and policy analyses in the area of television network broadcasting.

Drs. Karen Possner and Andrew Margeson are on the staff of the Subcommittee on Commerce of the House Committee on Interstate and Foreign Commerce. Dr. Margeson, an economist, said that the models developed by Dr. Besen and his associates were used as an aid in understanding the economic incentives involved in television network broadcasting. Dr. Possner is

more familiar with and has made greater use of the cable television studies which Dr. Besen has completed since the expiration of the NSF grant.

No attempt was made to reach the general readership of the journals in which the project's papers were published. However, an article in The American Economic Review incited sufficient interest to inspire a lengthy published comment by two readers (ref. 9) and a published reply by Dr. Besen (ref. 10).

Features

Unlike a number of the other NSF/RANN projects for which utilization case studies have been prepared, this project had no utilization plan as such. Project funds were appropriately used to develop professional capability and demonstrate this capability by publishing refereed papers in appropriate journals. There is a logical user group for research such as that performed at Rice (e.g., OTP and FCC), but this group was not involved with the planning or execution of the research. The Principal Investigator intended that his project be an independent research effort, and the user group was not involved except in the initial review of his research proposal. It was only by coincidence that an opportunity arose to address part of the research effort to an ongoing issue under consideration by OTP and FCC. When the opportunity arose, it was taken; and independently prepared research papers were entered into the docket of the FCC proceeding. Except for this special occasion, the research utilization followed the intended professional channels.

The most direct utilization planned for the project by NSF/RANN was that it produce a follow-on proposal. As discussed under Research History,

there was no follow-on proposal, apparently because of a mistaken impression which the Principal Investigator received from the Program Manager. The participants in the project continued to perform research in telecommunications policy, but the level of effort was reduced in the absence of continuing NSF/RANN support.

The Principal Investigator's comments about utilization are of special interest in this type of project. In his opinion, support by NSF/RANN permitted him to accelerate the development of his research capability--particularly with respect to the development of the econometric model used in the analysis of television broadcast regulation. This support also allowed him to involve other professionals in the field of telecommunication policy. Since he is now continuing to perform research in the field and to consult with the Rand Corporation and the OTP, he will continue to work toward the long-range goal of more rational approaches to television regulation.

Conclusions

Utilization of the products of the Rice University project has been good with respect to the audience to which it is directed. Since the objectives of this planning grant to Rice did not call for research related to any specific problem or agency, the several examples of direct application to Rand Corporation research and to FCC hearings are extra benefits.

It is concluded that the project achieved its short-run objectives of developing a telecommunications policy research capability at Rice University. Had there not been a misunderstanding about the direction of NSF telecommunications policy research, it is quite possible that Rice University would have continued to receive some level of NSF support for

Dr. Besen's program. However, Dr. Besen has continued with other sources of support; and the national need for better research support for telecommunications policy should continue to receive the benefits of the capability developed at Rice University under NSF/RANN sponsorship.

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RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 49

CRITICAL PROBLEMS OF THE COASTAL ZONE

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Case Investigator:

Michael v. E. Rulison

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:

B. J. Copeland

Department of Zoology
North Carolina State University
Raleigh, North Carolina 27607

and

Director, North Carolina Sea Grant College Program

Prepared under:

Contract No. NSF C76-17165
National Science Foundation
Research Applied to National Needs
1800 G Street, N.W.
Washington, D.C. 20550

CRITICAL PROBLEMS OF THE COASTAL ZONE

Introduction and Summary

The coastal zone is that important area where land and sea ecosystems interact to create an environment essential to the balance of natural systems, particularly marine life. The coastal zone is also that area where human population is more concentrated than in any other geographic zone. Because the population concentration and associated human activities affect coastal zone ecosystems, the natural balance is being disturbed and a variety of problems have arisen. The study, Critical Problems of the Coastal Zone, was sponsored by NSF/RANN in order to provide an interdisciplinary assessment of these problems and of the research approaches needed for understanding and coping with them.

More than half the population of the United States lives in counties that border the oceans or the Great Lakes. Most of our large cities are located in the coastal zone; this is also true in most other parts of the world. Accordingly, the impact of human use falls more heavily on the coastal zone than on upland or oceanic regions. In addition to these impacts created by habitation, industry, and the many associated activities, the sea of the coastal zone is also the repository of much of our wastes, either because those wastes are created in the coastal zone or because they are carried there by rivers. In fact, an important problem is that the capacity of the coastal zone for absorbing wastes is being strained. In

some areas, the various human uses of the coastal zone are in conflict with each other, requiring that choices be made.

These human activities in the coastal zone have other important impacts on natural systems. The streams, estuaries, and marshes along the coasts are habitats of many fish, crustaceans, and mollusks during part or all of their life cycles; in a real sense the coastal zone is the ocean's nursery. Human uses of the coastal zone, in addition to affecting each other, have important effects on the pre-existing natural processes. A study of critical problems of the coastal zone is a study of the conditions under which such conflicts of use occur and of how they can be resolved to the long-term advantage of humans.

NSF/RANN funded the study of critical problems of the coastal zone for $123,800 in November 1971, with Dr. Bostwick H. Ketchum of Woods Hole Oceanographic Institution (WHOI) as the Principal Investigator. The goal of the project was to identify the critical problems and to evaluate how amenable they might be to scientific investigation. The project team also intended to "produce recommendations for actions, which if implemented, can delay, stop and possibly reverse the trend toward degradation and destruction of coastal ecosystems." Project data are given in table 49-1.

In execution, this project involved selection of ten 5-member working groups that would prepare and circulate papers on their assigned topics during the spring of 1972. This was followed by a workshop at Woods Hole, Massachusetts in May 1972. The objective of the workshop was to write a book presenting findings and recommendations with respect to natural and behavioral science problems of the coastal zone.

Table 49-1. PROJECT INFORMATION

Project Title: The Study of the Critical Problems of the Coastal Zone	Grant/Contract No. GI-31758
RANN Program Manager Dr. Richard C. Kolf (now Associate Program Director, National Sea Grant Program, NOAA)	RANN Program Area Regional Environmental Systems
Principal Investigator(s) Dr. Bostwick H. Ketchum, Associate Director	Schedule Start: November 1971 End: April 1973
Institution Woods Hole Oceanographic Institution Woods Hole, Massachusetts 02543	Funding NSF $123,800 Other $ 5,000 Rockefeller Foundation
Contributors/Collaborators Approximately 65 persons, with expertise in various aspects of the coastal zone, who participated in working groups and in the workshop toward which this project was directed.	
User Advisory Committee Steering Committee of five (later 13) persons from academic and research institutions.	
Precursor Acitivties Coastal Ecosystems Conference at the University of Houston in June 1971	

After a subsequent follow-up meeting by project leaders, the resulting text, The Water's Edge, Critical Problems of the Coastal Zone, was published by the MIT Press in October 1972. This was the intended, and only, physical product of the study. To date nearly 7000 copies have been sold or distributed gratis. A second important product of the study is the formation of relationships among the diverse participants during the process of studying and working together to produce the publication. The project ended after 18 months, in April 1973.

Utilization of The Water's Edge was certainly enhanced by its publication within weeks of passage of the national Coastal Zone Management Act that mandated actions in each of the coastal zone states. This created a market for the book among the persons assembled to staff the agencies that were formed to carry out this mission. Utilization was also probably enhanced by publication through a commercial press, compared to publication as a project report, because of the incentive of a commercial publisher to advertise and promote the sale of the book.

From the reception obtained by the book and the response to it, as well as the response of workshop participants to the interactive process, it appears that this study has been well utilized and has significantly impacted coastal zone management and relevant research that has subsequently taken place.

Research Description

The project, Critical Problems of the Coastal Zone, grew directly out of the Coastal Ecosystems Study Conference held the previous year (June 1971) at the University of Houston under the auspices of The Institute of

Ecology, which was newly-formed at that time. At that conference, which covered a broad range of topics, a five-member committee of academicians was appointed to develop approaches for further studies of the coastal zone. That committee, which included Dr. Ketchum, first developed the idea of a major effort to collect and analyze both primary and secondary physical data describing the state of the coastal zone between Cape Cod and Cape Hatteras. After preliminary discussions with NSF/RANN program manager, Dr. Richard C. Kolf, the need for problem assessment was agreed to have higher priority.

To accomplish this objective, the committee decided on an intensive workshop, preceded by working group studies, as the process for developing the statement of critical problems. A critical problem was defined as one that would "cause major, possibly irreversible, effects on man's continued use of the coastal zone" unless corrective action is taken.

Minutes from a planning committee meeting on 15 December 1971 indicate that the workshop was to focus on interdisciplinary meetings, improvement of problem solving capability and, hopefully, the ability to predict. Moreover, "Throughout the planning session it was emphasized that the practitioner as well as the researcher must influence the workshop. Federal and State agencies should be encouraged to identify their immediate and long-range goals that concern the coastal zone. Government and industry should be invited to supply participants to the working groups in order to create an interaction that will result in a practical and comprehensive treatment of a variety of problems that are involved." (Meeting minutes issued 12 January, 1972.)

Dr. Ketchum, in response to the committee's desire to include Federal and state program administrators, wrote to the Steering Committee in

February 1972 that he was still concerned about getting participation by qualified persons in Federal and State agencies. Even if it were not possible to include them in the working groups preparing for the workshop, he suggested that such persons might attend the workshop as consultants, observers, or advisors. Wrestling with the necessity for limiting the size of the workshop, Dr. Ketchum sought comments from the committee.

But project participation ended as it began, with major emphasis upon the involvement of persons from academic and research positions. Participation in the workshop was virtually determined at the time NSF/RANN approved the original budget, providing per diem subsistence for about 65 persons. Given ten working groups, there were slots in each group for only five persons in addition to the chairman. Thus, the effort to increase representation by action agency personnel was suppressed by budget constraints. Moreover, obtaining commitments to contribute writing and leadership from already active professionals is a difficult task; participation is partly determined by the timing of the project; a shift of six months or a year would change the individuals who could participate.

Each working group represented a unique discipline and produced drafts that were circulated for criticism within the group. At the suggestion of Dr. Ketchum, however, the workshop was organized into the problem groups listed in table 49-2, the members of which were intentionally drawn from different disciplines. Dr. Ketchum noted that this procedure created about three days of difficulty and confusion as members of the problem groups learned to talk meaningfully to one another, but he believes the increased depth of understanding was very worthwhile for the final product.

Table 49-2. Coastal Zone Workshop Problem Groups

Coastal Zone Management and Planning
Municipal, Industrial, and Recreational Use
Legislative and Legal Aspects
Hydrographic and Meteorological Factors
Exploitation of Non-renewable Resources
Pollutants in the Coastal Zone
Fisheries Resources
Ecological Effects of Man's Activities
Habitats and Conservation
Systems Analysis (added during workshop)

As plans for the workshop were developed in the spring of 1972, funds were sought for the expenses and honoraria for a number of distinguished lectureships, with the lectures to be given at plenary sessions of the workshop. The Rockefeller Foundation provided some $5,000 to support this activity.

The primary product of this project was information and policy recommendations in book form. The results of papers developed by working groups and at the workshop held 22 May - 3 June 1972 at Woods Hole Oceanographic Institution were published as The Water's Edge, Critical Problems of the Coastal Zone by the MIT Press, Cambridge, Massachusetts.

An additional important product of the workshop was the enhanced personal interaction established among participants with similar interests working together at the workshop. Establishing and maintaining this network of personal relations has a substantial, though not readily measurable, value.

Ultimately the workshop was attended by 60 participants. The project staff numbered 15, and 52 additional persons were named as contributors who were involved in the pre-workshop preparations or attended only part of the workshop. Based on the listing in The Water's Edge, the "participants" at the workshop 40 were associated with academic or research institutions, 7 came from Federal agencies, and 3 from state agencies; the remaining 10 participants were connected with environmental groups, private firms and overseas organizations. Among the "contributors" the comparable numbers were, respectively, 29, 4, 7, and 12.

Utilization Objectives

The intended utilization of the results of this project are contained in the proposal statement that the project would "produce a definitive, published report identifying critical problems of the coastal zone and defining desirable plans for action." The implication was that the results would be a guide to any persons contemplating research on some aspects of the coastal zone.

Accordingly, users would include both teachers and students in the academic community, especially those concerned with research. In fact, because of its final content and time of publication, The Water's Edge not only was used to spark research proposals, but also served a body of users

staffing the agencies set up in coastal states just after the book was published in October 1972. Likewise, establishment of the Office of Coastal Zone Management in the National Oceanic and Atmospheric Administration (NOAA) created another set of personnel with a need for perspective on coastal zone issues. At the time it was issued, this book was a highly relevant, up-to-date document for which there were no major substitutes. It provided detailed background across the set of issues relevant to the coastal zone.

Other than commercial publication of workshop results, no utilization plan was described in the project proposal reviewed by NSF in the summer and fall of 1971. When the publication contract was made with MIT Press, however, it provided 1500 copies free to WHOI for distribution, which was handled by Dr. Ketchum. The publisher was responsible for promoting sales through advertisements and distribution of copies to journals likely to publish reviews. At this time (June 1976) MIT Press has sold about 5,450 copies at $3.75; total domestic and international distribution is approaching 7,000 copies.

Utilization Obtained

Utilization information was sought among the participants in the workshop and among readers of The Water's Edge since these were the only avenues for dissemination. A majority of these users are found to be concentrated in the academic research community and among state personnel who are involved in coastal zone management.

Academic Researchers

University of Michigan
Ann Arbor, Michigan

Dr. John Armstrong
Director, Coastal Zone Laboratory

Dr. John Armstrong was a member of the Steering Committee for the project, chaired one of the panels at the workshop, and was co-author of one of the chapters in The Water's Edge. Dr. Armstrong has used the book in directed reading programs for some of his students but has not yet taught classes in which it could be used as a text. He was responsible for distribution of the book to persons in several agencies in Michigan state government shortly after it was issued.

Dr. Armstrong believes the book has been used by a number of persons at the state level to learn about coastal zone management and its problems. As an example of dissemination and activities following upon the project he cites a meeting held in 1973 on Great Lakes Coastal Management at which the report was displayed and publicized. He also called attention to the Interregional Seminar on Coastal Area Development attended by representatives of some 35 developing countries held earlier this year (1976) in Berlin under the sponsorship of the German Foundation for International Development. Dr. Armstrong said he took copies of The Water's Edge to this meeting for display and reference. He expects that this exposure will create a demand for copies from overseas, especially from countries that are just beginning to develop coastal zone programs.

Turning from the printed report to the project process of papers, committees, and discussions, which was the second objective of the project, Dr. Armstrong focused on the significance of the final days of the workshop. In that period, key congressmen and members of their staffs were invited to

Woods Hole to hear summaries of the findings and recommendations. He remembers these presentations as a major output of the conference, says they were quite specific, and believes that these sessions did have an impact on the Federal Coastal Zone Act that was under debate in Congress during the spring and summer of 1972.

Institute of Urban and
Regional Development
University of California
Berkeley, California

Dr. Jens Sorensen
Research Specialist

Dr. Jens Sorensen was a participant in the project workshop. He uses The Water's Edge as part of the reading material in courses he teaches and describes it as a good teaching device for those being exposed to the field for the first time. In his opinion, at the time it came out, this book was the only one on the subject, provided a good overview, and raised the consciousness of persons becoming involved with coastal zone management. Today, several years later, however, it appears that some problems are less tractable than was indicated in the book. This is perhaps inevitable, according to Dr. Sorensen.

He criticizes weak linkages between chapters as being one of the defects resulting from chapter authors working in isolation and not having time to check fully for omissions and duplications.

In considering another project of this sort, Dr. Sorensen would emphasize strong definition of problems at the start of the project. Problems such as outer continental shelf oil development, recreation, and dredge and fill actions should be included with the aim of identifying major conflicts among them.

Center for Environmental and Estuarine Studies
University of Maryland
Cambridge, Maryland

Dr. L. Eugene Cronin
Associate Director for Research

Dr. L. Eugene Cronin was a participant in the workshop and reports turning to The Water's Edge frequently for background when considering research needs, as well as for information in developing proposals to State and Federal agencies relating to coastal zone management. He describes the book as a "very useful single repository of good information." Although observing that no one conference or document can encompass all of a subject, Dr. Cronin believes that the product of this project is one of the best single documents available.

He describes the workshop as a substantial professional experience because of the personal knowledge gained from, and about, other persons working in the field. Dr. Cronin asserts that in working together they developed ideas that would not have been possible without the stimulating environment of the workshop. In commenting about barriers to utilization Dr. Cronin notes that he continues to encounter persons who should know of the work but do not, so he endorses wider dissemination.

University of Washington
Seattle, Washington

Dr. Marc J. Hershman
Associate Professor of Marine Studies
Adjunct Professor of Law

Dr. Hershman is editor-in-chief of the Coastal Zone Management Journal and during this project was a member of the workshop group on legislative and legal aspects of coastal zone problems. He was aware of and became a participant in this project through prior professional activities and contacts. He believes The Water's Edge is referenced in most university courses on coastal zone management and is used as a source in most of the dozen or so

undergraduate courses on the subject. Dr. Hershman characterizes the book as providing background that frames the problems of coastal zone management. He notes that when it was issued it was extremely valuable because it was the only work of its kind and the national coastal zone legislation was creating a demand for the information it supplied.

While recognizing the timeliness of project output, Dr. Hershman observes that the project was operated on a schedule that may have been too tight to obtain the best product and the maximum value for funds invested. He feels that more time should have gone into the committee work and position papers prior to the workshop. As it was, he believes participants did not have enough time to really think about the significance of some of the material that was being produced and that, in some cases, the problem group reports were largely the thoughts of their chairmen, not the members. In retrospect, he would prefer a project developing over about two years with papers and workshops followed by a main conference and finally a period of editing.

An institutional factor limiting the usefulness of the project report was the Federal coastal zone legislation itself. This act imposed its own framework and logic on the process of coastal zone management and that framework was not the same as that developed by participants in this project.

State Agencies

Coastal Zone Management Program
Massachusetts Executive Office
of Environmental Affairs
Boston, Massachusetts

Mr. Marc Kaufman
Public Information Officer

The Coastal Zone Management Program in Massachusetts has been active since late 1974, and presently has a staff of about 15 persons. Mr. Kaufman

describes The Water's Edge as "the introductory bible to coastal zone management," and says it lays a clear foundation for work in this field. Each new staff member is given his own copy to read and use for reference.

He points out another, less direct form of utilization stemming from continuing contacts between agency staff and persons who participated in the workshop part of the project. Contacts with these participants occur both during the education of current workers as undergraduate and graduate students and through professional relations after these students take jobs.

As one who did not participate in the project, Mr. Kaufman has no comments on how the project might have been handled differently. But if a similar project were to be started now, he would be certain to include directors of state coastal zone programs to temper the mix of participants with persons who are dealing with daily administration of the coastal zone program as it occurs in practice and who must deal with the legislature, the governor, and a variety of publics. He would be especially interested in assessing how local political structures have affected the way in which the coastal zone program is being implemented in different states. He believes that such a project would provide an opportunity to assess the application and implementation of some of the best thinking done up to the time of the original project on the issue of coastal zone management.

Coastal Area Management Program
Connecticut Department of
Environmental Protection
Hartford, Connecticut

Mr. Joseph M. D'Eugenio
Senior Environmental
Analyst

Mr. Joseph M. D'Eugenio has recently joined the Coastal Area Management Program in Connecticut. In his graduate studies at the University of Rhode Island he used The Water's Edge as part of the reading material for such

courses as marine science policy and the environment, coastal zone law, and fisheries law. In addition, he referred to it in working on research assignments. Mr. D'Eugenio characterizes the book as extremely good in breadth of coverage, but he found that he often wanted greater depth of treatment for specific subjects than was provided.

North Carolina Department of
Natural and Economic Resources
Raleigh, North Carolina

Dr. Arthur W. Cooper
Assistant Secretary

Dr. Cooper is generally aware of The Water's Edge and has read some of it. He notes that North Carolina has developed its own Coastal Area Management Act, passed in 1974, and that as a result of its activity to develop this act had its own data and material for background. Therefore he feels The Water's Edge did not play a great role in activities in this state.

Coastal Management Program
Wisconsin State Planning Office
Madison, Wisconsin

Mr. Al Miller
Administrator

When the Coastal Management Program was started in Wisconsin in 1974, Mr. Miller and others on the staff used The Water's Edge to get a sense of the issues in the Great Lakes coastal zone. They also used it as a reference document in preparing their initial grant application to the Office of Coastal Zone Management. Mr. Miller says they were aware of the book through their close and continuing contacts with persons working in the sea grant program in Wisconsin. One of these persons, for example, is Robert A. Ragotzkie at the Marine Studies Center of the University of Wisconsin, who chaired a working group and was a member of the Steering Committee as well as a participant in the project workshop.

Bureau of Coastal Zone Planning
Division of Resource Management
Florida Department of Natural Resources
Tallahassee, Florida

Mr. Bruce Johnson, Chief
Ms. Mary Lou Stursa, Information Coordinator

Mr. Johnson attended only part of the project workshop and was therefore a contributor rather than a full participant. The Bureau of Coastal Zone Planning in Florida was originally named the Coastal Coordinating Council and was established in 1970, two years before national coastal zone legislation was passed. The following comments represent the joint views of Mr. Johnson and Ms. Stursa.

The views of these State agency workers are strongly affected by their experience in the practice of coastal zone management prior to both the passage of the Coastal Zone Management Act and the project workshop. Although seeing The Water's Edge as useful for new staff and sometimes as background, the main interest of Johnson and Stursa lies in the recommendations. These they often find to be of laudable intent, and good statements of ideals, but not really feasible in the context of coastal zone planning as it is actually carried out.

For example, General Recommendation V calls for creation of Coastal Area Preserves "for the permanent protection of the basic genetic stocks of plants and animals...." A major barrier to the feasibility of this is money; the stated recommendation requires levels of manpower and funding that are simply not forthcoming from either Federal or State governments, even though the goal may be desirable.

General Recommendation IV pressed for establishment of Coastal Zone Centers to coordinate research. Johnson and Stursa point out that if coordination is really intended, then all research moneys must be monitored

or flow through that agency. This would include state money as well as funds from NSF, the Sea Grant Program, and the Office of Coastal Zone Management. Otherwise, in their opinion, a coordinating agency will lack the authority to really coordinate.

They have, nevertheless, attempted to use some of the recommendations as "wedges" for justifying applications for funding or other actions. However, where the workshop recommended an independent coastal zone agency in each state, the Florida agency evolved into a component of an existing department.

Mr. Johnson and Ms. Stursa see the workshop and resulting book as products of a particular period in a continuing development. That is, its background and recommendations should be judged as very good, considering that the project was carried out before passage of the Federal act and that very few of the full "participants" were actually working in coastal zone management in action agencies. Because of the makeup of participants, these Florida workers view the results as not reflecting the actual problems of the planning process as it occurs in practice and therefore not as useful to action agency workers as they might have been.

Overall, Mr. Johnson and Ms. Stursa see the project as an excellent, though variable-quality, synthesis of material on coastal zone planning and feel that rapid changes in the field have outdated the book. Any new project along similar lines should insure substantial representation of managers of state coastal zone programs, as well as the academicians and researchers who dominated at the initial project.

Other Users

Department of Commerce
Washington, D.C.

Dr. Sidney E. Galler
Deputy Assistant Secretary
for Environmental Affairs

In the view of Dr. Galler the workshop held as a part of this project was a landmark meeting because it brought together a substantial number of workers in coastal zone matters and developed an "intellectually important focus." This meeting, and the ensuing publication, set the tone, according to Dr. Galler, for much of the effort to develop coastal zone planning that followed after the passage of the Federal Coastal Zone Management Act in the fall of 1972. Dr. Galler views the meeting process as even more important than the printed report.

In his opinion, a barrier to vigorous adoption of the findings and recommendations of The Water's Edge was the need to carry on what he terms the "political process" of establishing the national Office of Coastal Zone Management, pass coastal zone legislation in certain states, and establish state coastal zone agencies. As those actions were accomplished a group of users formed for the book and its background and recommendations. Dr. Galler suggests that a follow-up meeting, even this long after the original conference, could very definitely accelerate and amplify the recognition of the usefulness of the book. Thus, he implies that the book came forth a bit before the climate for it was right and that it could benefit from additional dissemination efforts.

The Nature Conservancy
Arlington, Va.

Dr. Robert Jenkins
Vice President and Director
Science Programs

(The Nature Conservancy is a nonprofit membership organization whose program is to preserve natural areas for present and future generations.)

At the time of this conference, the Nature Conservancy was developing a program in coastal ecology. Since that time this work has been shifted out of the organization so Dr. Jenkins has not been intimately concerned with coastal zone management. It is his impression, however, that the workshop associated with the project on Critical Problems of the Coastal Zone was one of the few that was long enough, specialized enough, and had enough of the right people to accomplish useful work. From that point of view he remembers this workshop as one that was more valuable than most in terms of benefits to the participants.

The Conservation Foundation
Washington, D.C.

Mr. John Clark
Senior Associate and Director of the Coastal Resources Program

(The Conservation Foundation carries on a program of research, education, and information to improve the quality of the environment.)

Mr. Clark participated in the project workshop. For the book, The Water's Edge, resulting from the project, Mr. Clark has both praise and criticism. Today, he says some of its concepts are outmoded; it lacks specificity of the type needed now, its organization is sometimes fuzzy and overlapping and it is out of date. Nevertheless, Mr. Clark asserts that The Water's Edge was "A landmark" in orienting readers towards the concept of a coastal zone and its management. He views the book as crucial in forming a national consciousness and says that the book could not have been done differently at that time in history.

Without the book, Mr. Clark believes the effects of the workshop would have been weakened greatly; the process and discipline of writing forced clarification of thinking. The project was, according to Mr. Clark, very timely. The workshop has paid off in terms of knitting together a group

that has stayed in close contact since that time. The meeting was important in forming the thinking of those participating.

On the other hand, Mr. Clark indicates that many participants came without background in coastal zone management. Thus some of those attending had feelings of futility about the workshop process and significant effort was involved in getting participants to communicate fully.

Although he personally has made use of the book only a few times, Mr. Clark says the project had an important effect on The Conservation Foundation, resulting in a shift from a communications program to a technical and research focus, of which the Coastal Resources Program is an example. The Foundation's present interdisciplinary staff of professionals in an outgrowth of that process. Considering barriers to use of the book, Mr. Clark suggests that a clear identification of the user, of the client for the book, was lacking at the workshop and that as a result the book was not sharply focused towards the needs of any particular set of users.

Office of Coastal Zone Management
U.S. Department of Commerce
Washington, D.C.

Ms. Michele M. Tetley
Technical Information Coordinator

Ms. Tetley describes The Water's Edge as the first and broadest document on coastal zone management, and a book that is on every reading list relating to the coastal zone. She notes that her Office has lost some 20 copies from its library, which is one measure of interest. As for further utilization, Ms. Tetley observes that workshop participants were the cadre from which persons were drawn to help set up the OCZM program and develop initial guidelines. She believes the workshop was "invaluable" in focusing people on this set of problems; it served as an important catalyst.

Features

In the opinion of the Principal Investigator, Dr. Bostwick Ketchum, utilization of the project product, The Water's Edge, was high because of its very timely publication, just as a new federal program was getting underway; because of the very high expertise of the persons contributing to the product; and because of the need of state coastal zone program personnel for such material. Dr. Ketchum believes these persons were often "ill-prepared" to move ahead with coastal zone programs at the time they received their responsibilities and that they were "grateful for an orientation course" in the form of The Water's Edge.

At the time this project operated, it is Dr. Ketchum's opinion that there were few persons with backgrounds enabling them to contribute to the project who were not in academic or Federal positions. This dictated the selection of participants from these two areas of interest. Were the project to be run today, or even a year later than it was, Dr. Ketchum indicates that a wider spectrum of professionals could be drawn upon.

The NSF/RANN program manager, Dr. Richard Kolf, was responsible for a complete re-direction of the project toward problem identification from that of the initial proposal, which focused on collection and interpretation of data on the status of the coastal zone from Cape Cod to Cape Hatteras. He also decided to reject supplementary proposals, offered in the spring of 1972, to expand the range of backgrounds of participants. He views the results as a timely collection of background on the coastal zone and its management, valuable primarily to those without prior work or technical background. Had Dr. Kolf stayed with NSF he believes he would have worked on promoting dissemination and follow-on activities.

Within NSF/RANN, and presumably in other agencies, such as NOAA, the project and The Water's Edge aided program development and review of proposals by providing program managers with perspective on the field of coastal zone management. According to Dr. Edward H. Bryan at NSF/RANN, this sort of follow-through from the project has continued into fiscal year 1976 at which point NSF dropped coastal zone research as a specific focus of its programs because of the emergence of national and state programs in this area.

Given the project format, with commercial publication of a book as the intended product, little additional dissemination activity was planned beyond the date of publication, except for carrying out the distribution of copies provided by the publisher to the project as part of the publishing contract. In effect, distribution was largely in the hands of the publisher with promotion occurring through advertising and reviews and notices in professional literature. The book and the project were mentioned, for example, in an editorial on the future of the coastal fringe published in the Bulletin of the Ecological Society of America in June, 1973 (Vol. 54, No. 2), and in an article in the SAIS REVIEW, 1974 (Vol. 18, No. 3, School of Advanced International Studies, the Johns Hopkins University).

It is quite apparent that the timing of this project, a few months before passage of major national legislation on the coastal zone, was quite desirable; prompt production of the book made it available just as significant demand became manifest.

The strength of this project lay in its concentration of research talent on interdisciplinary consideration of a particular set of environmental problems and in maintaining this concentration long enough (two weeks of workshop) to create the basis for a comprehensive report. Moreover, the

workshop was followed up promptly so as to complete writing, editing, and printing within half a year--a most significant accomplishment.

The weakness of this project lies in differences of opinion and philosophy about the objective of the project and the utilization of its product. A very important use of the book has been as a basic and comprehensive primer for staff in agencies with coastal management responsibilities. Persons active in such agencies prior to the project tend to be critical of the low involvement of representatives of such users in the planning and operation of this project. As noted above, ten of the 112 participants and contributors combined came from state agencies. (All members of the project steering committee came from academic or research positions and apparently did not represent the spectrum of positions among such professionals.) Action agency representatives assert that the research-oriented conference participants did not adequately address practical problems faced in operating agencies. On the other hand, new staff in these agencies have apparently often received their introduction to coastal zone management through this book and have found it a useful starting place.

By contrast, the research community was deeply involved in the planning and operation of the project and views the results as a good assessment of the status of the field at that time and uses the book in its teaching programs. In addition, the research community was the primary beneficiary of the personal contacts made possible through the project working groups and workshop.

Conclusions

The broad coverage of problems of coastal zone management provided by The Water's Edge and its prompt and timely publication have assuredly contributed to the usefulness of this major project product as an introduction to a new and rapidly developing field. The length (two weeks), selection of highly capable participants, and general arrangements of the workshop likewise resulted in a conference experience that is very favorably regarded by persons who were there. Overall, in its environment, this project must be rated as well utilized and as having a large impact on the field in which it was accomplished.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 50

AN ENGINEERING FEASIBILITY STUDY OF AN IONOSPHERIC TECHNIQUE TO IMPROVE TSUNAMI WARNING SYSTEMS

UNIVERSITY OF HAWAII

Case Investigator:

R. Whisnant

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:

W. A. Flood

Department of Electrical Engineering
North Carolina State University
Raleigh, North Carolina 27607

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1800 G Street, N.W.
Washington, D.C. 20550

AN ENGINEERING FEASIBILITY STUDY OF AN IONOSPHERIC TECHNIQUE TO IMPROVE TSUNAMI WARNING SYSTEMS

Introduction and Summary

Whenever a large earthquake occurs at relatively shallow depths near an ocean shore or on the continental shelf, one of the possible results is the generation of an ocean wave commonly called a tidal wave, or tsunami. Although the amplitude of these waves in the open ocean is quite small, there is an enormous mass of water involved. When the wave approaches the shallow depths near a shoreline, a wave or run-up is produced, which may reach 50 feet or more above normal high tides. The tsunami wave can travel thousands of miles across an ocean and impact a coastline with virtually no warning, causing great physical damage and loss of life. Following such an event in 1948, the Pacific Tsunami Warning System (PTWS) was established in Hawaii to provide warning of approaching tsunamis to coastal areas in the Pacific Basin, which, because of its geological structure, is the location of almost all tsunami occurrences. The Pacific Tsunami Warning System currently utilizes seismographic instrumentation and tide gauges throughout the Pacific to predict the occurrence of a tsunami. The prediction is difficult and semi-quantitative. It was the object of this research to provide an additional instrumentation methodology to improve the prediction accuracy.

The instrumentation methodology explored under this research is that of measurement of a Doppler shift in a high frequency radio signal occurring in the upper atmosphere as a result of an acoustic wave that has been generated by

Table 50-1. PROJECT INFORMATION

Project Title: An Engineering Feasibility Study of an Ionospheric Technique to Improve Tsunami Warning Systems	Grant/Contract No. GI-34973
RANN Program Manager Dr. John Scalzi	RANN Program Area Division of Advanced Environmental Research and Technology
Principal Investigator(s): Dr. Paul C. Yuen Co-principal Investigators: Dr. Kazutoshi Najita Dr. Augustine Furumoto	Schedule Start: June 1972 End: May 1976
Institution University of Hawaii	Funding NSF: $115,000 Other:
Contributors/Collaborators Dr. Gaylord R. Miller Research Oceanographer and Director Joint Tsunami Research Effort National Oceanic Atmospheric Administration	
User Advisory Committee None	
Precursor Activities Prior research relating to ionospheric radio propagation effects and coupling of acoustic waves generated by seismic waves.	

an ocean surface wave. This ocean surface wave, of a particular type called a Rayleigh wave, travels at much higher speeds than a tsunami and arrives at Hawaii (the only Pacific location where Rayleigh wave measurements are currently made) in sufficient time to measure its characteristics and attempt a prediction of a tsunami approach.

The instrumentation technique employed in this research program was originally conceived and developed under an NSF program investigating properties of the ionosphere. It was modified and adapted for this program and instrumentation has been constructed and operated to obtain data for analysis. The instrument system is ultimately intended to be incorporated in the Pacific Tsunami Warning System. However, additional research is required to prove the validity of the method developed for relating the data obtained to the nature of the earthquake event which generated the Rayleigh waves. Because of a gap in funding from 1974 to the present, no effort has been directed to resolving the remaining questions. In order to improve upon the current prediction techniques employed by the Pacific Tsunami Warning System, it is necessary that the analysis provide information regarding the presence of a vertical component to the earth motion during the earthquake. Utilization of the technique developed in this program will not take place until the analytical technique is proven. As described in later sections, the analytical technique is an adaptation of one published by Brune in 1960. Since that time, there have been substantial advances in hardware and techniques for analysis of complex signals, and it may be advisable to consider at this point whether some of these would be more appropriate to the objectives of this research than the techniques presently pursued.

Research Description

This program, "An Engineering Feasibility Study of an Ionospheric Technique to Improve Tsunami Warning Systems," was proposed to NSF/RANN in June 1971. The amount requested was $164,165 for a 36-month program. The program was subsequently funded for 24 months at $115,000. Dr. Paul C. Yuen has been Principal Investigator and Kazutoshi Najita and Augustine Furumoto have been Co-principal Investigators. Each of these participants has been active for several years in research relating to ionospheric radio propagation effects and the coupling of acoustic waves generated by seismic waves. Some of this work has been funded by the National Science Foundation, Division of Atmospheric Sciences.

The basic instrumental technique utilized for tsunami warning was developed for the previous NSF research work. It measures the Doppler shift in a high frequency radio signal produced by the motion of an ionospheric reflecting layer. To accomplish the measurement, a very stable transmitter emits a high frequency wave which travels into the upper atmosphere and is reflected from the ionosphere to a ground-based receiver. At the receiving site, another very stable oscillator is used as a reference to measure the instantaneously received frequency. Any change in the ionosphere through which the wave passes, such as an increase or decrease in the electron density at some height at or below the point of reflection, will cause a change in the phase path of the signal between the transmitter and the receiver. This change is detected and recorded by the system instrumentation as a change in the instantaneously received frequency. This method is simple and inexpensive because extremely stable signals are available from the transmissions of the National Bureau of Standards time-frequency standard station WWVH.

The technique is sensitive to large ground level energy changes, such as large explosions or earthquakes, which cause energy to be propagated upwards in the form of acoustic waves. The acoustic waves propagated upward consist of density changes in both neutral and ionized particles. The HF Doppler sounding technique can detect an energy release on or near the surface by detecting the resulting ionospheric electron density changes which it produces. Because of the exponential decrease in atmospheric pressure with height, the displacement amplitude of an upward wave also increases exponentially. Thus, a very small wave amplitude on the ground can increase to a very large amplitude at ionospheric heights. The first ionospheric detection of earthquake effects occurred in 1968.

The relationship between the ocean surface motion and the acoustic waves detected in the atmosphere needs to be understood with regard to tsunami prediction. An earthquake occurs when a portion of the earth's crust moves to relieve stresses which have built up there. The motion is abrupt and releases vast amounts of energy. Part of this energy flows outward from the epicenter in the form of several types of seismic waves, one of which is a surface, vertical-motion wave called a Rayleigh wave. The earthquake also produces body waves which travel through the mantle of the earth. In general, the nature of the waves propagated from an earthquake is complex and their detection is complicated by the dispersive nature of the medium through which they are transmitted. When earthquakes occur near bodies of water and at relatively shallow depths they may also produce tsunami waves of potentially great destructive power. Fortunately, the Rayleigh surface waves travel across the surface of the ocean with speeds many times that of the destructive long-period tsunamis, and hence reach distant points many hours before the tsunami waves. This is

also true of the seismic waves which travel through the earth's mantle, so that seismograms of a particular earthquake are also available long before tsunami waves that must travel any appreciable distance. The Pacific Basin and its continental shelf are known to be particularly susceptible to earthquakes and, therefore, the tsunami is a phenomenon which is primarily characteristic of the Pacific Ocean.

Since the Rayleigh wave travels at high speed and arrives at points distant from the epicenter long before the tsunami wave, detection and analysis of the Rayleigh wave can be used as a warning for the approach of a tsunami. Rayleigh waves are characterized by long periods, ranging from a few seconds to a few hundred seconds, and those of particular interest for ionospheric detection are in the upper end of this range. Attempts have been made at the University of Hawaii to develop seismographs which can detect these long period waves. However, such seismographs also coupled to other seismic waves complicate the analyses of the seismic records. The Principal Investigator's opinion is that this necessitates another method of detecting and measuring Rayleigh waves; thus, he has investigated measurement of the acoustic waves generated by Rayleigh waves on the ocean surface. Rayleigh waves have a very small amplitude, on the order of a few millimeters, in the ocean. However, the long period of these waves is attended by a large area of surface motion that generates substantial acoustic energy in the air above the ocean. The acoustic waves thus generated travel into the ionosphere where they can be measured by the Doppler shift technique.

There is an additional phenomemon which aids this detection method. Upward traveling acoustic waves launched by the Rayleigh wave increase rapidly in amplitude with height. However, when the gas density decreases to the level

where the mean free path of the neutral gas particles becomes comparable to the wave length of the acoustic wave, the gas particles begin to move out of step with the wave motion and the wave is attenuated. The height at which the attenuation becomes important increases with increasing wave length. The longer the period of the wave, the greater the height a wave can reach before it begins to attenuate. By proper selection of the radio frequency, a suitable reflection height can be chosen to permit the proper amount of filtering to eliminate higher frequency components and, hence, produce Doppler records most useful for tsunami warning analysis. This obviates the need for analog or digital filtering of the Doppler signal.

Most earthquakes occurring at relatively shallow depths produce Rayleigh surface waves, but not all of these earthquakes will produce a tsunami. The orientation of the fault in the earth and the type of motion with respect to the fault must have particular characteristics to produce a tsunami. Basically, it is necessary that the earth motion have a vertical component to produce a tsunami. Such an earthquake is said to be a dip-slip character or source-mechanism. Once the Doppler record generated by the Rayleigh wave has been recorded, the problem is reduced to one of analyzing the complex wave form to determine the nature of the earth motion at the epicenter, and particularly whether it had a vertical component. The method of analysis described in this research is based on a method of surface wave analysis developed by Brune.* Brune's method makes use of the fact that if a disturbance occurs at a given point in a dispersive medium, the motion at any distant point is determined by the phase velocities of the spectral components and the characteristics of the initial disturbance. In applying Brune's method, the phases of the various

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*James N. Brune, John E. Nafe, Jack E. Oliver, "A Simplified Method for the Analysis and Synthesis of Dispersed Wave Trains," Journal of Geophysical Research, Vol. 65, No. 1, January 1960.

spectral components at the origin, their phase velocities, and the relative phases of different frequencies components at the point of observation are related to each other. If two of these quantities are given, the third may be determined in most cases. In applying the method, actual seismograms are analyzed to determine which frequencies of the Rayleigh waves should be considered. From a selected type of stress pattern at the source, the waves of these frequencies are then theoretically generated and followed down a propagation path to the observation point to learn what kind of disturbance will be produced there. The disturbances at the observation point are displayed in the form of synthetic seismograms. If the synthetic seismogram does not agree with the observed seismogram, the stress pattern at the source is then changed and the process is started again.

In this project, the process of determining the source characteristics are similar to the method of Brune's. The spectral components of the Rayleigh waves are determined from the Dopplergram made at a point distant from the epicenter. Having determined from geophysics the phase velocity and wavelength of each of the components, the idealized wave trains are plotted along a line from a fixed reference point to the earthquake epicenter. From the phase shift angle of the components, a conclusion is then drawn as to the initial motion of the earthquake source to determine if it is of the type which might produce a tsunami.

The instrumentation developed for this research program is similar in principle to the system in use at the University of Hawaii for basic studies of the upper atmosphere. However, while data are collected and stored on magnetic tapes and reduced once every nine days in the atmospheric research system, the data in the tsunami warning instrumentation are analyzed in real time. The tsunami system utilizes a Doppler receiver and seismograph station located on the Manoa campus of the University of Hawaii on Oahu. The 5 and 10 MHz signals

used in the measurement originate from station WWVH, the time and frequency standard station on Kauai. The signal detection instrumentation consists of an RF amplifier following the antenna whose output is fed to a tracking filter and then into a mixer. The other input to the mixer is a reference oscillator whose output differs from the 10 MHz carrier by 6 Hz. The output of the mixer is lowpass filtered and fed into a frequency-to-voltage converter. The output of this converter is the Dopplergram which is recorded on the strip chart recorder. During periods when no earthquake has occurred, the recorder runs at a low chart speed. A seismometer, located in the Hawaii Institute of Geophysics building on the Manoa campus, provides a signal through a telephone hookup to the Radio Science Laboratory. When a seismic signal indicating an earthquake of a magnitude sufficient to be of interest is received, it is sensed and used to increase the chart recording speed, providing the required frequency resolution of the Dopplergram. The acoustic wave propagation time from the surface to the ionosphere is sufficient to permit this adjustment.

Instrumentation has been constructed to receive both 5 and 10 MHz carriers from WWVH, and both systems are identical except for the frequencies employed. This instrumentation is in operation and data from it are being taken on a routine basis. However the primary objective of the research has not been met. This was to verify that the analytical method for determining the earthquake source-mechanism from long period seismic Rayleigh wave data, as described by Brune, could be extended to the corresponding radio Doppler data. In order to carry out the modified analysis of Brune described above, it is necessary to know the group and phase velocities of the oceanic Rayleigh waves, the total time delay of the acoustic wave in the atmosphere, and the location of the epicenter. The location of the epicenter is determined by conventional seismic

data. The group and phase velocities of the Rayleigh waves are relatively well established for waves of periods greater than 100 seconds. In order to establish the reflection height of the acoustic waves, a set of curves was calculated from published dispersion relationships, providing reflection height as a function of delay time for various acoustic wave lengths. Having provided these relations for the acoustic waves, it is then possible to carry out the modified Brune method.

The basic justification for this research program is the improvement of tsunami warning information. Since tsunamis often travel thousands of miles before striking shorelines and have potential of causing substantial damage and loss of life, hours may be available in which to predict the tsunami approach and take protective measures to reduce the damage. Although tsunamis are rarer than earthquakes, their effect can be severe. For example, the Chilean earthquake of 1960 killed approximately 2,000 people in Chile and rendered about a 1/2 million people homeless. The property damage was estimated to be about $500 million. Tsunami damage from this earthquake occurred along the shores of South America, certain parts of North America (principally Southern California), the Hawaiian Islands, New Zealand, the Phillipine Islands, the Japanese Islands, and other areas in and around the perimeter of the Pacific Ocean. About $500,000 worth of damage was sustained by the Southern California area, while 61 deaths and damage estimated at $75 million were suffered by the Hawaiian Islands. The Phillipines suffered about 32 deaths, while Japan incurred approximately $50 million worth of damage and 180 deaths.

After the destructive tsunami generated in the Pacific Ocean by the 1946 Aleutian earthquake, the U.S. Coast and Geodetic Survey set up the Pacific Tsunami Warning System.

The Honolulu Observatory is located at Ewa Beach on the Island of Oahu near Honolulu. Mr. Sokolowski is acting head of the Observatory which has a staff of four full-time geophysicists and provided the following descriptions of the Pacific Tsunami Warning System. These personnel reside on the grounds of the Observatory and two are on duty at all times to respond to seismic alarms. Both short- and long-period seismographs are in operation at the Observatory and automatic alarms are located in the residences of the staff so that the seismographs are monitored 24 hours a day. The Observatory has teletype contact with 31 other seismic observatories in the Pacific Basin and 48 tide stations. Precoded messages are available for communication with the stations and observatories to request data following an earthquake and to provide tsunami information. The Pacific Tsunami Warning System was set up in 1948 following a major tsunami in the Pacific. Other tsunamis have occurred in 1952, 1957, 1960, and 1964. The maximum tsunami run-up elevation from the 1957 tsunami was 52 feet in the Hawaiian Islands, which gives some idea of the potential magnitude of these waves. The Honolulu Observatory is in telephone contact with local Civil Defense and police agencies to provide tsunami watch or warning information when it is required.

The prediction of tsunamis from the currently available information is a difficult task even to the trained geophysicist. The Honolulu Observatory currently investigates all earthquakes with a magnitude greater than 6.8 whose epicenters lie in a region where tsunami generation is possible. This generally consists of requesting tide gauge information and additional seismic data from other stations in the vicinity of the epicenter. Such earthquakes occur as frequently as 5-10 per month. The operating regulations for the Observatory require that a tsunami watch be issued for all earthquakes of greater than magnitude 7.5 with epicenters in the Pacific Basin. The tsunami watch requires

that appropriate government agencies be notified of the potential occurrence of a tsunami. If tide gauge information indicates that a tsunami has indeed occurred, the "watch" is escalated to a "warning." This occurs roughly once or twice per year.

The trained geophysicist can recognize certain characteristics of the seismogram which give indications of the depth of the earthquake, as well as its magnitude. For tsunami prediction, one of the first determinations which must be made is the epicenter location. This requires seismic data from several stations and, due to the communications difficulties often experienced, may require up to an hour after the first observation at the Honolulu Observatory. If the magnitude, depth, and epicenter locations favor the generation of a tsunami, additional tide gauge information is requested and evaluated. If a tsunami watch has not been required based on magnitude alone, one may be issued pending receipt of additional supporting information. If it is found that there is a high likelihood of a tsunami, then a tsunami warning is issued for the appropriate locations in the Pacific Basin. It is not uncommon for seismic or tide information to be delayed or nonexistent due to the disruption caused by the earthquake. Likewise, erroneous data are sometimes received. The geophysicist is thus often forced to make predictions of tsunamis based on incomplete information. The issuance of a tsunami warning sets in motion evacuation from low-lying areas and disrupts many normal activities. The expense of such an evacuation and preparation for a tsunami is not inconsequential. In the past, warnings have been issued when tsunamis did not materialize, and this tends to create a lack of confidence in the warning system. Therefore, the Honolulu Observatory personnel are very cautious about proceeding beyond the tsunami watch stage and would certainly welcome improvements in their capability to accurately predict tsunamis.

Although there is no question about the potential destructive capacity of the tsunami, its occurrence is infrequent and not all earthquakes, not even major ones, produce a tsunami. The last major tsunami occurrence in the Pacific was in 1964. Regardless of their frequency, however, any reasonable method that improves substantially the ability to predict their approach in a more quantitative fashion would be a valuable addition to the current warning system. Whether the methods developed under this program can be shown to accurately and quantitatively predict the type of earthquake occurrence which produces a tsunami remains to be proven. If it does, then it can certainly be integrated into the Pacific Tsunami Warning System and enhance the capability of that system.

The Doppler measurement system described previously has been constructed and placed in operation during this research program. It is operated on a continuous basis to gather data which may be examined and correlated with seismic data. The instrumentation has been documented in an unpublished manual which includes circuit descriptions and diagrams, parts lists, and operational procedures. A first annual report, dated July 15, 1973, was published describing the work to that point. The proposal for a Phase II effort beginning July 1, 1976, also contains additional documentation of progress. The Principal Investigators have published a paper in the Proceedings of the IEEE describing the Doppler instrumentation technique. The work was also described in a conference paper presented to the American Geophysical Union meeting in Washington, D.C. in 1973.*

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*K. Najita, P.F. Weaver, P.C. Yuen, "A Tsunami Warning System Using an Ionospheric Technique," Proceedings of the IEEE, Vol. 62, No. 5, May 1974. K. Najita and P. Yuen, "A Tsunami Warning System Using Our Atmospheric Technique" 54th Annual Meeting, American Geophysical Union, Washington, D.C. 1973.

Utilization Objectives

From the standpoint of direct utilization for the prediction of tsunami occurrence, there is one potential user for this research: the Pacific Tsunami Warning System (PTWS). The PTWS is headquartered at the National Weather Service, Honolulu Observatory, on the Island of Oahu. The National Weather Service is administered by the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce. Honolulu Observatory is connected by teletype communication with 31 other seismic observatories and 48 tide stations in the Pacific Basin.

The basic objectives of the Pacific Tsunami Warning System are to:

1. detect and locate major earthquakes in the Pacific region;
2. determine whether they have generated tsunamis, and
3. provide timely and effective tsunami information and warnings to the Pacific population in order to minimize the hazards of tsunamis.

There are other tsunami warning systems operated by Japan and Russia in the Pacific, but no attempt was made to assess utilization of this research by those systems.

From the standpoint of professional or academic interest in this research program, the Joint Tsunami Research Effort (JTRE) of NOAA, located on the Manoa campus of the University of Hawaii, is another potential user. Dr. Gaylord R. Miller, Director of JTRE, has assisted in this program as a consultant.

The Joint Tsunami Research Effort, an organization of about six people, is housed with the Hawaii Institute of Geophysics on the University of Hawaii campus. Its research programs are concerned with various aspects of tsunami effects and prediction. Areas of investigation include the hydrodynamics of the tsunami wave interaction with the shoreline, preparation of hazard maps delineating the potential damage from tsunamis of various intensities, and the prediction of tsunamis from pressure sensors located on the ocean floor.

Other organizations with a potential interest in this research would include the various oceanographic research organizations in the United States, as well as academic institutions with programs in oceanography, seismology, or geophysics.

The basic plan for utilization of this research is to integrate the experimental instrumentation and analysis methodology into the operations of the Pacific Tsunami Warning System. Initially, the Rayleigh detection and source-mechanism determination is to be carried out at the Radio Science Laboratory at the University of Hawaii, and the results are to be reported via telephone to the Honolulu Observatory. However, it is intended that a system be designed and instrumentation assembled through which PTWS personnel can call the Radio Science Laboratory and have the data on the long-period Rayleigh waves transferred from storage and transmitted to the Honolulu Observatory for analysis. During this interim stage, the analysis will be carried at the Laboratory and at the PTWS. Later, the entire operation is intended to be transferred to the PTWS. A new grant (AEN7615773) was made to the University of Hawaii on July 15, 1976 to continue the research. The grant amount was $132,400, with Dr. K. Najita as Principal Investigator. The stated objectives for this continuation of the research are:

1. Operational tests of the ionospheric tsunami warning system and further improvement of the electronic units,
2. Integration of the system into the PTWS on an experimental basis, and
3. Improvement and possible simplification of the source-mechanism analysis method to determine numerical probability for tsunami generation.

It is intended by the research Principal Investigators that the ionospheric

technique will ultimately provide the PTWS with a means of relating long-period Rayleigh waves to the earthquake source-mechanism and thus provide a more definitive measure of the likelihood of a tsunami in the Pacific Basin.

Utilization Obtained

Up to this point, no utilization has taken place except for accumulation of Dopplergrams for the purpose of developing the modified Brune method of earthquake source-mechanism determination. However, in order to evaluate the likelihood of future utilization, interviews were held with Mr. Tom Sokolowski, at the Pacific Tsunami Warning System, Dr. Gaylord Miller of the Joint Tsunami Research Effort, and Dr. David Stewart, Director of the McCarthy Geophysics Laboratory at the University of North Carolina at Chapel Hill. In addition, after Dr. Stewart became familiar with the details of the program, he contacted James N. Brune, who published the paper on which the source-mechanism analysis of this research is based, with regard to his opinion of the application of his work to the present research objectives. Information obtained from these interviews is summarized in the following paragraphs.

User Survey

Mr. Tom Sokolowski, Principal Geophysicist, National Weather Service, Honolulu Observatory, Pacific Tsunami Warning System, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

In discussing the merits of the ionospheric measurement technique, it was evident that Mr. Sokolowski was not very familiar with it, although he had attended some briefings on it in its early phases. He has had no direct contact with the project personnel in about a year and a half. Mr. Sokolowski expressed an interest in seeing the ionospheric technique incorporated into the PTWS once

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its usefulness has been proven. It was evident from the discussion with him that the current warning system capabilities provide at least a semi-quantitative basis for tsunami prediction, and any additions to the system should provide an improvement in the quantitative assessment of the tsunami potential of any given earthquake.

Dr. Gaylord R. Miller, Research Oceanographer and Director, Joint Tsunami Research Effort, Pacific Marine Environmental Laboratory, Environmental Research Laboratories, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

As mentioned previously, the JTRE is collocated with the Hawaii Institute of Geophysics on the University of Hawaii campus. It is concerned with research in such areas as the interaction of tsunami waves with shoreline configurations and structures, the prediction of tsunamis from pressure sensors on the ocean floor, and preparation of tsunami hazard data and maps for various locations in the Pacific Basin. Dr. Miller expressed the opinion that the correlation of the ionospheric measurements of the Rayleigh waves with the earthquake source-mechanism and its capacity for tsunami generation remain to be proven. He appears to feel that the location of a relatively few pressure sensors on the ocean bottom at strategic locations with the pressure measurements telemetered back to a warning system from buoys would provide a superior means of predicting tsunamis. This technique is under active consideration at present.

Dr. David Stewart, Director, McCarthy Geophysics Laboratory, University of North Carolina at Chapel Hill, Chapel Hill, N.C.

Because of his expertise and experience in seismology, Dr. Stewart was requested to read the pertinent documents and discuss the feasibility of correlating the Dopplergram with the earthquake source-mechanism. Dr. Stewart points out that the conventional, and most reliable, method of determining the source-mechanism is to determine the orientation of the fault at the epicenter through calculations based on seismograms recorded at several locations distant

from the epicenter. This type of calculation is generally not suitable for tsunami prediction due to the number of seismograms required and the time consumed making them available and carrying out the calculation. In reviewing the Dopplergram method in light of the more conventional techniques, Dr. Stewart was skeptical of whether the earthquake source-mechanism could be determined from a single Dopplergram and it was decided that he should contact Dr. Brune, whose paper provided the background for the Doppler method. Parenthetically, it might be noted that neither Dr. Stewart or Dr. Brune were aware of this research program.

It was Dr. Brune's opinion that it would be theoretically possible to determine the occurrence of a simple dip-slip source-mechanism, given the magnitude of the earthquake, the epicenter location, the azimuth from the observation point to the epicenters, and some knowledge of the geological structures in the vicinity of the epicenter. It was his feeling that this represents such an ideal case that the Dopplergram method does not constitute a viable practical tsunami predictor. Dr. Brune expressed the opinion that much more modern methods of source-mechanism prediction are now available and the one suggested by his paper is somewhat outmoded. He believes it is possible to measure the long-period Rayleigh wave directly with the seismograph without going through the ionospheric technique, and he states that he has built seismographs to measure Rayleigh waves with periods of greater than 50 seconds. He also states that horizontal shear (Love) waves contain some of the best information for source-mechanism analysis. These can also be recorded on seismographs, and, when combined with Rayleigh wave information, constitute the best information for source-mechanism determination.

Features

It would appear that Drs. Yuen and Najita have considerable experience in measurement of atmospheric properties through the use of Doppler techniques, and are familiar with the electronic instrumentation required to make these measurements. Based on the comments of Stewart and Brune, it is less clear whether the technique for source-mechanism analysis is viable and an improvement on the present tsunami analysis techniques. Dr. Najita pointed out during the interview with him that the correlation of the Dopplergram and the source-mechanism remains the most important area of future investigation.

The communication and coordination between the Principal Investigator and those responsible for the program at NSF appear to have been minimal. The program was funded in 1972 for two years as opposed to the three years requested by the proposal. No funding has been received since and the funds which were originally allocated for equipment purchase have been utilized, with the permission of NSF, for operation of the prototype equipment and the collection of data. A no-cost extension of the project to May 31, 1976 was requested and approved by NSF. Since the Principal Investigator visited NSF in 1973, there has been no other communication with the program manager. This lack of communication has not been beneficial to the effectiveness of the program.

There has been no formal user committee organized for this program. Moreover, the participation and collaboration from the major potential user, the Pacific Tsunami Warning System, has been very limited. The PTWS personnel view the program as pure research and one which requires considerable further development before its value to the PTWS is shown. One of the Co-principal investigators, Dr. Furumoto, is a member of the Hawaii Institute of Geophysics staff, and he was evidently active in the project in its early stages. However, it appears that his projected involvement in further project activities is more limited. This is true despite the fact that the remaining technical

issue, that of relating Dopplergrams to earthquake source-mechanisms, is one requiring particularly the expertise of the geophysicist or seismologist.

The dissemination of the program activities and accomplishments consist of a paper presented to the American Geophysical Union and a paper published in Proceedings of the IEEE. In addition, several graduate and undergraduate theses have explored technical aspects of this experimental method. Utilization has been negligible up to this point. The limited dissemination and utilization is in part due to the incompletness of the research.

The major barrier to utilization of this research would appear to be the establishment of the validity of the Doppler technique as a predictor of the earthquake source-mechanism. Based on the comments of Brune, the method could be used only in rather idealized cases and, therefore, may not be viable for the more complex cases often encountered in practice. There is no disagreement among those interviewed, including the Principal Investigator, D. Najita, that the validity of the proposed source-mechanism analysis technique remains to be proven.

The program has several obvious strengths. The Principal Investigators have had several years of experience in research relating to the properties of the ionosphere and wave propagation therein. The research relating to tsunamis is being carried out in proximity to the Hawaii Institute of Geophysics (HIG), the Pacific Tsunami Warning System headquarters, and the Joint Tsunami Research Effort of NOAA. Each of these organizations provides staff and other resources which should be valuable to the research program if effectively utilized. The location of the program at the University of Hawaii places it geographically in a position to obtain seismic data for analysis and central to the area of concern over the occurrence of tsunamis. There are also several apparent weaknesses in the program. The lack of communication and coordination with NSF,

and the lack of funding for the past two years has obviously been detrimental. It would also appear that the available technical resources of the PTWS, JTRE, and HIG have not been utilized to the extent that should be possible. The major unsolved technical problem in the Doppler technique is that of source-mechanism analysis and this is essentially a problem of geophysics. The involvement of geophysics expertise in the program at this point appears to be less than optimal.

It occurs that due to the time elapsed since the inception of the project, it would be well to reconsider the major technical directions of the program. First, whether the detection of Rayleigh waves through coupling to the ionosphere is the most advantageous way to obtain long-period seismic data should be determined. Consultation with other experts in geophysics and seismology, such as Brune, might provide some fresh insights into the best instrumentation for obtaining seismic data. Second, recent advances in special-purpose instrumentation for providing spectral analysis through the Fast Fourier Transform, the availability of high speed analog-to-digital converters and advances in telecommunications may make it feasible to consider these components in terms of their applicability to analysis of seismic data for source-mechanism determination. As the Principal Investigators have pointed out, the limited time available to collect and analyze data in order to predict a tsunami before it strikes land is a crucial factor in the prediction methodology. However, this may be the appropriate time to consider whether other techniques (i.e., long-period seismograms analyzed by current spectral analysis techniques/equipment or direct pressure measurements of Rayleigh waves) are more likely to produce a substantial improvement in current tsunami warning capabilities. Since substantial data have been collected, analyses to correlate the measurements with known earthquake events might be done to provide additional evidence of the utility of the Doppler method.

Conclusions

This project has obtained essentially zero utilization because of the incompleteness of its investigations. The utilization by the Pacific Tsunami Warning System in the future will depend on the outcome of the currently funded effort. This may be accomplished under the new grant which is now in effect.

Appendix A

PUBLICATIONS AND PRESENTATIONS

Publications

a. Najita, K., P.F. Weaver and P.C. Yuen, A. Tsunami Warning System Using an Ionospheric Technique, PIEEE, 536-567, 1974.

b. Kamikawa, Neil, Design of a Long Period Measuring Electronic Instrument Using a Phase-Locked Loop, Senior Honors Thesis, December, 1974.

c. Lau, Chi K., Hilbert Transform Method for Determining the Period of Rayleigh and Acoustic Wave Generated Ionospheric Doppler Records, Senior Honors Thesis, December, 1974.

d. Suenaga, Wayne, An Investigation of Two Models of the Doppler Recordings Associated with Earthquake Rayleigh Waves, M.S. Thesis, December, 1973.

e. Huang, Y., Dynamic Response of the Ionosphere to Geomagnetic Sudden Commencement, Dissertation for Ph.D. in Electrical Engineering, December, 1973.

f. First Annual Report to NSF, An Engineering Feasibility Study of an Ionospheric Technique to Improve Tsunami Warning Systems, July 15, 1973.

g. Second Report to NSF, An Engineering Feasibility Study of an Ionospheric Technique to Improve Tsunami Warning Systems, September 30, 1976.

Presentations

a. A Tsunami Warning System Using our Ionospheric Technique, Spring 1973, 54th Annual Meeting of the AGU, Washington, D.C., Presented by K. Najita and P. Yuen.

b. Effects of Tsunami-generating Earthquakes on the Earth's Inosphere, Fall 1973, Electrical Engineering Department Seminar, Presented by K. Najita.

c. Long Period Acoustic Wave Propagation into the Upper Atmosphere, Spring 1974, Meteorology Department Seminar, Presented by K. Najita.

d. Signatures in the Sky, Spring 1976, Electrical Engineering Department Seminar, Presented by K. Najita.

RESEARCH TRIANGLE INSTITUTE N.C.

RANN UTILIZATION EXPERIENCE

CASE STUDY NO. 51

PHOTOCHEMICAL CONVERSION OF SOLAR ENERGY

BOSTON UNIVERSITY

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Case Investigator:

R. Alberts

Research Triangle Institute
P.O. Box 12194
Research Triangle Park
North Carolina 27709

Technical Reviewer:

K. DeArmond

Department of Chemistry
North Carolina State University
Raleigh, North Carolina 27607

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1800 G Street, N.W.
Washington, D.C. 20550

PHOTOCHEMICAL CONVERSION OF SOLAR ENERGY

Introduction and Summary

Of the many technologies that convert solar energy to forms which can displace conventional energy supplies (fossil fuels primarily), those receiving major emphasis include use of solar thermal energy (solar heating and cooling, thermal electric power, ocean thermal), wind energy, photovoltaic conversion, and bioconversion. Closely related to the latter two categories are photochemical conversion processes that result in either electrical energy or useful fuels. In these processes, solar energy interacting with chemical systems causes either the direct transfer of electrons to electrodes (photogalvanic processes), thus producing electrical current in external circuits, or the production of reduced chemical species that can subsequently serve as fuels.

The potential for photochemical conversion of solar energy was recognized in the formulation of RANN's solar energy program. Thus, when a proposal was received from Boston University (BU) for research on photochemical conversion of solar energy, it was recognized as a potentially valuable component of the program. A cooperative effort between BU's Department of Chemistry and EXXON Research and Engineering Co.* was proposed. EXXON had recently developed a new version of a photogalvanic cell that exhibited some of the properties required for efficient solar energy conversion. Fundamental investigations in photochemical processes

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*Then the Esso Research and Engineering Co.

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would be accomplished at BU while applied research on photoconversion cells and the fabrication and demonstration of devices would be performed by EXXON. Although research on organic compounds and reactions was also proposed, it was deleted from the proposed program prior to award of the grant.

Review and evaluation of the proposal resulted in its being funded with a starting date of June 1, 1973. Relevant project information is given in table 51-1. The specific goals of the 3-year program were:

1. Construction and demonstration of a photogalvanic cell which has 5 percent engineering efficiency, i.e., converts at least 5 percent of the energy of the solar flux at ground level into electrical power.

2. Achievement of 25 percent quantum efficiency of photogeneration of useful fuel by photoredox reactions of homogeneous inorganic aqueous solutions.

Quantum efficiency refers to that percentage of the incident light quanta or photons that are incident on the cell and which participate in the desired reaction. Photons that do not participate in the reaction are reflected, transmitted, or absorbed in non-productive processes.

In pursuance of these goals, research has been performed on (1) iron-thionine* and iron-thiazine photogalvanic cells and on the fundamental chemistry of the electrolytes, and (2) on the photodecomposition of ferric bromide to produce fuel. In the photogalvanic cells, the incident light photons excite molecules and produce higher energy chemical species. These higher energy products release their energy electrochemically as in an

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*Thionine, a dark crystalline basic dye of the thiazine class, is the parent compound of methylene blue and is commonly used as a biological stain.

TABLE 51-1 PROJECT INFORMATION

Project Title: Photochemical Conversion of Solar Energy	Grant/Contract No. AER72-03579 Formerly NSF·GI-38103
RANN Program Manager Dr. Tapan Mukherjee	RANN Program Area Advanced Energy Research & Technology
Principal Investigator(s) Dr. Norman N. Lichtin	Schedule Start: 1 June 1973 End: March 1977
Institution Boston University - Department of Chemistry	Funding NSF $461,000 Other None
Contributors/Collaborators Prof. Morton Z. Hoffman, Dr. Elliot Berman, Asst. Prof. Michael J. Clark, Asst. Prof. John N. Armor } faculty at B.U. Dr. Peter D. Wildes, Dr. James N. Braddock, Dr. Russel P. Cheney, Dr. George S. Patterson, Dr. Schoen-Nan Chen } Research Associates Dr. John A. Eckert, Dr. Dale Hall, Dr. W. D. K. Clark } Exxon Research and Engineering Co. Prof. Gabriel Stein, Hebrew University of Jerusalem, Israel	
User Advisory Committee None	
Precursor Activitities Exxon had previously demonstrated a photogalvanic cell for conversion of solar to electrical energy.	

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ordinary battery to give electrical energy. In the second area, i.e., the fuel-forming research, the simple iron-bromine system was chosen for study. In this, the products of ferric bromide photodecomposition spontaneously recombine in the dark with the release of thermal energy.

Apparently none of the quantitative goals of the research have been achieved. Sunlight engineering efficiencies (conversion of incident solar power to electrical output power) of iron-thionine photogalvanic cells have not to this date exceeded 0.1 percent. Quantum yields of up to 5 percent at 42 °C were obtained for the photoreduction of ferric bromide before this phase of the research was terminated in June 1975 in order to focus all resources on the photogalvanic cell research. The research results therefore consist of a body of knowledge on the complex photochemistry of iron-thionine and iron-thiazine photogalvanic cells, their electrolyte systems, cell design and performance, and on the photodecomposition of the ferric bromide system.

The research results have had little utilization, primarily because of the lack of success in meeting the research objectives. Apparently, the state-of-the-art was much less developed than it was perceived to be and rather than achieving a product suitable for development, relatively basic research was performed. Competitive photogalvanic reactions and photoformed fuels produced by solar energy conversion appear to be an elusive goals, particularly for the specific approaches that were the focus of this research. While sunlight engineering efficiencies have been improved by two orders of magnitude, improvement by a similar additional factor is considered essential before a practical device is feasible.

A second reason for the low level of utilization is the limited dissemination of the results. While a number of papers have been presented

at conferences, symposia, and workshops, publication in refereed or scientific journals has been limited. Lists of publications and presentations are given in the appendixes. The Principal Investigator reports that he has received and responded to 125 requests for a report on a workshop on photochemical formation of fuel arranged by BU in 1974. However, potential users who were queried concerning the research indicated little awareness of the research accomplishments.

A third reason for poor utilization is traceable to the relative success of parallel competitive technologies for solar energy conversion. Semiconductor photovoltaic cells, for example, during the period of this research, were greatly reduced in cost, and research results indicated a potential for much further improvement. Photochemical cells, based on excitation of semiconducting electrodes, were another competitive technology gaining attention during this period. These successes detracted from attention that the BU-EXXON effort may otherwise have obtained.

In summary, it can be concluded that this research appeared as a good idea at the right time but the establishment of overly optimistic initial goals led to expectations that have not been realized thus resulting in little utilization of the results. The research appears, however, to have identified several specific problems that must be solved if the initial goals are to be met and has made progress toward their solution.

Research Description

The high cost of photovoltaic devices and the need for alternative solar energy conversion techniques have provided impetus for reexamination of the photogalvanic process. Further, photogalvanic cells appear to afford certain advantages as solar energy converters. For example:

. Products of photodriven reactions can possibly be separated and stored;

. Optical and chemical properties of liquid solutions can be modified to obtain maximum use of the solar spectrum and a variety of reactions, and

. Purification and preparation of solution materials can be accomplished at moderate expense.

Photochemical cells in which light is used to generate a useful fuel have focused upon the decomposition of water to obtain hydrogen.* Of most significance are the so-called "cyclically operated photogenerative cells," storage batteries in which the cell discharge products can be illuminated to regenerate the original cell chemicals. The iron-thionine redox reaction is the basis of a photogenerative galvanic cell first described by Rabinowitch in 1940.** Other photoredox reactions including a ferrioxalate system exhibit a photogalvanic effect.*** Photoredox couples have been used in photoregenerative galvanic cells to generate potentials up to 200 mV.

The main purpose of the BU-EXXON research project was to demonstrate a photoregenerative galvanic cell with a 5 percent sunlight engineering efficiency. Engineering efficiency is the ratio of the electrical power delivered to a load divided by the total incident sunlight power. That portion of the research conducted at Boston University had as its primary focus the identification and the systematic optimization of the factors affecting the

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*A. Fujishima and K. Honda, Nature, 238, 37 (1972).
G. Sprintschnik, H. Sprintschnik, P. Kusch and D. Whitten, J. Amer. Chem. Soc., 98, 2337 (1976).

**E. Rabinowitch, J. Chem. Soc. 8 551 & 560 (1940).

***K. Yamashita and H. Imai, Bull. Chem. Soc. (Japan) 41 1339 (1968).

solution performance while the main effort at EXXON was to identify and systemically optimize the parameters affecting the cell electrochemistry.

The research objectives as stated for the first year of the project were:

1. Achievement of a quantum efficiency greater than 1 percent for conversion of absorbed light to electrical power by a photogalvanic cell based on the iron-thionine photoredox system.

2. Full characterization of the photoredox properties of aqueous solutions containing iron, thionine, and other components of the experimental EXXON photogalvanic cell.

3. Performance of initial research on conditions needed to optimize the performance of the iron-thionine photogalvanic cell. This work was also to serve as an initial study of the photoredox properties of Fe (II)/Fe (III) relevant to the photoformation of fuel.

In pursuance of these goals, initial research focused on the relation between photogalvanic efficiency and cell parameters, the fundamental photochemistry and thermal chemistry of the iron-thionine system, and on photolysis* of aqueous ferric bromide. Sunlight engineering efficiency of the cells was improved during the first year but was still below 0.1 percent.

A set of goals for the second year of the project relating to research on both photogalvanic cells and the photoformation of fuel was also specified but due to limited progress in the course of the research were subsequently modified to be a 1 percent sunlight engineering efficiency photogalvanic cell and 25 percent quantum efficiency in the photoreduction

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*Photolysis is defined as chemical decomposition by radiant energy.

of ferric bromide to yield free bromide and ferrous bromide. In the third year, only one goal of the research was stated, i.e., to achieve 5 percent sunlight engineering efficiency in a photogalvanic cell.

The iron-thionine photogalvanic cell is believed to depend on reactions of the type:

lighted electrode $\cdot TH_2^+ \rightarrow TH^+ + H + e^-$

dark electrode $Fe(III) + e^- \rightarrow Fe(II)$

combined $\cdot TH_2^+ + Fe(III) \rightarrow TH^+ + H^+ + Fe(II)$

In this process, no reactants are consumed and only electrical power is withdrawn from the cell. Potentials at the electrodes are generally in the range 0.05 to 0.10 V at the maximum power point. Currents from small experimental cells were in the range of 10 to 20 A/cm^2 at 100 mW/cm^2 incident light intensity. It was found that if one electrode is transparent (such as tin oxide) then both electrodes can be illuminated. This greatly simplifies cell construction. In its simplest form, the photogalvanic effect is observed when two electrodes are inserted in an aqueous solution containing thionine and iron salts and the solution is illuminated. When this is done, the solution, which has a purple color, becomes colorless. When the illumination is removed, the purple color reappears.

Optimization of the electrolyte parameters required: (1) improvement in solution absorption characteristics, (2) increasing the primary photochemical yield of charge carriers, and (3) greater efficiency in the delivery of charge carriers to the electrode.

To obtain improved solution absorption characteristics, efforts were directed towards obtaining maximum optical density in the 300 nm to 850 nm

wavelength region. The utilization of short optical paths and the bleaching of the dye (thionine) necessitate high dye concentration to obtain maximum light absorbtion. The tendency of the thionine dye to aggregate at high concentrations in pure water diminishes the number of photoactive species and requires use of other solvents to minimize aggregation. Moreover, some degradation of these solutions is observed in air. The use of a mixture of dyes and sensitizers was found to increase the cell efficiency in white light by a factor of 5.8 over solutions without sensitizers.

Study of the sensitized iron-thionine system indicated that the generation of charge carriers is dependent upon the competition between the unimolecular decay of triplet thionine ($\cdot TH_2^+$) which is useful, and a quenching reaction with iron ions that changes the chemical nature of the thionine to an inactive species. The rate constants for quenching are a function of solvent, anion, pH and ionic strength while the unimolecular decay constants were essentially independent of these parameters, therefore permitting optimization of the quantum yield of charge carriers.

Improvement of the cell efficiency was sought by varying the anode e.g., (dye) materials and the cathode (inorganic salt) couple. The thiazine dyes thionine, methylene blue, azure A, azure B were determined to be superior (higher current output) to nonthiazine dyes, e.g., neutral red, crystal, violet. No substantial variation in the degree of aggregation could be determined for the thionine dyes. The most effective cathode reaction was determined to be the aqueous ferrous-ferric couple. Iron complexes of other ligands were found to be much less efficient. Various cobalt complexes examined were also found to be unsatisfactory.

Efforts to optimize electrochemical parameters have focused upon the nature of the electrodes, the electron transfer occurring at the electrodes, and the cell configuration. 2/7

Semiconductor electrodes transparent to visible light made possible the construction of cells in which both cathode and anode could be illuminated. The semiconductor anode could then selectively oxidize the dye material. A sunlight engineering efficiency of 0.036 percent has been achieved by total illumination normal to the electrode of a thin layer cell. Higher efficiencies have been obtained with edge illumination. A sunlight engineering efficiency of 0.07 percent has been obtained with a four-layer thin layer totally illuminated (Tl-TL) iron-thionine cell. Certain transparent semiconductors, e.g., $InSnO_2$, were found to be suitable for replacing the platinum cathode material. Ohmic resistance of the tin oxide electrode and parasitic electrolyte reactions are suspected to be major factors limiting the output.

Investigation of electrode material stability indicated that tin oxide electrodes were degraded by the iron thionine solutions. An anode produced by sputtering titanium oxide onto glass and reducing it in flowing H_2 was incorporated into a TI-TL cell with a platinum cathode (80 μm spearation). Gallium nitride was also investigated as an anode material but was found to be unsatisfactory because a dark response occurred and there was no dye activity at the electrode. Cadmium stannate on glass was found to possess low resistivity and high transparency. Its behavior as an anode was inadequate but cells in which that compound was used as a cathode showed good output characteristics relative to the cells using platinum cathodes.

The major achievement in the optimization of cell configuration was the doubling of the quantum efficiency by reduction of the cell spacing from 80 m to 25 m. This result was consistent with the effective diffusion length calculated (40 m) for the iron-thionine system. Electrical shorting

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of the cell elements due to the close spacing precluded construction of a multi-layer cell with this geometry.

Investigation of the photodecomposition of aqueous ferric bromide by the reaction:

$$2\,Fe^{3} + 2Br \underset{}{\overset{h\nu}{\rightleftharpoons}} 2\,Fe^{2} + Br_2$$

$$-14.6 \text{ kcal/mole}$$

was carried out in 1974. Since the reverse reaction is spontaneous in the dark, the materials produced can be used as fuel. A quantum efficiency of 5 percent was obtained in the reaction using 436 nm light.

With respect to materials, the success of the iron-thionine photogalvanic cell if judged by the best solar engineering efficiency obtained, 0.07 percent, was not substantial. The difficulties can generally be divided into those associated with the solution behavior and with the electrochemistry.

The iron-thionine solution possesses adequate chemical stability, the complicated kinetics of charge transfer are sufficiently understood and the dye aggregation problem appears to have been partially solved. The addition of sensitizer substances, while creating additional problems, appears, in part, to optimize absorption characteristics. The use of closely spaced electrodes, while partially solving the bulk back reaction problem, has resulted in reduced solar absorption and concomitant fabrication problems for the multilayer cells.

The primary hardware products of the research were the totally illuminated-thin layer (TI-TL) and the totally-illuminated multi-thin layer (TI-MTL) cells. These electrochemical cells permit total illumination of the photoactive solution through the transparent anode and cathode. The

thin layer of active solution minimizes parasitic reactions, thereby increasing cell efficiency. These cells are essentially planar configurations with transparent electrodes. In the multilayer cells the layers are stacked on one another and form a battery. The low level of light adsorption in the thin cell permits this configuration.

Utilization Objectives

Because RANN sponsored research is directed toward the satisfaction of a national need, the ultimate utilization of the BU-EXXON research should be commercialization by industry in the marketing of a solar energy conversion system. However, as previously mentioned, the overly optimistic initial goal generated expectations that could not be realized without first performing basic research on the photogalvanic process. Consequently, research results are limited to breadboard-type products suitable for further development, information of value to other researchers, or serendiptious utilization. Utilization of the BU-EXXON research results to date must be evaluated in this light.

The user community, if it is now assumed to be peer group research teams, has been fairly well informed of the program status and results. An NSF sponsored workshop in 1974 and the resulting report probably helped greatly in this aspect of the program. The photogalvanic process was described in reports that were distributed to RANN principal investigators and others. Papers describing various aspects of the research were presented at scientific meetings such as the International Conference on the Photochemical Conversion and Storage of Solar Energy held at London, Ontario in 1976. No evidence has been found of efforts to disseminate the results

of the research other than through normal channels of scientific reporting. The lack of significant results correlate with this modest level of dissemination.

It is of interest to note that the BU workshop held in September 1974 was attended by less than 60 people and, of these, more than one third came from BU, EXXON, and NSF. However, this pioneering conference was attended by the leaders in the field and the subject matter was well covered. Thus, the conference itself resulted in limited direct dissemination although a report on the workshop has been widely distributed. The conference was effective in focusing attention on photochemical formation of fuels and on photogalvanic cells.

It is apparent that the inclusion of EXXON in the active research program was directed at effective transfer of the research to a potential user. The only other utilization efforts cited in the proposal were the normal scientific publications and presentations, project reports, and non-technical literature for interested laymen and the media.

Utilization Obtained

The nature of this research was such that two types of products could have resulted: (1) products or processes for photochemical production of electricity or fuels and (2) research results relevant to the phenomena, reactions, or methods. However, because no products or processes have been produced, this utilization study is focused on the research results of which the total illuminated-thin layer cell using the thionine-iron solution is the best characterized example.

To obtain a measure of the utilization of the research results representative active researchers were contacted. Of these, Dr. William D. K.

Clark, Dr. Mark S. Wrighton, and Dr. Keith DeArmond were in essential agreement. Dr. Clark was with EXXON at the beginning of this research but now is participating in photochemical conversion research at Brookhaven National Laboratory. Dr. Wrighton is with the Department of Chemistry at MIT and is a leading researcher in photochemical phenomena. Dr. DeArmond, Department of Chemistry at North Carolina State University, is active in photochemistry and attended the 1976 Conference in London, Ontario.

Each of these individuals suggested that the concept for photochemical conversion of solar energy as proposed by BU and EXXON in 1973 had been known since 1940 and was an interesting approach to solar energy utilization. Research results to date indicate that several orders of magnitude improvement in sunlight engineering efficiency are required to make photogalvanic cells competitive in today's market. As basic research, however, the work appears to be of value. However, this value is difficult to evaluate at this time. In general, they noted that researchers have migrated away from methods using electrolyte photoredox reactions to what they consider more profitable and progressive research areas, particularly those employing semiconductor devices. For example, Dr. Wrighton recently published results on a cadmium telluride cell that produces electrical power, and has also demonstrated a strontium titanate cell for the production of hydrogen and oxygen with 30 percent quantum efficiency in the ultraviolet region of the spectrum.

Dr. Clark stated that he had abandoned this area of research because of the lack of progress and an absence of commercial interest. He felt that practical energy conversion by photochemical processes is at least 20 to 30 years in the future and is unwilling to make any forecast of the future for the iron thionine device, particularly because of the relative success being

demonstrated by semiconductor devices. He also stated that, at this time, efficiencies and cost estimates for useful devices are nebulous because of the lack of results. Therefore, it is extremely difficult to place this particular research in the perspective of the ongoing activities.

Each of these researchers is now focusing his research on cells typified by the Honda cell* using a TiO_2 electrode and each feels that the Boston University-EXXON effort should be treated as a basic research program with emphasis on scientific principles, understanding, and contributions to the store of knowledge. It should exclude particular device development goals. None of these researchers had utilized the BU-EXXON research directly in his program. However, the availability and propagation of negative results have some advantageous effect.

To add to the comments by these three researchers, contact was made with various participants in the research. Dr. Dale Hall of the EXXON Research and Engineering Company is both a participant in and potential user of the results of the research. He stated that EXXON was responsible for fabrication and efficiency measurements and, if a useful device were developed, for its commercialization by Solar Power Corporation, a subsidiary of EXXON. He estimated that the efficiency of the research cell was approximately 0.07 percent, and he further projected that a cost of approximately 20¢ to 30¢ per watt might be possible if the device were improved by two orders of magnitude.

At Dr. Hall's suggestion, contact was made with Dr. Hal Richtal, Professor of Chemistry at the Rensselaer Polytechnic Institute.

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*A. Fujishima and K. Honda, Nature 238, 37 (1972).

He stated that he was interested in photochemical, photochromic, and photogalvanic processes. His initial research efforts are concerned with dye systems. He was not aware of the work at Boston University when he began his research and felt that very little data was presented on the research at the London, Ontario, meeting. He also was troubled by the general lack of technical presentations in this field. Dr. Richtal believes that energy storage is an extremely important factor in the research. He is aware of very few other researchers interested in photochemical conversion.

Dr. Elliott Berman, Director of BU's Center for Energy Studies, was originally with and is currently a consultant at EXXON Corporation. He has performed extensive research on the photogalvanic process. At this time, he foresees no commercialization potential for the iron-thionine cell. He stated that much fundamental research in progress at Boston University could support the present efforts at device development. However, it now appears to him that a whole new set of anodes, cathodes, solutions, and dyes are required for commercial devices. In Dr. Berman's opinion there has been little publication due to the highly developmental nature of the work, i.e., it was not really suitable for publication.

A key item that Dr. Berman commented on was that he considered the device to be a potential conversion and storage device in a single integrated form. Therefore, whatever engineering efficiency it achieves must be compared to a photovoltaic device/battery combination to provide a fair cost-efficiency-weight comparison. He admitted that while the original proposal expressed concern with energy storage, storage was never mentioned in any of the ensuing reports. It was Dr. Berman's understanding that Brookhaven, Hebrew University, and Miami University were now beginning

research in photochemical systems directed toward goals similar to and partially motivated by the BU-EXXON research.

As these contacts indicate, the few researchers in the field of photochemical conversion identified as being aware of the BU-EXXON research have made little use of it. Even those who, because of close association with and participation in the research, are familiar with the results recognize that utilization by other than peer researchers is still remote.

Features

Dr. Norman Lichtin, the Boston University Principal Investigator, believes the utilization of this research to be very low. He reports that there have been no user advisory committees, user collaboration, or appreciable dissemination efforts outside of the EXXON participation in the research. However, he does feel there is much ultimate significance to the products envisioned. In general, these opinions are shared by Dr. Tapan Mukherjee, NSF Program Manager; by Dr. Wrighton of MIT; by Dr. Clark, Brookhaven National Laboratories; and by Dr. DeArmond of North Carolina State University.

All individuals contacted consider the research to be basic in nature. The eventual fulfillment of a national need from this research is many years away. At the same time, products such as photovoltaic solar cells and other processes for the generation of hydrogen and other fuels appear to hold more promise for meeting the needs addressed by the BU-EXXON project.

Reasonable attempts have been made to disseminate the information by both the NSF management and the Principal Investigator. The funding and staging of the Osgood-Hill Workshop along with presentations at the recent

Photochemical Conversion and Storage of Solar Energy Conference in London, Ontario are about as much as could be expected in view of the limited nature of the results.

Conclusions

At the time of the original funding, it was thought that the inclusion of Exxon in the program would enhance the development of a product and would assure its transition to a practical device. There are no results to indicate that the early promise was fulfilled. The processes being researched did not attain the levels of efficiency that were expressed in the goals. There is considerable evidence that the utilization and cell design efforts expended by EXXON were premature and hence largely wasted since they were predicated on the success of the BU effort that did not materialize.

At least a 100:1 improvement in the efficiency of conversion of solar energy to electricity is required before developmental funding could be seriously considerd. Since much of this gain is likely to be sacrificed in the engineering of the final product, a 200:1 improvement in the research would be a more realistic goal for a competitive product.

There appear to be no barriers to the utilization of a product that might result from this research. Needs exist for efficient solar energy conversion devices.

A capable group of photochemical research practitioners under Dr. Norman Lichtin at Boston University proposed the reinvestigation of the iron-thionine photogalvanic cell at a time when any good idea for potentially low-cost solar energy conversion would have been well received. The

coupling of the research with the EXXON Research Laboratories gave it an aura of development and application, and perhaps an overenthusiasm for anticipated results. Also the industrial coupling might have been perceived as automatically accomplishing the required technology transfer or utilization. There are also indications that the extreme closeness of the organizations may have inhibited the critical review processes, the prompt dissemination of results, and most important, the exposure of ideas and results to other groups that might have interacted productively with the effort.

The principals have now proposed additional research to ERDA on the basic science of photogalvanic action and on photogalvanic devices with approximately the same goals as expressed in 1973.

A primary result that is influencing energy development activities is the awareness that photochemical conversion of solar energy to electricity or useful fuels based on solution photoredox reactions is difficult to accomplish. The relatively small number of researchers in this area are now directing their interest to processes with a higher probability of payoffs. Thus the BU-EXXON effort has aided in giving a proper perspective to this field of activity.

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Appendix A

PUBLICATIONS

1. P.D. Wildes, M.Z. Hoffman and N.N. Lichtin, "Dependence of Specific Rate of Disproportionation of Photochemically Generated Semithionine Radicals on Solvent," Abstracts of 11th Informal Conference on Photochemistry, Nashville, Tennessee, June, 1974, pp. 266-271.

2. W.D.K. Clark, "Development of a Photogalvanic Cell Based on the Iron-Thionine System," Abstracts of the 11th Informal Conference on Photochemistry, Nashville, Tennessee, June, 1974, pp. 270-271.

3. P.D. Wildes, M.Z. Hoffman and N.N. Lichtin, "Flash Photolysis Study of the Ferrous-Induced Photoreduction of Thionine in Aqueous-Organic Solvent Mixtures," Abstracts of Second Annual Meeting, American Society for Photobiology, Vancouver, B.C., July, 1974, p. 130.

4. N.N. Lichtin, editor, "The Current State of Knowledge of Photochemical Formation of Fuel," Report of a Workshop held at Boston University's Osgood Hill Conference Center, North Andover, Massachusetts, Sept. 23 and 24, 1974, 196 pages.

5. M.Z. Hoffman, Photoredox Reactions and the Direct Generation of Electricity," in "The Current State of Knowledge of Photochemical Formation of Fuel," report of an NSF/RANN workshop held on Sept. 23-24, 1974 at the Osgood Hill Conference Center, North Andover, Massachusetts, N.N. Lichtin, Editor, pp. 86-98.

6. W.D.K. Clark and J.A. Eckert, "Photogalvanic Cells," in "The Current State of Knowledge of Photochemical Formation of Fuel," report of an NSF/RANN workshop held on Sept. 23-24, 1974 at the Osgood Hill Conference Center, North Andover, Massachusetts, N.N. Lichtin, Editor, pp. 121-133.

7. N.N. Lichtin, "The Iron-Thionine Photogalvanic Cell: Photochemical and Chemical Aspects," Abstracts of 146th Meeting, The Electrochemical Society, New York, New York, October, 1974, p. 41 (invited paper).

8. W.D.K. Clark and J.A. Eckert, "Photogalvanic Cells," Solar Energy, 17, 147-150 (1975).

9. D. Hall, W.D.K. Clark and J.A. Eckert, "Recent Advances in Photogalvanic Cells," Abstracts of the 1975 annual meeting of the American Ceramic Society Meeting, May 7, 1975, Washington, D.C.

10. N.N. Lichtin, "Optimization of the Iron-Thionine Photogalvanic Cell," Abstracts of the 25th IUPAC Congress, Jerusalem, Israel, July 6-11, 1975, p. 269 (invited paper)

11. G. Stein, "Chemical Storage of Solar Energy and Photochemical Fuel Formation," Abstracts of the5th IUPAC Congress, Jerusalem, Israel, July 6-11, 1975, p. 269 (invited paper).

12. P.D. Wildes, N.N. Lichtin and M.Z. Hoffman, "Solvent Effects on the Electron-Transfer Disproportionation Rate Constant of Semithionine Radical Cation," J. Amer. Chem. Soc., 97, 2288-2289 (1975).

13. N.N. Lichtin, "Optimization of the Iron-Thionine Photogalvanic Cell," VIII Intl. Conference on Photochemistry, Edmonton, Alberta, Canada, August 7-13, 1975, Abst. J3 (invited paper).

14. N.N. Lichtin, P.D. Wildes, M.Z. Hoffman, "The Reduction of Excited Triplet Thiazine Dyes by Ferrous Ion: A Laser Flash Photolysis Study," VIII Intl. Conference on Photochemistry, Edmonton, Alberta, Canada, August 7-13, 1975, Abst. U3.

15. S.N. Chen, N.N. Lichtin and G. Stein, "Fuel Formation from Aqueous Ferric Bromide by Photolysis in the Visible," Science, 190, 879-880 (1975).

16. N.N. Lichtin, P.D. Wildes, M.Z. Hoffman, "Optimization of the Iron-Thionine Photogalvanic Cell: Photochemical Aspects," Abstracts of the 12th Informal Conference on Photochemistry, Gaithersburg, Md., June 29, 1976, Abst. 13-1.

17. N.N. Lichtin, "Photogalvanic Processes," Abstracts of the Int'l Conference on the Photochemical Conversion and Storage of Solar Energy, London, Ontario, August 24-28, 1976, page D1 (invited paper).

18. P.D. Wildes, K.T. Brown, M.Z. Hoffman and N.N. Lichtin, "The iron-Thionine Photochemical Steady State," Abstracts of the Int'l Conference on the Photochemical Conversion and Storage of Solar Energy, London, Ontario, August 24-28, 1976, page D6.

19. W.D.K. Clark, J.A. Eckert, D.E. Hall, N.N. Lichtin, P.D. Wildes, "A Photogalvanic Cell with Semiconductor Anode," Bull. Amer. Ceramic Soc., in press.

20. P.D. Wildes, N.N. Lichtin, M.Z. Hoffman, L. Andrews and H. Linschitz, "Anion and Solvent Effects on the Rate of Reduction of Triplet Excited Thiazinyes by Ferrous Ions," Photochem. and Photobiol., in press.

21. D.E. Hall, J.A. Eckert, N.N. Lichtin, P.D. Wildes, "A Multilayer Iron-Thionine Photogalvanic Cell," J. Electrochem. Soc., 123, 1705-1707 (1976).

22. P.D. Wildes, M.Z. Hoffman and N.N. Lichtin, "Application of Solution and Photo Dynamics to the Optimization of Output of Iron-Thiazine Photogalvanic Cells," Proceedings of the Int'l Symposium on Solar Energy, The Electrochemical Society, Princeton, NJ, 1976, J. Berkowitz and I. Lesk, editors, papers 128-138.

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23. N.N. Lichtin, "Photogalvanic Processes," Plenary Lecture at Int'l Conference on Photochemical Conversion and Storage of Solar Energy, August 24-28, 1976, in press in Symposium Volume, Acad. Press, J.R. Bolton, Editor.

24. P.D. Wildes, D.R. Hobart, N.N. Lichtin, D.E. Hall and J.A. Eckert, "Sensitization of an Iron-Thiazine Photogalvanic Cell to the Blue: An Improved Match to the Insolation Spectrum," submitted to Solar Energy, September 1976.

25. P.D. Wildes, K.T. Brown, M.Z. Hoffman, N.N. Lichtin and E.E. Hall, "The Dependence of Current Output of the TI-TL SnO_2/Pt Iron Thionine Photogalvanic Cell on Photostationary State Composition," submitted to Solar Energy, December 1, 1976.

26. D.E. Hall, J.A. Eckert, P.D. Wildes and N.N. Lichtin, "Electrochemical Aspects of the Iron-Thionine Thin Layer Photogalvanic Cell," in preparation for submission to Electrochimica Acta.

27. U.S. Patent Application Serial No. 463057, filed April 22, 1974 by EXXON Research and Engineering Co., assignor, W.D.K. Clark, Wholly Illuminated Photogalvanic Cell."

28. U.S. Patent Application Serial No. 699725, filed June 24, 1976 by Boston University, assignors, N.N. Lichtin and P.D. Wildes, "Electrolytes Which Are Useful in Solar Energy Conversion."

Appendix B

PRESENTATIONS

June 3-5, 1974. Dr. Lichtin reviewed work on the iron-thionine Photogalvanic cell and other approaches to photochemical conversion of solar energy at a closed meeting of representatives of the Japanese "Project Sunshine" with American workers in the field of solar energy at NSF headquarters in Washington, D.C.

June 7, 1974. Six members of the Japanese "Project Sunshine" team of experts visited Boston University for several hours and were informed of the project's work.

June 16-19, 1974. Drs. Clark and Wildes presented papers on their research at the 11th Informal Conference on Photochemistry at Vanderbilt University, Nashville, Tenn. See Appendix I references.

June 18-21, 1974. Dr. Lichtin reported on progress of the project at the first semiannual photovoltaic program review meeting held in Pasadena, California.

June 27, 1974. Four members of the Soviet Working Group on Solar Energy visited Boston University and were informed of the project's work.

July 22-26, 1974. Prof. Hoffman presented a scientific paper based on project work at the 2nd Annual Meeting of the American Society for Photobiology, in Vancouver, British Columbia. See Appendix I for reference.

August 20-23, 1974. Dr. Eckert presented a paper on the iron-thionine photogalvanic cell at the meeting of the U.S. Section of the International Solar Energy Society.

September 23-24, 1974. Papers describing photogalvanic cell research were presented by Drs. Hoffman and Eckert at the Osgood Hill workshop on photochemical formation of fuel. See Appendix I for references.

October 17, 1974. Dr. Lichtin presented a paper on the iron-thionine photogalvanic cell at the 146th meeting of the Electrochemical Society in New York City. See Appendix I for references.

December 16-18, 1974. Dr. Lichtin reported on progress of the project at the second semiannual photovoltaic program review meeting in Philadelphia, PA.

May 7, 1975. Dr. Hall presented a paper "Recent Advances in Photogalvanic Solar Cells," at the national meeting of the American Ceramic Society in Washington, D.C. See Appendix I for reference.

July 10, 1975. Dr. Lichtin presented a paper on photochemical conversion of solar energy at the symposium on chemical aspects of future energy sources of the Division of Applied Chemistry at the 25th IUPAC Congress in Jerusalem, Israel. See Appendix I for reference.

July 25, 1975. Dr. Berman reported on progress of the project at the third semiannual photovoltaic review meeting in Los Angeles, California.

August 11-12, 1975. Drs. Lichtin and Wildes presented papers on photogalvanic research at the VIIIth International Conference on Photochemistry, Edmonton, Alberta, Canada. See Appendix I for references.

January 20-22, 1976. Dr. Lichtin reported on progress of the project at the fourth semiannual photovoltaic review meeting in Lake Buena Vista, Florida.

May 5, 1976. Dr. Wildes presented a paper "Application of Solution and Photo Dynamics to the Optimization of Iron-Thiazine Photogalvanic Cells" at the International Symposium on Solar Energy of the Electrochemical Society in Washington, D.C. See Appendix I for reference.

June 22-24, 1976. Dr. Lichtin presented a poster paper on application of the dynamics of iron-thiazine photo reactions to optimization of photogalvanic cell performance at the Organic Reaction Mechanisms Conference at Williamsburg, VA.

June 28-30, 1976. Dr. Wildes spoke on optimization of the iron-thionine photogalvanic cell at the 12th Informal Conference on Photochemistry at Gaithersburg, MD. See Appendix I for reference.

August 24-28, 1976. Dr. Lichtin presented a plenary lecture on photogalvanic conversion at the first International Conference on Photochemical Conversion and Storage of Solar Energy, at London, Ontario, Canada. He also presented a poster paper on use of solution photodynamics in optimization of cell performance. See Appendix I for references.

INVITED SEMINARS ON PHOTOGALVANIC CONVERSION

"Optimization of the Iron-Thionine Photogalvanic Cell," Hebrew University, Dept. of Physical Chemistry, Israel, July 1975.

"A Chemist's Approach to the Conversion of Sunlight into Electricity: Optimization of the Iron-Thionine Photogalvanic Cell," IBM Watson Laboratories, Yorktown heights, New York, December 16,1975.

"A Chemist's Approach to the Conversion of Sunlight into Electricity: Optimization of the Iron-Thionine Photogalvanic Cell," University of Massachusetts (Boston), March 31, 1976.

"A Chemist's Approach to the Conversion of Sunlight into Electricity: Optimization of the Iron-Thiazine Photogalvanic Cell," University of Delaware, Dept. of Chemistry October 27, 1976.